Matthias Kuehle-Weidemeier (ed.)

Waste-to-Resources 2009

III International Symposium MBT and MRF

Mechanical biological waste treatment and material recovery facilities

Proceedings

12. - 14. / 15. Mai 2009

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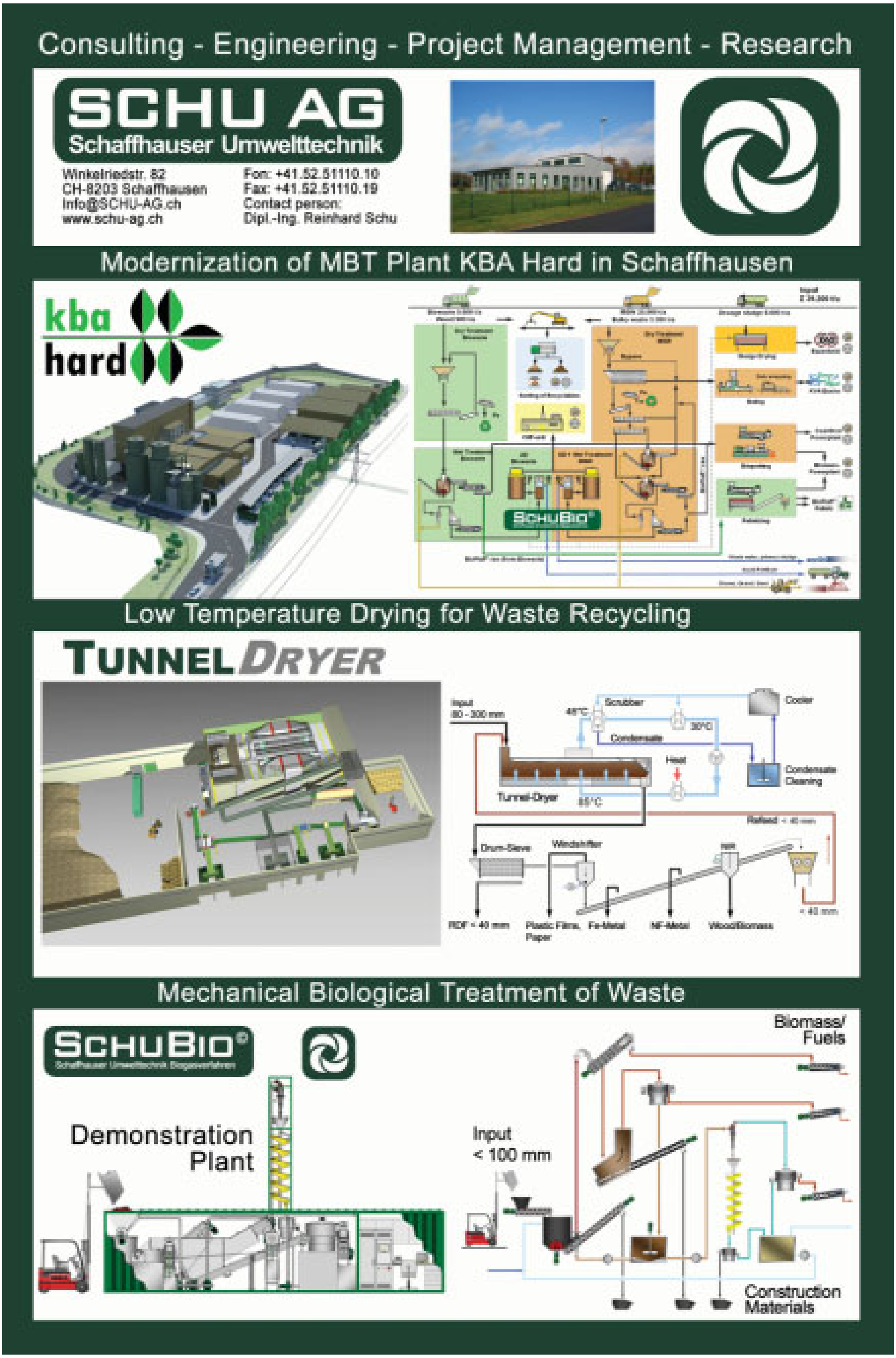
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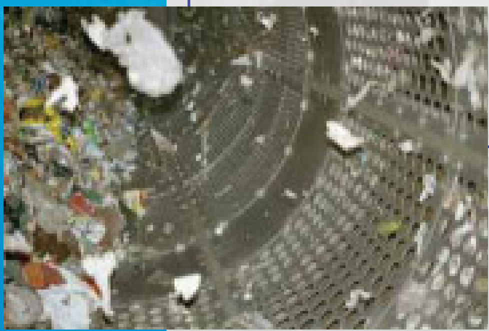

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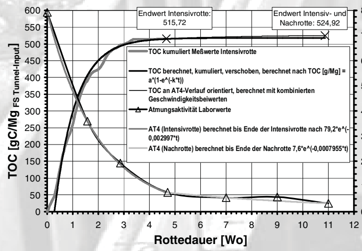

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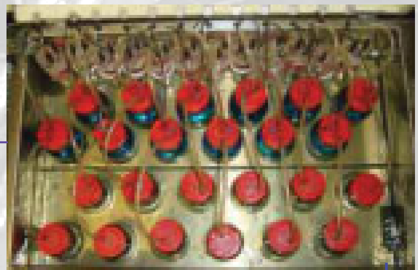

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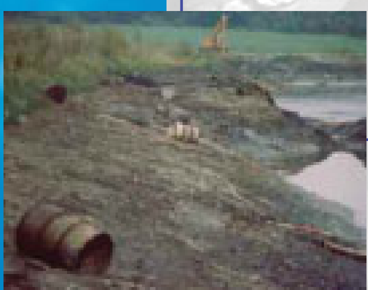

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Mechanical Biological Treatment and its role in Europe

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1 Introduction

Mechanical Biological Treatment (MBT) is a generic term for the integration of a number of waste management processes such as materials recovery facilities (MRF), refuse derived fuel (RDF) production, mechanical separation, sorting, composting and pasteurising. In order to minimise environmental nuisance for odour, fly and noise nuisance, these facilities are required to be housed within a building and normally under negative pressure. The use of bio-filters is also required to treat any odour problems.

The MBT process is designed to take residual or black bin waste and process it so that valuable recyclable materials can be separated out and the biomass or "compostable" element is separated out and processed through an In Vessel Composting (IVC) or an Anaerobic Digestion (AD) system.

2 MBT Systems

MBT is often referred to 3 main types of MBT system that can process the organic element of the waste stream:

- Aerobic stabilisation
- Anaerobic digestion
- Biological drying

What is common to all types is that there is a front end mechanical processing of the waste. This will be through some form of shredding and additional treatment to separate the materials from organic to non organic materials. The differences are in the type of the biological treatment (aerobic or anaerobic) and the treatment target (stabilisation or drying to foster subsequent separation stages).

2.1 Aerobic Stabilisation

The key target of this approach is to stabilise the waste and hence reduce the amount of biodegradable municipal waste (BMW) going to landfill. This is based on the requirements of the EU landfill directive and was implemented in different EU member states with different methods to determine the reduction of the biodegradables content in the waste (see section 3).

For the purpose of BMW diversion from landfill an MBT plant could simply compost all waste without any separation and landfill the residues. This might be a first stage of the development of a waste treatment system and would help to meet current legal requirements in terms of BMW diversion. It would be a straightforward solution which would not rely on markets for products from the process like RDF etc.

The more common approach is shown in figure 1 to combine the biological treatment with mechanical processing steps to separate products from the waste prior or/and after the biological treatment. The configuration can comprise a wide range of technologies and a wide range of products. This is reflected in the mass flow diagram which shows a fairly high range for the products that can be separated.

A common approach is the front-end separation of a RDF fraction which will be utilised in industrial processes like cement kilns, coal power plants, purpose built combustion facilities (e.g. to feed the energy to an industrial process) or in a mass burn incineration.

In case of a front end separation the material left after the separation stage is enriched with easily degradable components like kitchen waste and “dirty” paper, like tissues, which are not suitable for recycling. This material is then treated through an aerobic process (composting) where aerobic (oxygen breathing) bacteria and other micro-organisms digest organic wastes. In the process the bacteria grow and reproduce by using some of the energy and material in the organic matter. This process yields carbon dioxide and heat. The time taken for composting is usually determined by the rate at which the feed can be hydrolysed. Higher temperatures accelerate the hydrolysis stage, but the number of micro-organisms that can survive these higher temperatures is reduced.

The continuation of the composting process requires the addition of water. Water is needed to hydrolyse the feeds and progress the other biochemical reactions. The stabilised waste can then be landfilled. An alternative discussed in some countries in Europe is a compost like product that can be produced through a post-refinement stage. At this stage other material, like RDF or aggregates can be separated as well if a market is available and the process is economically viable.

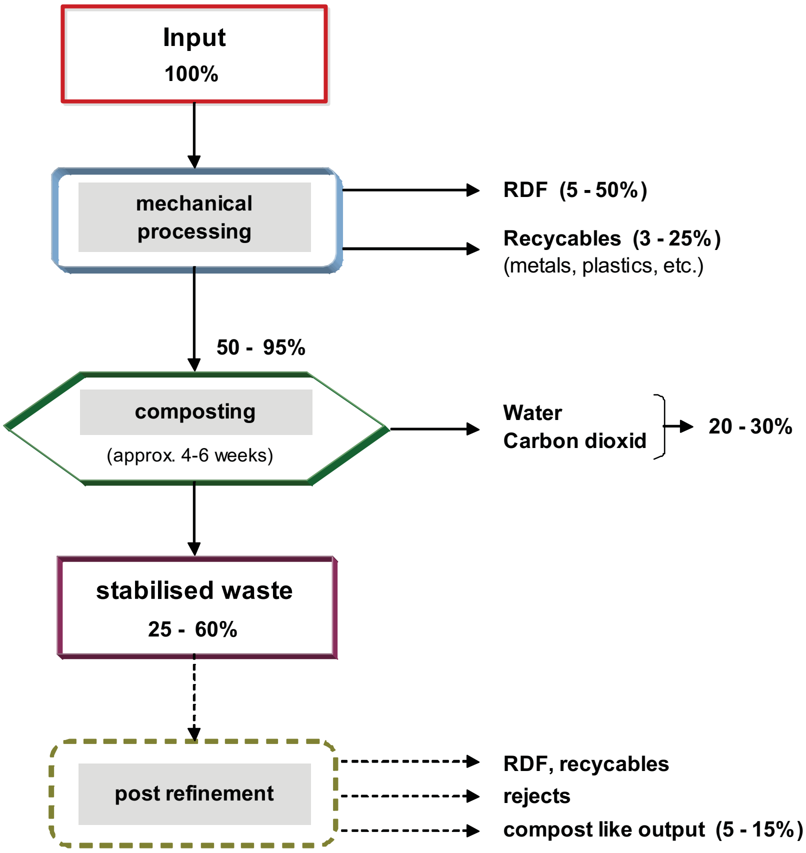

Figure 1: MBT for stabilisation

2.2 MBT with Anaerobic Digestion

Anaerobic Digestion is a biochemical process which takes place in a vessel in the absence of oxygen and results mainly in the formation of a carbon dioxide and methane gas mixture known as "biogas"

Anaerobic Digestion is very often referred to as a separate MBT approach. This might be justifiable for the aspect that renewable energy is produced. If looking at with respect to legal requirements for waste treatment AD is just one component of a MBT strategy. The most common approach where AD is involved is through the stabilisation approach. AD in such a context would then be used as the first stage of the biological treatment which focuses on the anaerobically easily degradable waste components. The "biogas" produced during digestion is used to provide internal electrical power generation and heating requirements. Surplus electrical power (and heat) can be sold as renewable energy.

The digestate is usually dewatered and treated aerobically (composted; often referred to as “maturation”). The purpose of the second stage is to further stabilise the waste, reduce the mass and reduce the odour of the material.

Figure 2 shows such an approach. The flow diagram looks very similar to the "stabilisation" approach. There is a significant impact in terms of process technology involved and the invest costs of such an approach are higher. On the other hand revenues from the biogas utilisation via CHP can be generated which might offset the higher investment costs.

An alternative to the approach of dewatering and further composting is the direct use of the digestate as a liquid fertiliser/soil conditioner. This is subject to meeting any legal requirements and conditions imposed. The key impact on the plant design will be in terms of achieving the sanitisation requirements imposed by the animal by-products legislation.

Figure 3 below shows the development of anaerobic digestion facilities in Europe for both biowaste (source separated kitchen and garden waste) and residual waste through MBT. It can be seen that anaerobic digestion of residual waste has rapidly increased over the last 5 – 7 years.

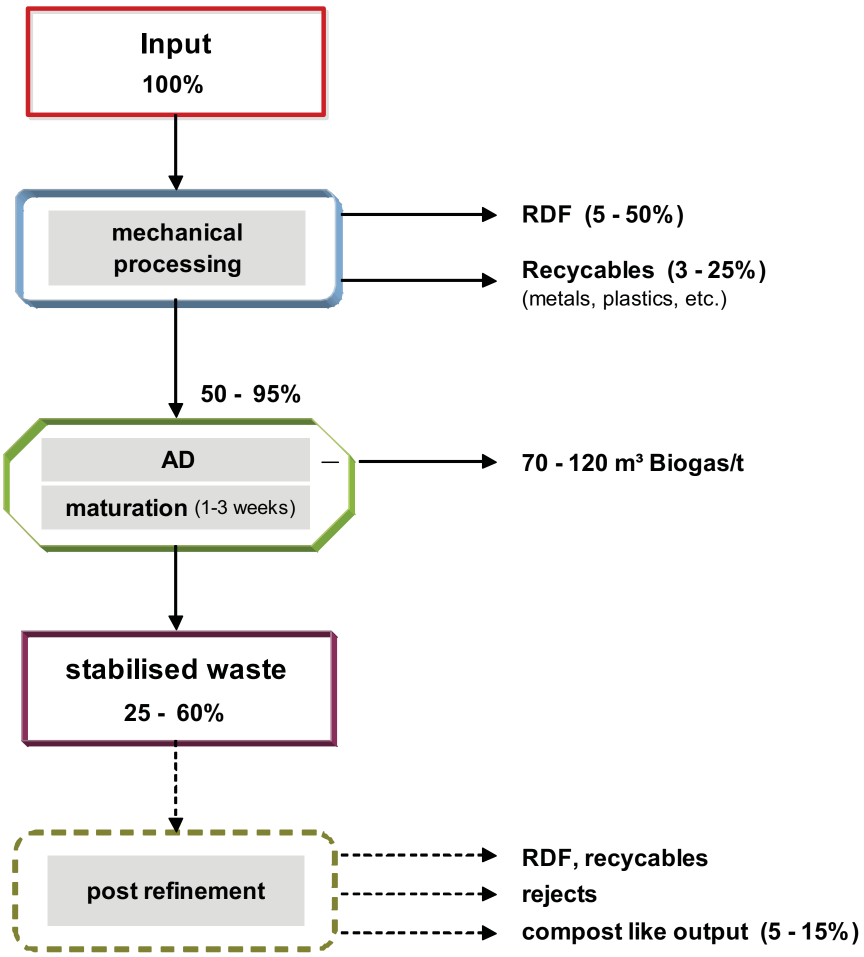

Figure 2: MBT with Anaerobic Digestion

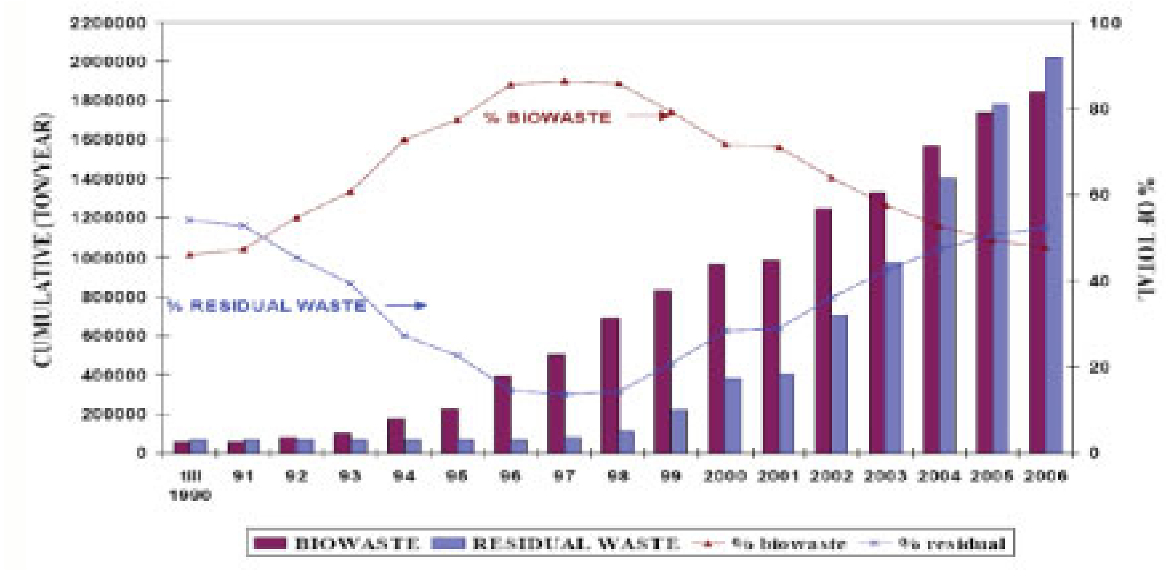

Figure 3: Development of MBT plants in Europe (deBare, 2007)

2.3 Biological Drying

“Biological Drying” is the other fundamentally different MBT approach. The scope of this approach is to make use of the energy content of the waste by means of the production of a (high quality) RDF which is the used for energy production.

The most well-known technology suppliers/developers of this approach are “Herhof” (Germany, now owned by the Greek civil construction company “Helector”) and “Eco-deco (Italy)”

The main purpose of the biological part of the process is to produce the heat which is used to drive of the moisture from the waste in order to enable easier and more efficient mechanical separation. Hence the mechanical separation is performed after the biological treatment.

The waste is shredded and placed in enclosed bio-drying boxes for a pre determined period. Air is forced through the waste creating optimum conditions for microbial respiration, and hence drying of the waste. The warm air is extracted from the boxes and is passed over a heat exchanger. Air passed through the boxes is re-circulated, which is significantly reducing the volume of exhaust air.

Often associated with the biological drying approach is the production of a high quality RDF which can be burnt in industrial plants like cement kilns for a lower price than in a combustion facility or mass burn incineration. Another benefit of the drying of the waste is the increase of the calorific value of the material. There are also a few examples of existing facilities where no biological system is used for the drying process but a physical drying is used instead using gas or oil to produce the heat for evaporating the moisture from the waste.

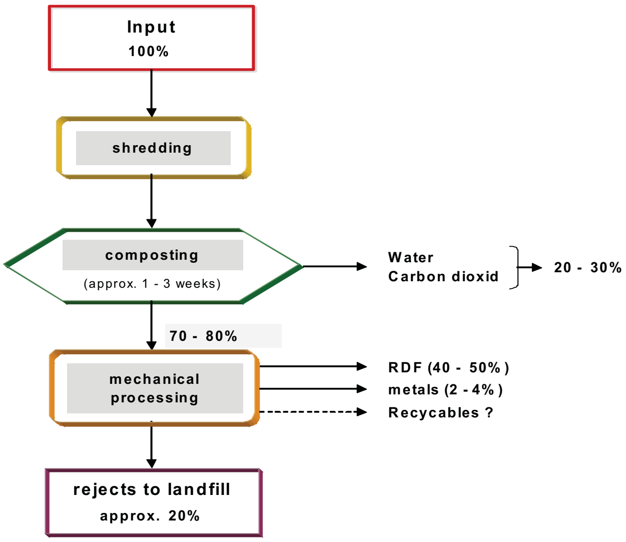

Figure 4: MBT – biological drying

3 Parameters to assess biodegradability

3.1 Background

The EU landfill directive requires a reduction of 65% in the amount of biodegradable waste which is landfilled (Art. 5). The main purpose of this requirement is a reduction in the adverse effect to the environment of the landfilling of untreated waste. The major problem with organic waste is that it degrades to the greenhouse gas methane in a landfill. Methane is a greenhouse gas that is 26 times more potent than Carbon Dioxide. Even with a state of the art landfill design incorporating methane capture, substantial amounts of methane will still escape to the atmosphere and contribute to global warming.

In Norway the government suggests the introduction of a threshold for biodegradable content in waste going to a landfill, defined by 10 % total organic carbon (TOC) or loss of ignition (LOI).

3.2 Parameters in different countries

While this general context is clear, the EU landfill directive does not give a clear guidance as to how to determine what is biodegradable. As methane is produced in landfills by a biological process, a suitable parameter to determine "organic waste" has to be established to measure it. In extensive research, predominantly in Germany, but also in Austria, Italy and other countries it has been demonstrated that several parameters may be used to determine the biodegradable content of waste. However, different biological tests measuring the aerobic (respiration) or anaerobic (gas formation) decomposition have been selected in individual countries and implemented in national regulations or guidelines:

Table 1: Parameters to assess MBT in different countries

Country	Parameter	Limits	Method/regulation
Germany	Static respiration index "AT4" Gas formation test "GB21"	< 5 mg O_2/g dm < 20 Nl/kg dm	Fixed in German landfill ordinance[1]
Austria	Static respiration index "AT4" Gas formation test "GB21" or "GS21"	< 7 mg/g O_2 dm < 20 Nl/kg dm	Fixed in Austrian landfill ordinance [2]
Italy	Dynamic respiration index (Adani method) DRI [3]	< 1,000 mg O_2/(kg VS x h)	Regional require-ments
England and Wales	Change of biodegradability in from beginning to end of a treatment process, biodegrad-ability parameters: - Biological methane potential in 100 days "BM100" - Dynamic respiration index "DR4"	No limits but deter-mination of the re-duction of the gas potential in a treat-ment plant	UK Envrionment Agency guidance[4]
Scotland	Change of organic content from beginning to end of a treatment process Assessment parameter pro-posed: - LOI (loss on ignition) Alternative approaches are pos-sible	Equivalent to Eng-land/Wales	Scottish guidance [5]
EU	Static respiration index "AT4" Dynamic respiration index (Adani method) DRI	< 10 mg O_2/g dm < 1,000 mg O_2/(kg VS x h)	2nd draft EU biowaste directive 2001, with-drawn [6]

1 German Ministry of Environment, 2001: Ordinance on Environmentally Compatible Storage of Waste from Human Settlements and on Biological Waste-Treatment Facilities; 20 February 2001; http://www.bmu.de/files/pdfs/allgemein/application/pdf/ablagerungsverordnung.pdf

2 Verordnung des Bundesministers für Umwelt über die Ablagerung von Abfällen (Deponieverordnung); modified 23.01.2004 StF: BGBl. Nr. 49/2004; http://ris1.bka.gv.at/authentic/index.aspx?page=doc&docnr=1

3 Riffutti e combustibili rcavati da rifiuti, Determinazione della stabiliata biologica mediante l´indeice di Respirazione Dinamico (IRD); UNI/TS 11184, ottobre 2006; www.uni.com

4 Environment Agency (2005): Guidance on monitoring MBT and other pre-treatment processes for the landfill allowances schemes (England and Wales); http://www.environment-agency.gov.uk/commondata/acrobat/the_final_outputs_1096040.pdf

5 Landfill Allowance Scheme (Scotland) Regulations 2005: SEPA Guidance on Operational Procedures; http://www.scotland.gov.uk/Publications/2005/06/08111144/11463

Whilst in other European countries parameters to assess the organic content in waste have not yet been implemented in the national regulations, the parameters and limits proposed in the 2nd draft EU biowaste directive 2001 are often used on a regional level.

The limits applied in Germany and Austria are somewhat stricter than in the 2nd draft of the EU biowaste directive. This is because the limits have been derived from an existing technical guideline (“TASI”; TA Siedlungsabfall), where limits for LOI (<5%) and TOC (<3%) were specified. In a court case it has been successfully demonstrated that the 3% TOC could be fully degradable organic material like sugar. From one tonne of waste with a 3% sugar content about 55 m³ of landfill gas could be produced in a landfill. This sets the benchmark for stabilised waste. It can then be demonstrated from repeated landfill simulation tests with biologically stabilised waste that waste with a respiration rate AT4 of 5 mg O_2/g dm shows a gas potential of usually less than 55 m³ landfill gas. Furthermore the gas potential of waste with an AT4 <5 mg O_2/g dm is reduced by over 90% compared to fresh, untreated waste. If assuming that the 65% reduction requirement in the EU landfill directive refers to a reduction of landfill gas production, then the limits set in Germany and Austria exceed the EU landfill directive requirements. A 65% reduction of the landfill gas production corresponds more closely with the limits set in the 2nd draft EU biowaste directive.

3.3 Which is the best parameter?

Much research has been done on the several parameters which are capable of measuring biodegradability, including various biological physical and chemical tests.. For many situations, correlations between the parameters has demonstrated that several parameters are, at least in principal, suitable for the determination of biodegradability.

In the regulations in place currently, biological parameters have been chosen because it is felt that they are more direct and comprehensible. In various round robin tests, the reliability and accuracy of the various parameters have been examined.

From these tests it can be concluded that the tests in place in Germany and Austria had been designed and approved suitable for biologically treated and stabilised waste. (AT4 below 20 -30 mg O_2/g dm)

With fresh waste, the AT4 test sometimes shows an unexpectedly low result and hence results from fresh waste need to be carefully assessed and revised if necessary. The same applies to the Italian DRI.

6 EUROPEAN COMMISSION; Working document; Biological Treatment of Biowaste, 2nd draft; http://www.compost.it/www/pubblicazioni_on_line/biod.pdf

Because of a different approach taken to assess MBT in England and Wales, the parameters proposed are more suitable for fresh waste. The disadvantage of these tests are that they are more complex (DR4) or take very long time (BM100, 100 days). The latter can cause problems especially during commissioning of new plants as it delays the determination of whether a plant is performing successfully or not.

One criticism of biological tests sometimes expressed is that there may be toxic substances in the waste which could inhibit biological activity during the test and hence show a lower biodegradability than in reality. Whilst this might be relevant for untreated waste it is less relevant for waste that comes from a biological treatment plant because if there was a toxic component in the raw waste it would have had an impact in the biological process and hence would have been detected earlier. Nevertheless, an additional non-biological test could be introduced in the Norwegian landfill regulation to mitigate this risk. At the moment there are experiments underway to develop such quick tests, the latest stage in the development of the various approaches should be assessed before selecting an appropriate parameter.

4 MBT Capacity in Europe

MBT is well established in many countries in Europe with major capacity in Italy (about 11 Mio t), Germany (5 Mio to); Spain (3 – 4 Mio t) and Austria (1 Mio t). Many other countries are introducing MBT and substantial plants are under development or proposed, for example, in the UK and France as well as in Eastern European countries .

Whilst in Germany, Austria and Italy the purpose of the biological process is to stabilise the waste prior to landfill, in other countries the production of low grade compost is a part of the MBT concept. Because of the higher content of pollutants compared to compost produced from source separated organic (kitchen and garden waste), the use of such compost can be very controversial. The major country to promote the use of mixed waste compost is France, but it is being discussed and used in several other countries.

5 Key Advantages of MBT

MBT is often perceived as a “greener” solution for the treatment of waste when compared with mass burn incineration. As a consequence, it is easier to obtain planning permission than it is for incineration.

MBT is based on existing and well known technology (mechanical treatment stages, composting)

MBT is a versatile and flexible concept which can be adapted to a wide range of conditions.

MBT can be economically viable for low waste quantities and be part of a wider waste infrastructure where, for example, several smaller plants which prepare the waste are combined with a bigger unit for producing fuel or recycled materials. This saves transport costs and adheres to the proximity principle.

Smaller scale plants built for a local community are often more acceptable to the public than bigger plants for a wider collection area. Hence planning consent can often be more easily achieved for such plants

MBT can be developed quicker than alternative treatment technologies and may be the quickest option for local authorities to achieve and therefore might even be the only realistic option to meet the UK´s (local authorities) LATS targets.

MBT is a fairly flexible system approach which can be adjusted to local conditions and treatment targets, it can be developed gradually through a /modular system and also cope with a wide range of waste quantities and waste types.

MBT can be developed to optimise the energy yield from waste, including the production of renewable energy via AD and heat and power via RDF combustion. With MBT a more uniform and homogenous fuel (RDF) can be produced which can be used more flexible and hence increase energy efficiency. As the energy production is decoupled from the waste treatment process the energy might be produced where it is needed and hence the overall efficiency is higher compared with a mass burn incineration.

MBT reduces the volume of residual waste due to the breakdown of the waste. This minimises the amount of landfill and therefore the landfill space taken for any residual waste, which maximises landfill resource.

Hazardous waste contaminants, such as batteries, solvents, paints, fluorescent light bulbs etc, can be separated through an MBT plant and it is a requirement that hazardous waste is not disposed of through municipal landfill sites and it is essential that it does not go through into the organic waste stream.

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Municipal Solid Waste Treatment - Experiences getting from practice

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Abstract
Looking for a suitable municipal waste management's method for town and district is an important task for Vietnam. In such areas the generated waste amount is not big and waste service hardly joins to the public Urban Environment Company's system, due to a high cost of transportation. In this case, therefore a private company, the Hydraulic-Machine Co., LTD has developed an appropriate technology made in Vietnam. This technology uses for "Treatment of Solid Waste into Fuels" (MBT-CD.08), which has got the Certification of Vietnam Technology Ownership and it is being on the way of extend its application throughout the country. Schematic diagram of the MBT-CD.08, material flow, heat value of the RDF product and the emission as well as scientific comments were reported.

Key words
Technology, treatment, solid waste, fuel, material flow, heat value, emission, hazardous substance, mechanical sorting.

1 General fact

According to the Vietnam Ministry of Construction (MoC), the total amount of waste (urban and rural) is estimated at 12.8 million tons per year[1], of which urban areas (class 4 upwards) produce 7.2 million tons per year (54%). This amount is forecasted to reach 22 million tons in 2020 (MoC website October 2008). A total of 82% of the current 19,685 is collected and out of that amount approximately 10% (20,000 tons) is recycled and 12% treated (MoC, January, 2009).

Percentage of household in Urban Areas by methods of garbage disposal (WB2006)

Location	Garbage truck	Burning	Burying	Throwing to river	Throwing to animal closu-re	Other
Rural	6.8	63.0	23.0	15.0	16.7	18.9
Urban	71.0	20.0	7.5	6.3	4.1	2.8
Total	**21.9**	**52.9**	**19.4**	**12.4**	**13.7**	**15.1**

[1]Ministry of Natural Resource and Environment (MoNRE) on its website states that this amount is 17 million in 2007

Urban solid waste is normally managed by Urban Environment Company (URENCO), a public nonprofit owned by the Provincial People's Committee / City People's Committee. URENCO's task is to collect, transport and dispose of waste generated in urban areas. But in suburban, small commune and town unfortunately do not exist yet Urencos. The waste service is taken care by environmental sanitation teams under the control of the municipality but not all of them do the work effectively.

Most of urban solid waste in Vietnam is disposed in landfills. Only 15% of the landfills are being considered sanitary, while the others are just open dumping sites. This lack of hygienic treatment is resulting in leakage from dump sites creating serious pollution problem for the surrounding land, and ground water.

According to this situation, one positive sign are the private enterprises who involve more and more in waste collection, treatment and disposal business which may have great potential growth in Vietnam. There are different models of cooperatives, private enterprises, and “equities” enterprises providing solid waste collection, transportation, treatment and disposal of solid waste in urban and rural areas. Besides solid waste fees, the enterprise can also get additional income from recovery of valuable materials such as plastics, papers, metals, etc. and from recycled products such as compost fertilizers, plastic goods [1].

Based on the knowledge waste in Asian towns is usually largely organic, the United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) carried out in Vietnam, Quy Nhon province a project by building community based composting facilities.

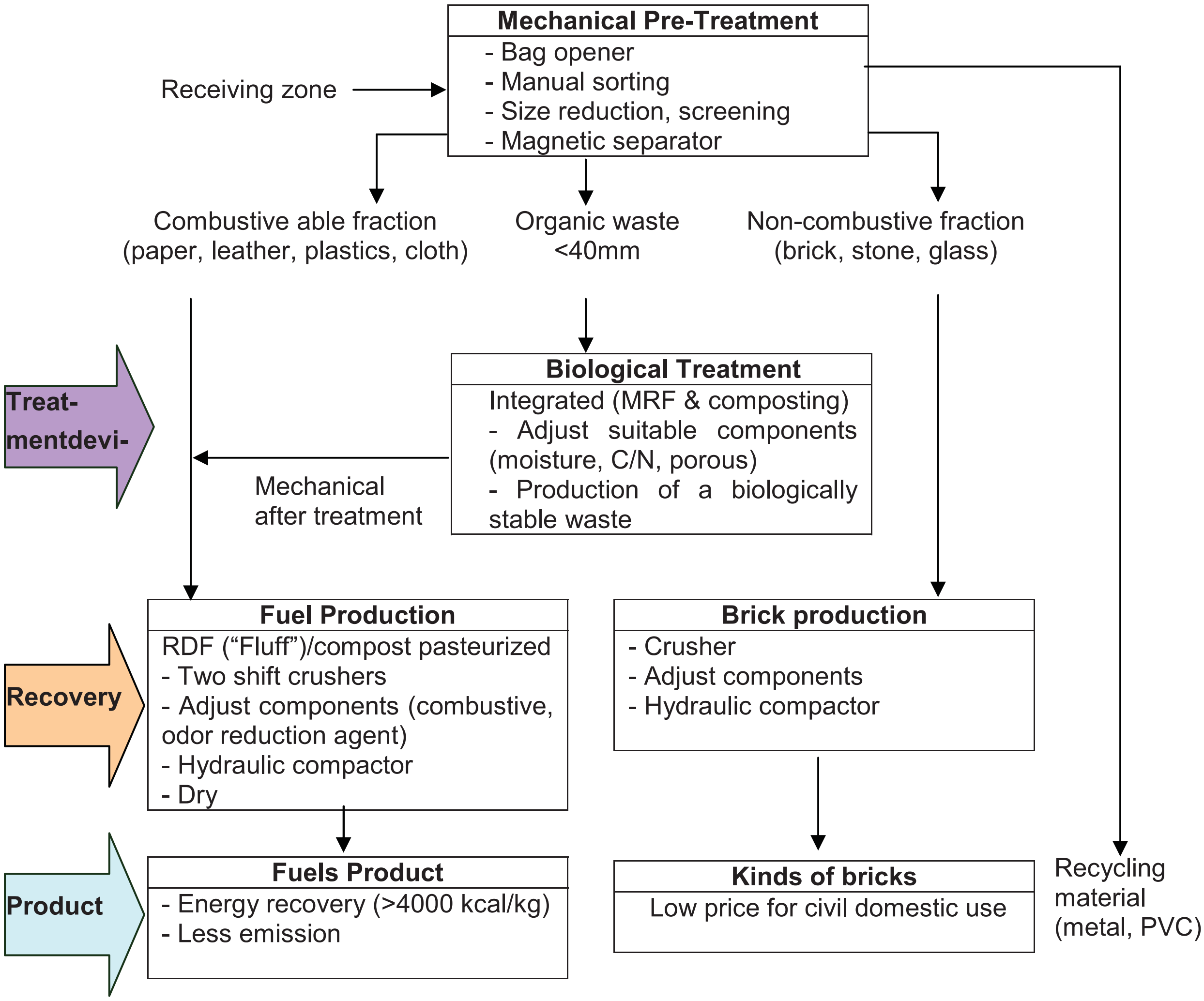
The project organized daily door-to door organic waste collection. Once organic waste was collected it was then transferred to a community plant built by the project capable of treating 2 to 3 tons per day.

The facility has been running a small consistent profit since its completion. The plant currently generates revenue of 1,130 USD per month. Of this amount, 750 USD is from collection fees, with each household paying fees of 0.60 USD per month. The remainder of the revenue is from the sale of organic fertilizer (approximately 340 USD per month). The operating cost of the facility is 972 USD, resulting in a small profit (around 150 USD). The ability of the plant to sell its organic fertilizer remains critical to its profitability. While the current number of buyers is high and the benefits of organic fertilizer are being recognized, the market price of organic fertilizer is still low (www.housing-the-urban-poor.net/Docs/WUF-IV/SWM-ENDA.pdf).

There is a fact that composting facility has been not yet accepted as a favorite municipal waste treatment facility. Since waste is not yet segregated at source, quality of compost is low. From the mix waste receive only 20 - 30 % compost product [2]. The residues must be land filled. Beside that compost's market is not yet developed. The investment and maintenance for composting plant require very high. Based on these reasons a new technology for municipal solid waste treatment facility has been declared by a Vietnamese company, which called "Technology for Treatment of Solid Waste into Fuels" (MBT-CD.08).

2 Introduction to the MBT-CD.08

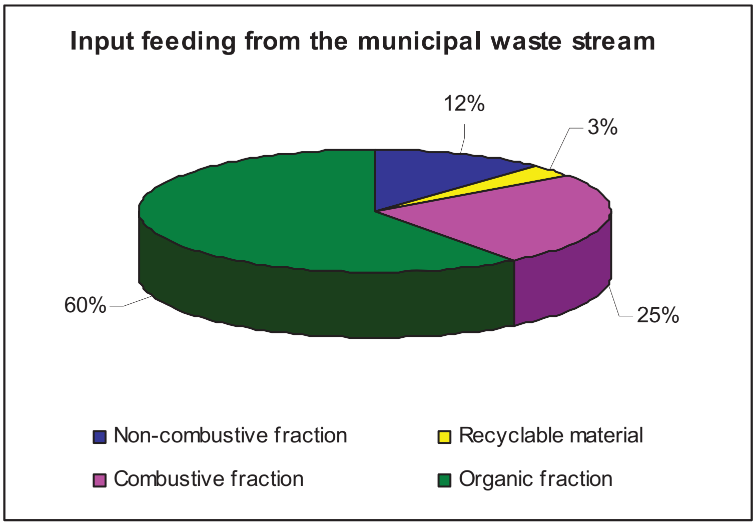
Schematic diagram of the MBT-CD.08 is as follows:



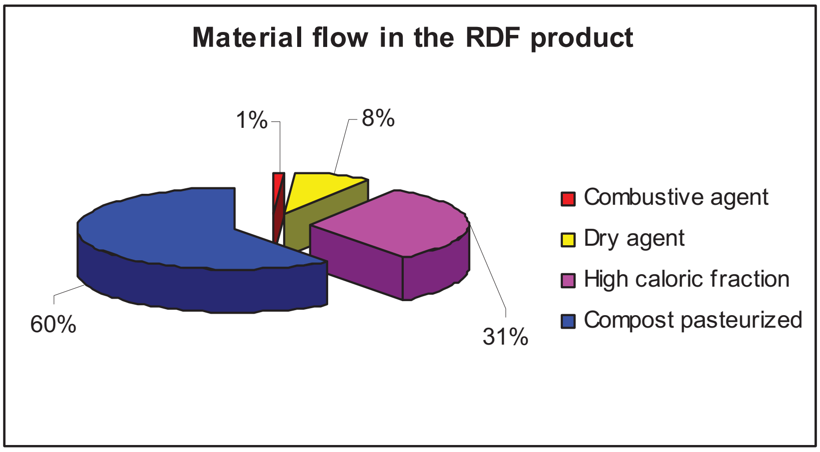
The MBT-CD.08 is used for a capacity of 15 tons/day, which has been tested successfully in Duy Tien district, Ha Nam province since June 2006; it is therefore suitable for small town or district. However the system is constructed with module, the capacity can reach to 100 tons/day if more modules are connected, therefore it can be applied also for cities. Waste of the commune was collected and treated right away in a day. Fuels product was distributed without any difficulty for domestic use (industrial power plant, heat, stream and power). Ash remains 30 - 40 % after burn, which is used for construction purpose.

3 Material flow in the MBT-CD.08

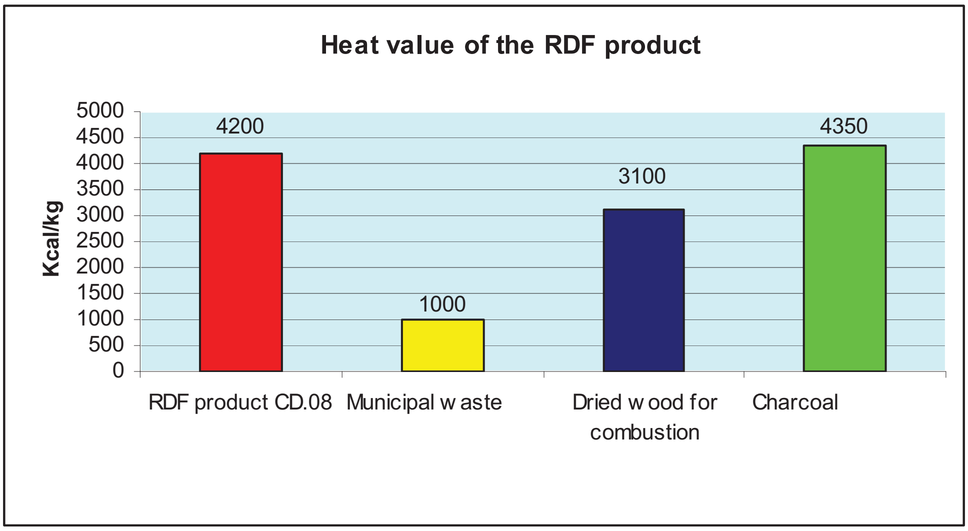
Input feeding from the municipal waste stream of Duy Tien district:



Material flow in the RDF product



Heat value of the RDF product CD.08 and others



Emission from compactor bricks of residual from RDF process

Parameter	Test No.[1]	Unit	Result	Standard of Viet-nam (TCCP867/1998/QD-BYT)
Lead	867/1998/QD-BYT & VA231/1	ppm	0,098	2
Cadmium	867/1998/QD-BYT & VA231/1	ppm	< 0,1	0,2
Arsen	867/1998/QD-BYT & ICP-MS	ppm	0,032	0,2
Antimon	867/1998/QD-BYT & ICP-MS	ppm	0,019	0,2

[1]Quatest 1 - 2/7/2008

4 Conclusion

The technology for Treatment of Solid Waste into Fuels (MBT-CD.08) has been developed from a private company, the Hydraulic-Machine Co.,LTD, which has gained experiences from municipal waste treatment for years. With the waste situation of Vietnam this technology seems to be suitable because of the low price of investment and simply maintenance. It is especially attractive because the RDF product was easily sold. Profit received from this facility is about 300 VND/kg waste (about 2 USD/ton), but since the municipality has to spend money for waste service, now they can earn by apply this technology made in Vietnam. This technology however still remains some problems.

More discussion about the biological process needs to be done as the temperature of process was higher than existed in theoretical aspect [3]; the flue gas was not yet tested; the RDF quality needs to be increased or reduction of hazardous substances in RDF needs to be investigated; the research on influence of mechanical sorting technologies on hazardous chemicals distribution needs also to be done; … [4]. However "low technology" does not mean "low quality", this technology has been high considerate in some provinces of Vietnam, which needs to proceed forward.

5 Literature

InWEnt-Capacity Building International, Germany	2/2009	Background Paper "Sustainable Urban Development Forum 2009", p. 13, Hanoi 26th - 27th February
Nguyen Binh	2/2009	Hydraulic-Machine Co.,LTD Report Hanoi
Nguyen Thi Diem Trang, Kay Silabetzschky	4/2008	"Fundamental of waste management - mechanical biological treatment", Proceedings of Workshop Hanoi
B. Bilitewski	4/2008	„Production and Energy Usage from RDF in Germany", Proceedings of Workshop Hanoi

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Policy and technology status regarding Waste-to-Energy and the role of MBT in Korea

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Abstract

The Ministry of Environment has established 'Comprehensive Master plan for Waste to-Energy' in response to high oil prices, greenhouse gas reduction, and control of ocean dumping of liquid organic waste. The goal of waste control policy has always been the safe and sanitary disposal of wastes; from now on, however, it will include the recovery of energy as well as the safe disposal of wastes. Specifically, energy recovery shall be promoted with 33,376 tons/day of combustible wastes for landfill and liquid organic wastes dumped into the ocean to achieve the 31% goal by 2012 and 100% goal by 2020. Likewise, 57 facilities shall be built including MBT facilities, RDF power plants, biogasification facilities, and power plants for 31% energy recovery by 2012. To carry out these measures, approximately USD 2.16 billion needs to be invested; thus generating economic benefits of USD 877 million per year beginning 2012, creating 17,000 jobs, and enabling Korea to respond to international treaties related to climate change.

Keywords

Waste-to-Energy, Combustible wastes, Organic wastes, MBT, Biogasification, Energy recovery, Power plant

1 Background for Promotion

With the global consumption of resources and energy expanding due to the increase in economic activities, which in turn caused the increase in fossil fuel use and rise of BRICs, the whole world suffers from the environmental crisis involving resources such as the rapid rise in oil prices and climate change. Moreover, with international oil prices starting to swing upward rapidly beginning the latter half of 2007, we have been in the era of excessively high oil prices (exceeding USD 100 per barrel and continuing to increase since the start of 2008).

Table 1 Change in Oil Prices by Year

Year	'02	'03	'04	'05	'06	'07	'08	'09 (as of Mar. 6)
Unit cost (USD/barrel)	23.88	26.8	33.77	49.37	61.55	68.43	95.08	43.04

Note) Source: yearbook on energy statistics by the Korea Petroleum Association (based on Dubai oil)

Korea is the 10th biggest energy consuming nation in the world, importing 97% of energy. Therefore, developing plans for easing the dependence on import for energy by expanding the manufacture and spread of new & renewable energy that can serve as substitute for primary energy sources such as petroleum and coal is a matter of urgency. As of 2006, the ratio of gross domestic primary energy to new & renewable energy is only 2.24%. With the government working to increase the diffusion rate of new & renewable energy to 4% by 2012, Waste-to-Energy is emerging as the most efficient method for the diffusion and spread of new & renewable energy. This is because 76% of new & renewable energy output uses wastes. Its unit cost of production is also cheap (up to 10% of solar energy, 66% of wind energy).

Waste-to-Energy is emerging as a potent solution to climate change as well as excessively high oil prices due to the substitution effect for fossil fuel and high 'Global warming potential' (21 times carbon dioxide) of methane gas (biogas). Recently, international efforts to reduce greenhouse gas emissions have intensified through Waste-to-Energy including refuse derived fuel (RDF) from combustible wastes and biogasification of organic wastes. In the case of Korea, its greenhouse gas reduction obligations are expected to be fulfilled beginning 2013 with the ratification of the 'Kyoto Protocol (1997)'. Domestic carbon dioxide emission stood at 591 million tons as of 2005, increasing at an average annual rate of 4.7% since 1990; thus making Korea no. 1 among OECD nations.

In addition, according to the 'London Convention-1996 Protocol' that took effect in March 2006, reinforced control of ocean dumping is required worldwide. In the case of Korea, organic wastes including food wastewater generated in the process of food waste recycling, sewage, and wastewater sludge and animal excreta dumped into the ocean amount to about 20,000 tons/day (in 2006). For the conservation of the ocean environment and safety of marine products, dumping of sewage sludge and animal excreta into the ocean shall be prohibited beginning January 2012, and that of food wastewater, beginning January 2013; hence the urgency of measures for shifting to land disposal. Note, however, that the landfill processing of these wastes gives rise to problems of landfill safety and odor (bad smell). On the other hand, incinerating these wastes causes air pollution due to dioxin and incurs high disposal cost. Therefore, the productive disposal of new & renewable energy for greenhouse gas reduction through the biogasification of organic waste should be explored as an alternative land disposal method to landfill and incineration.

Amid the increasing interest in global warming and national energy security, EU presented a 'Greenpaper' on energy security in 2000. It prepared a roadmap aimed at further spreading new & renewable energy from 6.5% in 2005 to 12% in 2010. It also defined organic wastes including food wastes, animal excreta, and sewage sludge and wood as ‘Biomass’ and pushed for their energy recovery while prohibiting the direct landfill of wastes whose energy recovery is possible through ‘Landfill Directive ’99’. Germany developed the world’s first technology for separation and selection, producing more than 3 million tons of RDF from 5~6 million of combustible wastes using the best technology as applied to power plants exclusive for RDF and thermal power plants. In addition, it operates 3,700 individual farmhouse-type biogasification facilities using organic wastes. Japan has also promoted the construction of ‘Biomass Town’ together with the ‘New Biomass-Nippon Comprehensive Strategy’ in 2006 while actively promoting Waste-to-Energy by replacing small and medium-sized incinerators generating large amounts of dioxin with 57 MBT facilities and 5 RDF power plants since 2007. Since the development and spread of alternative energy in response to the depletion of fossil fuel and global warming are considered an urgent matter, wastes are regarded as new resources and used as in the case of developed countries. For the conversion of waste management systems for sustainable development and creation of Zero waste society in particular, Waste-to-Energy has recently been used as a useful policy means of addressing the complex challenges emerging in the present age such as the environment, economy, and global warming.

2 Current Status and Problems of Waste-to-Energy in Korea

A total of 5.23 million TOE of new & renewable energy was produced in Korea in 2006, with waste energy making up about 4 million TOE (including waste gases). The production of waste recovery energy excluding waste gases (including biogas) stands at 2.44 million TOE, accounting for 1% of primary energy and 61% of new & renewable energy. This is the amount that is mainly recovered from the remaining heat in the incineration facilities for solid wastes or waste landfill gas that cannot be regarded as the result of the active implementation of the Waste-to-Energy policy by the government.

Table 2 Current Status of Recovery and Use of Residual Heat in Incineration

Capacity of Facilities (tons/day)	**Generation of Residual Heat (Gcal/year)**	**Uses of Residual Heat (Gcal/year)**		
		Total	**Power Generation**	**Heat Supply, Etc.**
12,468	5,521,278	4,891,184	Subtotal: 1,133,708 Sales: 238,707 Own use: 895,001	Subtotal: 3,757,476 District heating: 2,133,360 Residents’ support: 8,085 Benefit facilities: 42,377 Own use: 1,573,653

Table 3 Current Status of Recovery and Use of Waste Landfill Gases

Classification	Power Generation		Gas Supply	
	Places	Capacity (MW)	Places	Capacity (㎥/day)
Total	11	80.83	4	917,280
Metropolitan areas	1	59.88(74%)	1	662,000(72%)
Non-metropolitan areas	10	20.95(26%)	3	255,280(28%)

Therefore, for more positive Waste-to-Energy, business fields including RDF production using combustible wastes as well as exclusive power generation, power supply, and refining use through the biogasification of organic wastes should be activated. As of 2007, however, only the MBT facility in Wonjoo City and 34 leading private RPF manufacturing facilities (37,000 tons/year) are being operated in the field of waste solid fuel and some MBT facilities and RDF power plants are being constructed. Biogasification using food wastes, sewage sludge, and animal excreta is carried out in part in the livestock wastewater treatment plant in Pajoo, Kyunggido, a landfill in Saenggok, Busan City, and some sewage treatment plants in Dongraegu, Busan City and Nam-gu, Ulsan City. The scale of facilities and business profiles leave a lot to be desired, however.

The low level of Waste-to-Energy in Korea can be attributed to the passive response of the government to energy recovery even as it has promoted a waste control policy centering on material recycling. As of 2006, the 83.6% waste recycling rate increased by 50% compared to 1996. In contrast, the landfill rate decreased to one-fifth due to the implementation of separate collection and application of Extended Producer Responsibility (EPR). Moreover, since the support of national treasury was concentrated on waste recycling and expansion of incineration and landfill fields, the budget for energy recovery was dismally small. The Ministry of Knowledge Economy, which is in charge of the development and spread of new & renewable energy, mainly supported the solar, wind power, small hydropower, and geothermal fields; general political and financial support for the waste field was sorely lacking, i.e., insufficient support for the development difference (the fixed rate is not set, and the floating rate is set low). In addition, the technology for the RDF from combustible waste in the field of energy recovery technology is currently being tested. In contrast, the biogasification technology for organic wastes is in the establishment and operation stages (first stage) at the pilot plant and is small in scale compared to developed countries. Thus, the conditions of the private market can be said to be very poor. Problems related to distrust in the waste solid fuel (RDF, RPF) quality, unstable market, and low supply unit cost also hinder the activation of private markets. The biogasification of organic wastes is another factor, considering the excessive initial investment costs and uncertainty of success. The activation of recovery of residual heat in incineration is also restricted due to the absence of supply standards and remarkably low supply costs.

3 Promotion plan

3.1 Promotion Goals

The Ministry of Environment established the ‘Comprehensive Masterplan for Waste-to-Energy (’08~’12)’ as a method for economic revitalization and in response to climate change. These measures have set the capacity for energy recovery to 12.18 million tons/year of combustible wastes for direct landfill and organic wastes dumped into the ocean (food wastewater, sewage and wastewater sludge, and animal excreta) among the generated wastes by 2020. They also target energy recovery of 3.8 million tons/year by 2012, focusing on public and general wastes whose actual energy recovery is possible. At the same time, a promotion goal for the recovery and use of 1.28 million Gcal/year of residual heat in incineration and 308,160 m3/day of landfill gases has been set. Note that these levels are deemed effective in terms of scale and economic efficiency.

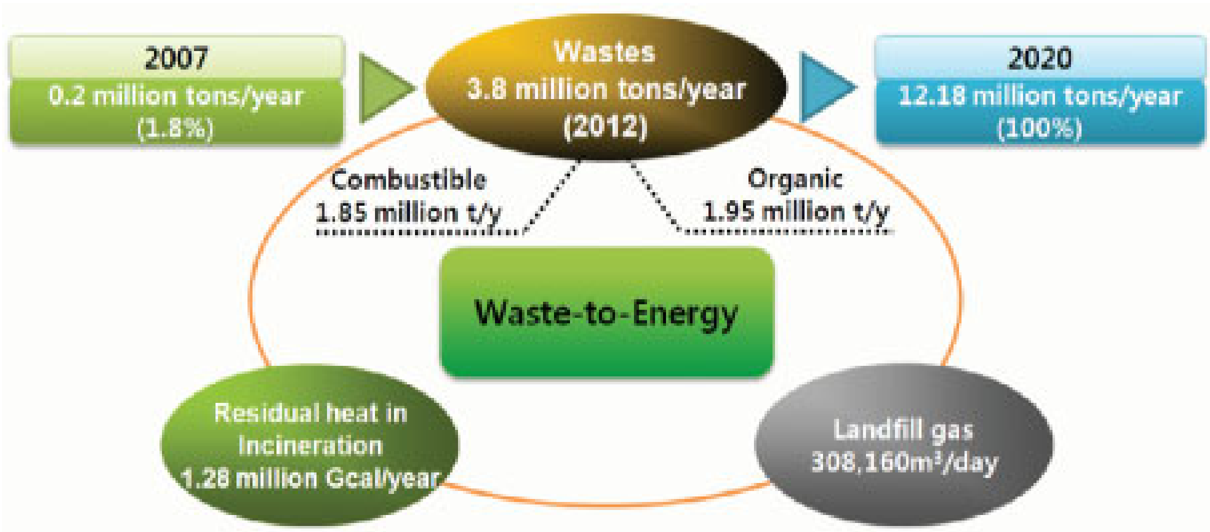

Figure 1 Promotion Goals

3.2 Promotion Contents

3.2.1 Laying down the Foundation for Waste-to-Energy Promotion

To support the effectiveness of these comprehensive measures and ensure smooth promotion, a 'Practice Plan for Comprehensive Master plan' was prepared on the end of 2008. It is expected to prevent waste factors in the national budget in advance by examining the appropriateness and economic efficiency by business field in detail and arrange the facilities expansion project by examining the actual demand related to the 'Waste-to-Energy project' by the local government in this practice plan. Discussion and settlement among local governments shall aim at the regionalization and concentration of energy recovery facilities and improvement of the system for the activation of Waste-to-Energy. An expert forum shall also be organized and operated; administration partnerships of city, county, and Gu shall be forged. A conference between the people and the government as well as policy tie-ups of the relevant authorities are also planned, thereby laying down the foundation for consultation on policy and technology, cooperation among local governments, collection of residents' opinion, and cooperation among the relevant authorities in the initial year (2008) based on the promotion of Waste-to-Energy.

For the political and systematic aspects of Waste-to-Energy, Waste-to-Energy facilities shall be expanded and converted instead of phased reduction and removal of the national treasury support as required for the establishment of landfills and incineration facilities of local governments. Fixed statutes for the reinforcement of waste landfill standards, imposition of landfill allotment, restriction on the establishment of simple incineration facilities, recovery of waste energy, and resetting of RDF quality standards shall also be pursued until 2010. Such will induce Waste-to-Energy actively by pre-examining waste solid fuel (RDF, RPF) use in the area of clean fuel use and through the acknowledgement of RDF (Fluff Type) that was not generated.

The side effects of individual facilities that are in disarray shall also be resolved, and economies of scale, ensured by promoting the regionalization and concentration of Waste-to-Energy facilities. The function of the market economy shall be stabilized and activated through the balance between supply and demand and by guaranteeing a reasonable supply unit cost. In addition, RDF markets shall be maximized through constant discussions with the Ministry of Knowledge Economy and by making efforts to set the fixed rate, increase the floating rate of RDF generation electricity, and actualize the supply unit cost of residual heat in incineration. Knowledge promotion will also be carried out among the people to establish a case of promoting the Waste-to-Energy policy in response to the high oil prices and climate change.

3.2.2 Promotion of Technology Development and Activation of the CDM Project

The Ministry of Environment started the ‘Eco-Star Project Promotion Agency’ in December 2007; it is planning to improve the technology level of Waste-to-Energy in Korea to the commercial scale of developed countries. This project will be promoted by 2014, aims at ensuring economically efficient, eco-friendly resources and activating the CDM project as well as promoting technology development in 14 fields including the use of fuel from combustible/organic wastes and biogasification technology by building organic connections and conducting joint research among industries, academe, institutes, people, and government. The Eco-Star Project will be linked and promoted together with the ‘Comprehensive Master plan for Waste-to-Energy’ being carried out to conform to the environment policy and ensure energy efficiency and environmental safety.

Meanwhile, the CDM project has been rapidly expanding worldwide (as of March 2009, 1,423 cases have been registered) since the Kyoto Protocol took effect in February 2005; 23 cases are registered, with 36 cases at validation in Korea. In particular, 2 cases are registered in the wastes field, and 10 cases are at validation. During the promotion of these Comprehensive Masterplan, the CDM project shall be actively supported through cooperation with local governments and affiliated organizations on the recovery of landfill gases, biogasification of organic wastes, RDF manufacture from combustible wastes, and recovery project for the residual heat in incineration.

3.2.3 Expansion Plan for Waste-to-Energy Facilities (’08~’12)

For the Waste-to-Energy of 3.38 million tons/year (9,260 tons /day) of public and general wastes by 2012, a total of 57 facilities (14,190 tons/day) including MBT facilities for combustible wastes and RDF power plants, facilities for the drying and solid recovered fuel of sewage sludge, biogasfication facilities merging food wastewater and organic waste, and power plants shall be expanded.

Table 4 Expansion Plan According to the Waste-to-Energy Facilities

Classification			Total		Town		Individual	
Total (places)			14,190	(57)	7,180	(16)	7,010	(41)
Facilities	MBT		5,840	(20)	2,400	(4)	3,440	(16)
	Power plants		2,800	(10)	1,400	(4)	1,400	(6)
	Organic	Use for fuel from sludge	1,280	(4)	1,000	(1)	280	(3)
		Biogasfication of food wastewater	2,690	(11)	1,820	(4)	870	(7)
		Cogenerated gas	1,580	(12)	560	(3)	1,020	(9)

Note) One of the facilities is established as combination gasification facilities merging food wastewater in towns (total of 4 facilities).

On the other hand, for the 420,000 tons/year of wastes generated in the private sector, the establishment of MBT facilities with capacity of 370 tons/day and facilities for the drying and solid recovered fuel of wastewater sludge with capacity of 1,070 tons/day shall be pursued and bankrolled by a national treasury loan.

Moreover, support for the establishment of recovery facilities for landfill gases is planned to recover 214 m^3/min (530,000 Gcal/year) of landfill gases from the 27 waste landfills in local governments. The development of 6 large-scale landfills (over 10N m^3/min) shall be promoted as a development project, and 21 medium-scale landfills (over 2N m^3/min), as an economic project. Such measure is expected to contribute to the early stabilization of landfills as well as recovery facilitation of landfill gases by promoting the Bioreactor Project with 14 medium-sized/large landfills. Moreover, a total of 1.28 million Gcal/year of residual heat in incineration including 630,000 Gcal/year from 42 general waste incineration facilities through the new establishment of or support for repair project for facilities for the recovery of residual heat by local governments are expected including 645,000 Gcal/year through the national treasury support for facilities for residual recovery in 27 private incineration facilities for industrial wastes.

Similarly, in establishing and operating facilities for Waste-to-Energy and MBT from combustible wastes, the biogasification for organic wastes and power plants should be integrated, connected, and clustered to enhance economic efficiency. A 'Environment-Energy Town' shall be constructed by sphere for such purpose. The Environment-Energy town construction project shall be promoted after dividing the entire country into 10 areas. Wide-area general waste landfills of local governments will be preferentially selected in the town site, and metropolitan area landfills in the middle region will be improved for the Environment-Energy town. For the remaining 9 areas, locations shall be provisionally selected through demand analysis by local governments; they shall be decided on and finally promoted through business public subscription, feasibility analysis, collection of residents' opinion, and consulting with the relevant local governments. On the other hand, facilities (ca. 5,780 tons/day) that can convert 4,748 tons/day of wastes into energy will be constructed in the town to treat approximately 50% of the total materials in the facilities expansion plan. Moreover, supply and demand relationships among small area-type individual MBT facilities in areas will be created through the establishment and operation of power plants in each town by area.

4 Requirements for Facilities Investment and Expected Effect

4.1 Requirements for Facilities Investment

Facilities investment of about USD 2.16 brillion is required to recover energy from 3.8 million tons/year of organic and combustible wastes, 1.28 million Gcal/year of residual heat in incineration, and 308,160m3/day of landfill gases by 2012. Among these, the investment costs for facilities requiring national treasury support and loan are pegged at USD 658 million; private investments in the establishment of RDF and biogas power plants are estimated at USD 856 million.

Table 5 Estimation of Investment Need by Financing

Total (unit : USD million)	National Treasury (subtotal: 658)		Local Treasury	Investment by Public Enterprises	Private Investment
	Issued	Guaranteed			
2,161 (100%)	593 (27.4%)	65 (3%)	630 (29.2%)	17 (0.8%)	856 (39.6%)

Note) The basis of the calculation above is the present issue system for national expenditure. Note, however, that investment requirement by financing including national expenditure, local treasury, investment by public enterprises, and private investment can vary according to conditions such as the financial situation of the nation and local governments, conditions for business promotion, and private markets in the process of promotion of comprehensive measures.

In the business field, USD 877 million (40.6%) are expected to be required for the establishment of a Environment-Energy town, and USD 741 million (34.3%), for the RDF manufacture and power plant project for combustible wastes. Investment requirements by year are relatively small at USD 24 million (1.1%) in the initial year (2008) and USD 138 million (6.4%) in 2009. Note, however, that the required construction expenses for facilities establishment from 2010 to 2012 when the feasibility analysis and basic practice design are completed and establishment is commenced are expected to be equal to the average yearly income of USD 667 million.

Table 6 Estimation of Investment Requirement by Business

Total (USD million)	Establishment of Environment Energy Town	Combustible Waste MBT, RDF power plant, etc	Organic Waste Biogasification, etc.	Recovery of Residual Heat	Technology Development, etc.
2,161 (100%)	877 (40.6%)	741 (34.3%)	324 (15.0%)	117 (5.4%)	102 (4.7%)

Table 7 Estimated Investment Requirement by Year

Total (USD million)	2008	2009	2010	2011	2012
2,161(100%)	24(1.1%)	138(6.4%)	536(24.8%)	851(39.4%)	612(28.3%)

4.2 Expected Effect

When all energy recovery facilities are completed and operated by 2012, a total of USD 892 million in annual economic effects including the reduction of cost of waste disposal is expected. Note that converting the petroleum substitution effect into the electricity output of energy in life yields 2,817GW per year or capacity average of 0.94 million for use by households in the city or 7.24 million Gcal when used for district heating (amount used by 460,000 households).

Table 8 Economic Effect of Waste-to-Energy

Total (USD million)	Reduction of Cost of Waste Disposal	Effect of Using Alternative Fuel	Greenhouse Gas Reduction Effect
892	572	287	33
	Incineration/Landfill disposal cost	(petroleum: 4.92 million barrels)	(3.8 million tons CO_2)

On the other hand, 17,000 jobs are expected to be created based on the employment effect resulting from the establishment and operation of Waste-to-Energy facilities in terms of the social aspect. In terms of the environmental aspect, the durability of landfills can be enhanced by up to 2.5~13 times as the amount of waste for landfill decreases to less than 20% of the current volume. The environmental load also decreases due to the reduction in leachate production. In addition, the establishment and operation of Waste-to-Energy facilities will help solve international problems such as fulfilling the obligation to reduce greenhouse gas emissions beginning 2013 and enable Korea to respond effectively to London Convention-1996 Protocol, which requires more reinforced control of ocean dumping.

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Experience of Tehran in Improving Integrated Waste Management- Focus on MBT Methods

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Abstract

The daily production of solid waste in Tehran is 7500 tons which according to analyses almost %65 is organic materials which can be composted (wet waste) %35 is dry waste. This study focuses on solid waste management in Tehran and the strategies for gaining to the best result with focus on BMT systems. As the MBT is the most important system in Tehran solid waste management hence there are different technologies that are more used in waste management. This paper proposes methodological approach for combination of above mention systems. The results show BMT adopts with Tehran waste characteristics carefully. Mean while, the MBT methodology has been applied for Solid waste management in Tehran.

In the other hand, According to our experience in solid waste management, the Tehran municipality is playing a vital role in protecting the environment by some achievements listed as below:

Build and operation of waste processing units according to MBT methods

- Compost production
- RDF Production
- Methane Gas extraction
- Reclamation of old landfill
- Construction of lechate treatment system
- Construction of sanitary landfill

Keywords: Waste Management, compost, MBT Methods, CDM

1 Introduction

The daily production of solid wastes in Tehran is 7500 tons (min 4000 – Max 11000 t/d) which according to analyses almost %65 is organic materials which can be composted (wet wastes) %32.5 is solid wastes and %2.5 is special household waste and the healthcare waste as almost 40 tons daily. As the waste decays fast it is collected once in 24 hours from the production sources. This method is based on a three years plan. Presently the collection is mechanized by implementing this project the 2 millions point of waste reduced to 70.000 bins which has a good effect on reducing the air pollution.

2 Materials & Methods

The proposed 4000 tone per day windrow composting operation at Kahrizak has been designed to treat municipal solid waste from the Municipality of Tehran on a 22 ha site in the present location of three waste screening plants located in the south section of Arad Kooh Compost Plant. The plant is designed to:

- to reduce the waste flow to the landfill;
- produce a safe and high quality compost;
- reduce the methane emissions at the landfill and to capture carbon credits for these emission reductions; and
- Meet international environmental and health and safety standards.

The design concept is based on the use of the least cost windrow technology for composting, use of robust and reliable equipment, availability of spare parts, local know how and intimate knowledge of the workings of the Tehran solid waste management system. Equipment such as mobile windrow turners will be purchased from abroad because of their high reliability and quality and low maintenance requirements. Equipment like destoners, shakers and related equipment has been avoided due to their high investment and maintenance costs. Glass and pebbles are mostly found in the screened compost fraction in the size range between 10 and 20 mm. The process flow sheet for the proposed composting facility is shown in Figure 1.

The input waste to the plant will be supplied from selected districts in Tehran, delivered to the plant in 20 tone semi-trailers, weighed and then unloaded at the reception area in front of the Sorting Halls. Bulky items like tires and broken furniture pieces will be collected at the reception hall and transferred to the landfill. The next stage of sorting involves drum screening with a mesh of 70 mm to produce an underflow which has a very high fraction of biodegradable organic waste suitable for composting. The overflow from the drum screens with recoverable recyclables is discharged onto a manual sorting conveyor belt. Major sorting activities to recover these recyclables will take place on both sides of the sorting conveyor belt and separated items will be dropped into chutes and collected in wheeled bins under the elevated sorting lines.

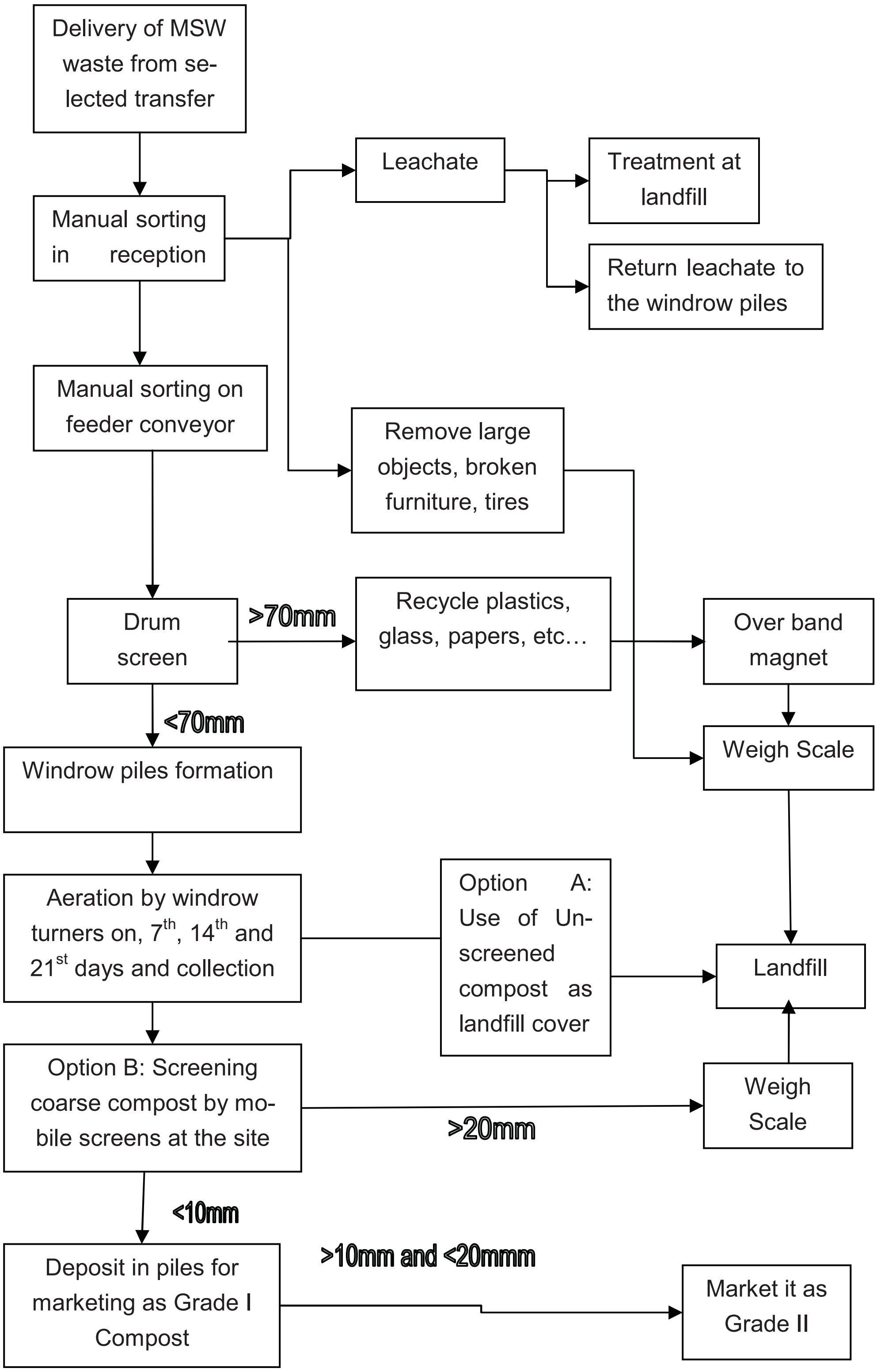

Figure 1 Process Flow sheet for the 4000 tpd Windrow Compost Plant

From here they will be taken to the baling area to compress items like plastics and cardboard to reduce the volume ready for collection and transport. Non-recyclable materials will discharge off the end of the sorting conveyor directly into pressing system and transported directly to the landfill after weighting.

3 Results & Discussion

The daily production of solid wastes in Tehran is 7500 tons which according to analyses almost %65 is organic materials which can be composted (Table 1). About 60 percent of incoming waste passes to the drum screen underflow and this fraction is collected on conveyor belts and discharged directly into the asphalt lined windrow pad. This pad is sloped and has facilities to collect any leachate that seeps from the windrows. Windrow piles will be formed by front end loaders and then by means of large mobile windrow turners will be turned on 7th, 14th, and 21st days and collected on 28th day. Moisture, oxygen levels and temperature in the windrow piles will be regularly checked by on-site quality control staff to ensure optimum conditions for the composting process. The windrow turners have provisions for spraying water and biologically active inoculums to speed up the composting process and produce a better quality product. The inoculums also considerably reduce odors.

Table 1 Test of waste compositions

Waste Type	Mass %
wet waste	65.22
bread	0.86
soft & hard plastic	1.52
PET	0.27
Plastic bags	7.73
Paper	3.41
Cardboard	9.20
Ferrous metals	0.67
Non-ferrous metals	0.04
Fabric	4.38
Glass	1.27
Wood	0.16
Tiers	0.00
Leather	0.50
Dust & Rubble	0.85
Special Waste	2.58
Other	1.34

The layout of the plant has been designed for two possible options after the first stage composting process, as follows:

3.1 Option A

The raw composted waste is loaded into trucks and taken to the Kahrizak landfill to be used as cover material for final reclamation of the landfill. The raw compost matures naturally as it is placed on the landfill. This composted material has several very important functions as final landfill cover: (i) it retains moisture; (ii) it oxidizes the methane and other gases that escape from the landfill even in areas that have gas extraction wells, but most importantly in areas where it is not economic to drill wells and capture the gas. This results in additional GHG emission reductions that could be counted as positive leakage in this Small Scale methodology if a sound technical method can be developed by OWRC to measure the methane emission reductions that have been achieved; (iii) it reduces leachate ; (iv) it reduces odors; (v) it provides an ideal substrate to support the growth of trees even fruit and nut producing species, thereby rehabilitating the landfill site for a productive use; (vi) it greatly improves the visual impact of the landfill; (vii) prevents destruction of vegetation by oxidizing the undesirable gases; (viii) purifies the air around the landfill site; (ix) reduces the cost of soil cover as less cover material is required; (x) reduces the investment and O&M cost for composting as well as the footprint of the composting site; and (xi) reduces the process emissions in the composting process.

3.2 Option B

After 28 days processing coarse immature compost will be taken to the fine compost area and screened with mobile screening equipment to produce three fractions: (i) an immature compost product with a size range <10 mm (Grade 1); (ii) a product between 10 and 20mm, which will be sold as Grade II after further maturation; and (iii) a reject oversize fraction of >20mm, which will be landfilled, or reused in the leachate treatment plant at the landfill. The two product grades will be taken to the covered product maturation building where it will be held for at last 20 days, monitored and turned with front end loaders as needed and then sold as bulk compost or bagged for sale through distributors to individual buyers. Additives will be incorporated before sale to enhance the effectiveness and value of the compost. Physical and chemical analyses of fine compost <10mm will be carried out on a regular basis to ensure that it meets government quality standards and market demands. This will include analyses for heavy metals, particularly lead and cadmium. The other heavy metals such as copper and zinc, which are found in the compost, have beneficial impacts on agriculture as they tend to be deficient in most Iranian soils. All materials entering and exiting the site will be weighed.

3.3 Design, Built and operation of Waste screening plants

The present four waste screening plants which processed approximately 4,000 tones MSW from the time they were installed in March 2008 until September 2008 operated some 300 days in the year. In order to reach the 4,000 tone/day design capacity of the proposed Kahrizak Composting Plants the following up-grades and expansions have been done:

- The 500 tone/day screening plant, which is located in the north section of Arad kooh mechanical compost plant site, will be relocated next to the second 500 tone/day screening plant in the southern section of the site to reduce management and maintenance costs. Both of these plants will be overhauled to ensure reliable operation under the expected future throughput
- The 2*500 tone/day screening plant also have been designed and constructed by local experts and the two sorting lines and the press system have been relocated under the sorting building. These 2 lines are expanded for working in 2 work shift. Consequently, the capacity will rise to 2000 tpd.
- A new 3*500 tpd sorting hall has been installed on the mechanical compost plant site
- The composting pad has been reconstructed to support heavy machinery and will be sealed with asphalt with drains to collect any leachate that seeps from the windrows. The leachate will drain to a sump and the collected leachate either re-used by spraying on the windrows or taken to the proposed leachate treatment plant at the landfill.
- A dedicated fuel storage and distribution center will be established to dispense fuel only for use by process equipment on the site as required under this Small Scale Methodology
- A well stocked spares parts warehouse will be installed to reduce the idle time.
- OWRC's laboratory on the site has been upgraded with analytical equipment, reagents and portable equipment to measure oxygen, temperature and moisture in the windrows, regularly analyze for C, N, moisture and ash as required by the monitoring methodology and carry out maturation and other tests described above on any compost that is sold for agricultural purposes.

After the overhaul and expansion the Kahrizak Composting Plants it is expected to treat 1,200,000 tone of waste annually, of which 720,000 tones of screened underflow will be composted, 36,000 tones of recyclable materials will be recovered and sold, and 444,000 tone of rejects containing very little biodegradable organic matter will be pressed and ready to change in to RDF. Each year the composting operation will produce some 230,000 tone of raw compost, which will either be used for rehabilitation of the landfill as under Option A, or processed as under Option B to produce 134,000 tone of Grade 1 and 48,000 tones of Grade 2 compost and 48,000 tones of screened rejects that will be landfilled. Under Option B the refined compost will have value as an organic fertilizer for certain crops under controlled application rates, as well as use in horticulture and for green areas in the city. Green area maintenance contractors should be required in their contracts to use this compost instead of mineral fertilizers to boost the local demand for the product and improve the profitability of the plant. The green areas can tolerate higher applications of trace metals than crops which are destined for human consumption.

3.4 Estimated Capital and Operating Costs for 4,000 tpd Composting Plant Options A and B (Table 2)

Table 2 Cost Estimation

Option	Capital Cost (US$)	Yearly O&M Cost (US$)	O&M Cost/tone Waste (US$/tone)
A	9,100,000	3,870,000	3.22
B	10,580,000	3,600,000	3.00

3.5 Compost plant management (present and past)

Before new construction and compost plant expansion, the Contractors are being paid 22,000 Rials, or US$ 2.4 as gate fee and are being charged 15,000 Rials (US$ 1.63) as a tipping fee by OWRC for disposing of their rejects in Kahrizak Landfill. The rejects are estimated at 40 percent of the input waste and the tipping fee is charged against their accounts on a monthly basis. The net revenue received by the Screening Plant contractor = 2.4 – 0.4*1.63 = US$ 0.98/tone waste. The revenue received by the Contractor from the Recyclers is US$ 0.35/tone, giving total revenue of US$ 1.33/tone waste. This is less than the tipping fee but the Contractors have been accumulating screened waste on the plant site and OWRC had the responsibility of clearing the site and the cost of transporting to the landfill. Hence OWRC is incurring real costs greater than the tipping fee and is not saving costs as a result of the operation of these screening plants as it may have thought in the beginning when it set their gate and tipping fees.

While OWRC would be responsible for the capital investments in the 4000 tpd composting plant it would contract with a Management Contractor to manage and operate the plant. At the present time, the Management Contractors cover its costs by selling valuable materials. Nevertheless, they also pay tipping fee on a monthly basis. Mean while OWRC manage fermentation zone and compost production by it self.

At the next step, The OWRC select contractor to produce fine compost at its own cost for installing the new screening equipment and marketing the compost. The contractor should be allowed to keep any revenues from compost sales which will provide an added incentive to process and compost the waste in a well managed way.

4 Conclusion

Hence, Assume Carbon Revenues of US$18,000,000 for 6 years from 2009 – 2014 and US$9,000,000 paid upfront for the capital cost of the plant. Therefore the Municipality will receive US$1.5 million per year from carbon revenues However, there will be many benefits from this investment by delaying costly construction of new landfill capacity and reducing leachate generation by about a half.

5 References

Tchobanoglous, G., Theisen, H. &Eliassen, R.	1977	Solid Wastes Engineering Principles and Mnagement Issues, McGraw-Hill, 77-102
Harati S.A.N. Jolous Jamshidi R. Abdollahi Nasab A.	2006	Investigation on landfill gas extraction potential from conventional landfills in Iran-Kahrizak case study, Sardinia Symposum, Italy
Ali Forouhar, Roger Batstone	2006	Feasibility Study for a Compost Plant at Kahrizak, Organization of waste recycling & composting, Tehran, Iran
Harati.S.A.N, Abdolahzadeh.R, Vafae.F, trategic	2008	Strategic Management and Decision Support System in Coastal Zone, Case Study of solid Waste management in north of Iran, Journal of science & technology, Iran

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Material Recovery Stations in City of Tehran: A Case Study

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Abstract

This paper presents practical experiences in design, manufacturing and management of the Material Recovery Station (MRS). In addition this paper uses some related information to report the current state of MRS in Tehran. Here, Tehran's MRS systems will be analyzed with respect to their performances. Considering the local needs, a tailor made cost-effective waste recovery system is proposed to optimize the current MRS. It is estimated that once the proposed MRS plant is implemented, it will increase the recovery rate by 5 to 10 percent. In other words, considering all the 22 stations in Tehran municipality equipped with the proposed system, at least 140,000 tons of waste per day can be recovered and hence diverted from the landfill.

Keywords

Material Recovery Station, Municipal waste, Source Separation, Recovery Line, Recovery System

1 Introduction

Municipal Waste Management is a serious environmental challenge confronting local municipal authorities in many countries around the world. This is especially true for the developing countries. As a result of rapid population growth and increasing rate of unplanned urbanization in many cities in developing world, volume of the MSW is increasing tremendously. (H.A. Abu Qdais, 2007)

Due to the high price of land around the large cities, landfilling that uses a large area of land will become costly. Distancing the landfill site from the cities may reduce the land price but instead will increase the transportation costs. The aforementioned costs are in addition to the environmental and social impacts that landfilling may cause.

Due to the economical, environmental and social problems with the landfilling, it will be acceptable to invest in alternative solutions. This means diverting the waste from the landfills. MRS is one of the best known solutions. (Horng-Guang Leu et al., 1998)

1.1 Waste Management in Tehran

Tehran, the capital and largest city of Iran, with the population of 7.8 Million people, produces approximately 6000 tons of municipal waste daily (OWRC, 2008) (SCI, 2006). Municipal solid waste includes more than 97% of Tehran's solid waste, while three other types of solid waste, hospital waste, industrial waste and construction & demolition waste comprise respectively 1.0%, 0.6% and 0.5%. (Abdolmajid Mahdavi Damghani et al., 2008)

Organization of Waste Recycling and Composting (OWRC) of Tehran is a subsidiary municipality organization responsible for processing waste produced in Tehran. This organization is responsible for Training programs, public awareness activities, dry waste (recyclables) collection and processing, and the whole final disposal treatments of the waste produced in Tehran.

Collection and transportation of the mixed waste from the household to the landfill through the transfer stations is the responsibility of a subsidiary municipality organization, called Motorized Services Organization (MSO).

Household SW is collected in two ways. First, the household SW is collected at doors, which is done once every night at 21:00. Second, recently public waste containers (660 and 1100 liter) provided by Tehran municipality is available on the road sides within each neighborhood as a part of its Program for the Mechanization of the SW Management System in Tehran (Abdolmajid Mahdavi Damghani et al., 2008).

The mixed waste is collected daily and transported either directly or through transfer stations to the Tehran's only landfill, in southeast of the city by MSO's private suppliers. Tehran's landfill, called Kahrizak, is being used to receive the whole waste of Tehran since almost 80 years ago. OWRC of Tehran has taken several steps to improve the use of Kahrizak landfill. Installing several compost plants and initiating a source separation program were part of this effort.

Unfortunately, despite all these efforts, there are still many problems in dealing with the enormous amount of the waste Tehran produces every day.

1.2 Source Separation Program

Tehran has 22 municipality districts. Each district has a MRS used to receive and sort the collected recyclables.

After some research, MROT started the Waste Management Plan of Tehran few years ago. The Tehran Source Separation Program (TSSP) was an important part of that. In the TSSP, free plastic bags are distributed between the households and, later on, filled bags are collected at doors once or twice a week. The dry waste collected from each household is transported into the separation stations.

Bags are transported to MRS of the same district where mixed recyclables are manually sorted. The sorted recyclables are simply packed into large bags and then without any further treatment they are sold to the dealers. Other cities in Iran follow similar schemes.

The collection frequencies can be variable in different places, or, households may receive free trash bins instead of free plastic bags.

The waste production rate and daily waste recovery rate in individual districts of Tehran are presented in Table 1. Based on information reported in Table 1, the Total amount of municipal waste produced in Tehran is calculated to be 5847 tons/day and the average recovery rate for the recyclables is 8.4% (OWRC, 2008). As it is shown in the Table 1, the recovery rates for some districts are higher than the rest. This is due to the better performance of the collection systems and availability of mechanized equipment in these stations. On contrary, in some other districts despite the larger MSW production, the recovery rate is much lower. This big difference is mostly due to the sorting line equipment deficiencies.

This paper uses the district 22 as a case study where different aspects of the proposed system are studied. The goal is to increase the waste recovery system's performance by proposing a mechanized sorting line for the MRS of the district 22.

1.3 Environmental Depletion Control

Implementing the new system will not only generate Tehran municipality the substantial financial advantages, but also will save the environment by recovering more recyclables and to prevent depleting and damaging the natural resources.

Tehran's current landfill site is currently receiving more than 7500 tons of municipal and industrial waste of Tehran and the suburb area daily. Recently the old landfill was completely filled and is now out of commission (Figure 1). Consequently a new sanitary landfill was prepared (Figure 2).

The new landfill is a well engineered facility with leachate and gas collection systems. Despite municipality's effort to design and implement a new cell under acceptable standards to control gas emission and the leachate, it still has to deal with the large amount of waste produced in Tehran daily. The current source separation program can only divert less than 10% of waste from landfill.

Table 1: Performance of all 22 Material Recovery Stations of Tehran Municipality (OWRC, 2008) (SCI, 2006)

District Number	Population	Produced Municipal Waste (ton/day)	Material Recovery (ton/day)	Recovery Rate (%)
1	379962	349	13	***3.7***
2	608814	478	54	***11.3***
3	290726	311	26	***8.3***
4	819921	569	45	***7.8***
5	679108	445	35	***7.8***
6	237292	300	35	***13.7***
7	310184	279	16	***6.4***
8	378725	233	34	***14.6***
9	165903	120	9	***7.5***
10	315619	219	7	***3.1***
11	275241	195	28	***14.6***
12	248048	273	32	***10.6***
13	245724	144	20	***13.7***
14	483432	262	24	***8.9***
15	642526	427	26	***6.1***
16	291169	213	23.5	***11***
17	256022	165	12	***7.6***
18	317188	250	5.5	***2.2***
19	247815	179	11	***6.2***
20	335634	256	15	***5.5***
21	159793	110	6.3	***5.7***
22	108674	70	6	***8.5***
Total	7797520	5847	483.3	

Figure 1: Tehran's old landfill

Figure 2: Tehran's new landfill

2 District 22 MRS: A Case Study

The 2008 statistics shows that the district 22 with an area of 62 km^2 had a population of 109 thousand people. Approximately 70 tons of MSW is produced in this district daily (OWRC, 2008).

Like most other MRS, the MRS of the district 22 is ran by the private sector and supervised by district municipality authorities. Based on the population density of the district, up to 5 special vans are assigned to collect the recyclables from the doors. District 22 is divided into several zones. Free plastic bags are distributed in each zone on weekly basis, different days for each individual zone. Consequently, the filled bags are collected from the doors on pre-assigned days. Unfortunately, only a limited number of households are cooperating with this source separation plan. Every now and then, the district authorities plan and execute encouraging programs to persuade more people to join the plan.

The collected plastic bags picked from households' door, are transported directly to the recovery station, where, they will be discharged in a room close to the conveyer. Bags are emptied on top of the conveyer belt, where they will be sorted. The whole process is performed manually. This process is depicted in Figure 3.

Figure 3: Sorting Line in Recovery Station of District 22

The recovered materials are packed in large bags. There is always a good market for recyclables in Iran. Most materials are sent to the second suppliers for further treatment before being sold out to the final customers. In this case, the compaction and shredding of the recyclables will decrease the transportation cost and increase the material value.

The rejected material will be collected at the end of the line and then transported to the landfill by municipality's public collection services.

Despite the current public training programs, only 8.6% of 70 tons of the waste is collected at doors and transported to the recovery station (OWRC, 2008). The rest of recyclables are still thrown away with the mixed waste and will end up in the landfill.

The current low rate of material recovery is mainly caused by two factors:

1. The lack of public awareness concerning the advantages of the recovering the recyclables.
2. The lack of proper mechanized equipment in this station (Mahak Sabouri, 2007).

The first factor will directly affect the number of people who will voluntary cooperate with the WMPT. To increase the number of volunteered families, more training and uprising programs for the different levels of the population is certainly required. This subject is out of scope of this paper (Abdolmajid Mahdavi Damghani et al., 2008).

As for the second factor, providing proper mechanized equipment can help to improve the current situation. Details of the proposed system are explained in the next section.

3 The Proposed Recovery System

In the MRS of the 22nd district, lack of a proper separating and sorting method is one of the main reasons that keep the recovery rate of the material low. In the current system, the sorting line is not designed properly. Therefore, the sorting labors don't have easy access to the recyclables on the sorting line (Mahak Sabouri, 2007).

In the proposed system, the conveyer belt should be with a right size (in width and length). It should be equipped with a speed controller, positioned on the right height. In the proposed recovery system a sorting conveyer belt with one meter width and 12 meters length is located a few meters above the ground (Mahak Sabouri et al., 2008).

Due to the low density of the recyclables, the second factor in decreasing the recovery rate is the high cost for the transportation of these materials. In the proposed plan, two press machines, one heavy duty and one light duty, will be used to compact the heavy and light recyclables, respectively.

As an overview on the whole system, the mixed recyclables delivered to the stations are discharged in the feeding hopper and then the waste will be transported to the sorting line through a declined T-conveyer. There is an electro-magnet at the beginning of the line to separate the metals. There is also a blower which flattens the compacted waste piles on the conveyer belt to make the manual separation easier in the following stages of the process. The block diagram of the process is depicted in Figure 4.

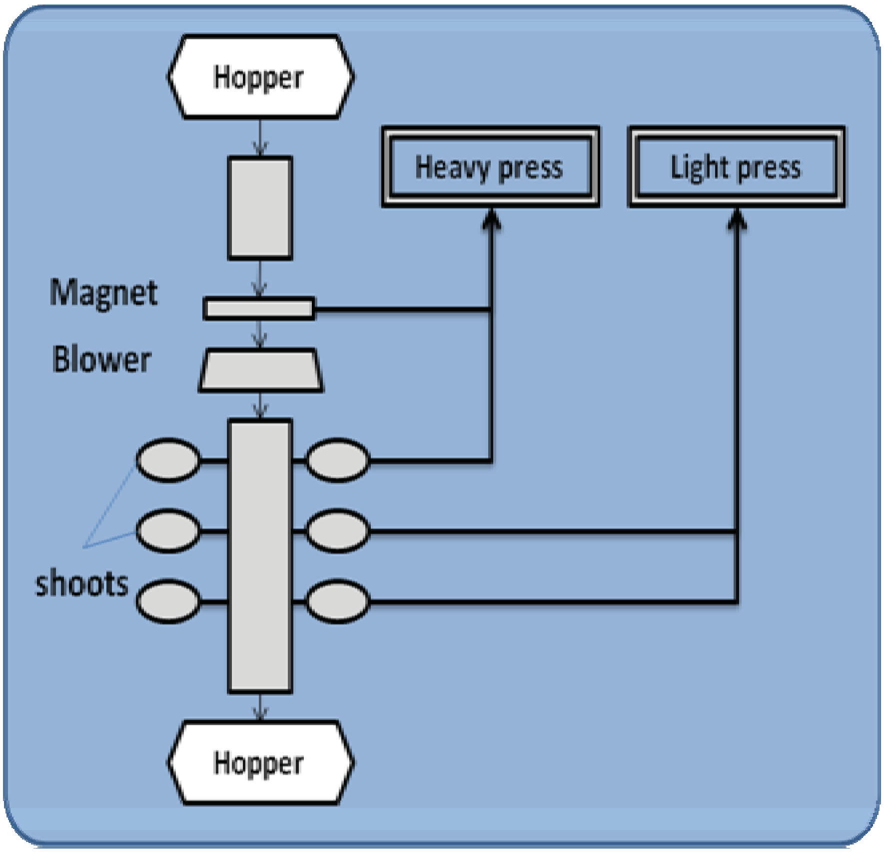

Figure 4: Sorting line

Applying the proposed system, the recovery rate is estimated to improve by at least 5%. This rate is based on the results of the questionnaire completed by managers of the recovery stations in nine districts of Tehran. This improvement is firstly due to the higher sorting efficiency in this process, and secondly due to the effect of the compaction of the materials and the increased transportation efficiency.

At the present, 70 tons of waste is separated at houses and collected by the dry collection system and transferred to the MRS daily. Considering 5% increase in recovery rate by implementing the new system, 3.5 tons more waste will be recovered and hence the same amount of waste will be diverted from the landfill daily.

4 Results

The approximate price of the mix recyclables in Tehran is 100 Euro/ton (Mahak Sabouri, 2007). The cost of waste collection from the doors, transporting them to transfer stations and then to the landfill and finally disposing the waste at the landfill site of the city, is 30 Euro/ton in 2008 (OWRC, 2008). Considering the aforementioned unit prices, the financial benefits of the proposed plan for the municipality is calculated and reported in the Table 2.

Table 2: Finantial profit of increased rate of recycling (Euro)

	Daily	Monthly	Yearly
Only in District 22	497	14,910	181,405
In all 22 Districts (for the whole city)	41,514	1,245,411	15,152,501

The cost of manufacturing and commissioning the sorting line by a local manufacturer is calculated to be around 190,000 Euros in year 2008. The sorting line equipment include feeding hopper, elevating inclined conveyer, blower, electro magnet, sorting conveyer, 6 shoots, 3 wheeled wagons, 50 and 100 tons press machines. (Mahak Sabouri et al., 2008)

It is estimated that implementing the proposed system only in district 22, the Tehran municipality will save at least 181,405 Euros annually (Mahak Sabouri et al., 2008). As reported in Table 2, municipality can save even more, once all 22 districts of Tehran Municipality are equipped with such new lines.

5 Conclusions

Tehran municipality is currently investing on increasing public awareness towards the general training programs. This paper is aimed to prove that investing on MRS will not only reduce environmental impacts of the municipality waste but also will help to save on the waste management costs. Selling the recovered recyclables will provide an additional income for the municipality. Considering all the 22 districts and only a 5% increase in the recovery rate, the municipality can save around 41,514 Euros per day in expenses through selling the recovered recyclables and diverting more waste from the landfill. The proposed system can be applied on any of the 22 districts in the city of Tehran. However, a few of them have initial waste treatment equipment. The proposed plan can be also applied to other cities where the source separation plan is in the planning phase or already started.

6 Future Work

Considering our previous experiences in design, manufacturing and managing similar systems in other Iranian cities, goal is to convince the Tehran municipality to consider the proposal and to implement the system in at least one of its districts.

Intension is to use new sensor technologies for the detection of the material. For example, sensor technologies such as Ultra-sound or Near Infra Red (NIR) can be used to detect the type of the material placed on the conveyor belt. Detecting the material of the objects, system can sort them automatically. As a result of implementing this approach the manual sorting will be eliminated.

7 Literature

SCI	2006	Census Results of Tehran population, Statistical Center of Iran
OWRC	2008	Statistics report on 2008. Organization for Waste Recycling and Composting, Tehran Municipality, Iran.
Abdolmajid Mahdavi Damghani, Gholamreza Savarypour, Eskandar Zand, Reza Deihimfard	2007	Municipal solid waste management in Tehran: Current practices, opportunities and challenges, J. of Waste Management, Elsevier Ltd., Vol. 28, pp. 929–934
Horng-Guang Leu, Sheng H. Lin	1998	Cost–benefit analysis of resource material Recycling, J. of Resources, Conservation and Recycling, Elsevier Ltd., Vol. 23, pp. 183–192
H.A. Abu Qdais	2007	Techno-economic assessment of municipal solid waste management in Jordan, J. of Waste Management, Elsevier Ltd., Vol. 27, pp.1666–1672
Mahak Sabouri	2007	Annual Performance Report of MRS of district 22, Behmand Technology Co.
Mahak Sabouri, Jalil Hejazian	2008	Proposed recovery system plan for district 22, PalaTech Sanat Asia Co.

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Environmental and Economical Aspects for Municipal Solid Waste Treatment Alternatives in Some Lithuanian Regions: Incineration and/or Mechanical Biological Treatment

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Abstract

Seeking to satisfy the requirements Lithuanian Strategic Waste Management Plan the feasibilities of two main alternatives like incineration and mechanical-biological treatment have been accessed for some Lithuanian waste management regions. This assessment has been performed by use of LCA-IWM assessment tool. It is evident that alternative of MMSW incineration in some energetic and environmental aspects is more advantaged than MMSW mechanical-biological treatment and subsequent incineration of obtained high calorific fraction (HCF). Also only during MMSW incineration the values of waste energy efficiency according to new EU Waste Directive are satisfied.

Keywords

Energy efficiency, environmental impact, high calorific fraction, incineration, life cycle assessment, mechanical-biological treatment, municipal solid waste.

1 Introduction

The implementation of requirements of Council Directives 1999/31/EC (Landfill of Waste) and 2001/77/EC (Promotion of Electricity Produced from Renewable Sources in the Internal Electricity Market) is actual both for Lithuania and for other many new EU members. The incineration of municipal solid mixed waste (MMSW) can be one from some possible means for realisation of these purposes. The main MMSW disposal method in Lithuania leaves still landfilling. It is necessary to underline that already before some years the Lithuanian scientists tried to evaluate the municipal waste incineration feasibilities the energetic and environmental point of view both for Lithuania in general (Denafas, 2003) and for separate Lithuanian regions (Wade, 2006; Rimaityte, 2006). However the Lithuanian government took these feasibilities up only after entrance of Lithuania to EU and corresponding obligation for fulfilment of above mentioned directives. To this aim the special pre-feasibility study had been prepared (Preparation, 2006). This study gave the motive for representatives of private business to construct the waste incineration plants (WIP) in some Lithuanian regions. But this intend rose the stonewalling of Vilnius (Lithuanian capital city) inhabitants, also the opposition of businessmen who planed the development of MMSW mechanical-biological pre-treatment (MBP). Therefore the aim of this publication is to present the MBP and different incineration feasibilities for some waste management regions in Middle-North Lithuania (Šiauliai, Panevėžys, Telšiai and Tauragė) and to perform the corresponding environmental and energetic assessment. The borders of all Lithuanian waste management regions are practically congruous with the borders of Lithuanian counties.

The assessment of MBP and incineration alternatives for mentioned waste management regions had been performed in concordance that according to Lithuanian State Strategic waste management plan and considering the recommendations of EU specialists (Deliverable, 2003) the separate collection and recycling of municipal waste fractions will be:

biowaste – 22 %
paper and cardboard - 60 %
plastics and composites – 25 %
glass – 60 %
metals – 50 %
other combustible waste (in fact – wood)) – 3%.

Figure 1 Waste management regions in Lithuania

2 The prognosis of municipal solid waste generation and content for selected waste management regions

By use of prognostic model LCA-IWM (den Boer, 2005) the forecasts of municipal generation have been performed (Figure 2.). Keeping in the mind the proposed separate collection the MMSW should be predominant nevertheless (Figure 3). The forecasted content of MMSW (with biowaste domination) is presented in the Figure 4.

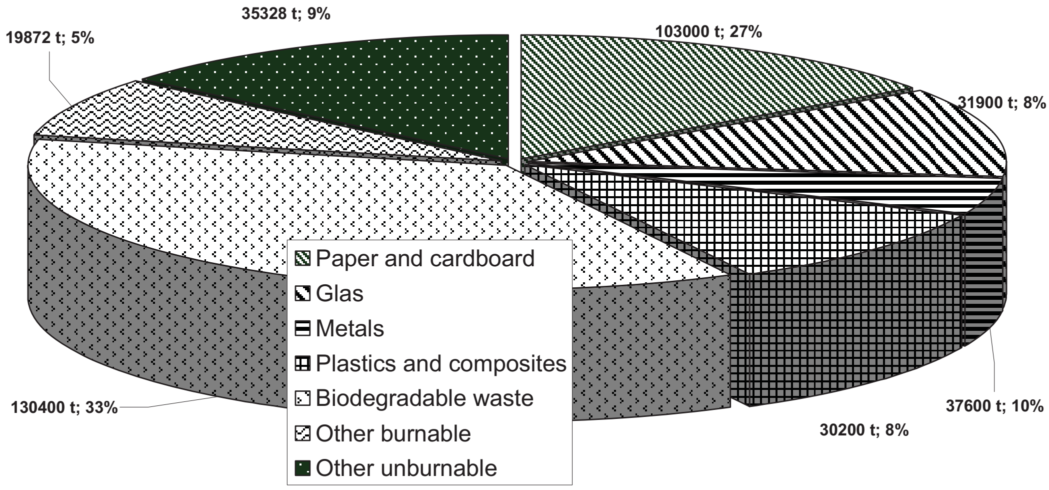

Figure 2 Municipal solid waste generation forecast (2013; Šiauliai, Panevežys, Telšiai and Tauragė waste management regions; Lithuania)

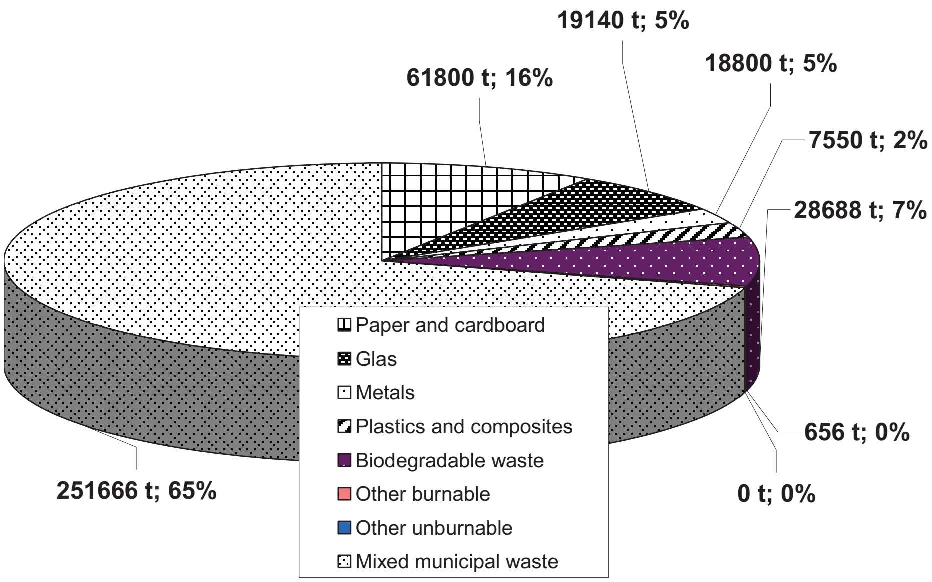

Figure 3 Municipal waste collection forecast (2013; Šiauliai, Panevežys, Telšiai and Tauragė waste management regions; Lithuania)

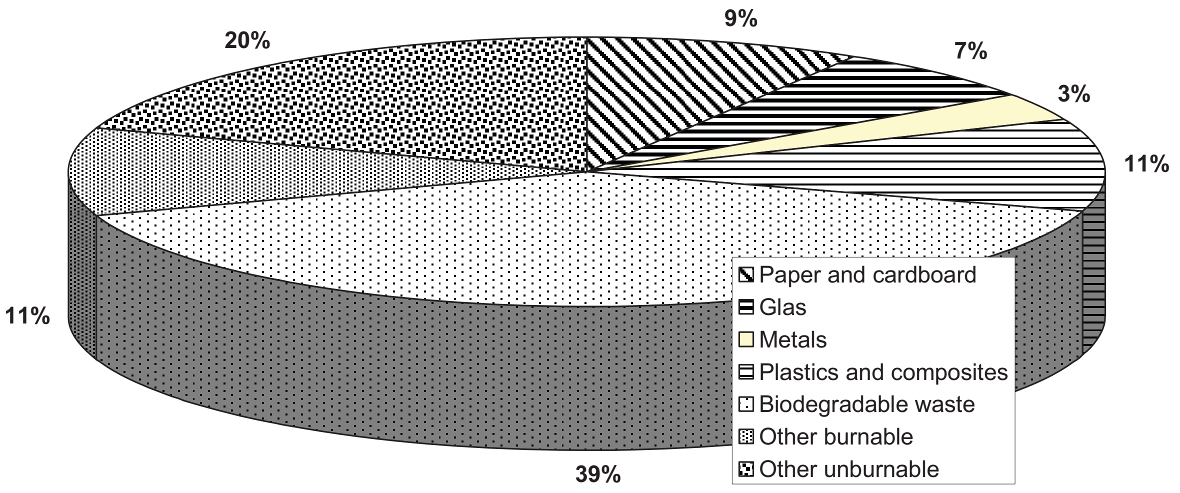

Figure 4 Mixed municipal solid waste content forecast (2013; Šiauliai, Panevežys, Telšiai and Tauragė waste management regions; Lithuania)

3 The alternatives of MMSW management

Furthermore by use of the assessment model with the same name LCA-IWM (den Boer, 2005) the some MMSW management alternatives are assessed and compared energetically and environmentally:

Zero alternative: ***MMSW landfilling.***

In this case the collected residual MMSW are landfilled.

1 alternative: ***MMSW mechanical-biological pre-treatment (MBP) and HCF incineration in cement kilns***

In this case:
- collected residual MMSW are treated mechanically with particularly metals separation and dividing to high calorific fraction (HCF) and low calorific fraction (LCF);
- separated metals go to recycling;
- LCF is treated biologically and the content of biowaste is significantly reduced;
- HCF is incinerated in cement kiln (SC “Akmenės cementas”, Naujoji Akmenė).

2 alternative: ***MMSW mechanical-biological pre-treatment (MBP) and HCF incineration in WIP***

In this case:
- collected residual MMSW are treated mechanically with particularly metals separation and dividing to high calorific fraction (HCF) and low calorific fraction (LCF);
- separated metals go to recycling;
- LCF is treated biologically and the content of biowaste is significantly reduced;
- HCF is incinerated in WIP with energy recovering, the 80% of formed slags is used for construction of ways;
- stabilised LCF and rest slag are landfilled.

3 alternative: ***MMSW incineration in WIP***

I this case:
- collected residual MMSW are incinerated in WIP with energy recovering;
- the metals are separated from formed slag and 80% of slag is used for construction of ways;
- the rest slag is landfilled.

The used assessment tool LCA-IWM evaluate the chemical content, moisture and caloricity of every waste fraction, also the pollutants emissions conditioned by each waste treatment technology (Deliverable, 2003). The tool considers that fire grate technology (as best available technology) with effective gas cleaning system is used for waste incineration. The tool also considers the parts of waste fractions to be divided between HCF and LCF, also the part of biowaste to be destroyed in the biological stage of MBP. The corresponding contents of HCF and stabilised LCF are presented in the Figures 5 and 6.

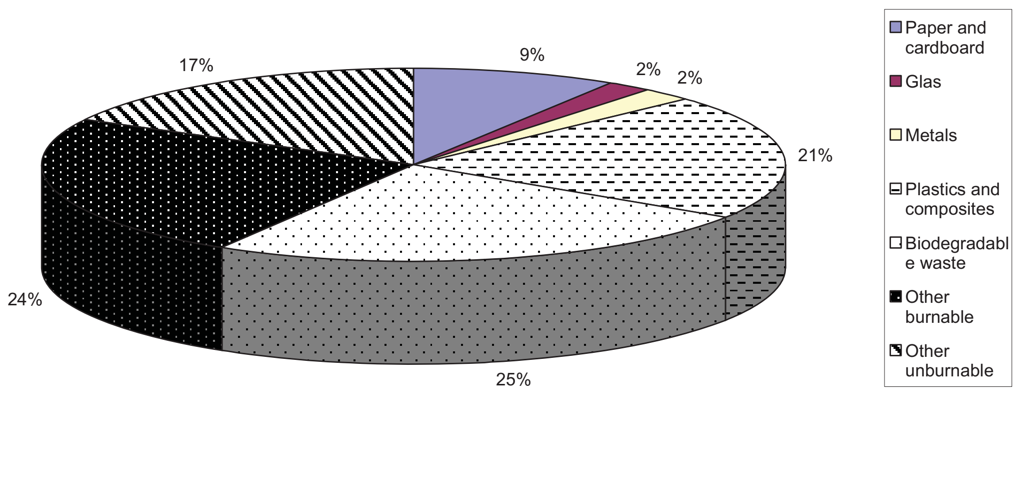

Figure 5 HCF content forecast (2013; Šiauliai, Panevežys, Telšiai and Tauragė waste management regions; Lithuania)

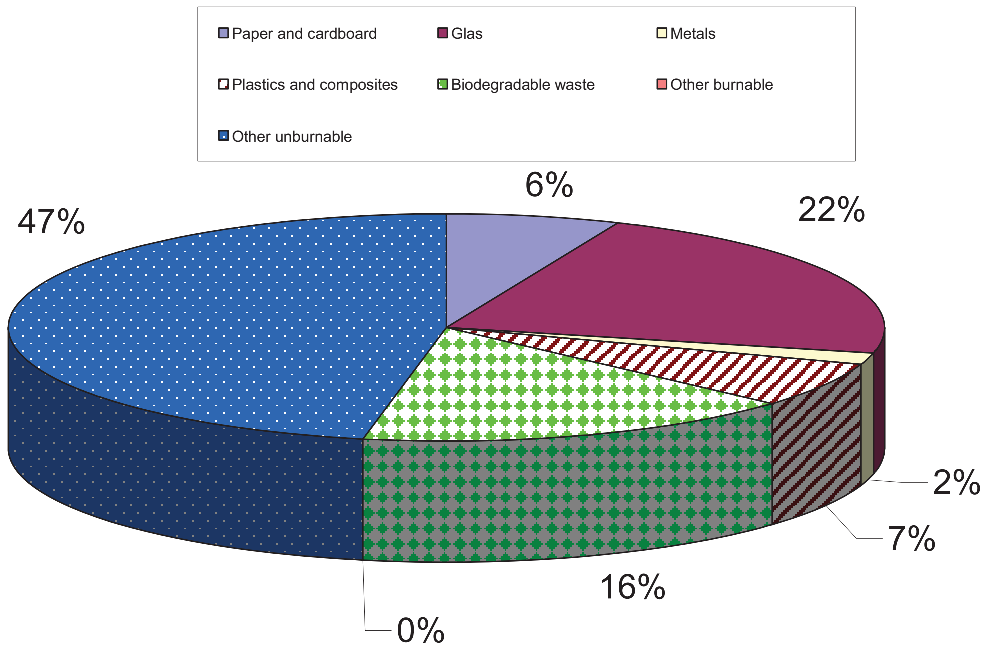

Figure 6 Dry stabilized LCF content forecast (2013; Šiauliai, Panevežys, Telšiai and Tauragė waste management regions; Lithuania)

4 Assessment results

First of all we review the differences of waste and/or waste treatment residues flows to the landfills for every alternative (Figure 7). It is evident that:

- due to MBP and following HCF incineration – 2,8 times;
- due to MMSW incineration - 17 times.

It is necessary to have in the mind that namely biowaste accessing to the landfill with MMSW and/or its treatment residues make mostly environmental impact problems because during anaerobic biowaste digestion the main amount of greenhouse gas (methane CH_4) and toxic compounds is emitted together with landfill gas and leachate. The emissions of these environmental pollutants during waste incineration (considering to gas cleaning efficiency) are significantly lower. Figures 8 and 9 clearly illustrate the advantages of MMSW incineration.

The economic assessment of investigated alternatives is characterised in the Figure 10. So the operating costs for MMSW incineration in the WIP are almost 2 times lower than for MBP. However the corresponding investment costs are about 3 times higher. The costs for exploitation of cement kiln during HCF incineration in the already functioning Lithuanian cement production facility are excluded.

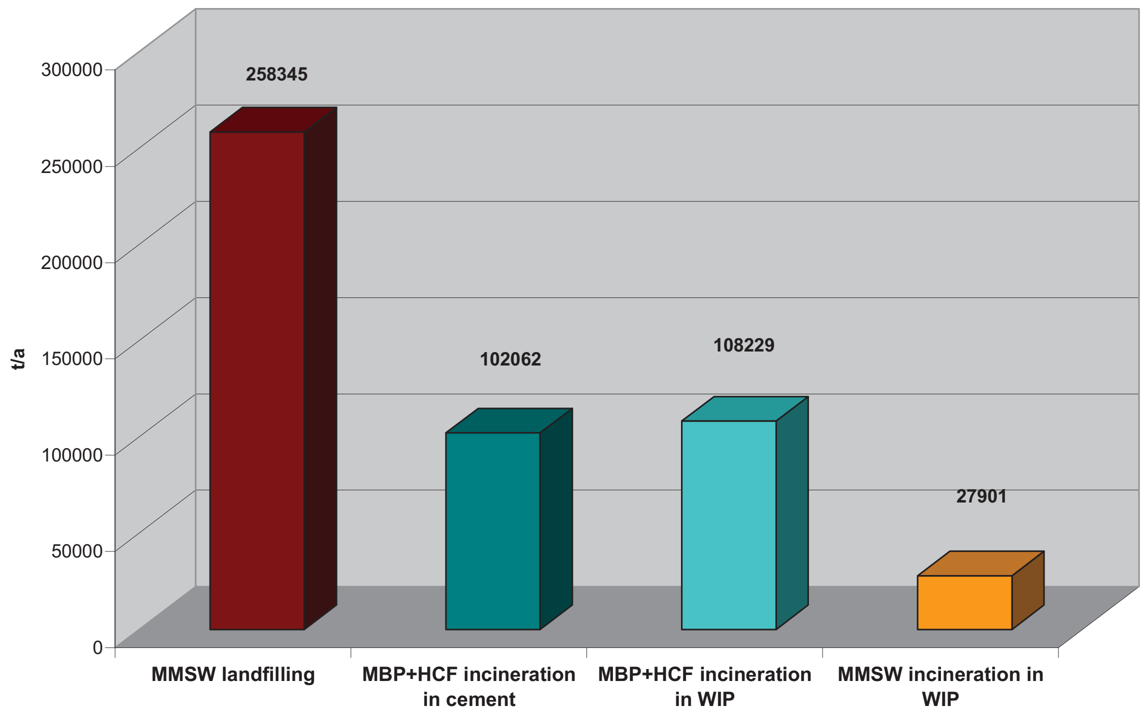

Figure 7 Waste or waste treatment residues flows to the landfill for MMSW treatment alternatives (2013; Šiauliai, Panevežys, Telšiai and Tauragė waste management regions; Lithuania)

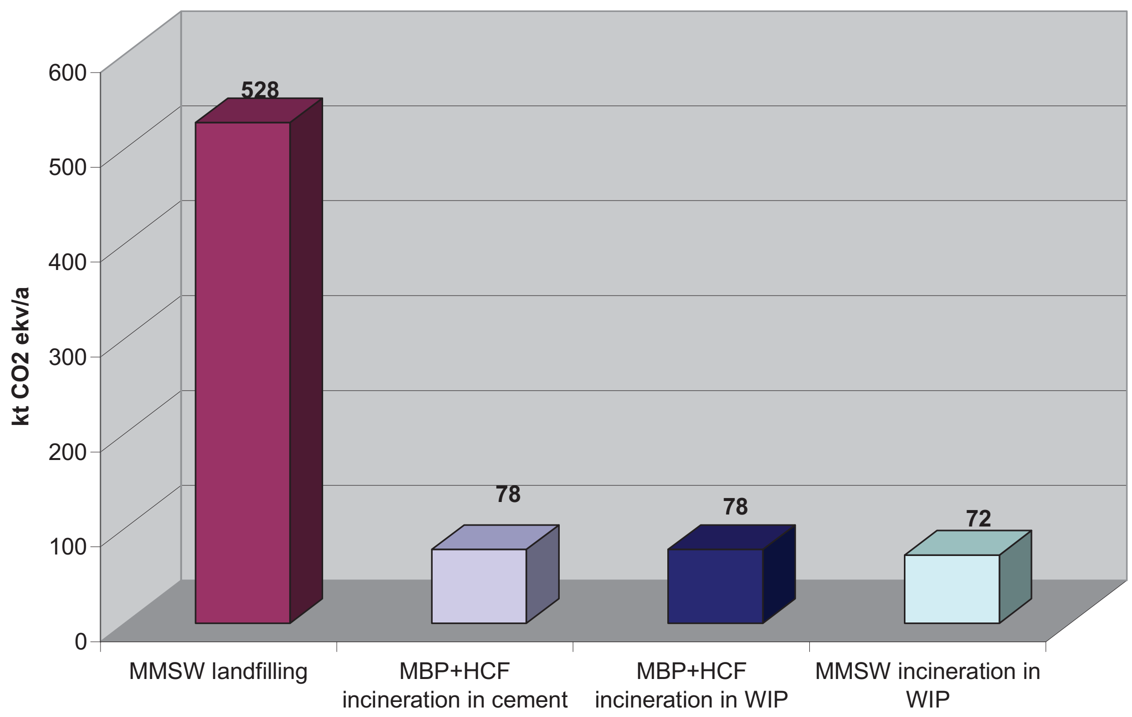

Figure 8 Greenhouse gas emissions for MMSW treatment alternatives (2013; Šiauliai, Panevežys, Telšiai and Tauragė waste management regions; Lithuania)

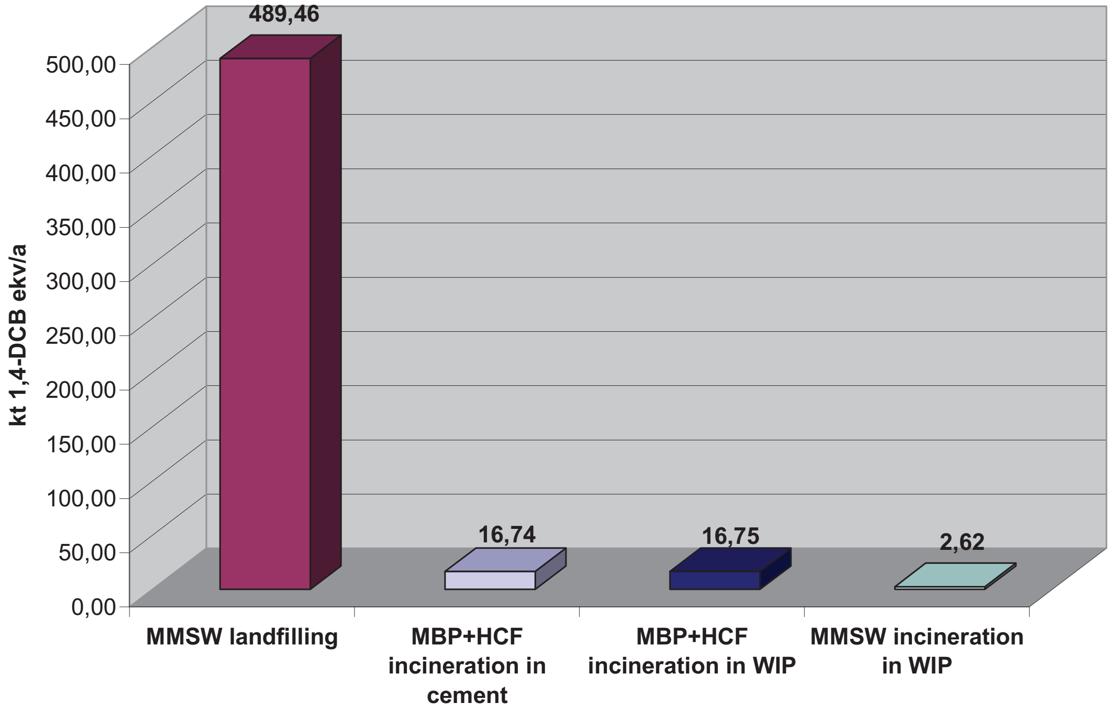

Figure 9 *Human toxicity for MMSW treatment alternatives (2013; Šiauliai, Panevežys, Telšiai and Tauragė waste management regions; Lithuania)*

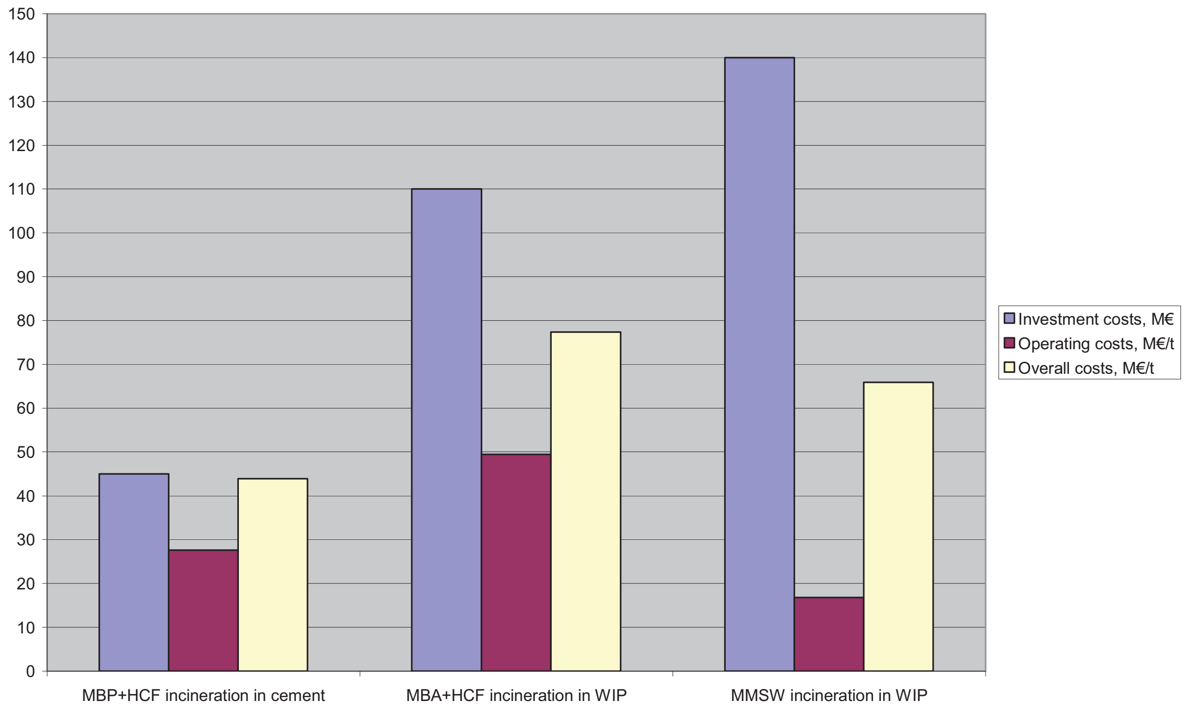

Figure 10 *Possible investment, operating and overall costs for MMSW treatment alternatives (2013; Šiauliai, Panevežys, Telšiai and Tauragė waste management regions; Lithuania)*

5 Conclusions

The performed assessment for Šiauliai, Panevėžys, Telšiai and Tauragė waste management regions in Lithuania shows that:

- Due to MBP process for MMSW and subsequent HCF incineration (both in cement kiln or in WIP) the waste or waste treatment residues flow to the landfill would be reduced about 2,8 times, due to MMSW incineration - 17 times. In comparison with incineration in WIP, HCF incineration in cement kiln reduce the total amount of treatment residues very unsignificantly;
- Due to MBA process and subsequent HCF incineration for MMSW the biowaste flow to the landfill would be reduced 5-6 times, due to MMSW incineration the biowaste flow to the landfill is excluded;
- In comparison with MMSW landfilling the MBP process with subsequent HCF incineration reduce greenhouse gas emissions 7 times, MMSW incineration – 11 times;
- In comparison with MMSW landfilling the MBP process and subsequent HCF incineration reduces the human toxicity 16 times, MMSW incineration - – 232 times.
- In comparison with MBP the economic advantages of MMSW incineration are evident concerning operating costs, however the corresponding investment costs for incineration in WIP are about 3 times higher. HCF incineration in existing cement production facility excludes the costs for construction and exploitation of incineration plant.

6 Literature

Deliverable Report on D3.1 and D3.2: Environmental Sustainability Criteria and Indicators for waste management (Work Package 3).	2003	The Use of Life Cycle Assessment Tool for the Development of Integrated Waste Management Strategies for Cities and Regions with Rapid Growing Economies (LCA-IWM). Contract number: EVK4-CT-2002-00087. – Darmstadt, 2003;
Denafas, G.; Rimaitytė, I.; Seeger, H.; Urban, A.	2003	Potential Contribution of Combustible Domestic Waste to the Energy Supply of Lithuania //Environment.Technology.Resources. Proceedings of the 4th International Scientific and Practical Conference June 26-28, 2003.
den Boer, E.; den Boer, J.; Jager, J.	2005	Waste management planning and optimisation. Handbook for municipal waste prognosis and sustainability assessment of waste management systems. – Ibidem-Verlag, Stuttgart, 2005. P. 283

Denafas, G (Hrsg.)	2006	Preparation of documentation for municipal waste incineration pre-feasibility study (Contract No. 2005/24/A/P/LT). Pre-feasibility study. Volumes I and II. – Kaunas University of Technology, 2006
Rimaitytė, I.; Denafas, G.; Račys, V.	2006	Implementation of Life Cycle Assessment Tools for Evaluation of Municipal Waste Management Scenarios // Environmental Research, Engineering and Management. Kaunas: Technologija, 2006, Nr.2(36), P. 68-76
Wade, A; Denafas, G; Račys, V.; Rimaitytė, I.; Povilaitytė, R.	2006	An Assessment of the variation facility of domestic waste management in Kaunas, Lithuania; A CASE STUDY // Waste Management & Research 24 (1): 27-36 FEB 2006

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Does EU waste legislation comply with the best available MBT technologies?

Indrek Paal

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Abstract:

My presentation is driven by the rejecting attitude we have faced during the establishing process of the very first mixed municipal solid wastes MBT terminal in the Baltic states. During the preparatory phase of the presentation, the presumable cause for the doubts of local Estonian officials became evident – sorry to say, but it all starts from the existing and emerging European legislation. MBT technology, especially processing mixed solid wastes and the subsequent products is described in a number of EU documents that regulate waste handling in a manner that allows them to be held an evolutionary dead-end, if desired. Ecocleaner has been engaged in investigating MBT problems for four years. We operate the Baltic first mixed municipal solid wastes MBT terminal since the 1st of January, 2008. The aim of the presentation is to introduce a possible utilization field that is already tested in practice, and the associated problems.

Keywords:

Municipal Solid Waste & MBT vs Composting & separately collected biowaste

1 Green Paper

1.1 One of the EU waste management basic documents "Green Paper"

… deals with MBT only in connection with operations that are carried out before landfilling mixed solid wastes. The preamble of the legal instrument declares that the strategic target of the EU is turning the EU population into a resource efficient and waste recycling society. At the same time, Articles 3.1 and 4.1 describe a mixed solid waste MBT as a very limited means of waste management. Green Paper instructs to increase sorted waste collection, as the biowastes collected this way are cleaner so that high quality compost or biogas could be produced. It is positive that landfilling is regarded the worst waste management ever and implementing waste hierarchy is underlined as essential.

2 End of Waste Criteria Final Report– Compost Case Study

2.1 Treatment Options

The other EU waste handling document defines the MBT status of mixed solid wastes once again declaring that usually it is not possible to produce quality compost from mixed solid wastes. We would eliminate much of the confusion and misunderstanding if waste handling legislation defined that not only quality compost producing is essential concerning biowaste separate collecting, as for maximal recycling/recovery possibilities of components in mixed solid wastes. As for municipal waste mass components recycling and from the economic point of view, there do exist other equivalent or better solutions.

As regards the environmental as well as the economic aspect, it is important, most essential that hazardous wastes must always be separated from municipal wastes and separately collected biowastes and the management must be more efficient. As for activating raw material reuse and recovery markets, it is important to notice that establishing uniform quality parameters for and supervision over treatment processes of potential secondary raw material products, produced from processed wastes, using whatever methods, including those of inferior quality at a first glance – will enhance trust towards them and create markets for them.

3 What is MBT?

There are a number of versions and perceptions about the Mechanical Biological Treatment, caused by traditions, laws and technical possibilities and ideas. This number is too big! Officials and practitioners often miss the point and it seems that neither party is able to understand the other one.

4 Compost from green waste or MSW

It is completely obvious that during the biodegradation processes there are no ways for plastics, glass or heavy metal residues to be added to the mass. The initial compost mass contains these materials, so such ingredients are included from the very beginning. The fact is that compost enterprises in Germany that have for decades processed biowastes, collected separately, get after producing high quality compost 20 – 60% such slug that could only be incinerated or simply landfilled. The pictures show biodegradable wastes, collected separately in Estonia – left, and the right one shows the MSW. The structure and moisture content of these two materials makes the difference. Based on experiments performed by scientists in Dresden Technical University and my personal experiences, I would state that it is easier to biodegrade the material shown right because oxygen access and water absorption structure, the composition of material and the carbon/nitrogen ratio is better there. I call your attention to the research work ADEME about compost markets in France. There are practically no differences in composts and growing substrates costs but the majority would like to consume them at 0-price.

Caption 1. Separately collected biowaste (left) and municipal solid waste.

5 MBT vs Composting

Although I do not see any difference in these operations as they cannot be separated, the Green Paper considers composting as treatment of separately collected biowastes and MBT as treatment of mixed municipal solid wastes. Still I will try to show the efficiency of the two different approaches in the table below. The given sample is based on Estonian enterprises. In order to achieve the same waste input volume by container composting, at least three up to five times the sum has to be invested. In an Estonian landfill where separately collected biowastes are treated by means of Envicont C900, about 20 000 tons of mixed solid wastes are deposited a year. In spite of the fact that biowastes have been separately collected in the area for several years, there have not been managed to collect it over 1000 tons per year.

Table 1. Comprasion of Ecocleaner MBT and composting container investment costs.

Parameter	**High Quality Compost**	**MSW treatment**	**Territory in use for biodegration**	**Incoming quantity per year**	**Outgoing quantity per year**	**Investment costs /EUR**
MBT with D.O.M.E method	Yes, depends on input material	Yes, main activity	2 ha	up to 35 000 Mt	ca. 60% SRF, ca. 15% Soil Improver, ca 25% CO_2+H_2O	1.5 Mio
Composting with Envicont in-vessel container	Yes, depends on input material	No, landfilling	1,5 ha*	1000 Mt	Up to 60% Fine Compost Residue for landfilling	0.4 Mio

* territory in use for after rotting process with maximum treatment potential up to 5000 mt p.a.

Caption 2. MBT with D.O.M.E. method and Envicont C900 composting container.

6 Waste separate collection and MBT

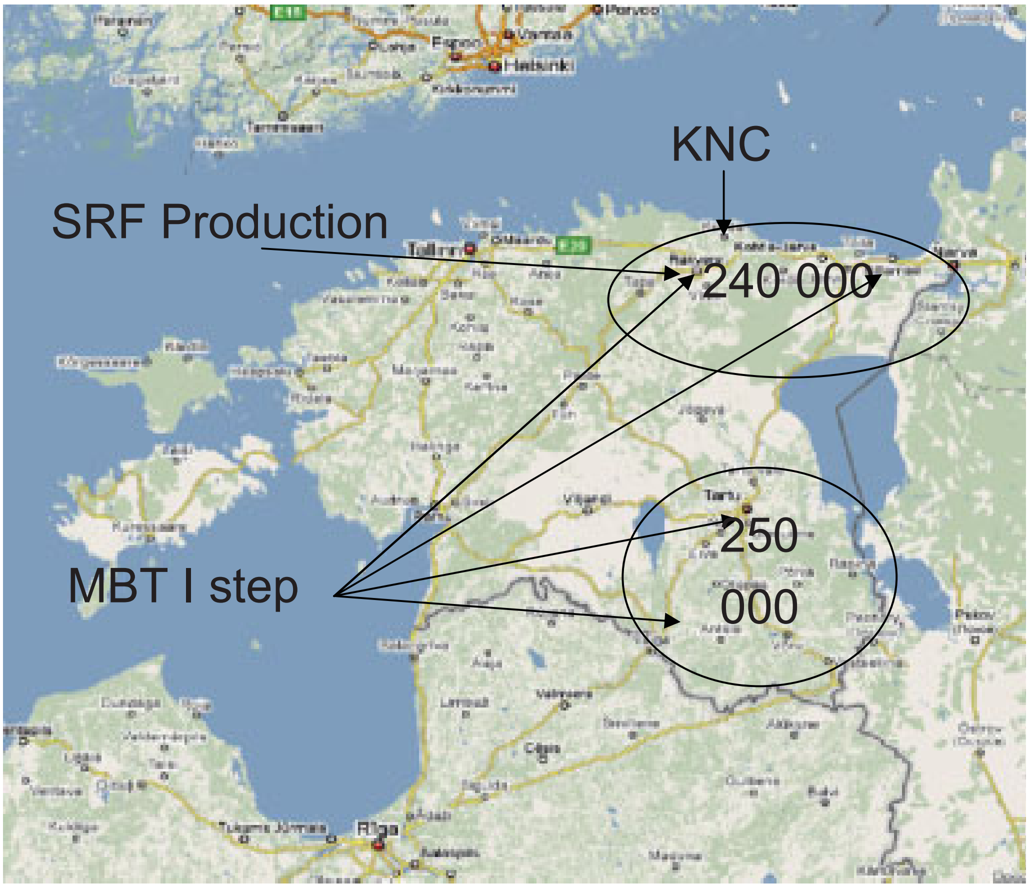
European Union law promotes separate collecting and composting of biowastes and considers the mixed solid wastes MBT technology and its products as low potential matters. The chain of collecting biodegradable wastes by categories is economically more expensive and less effective as it brings about the need for emptying several trashcans at different time (several logistical circles) and composting the material is expensive. Sorted waste collecting is the right approach to waste management in its essence as it enables in most cases to get pure material for recovery operations. Taking into account total expenses, waste collecting by all categories is not the most resources sustainable utilization at all. Estonian experience show that separate collecting of biowastes is uneconomical. Lots of other scraps are thrown into the material and the composting production cost is expensive due to the small amount of wastes located at distant sites in our low density areas. Sorted waste collecting plays an important role in reducing the amount of dangerous wastes that get into mixed solid wastes. According to Estonian Environmental Ministry research completed in September 2008, there could be up to 2% of such supplements.

7 Most cost effective BMT

Ecocleaner develops new BMT (Biological Mechanical Treatment) principles, being extremely cost-effective but at the same time, having quite simple structure and being environmental friendly. The next generation BMT technology aims for not only production of SRF fuel but re-utilisation of maximum of the volume of the material. Depending on SRF fuel certificate and the possible usage, the BMT technology waste recycling rate may reach up to 100%. Ecocleaner operates the BMT, practising covered stacks D.O.M.E aeration method for biodegradation processes, developed in Dresden University and in use in several places throughout Germany. The effectiveness of Ecocleaner BMT is based on performing rational treatment operations that minimize the number of operations (moves) necessary for getting the result. Operational expenses are minimized as the material needs no mixing (turning) during the rotting process and the ventilation does not consume any energy.

7.1 Ecocleaner BMT modul principe – two stages

I will give you an example of how MBT technology would provide real savings. Today, Ecocleaner operates one MBT terminal in Eastern Estonia – that could be named the first MBT stage – biodegradation and mechanical sorting and crushing of part of material are the procedures performed there. Additional three terminals are to be built within a year, located in a way that they would be as near as possible to the Eastern and South-Eastern low-density area waste produces. The second MBT process stage – fragmentation and refining of SRF fuel – is centralised and located within reach from a potential fuel consumer, Kunda Nordic Cement, an enterprise that belongs to the Heidelberg Group. There are ca 240 000 people living in the service area of the terminals in Eastern Estonia and respectively ca 250,000 in the South Estonia. The four terminals are calculated to treat 100,000 tons of municipal wastes a year. The haul distance of fresh wastes (humidity 50-70%) should not exceed 50 km and that of processed raw waste fuel (humidity avg 25%) 250 km. In the coming years, landfills and waste disposal will be our main competitors.



Caption 3. Map of Estonia and Ecocleaner MBT terminals location

7.2 SRF

The main product of BMT terminal, which outcome is up to 60 % of the volume of incoming wastes – is SRF fuel, parameters confirming with criteria of solid recovered fuels certificate CEN/TS 15359:2006, 3rd fuel class that is suitable for co-incineration in cement incinerators.

7.3 Soil Improver

The purpose of BMT terminal is not only to produce SRF fuel but some growing media as well. If the need occurs, the first stage of the terminal may also produce quality compost, provided that local governments arrange waste management so that necessary volume of separately collected biowastes for producing quality compost would be collected.

Subsequently, I would like to call your attention to the analyses of the compost which we produce from mixed solid wastes (MSW). European Commission Decision No 2007/64/EC of 15 December 2006 provides reference data. Figures in the table show that parameters of MSW produced soil improver comply with most of the required compost parameters. Ecocleaner would not be able to meet the quantity demand for soil improver presented in the table up to the year 2014 as Estonia will undergo an intensive process of recultivating landfills not yet meeting the requirements of EU Landfill Directive**.** We have actively started designing our product standard and certification process that will enable to expand the utilization field of the soil improver (producing fertile soil for exhausted quarry lands, peat bogs, industrial production sites, cultivation soil used in road building).

Caption 4. Ecocleaner Soil Improver 20 mm fraction, made 2009, Feb.

Table 2. Ecocleaner soil improver analyses.

Parameter/ Result	**Ecocleaner**	**2007/64/EC Commission decision of 16 Dec 2006**
Cu mg/kg	135	100
Cd mg/kg	1.50	1.0
Pb mg/kg	97.2	100
Hg mg/kg	0.344	1
Ni mg/kg	40.4	50
E.Coli 1g, MPN	48	1000
Salmonella 25 g	Absent	Absent
Helminth Ova 1,5g	Absent	Absent

8 EU laws enable to deny the utility of MBT

All aforementioned was targeted at calling your attention to the fact that the significant EU laws concerning waste management enable to deny the utility of MBT in treatment of mixed municipal solid wastes.

- Article 33 of Waste directive 2008/98/EC states that mixed municipal waste remains waste even when it has been subject to a waste treatment operation that has not substantially altered its properties. The statement gives a cause for regarding the compost produced from mixed municipal waste always as waste with very limited utilization field (the best available case – to be used for covering landfills).
- Today, MBT of MSW is considered to be a questionable technological solution in Estonia.
- Sorted collecting is a necessary and important means in waste management, enabling to get clean materials in order to facilitate the recycling process. But more important than to collect biowastes separately is to reduce the proportion of hazardous wastes in the mixed municipal wastes.
- Despite the EU basic rule – waste hierarchy – the Estonian Parliament processes a draft of legislation which enables to create additional “sure” waste handling solutions for European Union funding to Estonia – establishing of two brand new landfills and expansion of existing five landfills deposit areas.

9 Literature

Archer, E; Baddeley, A.; Schwager, J.; Whiting, K.	2005	Mechanical-Biological-Treatment: A Guide for Decision Makers, Processes, Policies & Markets. Juniper Consultancy Services Ltd. www.juniper.co.uk
European Commission	2006	COMMISSION DECISION of 15 December 2006 establishing revised ecological criteria and the related assessment and verification requirements for the award of the Community eco-label to growing media (2007/64/EC)
European Commission Joint Research Centre Institute for Prospective Technological Solutions	2008	End of waste criteria. Final report. European Communities. ISSN 1018-5593

European Commission	2008	Green Paper on the management of bio-waste in the European Union. {SEC(2008) 2936}. Brussels, 3.12.2008. COM(2008) 811 final
The European Parliament and the Council of the European Union	2008	DIRECTIVE 2008/98/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 19 November 2008 on waste and repealing certain Directives

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The situation of Austrian MBT-plants – a synopsis of data originating from a research project

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Die Situation der österreichischen MBA-Anlagen – eine Zusammenschau von Daten aus einem Forschungsprojekt

Abstract

The target of the FWF-research project (January 2007 to September 2009) is the development of prediction models for the determination of time consuming parameters. Respiration activity, gas generation sum and calorific value have to comply with the limit values of the Austrian Landfill ordinance before landfilling. The prediction models are based on infrared spectral and thermal analyses (differential scanning calorimetry DSC) and multivariate statistics. Due to many advantages these methods are promising tools for the application in waste management practice in the future. In the course of the project many data of all Austrian MBT-plants were generated using conventional and innovative methods. This study gives a short synopsis of the results obtained to date. Similarities and differences between the plants depending on input materials and process operation are presented. Variations of processes in the same plant due to changing operation conditions are visualized by FTIR spectroscopy, thermal analysis and by conventional parameters.

Inhaltsangabe

Das Ziel des FWF-Forschungsprojektes (Januar 2007 bis September 2009) ist die Entwicklung von Vorhersagemodellen zur Bestimmung zeitaufwändiger Parameter. Atmungsaktivität, Gasbildungspotenzial und Brennwert müssen vor der Ablagerung des behandelten Abfalls die Grenzwerte der österreichischen Deponieverordnung einhalten. Die entwickelten Vorhersagemodelle basieren auf infrarotspektroskopischen und thermoanalytischen Untersuchungen (Dynamische Differenzkalorimetrie). Aufgrund ihrer Vorteile sind diese Methoden Erfolg versprechend für die zukünftige Anwendung in der abfallwirtschaftlichen Praxis. Im Zuge des Projektes wurden viele Daten aller österreichischen MBA-Anlagen generiert. Diese Studie gibt eine kurze Zusammenschau der bisher verfügbaren Ergebnisse. Ähnlichkeiten und Unterschiede zwischen den Anlagen in Abhängigkeit von Input-Material und Prozessführung werden gezeigt. Unterschiede der Prozesse innerhalb einer Anlage durch Veränderungen des Prozessablaufes werden durch die neuen Methoden und durch konventionelle Parameter dargestellt.

Keywords

Austrian MBT-plants, material characterization, processes, data evaluation

Österreichische MBA-Anlagen, Materialcharakteristik, Prozesse, Datenauswertung

1 Introduction

1.1 Objectives

Since 2004 pretreatment of municipal solid waste and compliance with limit values according to the Austrian Landfill Ordinance has been required. In terms of reactivity and gas forming potential biological parameters are in the focus of interest. The calorific value provides information on careful separation of plastics and additionally on progressing degradation. The research project (1/2007-9/2009) concentrates on the development of prediction models for the time-consuming biological parameters (respiration activity and gas generation sum) and for the determination of the calorific value. The models are based on infrared spectroscopic and thermo-analytical investigations in association with multivariate statistics (Partial least squares regression). During the project approximately 300 samples originating from the 16 Austrian MBT-plants were collected. Apart from spectral and thermal analyses and the corresponding reference tests samples were additionally characterized by conventional parameters to complete the data set and to give a comprehensive survey of Austrian MBT-plants.

The huge data pool provides a basis for the assessment of process operation and of input materials. Due to the detailed insight weaknesses can be revealed.

1.2 Sampling and Applied Methods

The sample pool comprises materials of different degradation stages, from input materials to landfilled MBT-waste. Sampling took place several times over a period of one year to get information on seasonal variations. Samples and plants are marked by capital letters.

At the beginning several months were spent on sample preparation. The small sample amount for spectral and thermal analyses requires particle sizes <0,2 mm. Several steps of chopping, cutting and milling were necessary to obtain representative residue-free samples and reproducible results.

Conventional analyses such as water content, loss on ignition, total carbon, total nitrogen, NH_4-N and NO_3-N, carboxylic acids (C2-C5), pH and electrical conductivity were determined according to Austrian Standards. Biological tests (respiration activity and gas generation sum) were carried out from the fresh sample (BINNER et al. 1998). Humic acid extraction was performed according to GERZABEK et al. (1993). FTIR spectra were recorded in the mid-infrared range (4000-400 cm^{-1}) using the KBr pellet technique (MEISSL et al. 2008). Thermal analysis was carried out according to SMIDT and TINTNER (2007). Data evaluation was supported by multivariate statistical methods (Brereton 2002) using the Unscrambler Camo 9.2 software.

2 Results and Discussion

2.1 Characterization by conventional parameters

Figure 1 (a, b, c and d) illustrates the box plots of data obtained from all Austrian MBT-plants. The box plots indicate the minimum, the maximum, the median and the 25% and 75% quantile of the measured parameters. Abbreviations: TN = total nitrogen (% DM), EC = electrical conductivity (mS cm^{-1}), LOI = loss on ignition (% DM), TOC = total organic carbon (% DM), RA_4 = respiration activity within 4 days (mg O_2 g^{-1} DM), GS_{21} = gas generation sum/ 21 days (NL kg^{-1} DM); WC = water content (% WM), C2-C5 = sum of carboxylic acids, HAc = acetic acid only. The parameters WC, LOI, TOC, TN, pH and RA_4 comprise 280 to 300 samples, the other ones 100 samples, EC: 45 samples.

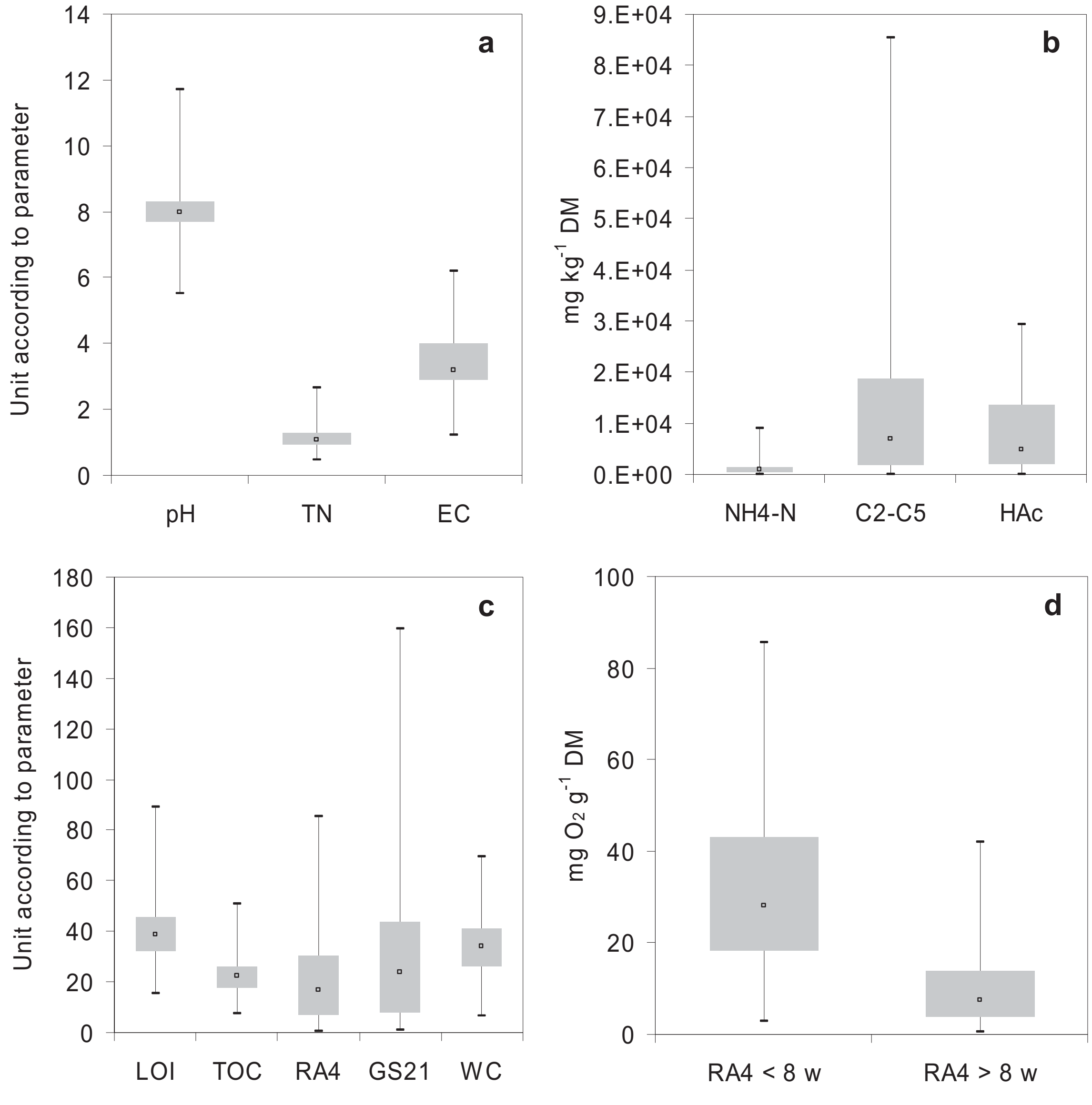

Figure 1 Box plots indicating the minimum, the maximum, the median and the 25 % and 75 % quantile of the measured parameters

The box plots visualize the range of the determined parameters from initial to final MBT-waste. Although carboxylic acids and NH_4-N are in general early metabolic products they were also found at later states of the biological treatment with high variability in the same plant. An unequivocal reason such as changes of material composition, could not be identified. Acetic acid contributed most to the sum of carboxylic acids (C2-C5). Figure 1d displays the range of respiration activities depending on the duration of biological treatment (< 8 weeks and > 8 weeks). It is clearly visible that most of the materials shift to respiration activities < 14 mg O_2 g^{-1} DM after 8 weeks. After an 8-week-treatment 12 materials reached the limit value of 7 mg O_2 g^{-1} DM.

2.2 Development of the loss on ignition and respiration activity during the biological treatment

The most noticeable decrease of the loss on ignition took place within the first 4 weeks, then it decreased continuously up to approximately 20 % DM (minimum: 15.4 %). Figure 2 demonstrates the development within the most intensive rotting phase. It has to be emphasized that the development is assembled by samples from different charges.

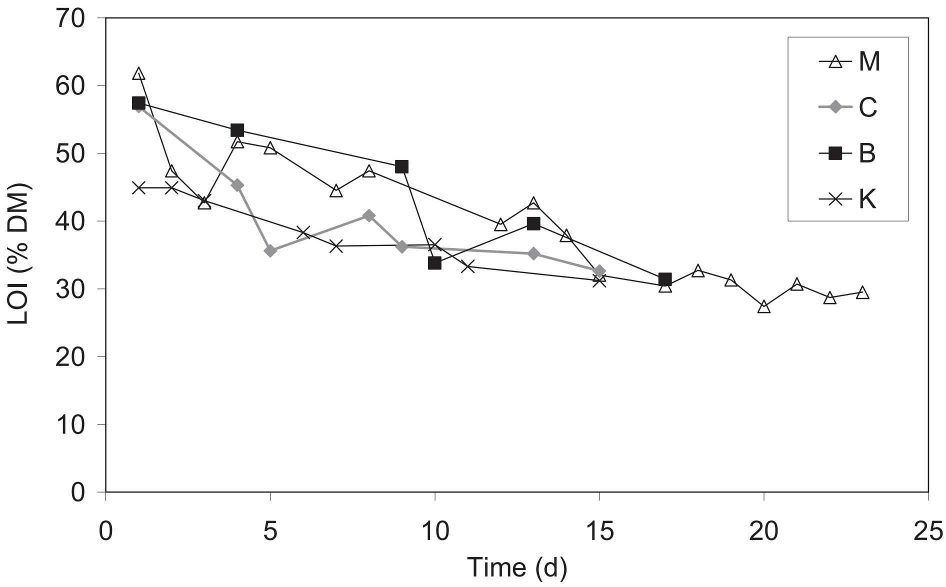

Figure 2 Development of the loss on ignition (LOI) in several selected MBT-plants

Compared to the loss on ignition (Figure 2) and the TOC (not shown), the gradient of the decreasing respiration activity is stronger. After two weeks microbial activity became weaker causing the curve to flatten. The subsequent decrease of respiration activity proceeded slowly. Figure 3 illustrates the particular decline of respiration activities depending on process operation. Plant “O” features a steep decrease due to strong aeration during 3 weeks. After 3 weeks the heavy fraction is separated from the light fraction. The light fraction comprises a considerable amount of organic matter that is combusted. The heavy fraction is landfilled.

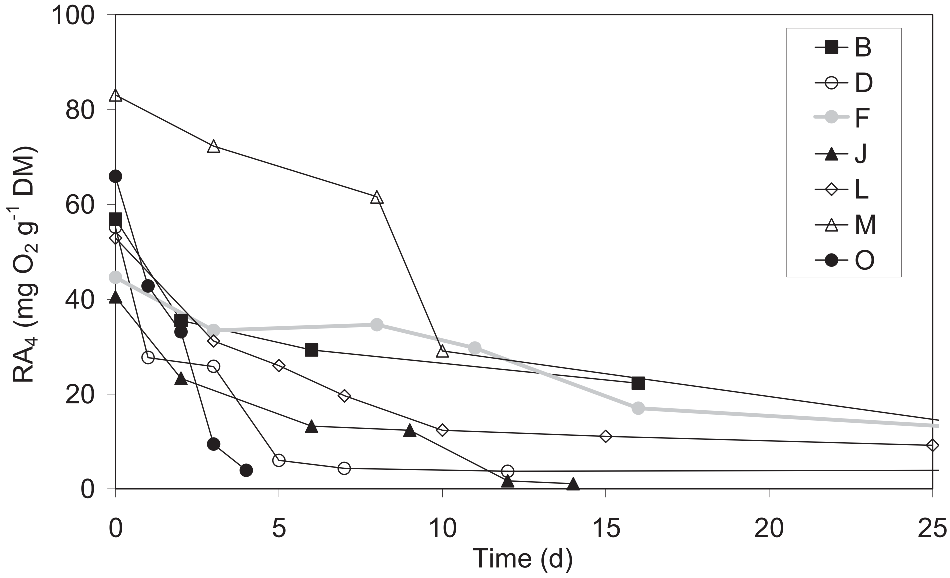

Figure 3 Development of respiration activities in several selected MBT-plants

2.3 Comparison of "landfill fractions"

Comparison of final materials intended for landfilling reveals the variability between different MBT-plants and between charges of the same plant. Data presented in Figures 4 and 5 (TOC and respiration activities) of the MBT-plants "F" and "O" visualize the differences. In general process conditions affected material properties more than seasonal diversity of input materials.

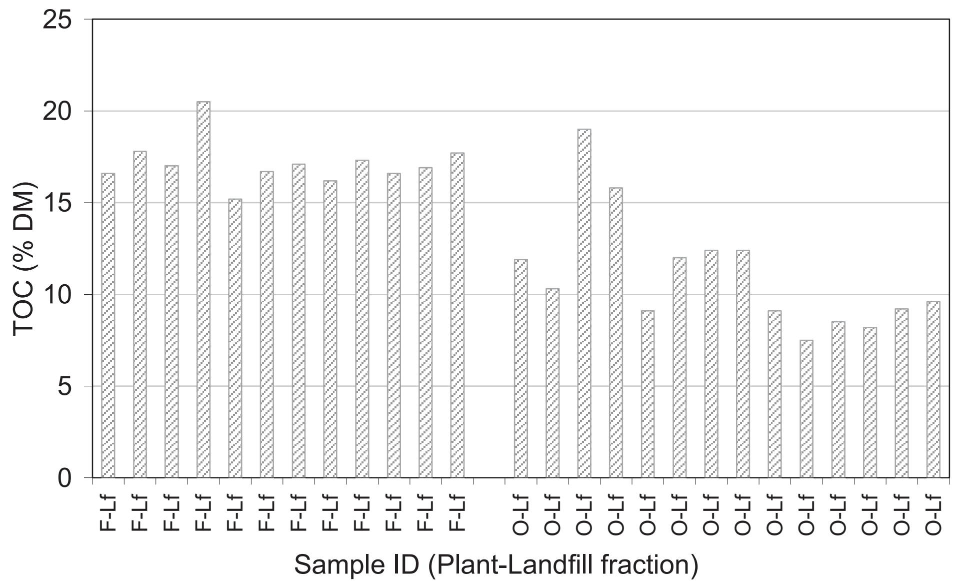

Figure 4 Variability of TOC in „landfill fractions" from two MBT-plants (F-Lf and O-Lf)

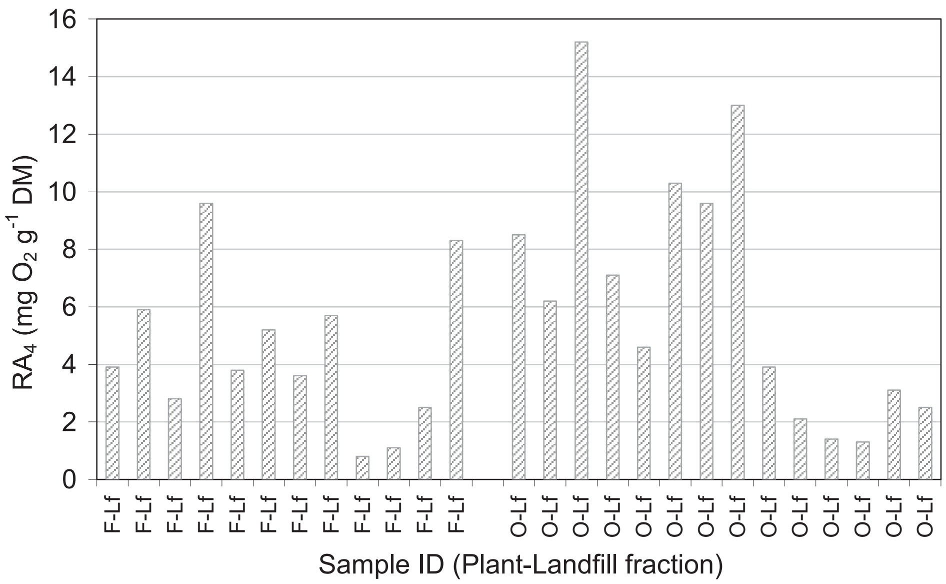

Figure 5 Variability of respiration activity (RA_4) in „landfill fractions“ from two MBT-plants (F-Lf and O-Lf)

In some cases the limit value of respiration activity (7 mg O_2 g^{-1} DM) was exceeded which led to closer inspection of process operation and process conditions.

2.4 Correlation of conventional parameters - evaluation

Parameters that were determined for all samples (LOI, TOC, TN, RA_4, pH, calorific value) were subjected to a principal component analysis to find out the relation among each other. The correlation loadings plot indicated a correlation between LOI and respiration activity. The calorific value was closer to the TOC than to the LOI. No correlation was found between LOI and TN, and all parameters and the pH.

Usually applied sum parameters such as LOI and TOC provide a rough estimation of a progressing process. They are less appropriate to compare different processes.

Considerable humification took place if the biogenic fraction was processed with MBT-waste. Biogenic materials contribute appropriate ingredients and therefore support humic acid formation. Stabilized MBT-materials feature in general humic acid contents of 10 to 12 % ODM. Humic acid contents of 28 % and 29 % were determined in MBT-waste “M” and “P” where biogenic waste is not separated. MBT-waste “M” additionally comprises sewage sludge. This fact confirms the hypothesis that biogenic materials contribute significantly to humic acid formation.

Determination of parameters such as NH_4-N, NO_3-N and carboxylic acids that is based on elution of the solid fresh sample are sensitive in terms of reproducibility. Composition and texture affect the elution behavior considerably.

2.5 Process conditions

The progress of the biological stabilization process depends on inherent properties of the material and process conditions. Material properties can be marginally influenced. Therefore attention is primarily paid to process conditions that need adaptation to specific requirements of the treated material in order to effectuate well running processes. Figure 6 displays data of gas measurements in the heap of two MBT-plants “F” and “G” (CO_2, CH_4 and O_2). Methane and CO_2 were still present in aged materials. Oxygen was missing in most cases.

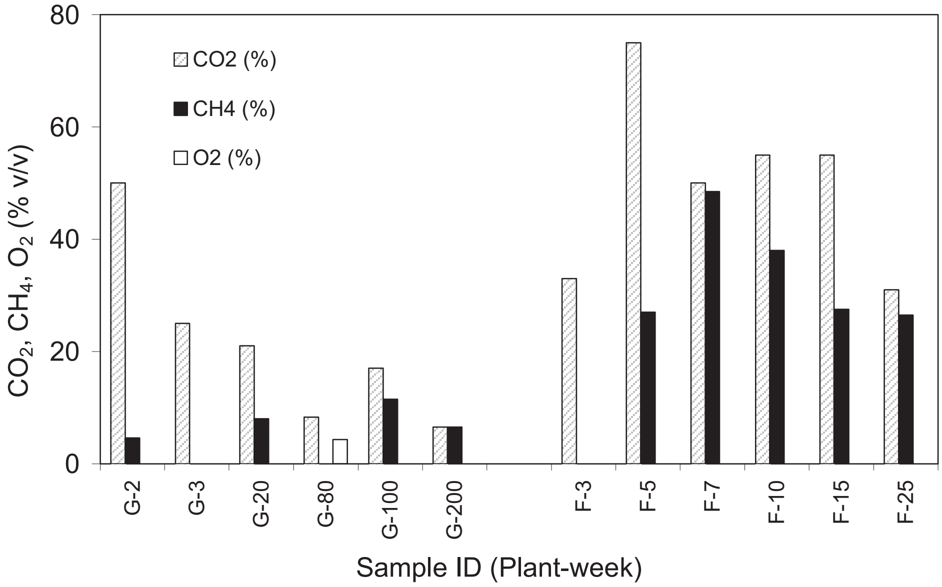

Figure 6 Measurement of gas composition in the heap at different stages of the biological treatment (MBT-plants “F” and “G”)l

In most cases inadequate air and water supply are responsible for retardation of the biological process and odor nuisance. Clogging of holes in the aeration system often prevent sufficient aeration. Water deficiency leads to weight saving, which might be preferable sometimes. However, dryness pretends stability that is disproved by biological tests.

2.6 Application of FTIR spectroscopy and thermal analysis

2.6.1 Characterization of MBT-waste by the spectral and thermal pattern

FTIR spectroscopy and thermal analysis provide comprehensive information on waste materials due to many data points that characterize the material. A principal component analysis (PCA) based on spectral and thermal data of all samples revealed that MBT-waste in Austria is not as different that it can be unequivocally assigned to each MBT-plant. The variety due to different degradation stages is more significant than the variety caused by different input mixtures. Nevertheless, specific features influence the position of samples in the scores plot. Figures 7 a and b show the PCA of (a) spectral and (b) thermal data (heat flow profiles). Clustering of samples is obvious. Samples „D“ represent the material of the typical MBT-plant (municipal solid waste being partly rid of biogenic waste). In plant „M“ municipal solid waste is processed with the biogenic fraction and sewage sludge. Plant “O” processes the typical MBT-waste, but applies a special technique as described in section 2.2. Fresh materials are located in the right corner. Progressing stabilization causes samples to shift to the left side as indicated by the arrow. Samples “O” are similar to samples “D” at the beginning. After separation of the “light” fraction samples are primarily located in the left corner.

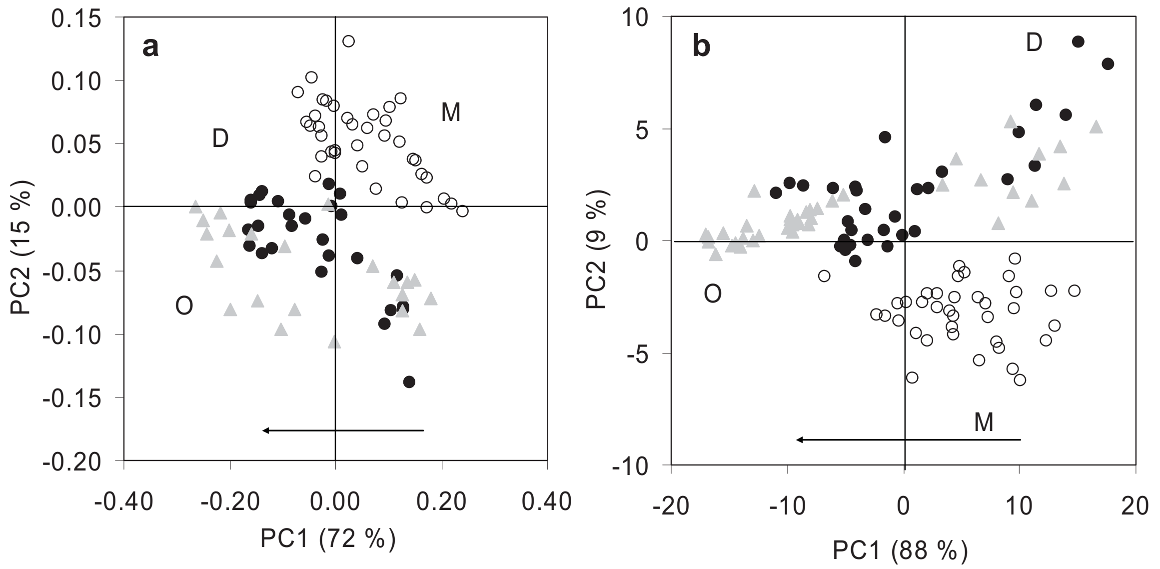

Figure 7 PCA based on (a) spectral and (b) thermal data of three MBT-plants (D, M, O)

2.6.2 Prediction of respiration activity, gas generation sum and calorific values

Multivariate statistical methods are helpful tools to evaluate huge data pools. Partial least squares regression has been used to develop prediction models of respiration activity, gas generation sum and the calorific value. These parameters are reflected by the infrared spectrum and the heat flow profile respectively. The development of prediction models is based on this correlation and requires large data pools. Model validation is performed by independent data sets to guarantee the validity of the model for all defined MBT-materials. Figure 8 demonstrates the correlation between the heat flow profiles and the calorific value that is a precondition within the scope of the preparatory work.

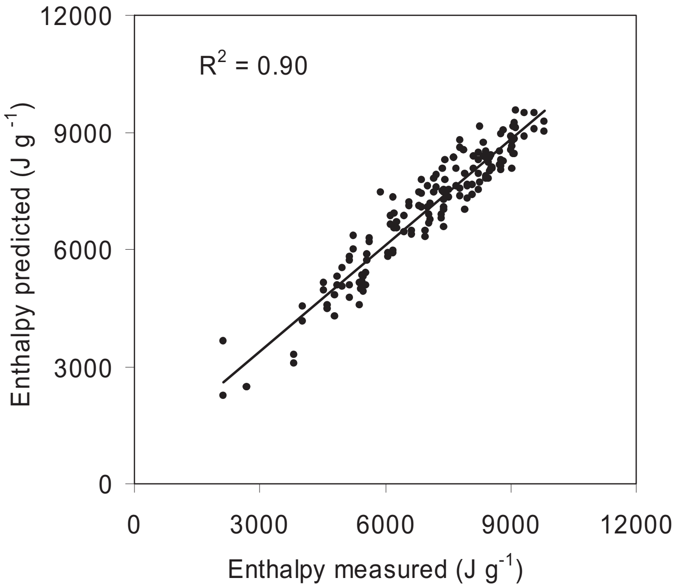

Figure 8 Correlation between the calorific value determined by the bomb calorimeter and by the heat flow profile

2.6.3 MBT-landfills as carbon sinks

Based on the data obtained the role of landfilled MBT-waste as carbon sink is assessed. For this purpose the determination of TOC is not sufficient. Due to diverse aspects of organic matter stability the term needs specification. The thermal behavior of materials seems to be a reliable indicator of stability. A current research topic focuses on the definition of “internal” stability that is an inherent property of waste and less dependant on environmental conditions. The correlation between decreasing enthalpy in the whole system, increasing enthalpy of remaining organic matter and bioavailability will be elucidated in future projects. Table 1 compiles data of enthalpies referring to dry matter (DM) and organic dry matter (ODM) of MBT-waste (3 weeks, 12 weeks, 120 weeks), landfilled municipal solid waste (MSW, 30 years) and an agricultural soil.

Table 1 Enthalpies of MBT-materials referring to dry matter (DM) and organic dry matter (ODM); w = week, y = year

Enthalpy	MBT 3 w	MBT 12 w	MBT 120 w	MSW 30 y	Soil
J g^{-1} (DM)	6,892	4,966	4,333	3,627	3,532
J g^{-1} (ODM)	14,733	21,286	24,718	33,245	48,920

3 Conclusion

So far the largest part of the project has been carried out. As shown by principal component analysis the composition of municipal solid waste in Austria does not differ considerably, neither by regional nor seasonal factors. Addition of sewage sludge or special treatment procedures cause a specific pattern that is identified by infrared spectroscopic and thermal analyses. Difficulties of biological treatment are primarily caused by unfavorable conditions for microbial activity, especially missing air and water supply. There is a potential of optimization in some cases. The development of adequate analytical methods that are fast and easy to handle is a crucial target to support process control. FTIR spectroscopy and thermal analysis are promising tools to achieve this purpose. They could replace several time consuming and error-prone parameters. The sampling procedure and sample preparation are still current topics to get reliable results.

It can be assumed that the improvement of separation technologies leads to a more homogenous organic fraction that is transformed to stable organic matter by biological processes. Optimization of internal stability is a target to be reached by appropriate process operation. In association with mineral compounds MBT-landfills will represent substantial carbon sinks in the future.

4 References

Binner, E., Zach, A, Widerin, M., Lechner, P.	1998	Auswahl und Anwendbarkeit von Parametern zur Charakterisierung des Endproduktes aus mechanisch-biologischen Restmüllbehandlungsverfahren. Schriftenreihe des Bundesministeriums für Umwelt, Jugend und Familie, Wien, pp. 147.
Brereton, R.G.	2002	Chemometrics: Data analysis for the laboratory and chemical plant. John Wiley & Sons Ltd., Chichester, England, pp. 489.
Gerzabek, M.H., Danneberg, O., Kandeler, E.	1993	Bestimmung des Humifizierungsgrades. In: Bodenbiologische Arbeitsmethoden. Schinner, F., Öhlinger R., Kandeler, E., Margesin, R., Eds., Springer Verlag, pp. 107-109.
Meissl, K., Smidt, E., Tintner, J.	2008	Reproducibility of FTIR spectra of compost, municipal solid waste and landfill material. Applied Spectroscopy, 62/2, 190-196.
Smidt, E. and Tintner, J.	2007	Application of Differential Scanning Calorimetry (DSC) to evaluate the quality of compost. Thermochimica Acta 459, 87-93.

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Advances in waste processing and diversion from landfill in Australia

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Abstract

In Australia, economic growth over recent years has increased waste generation rates per capita beyond levels that would normally be attributed to population growth. On the positive side, an increased focus on recycling and waste minimisation by State and Local Governments has meant that waste recovery rates have been increasing at a much greater rate than waste generation rates, reducing the growth rates of waste disposal to landfill.

Economic instruments such as high waste levies in some states have also made recycling more attractive and supported the introduction of alternative waste technologies (AWT), which are seen as providing more sustainable long term disposal arrangements than landfills. The proposed introduction of a Carbon Pollution Reduction Scheme (CPRS) that covers methane emissions from landfills has provided increased focus on non-landfill based solutions.

Alternative waste technologies are expected to be the main focus for improved processing and resource recovery of municipal wastes in the immediate future. There is scope to extend this to commercial wastes. In NSW, there are already three AWT facilities in operation, two more being built and two more planned to be operating by 2010.

This paper discusses current progress in implementing AWT in Australia, and provides an update of recent projects and factors driving the implementation of new waste technologies in Australia.

Keywords

Alternative waste technology, AWT, sustainable waste management

1 Waste generation and recovery rates

In Australia, the amount of waste being produced and disposed of per head of population has progressively increased every year over the last decade. This has been mainly the result of a strongly growing economy, and higher standards of living.

1.1 Waste generation rates

High disposable incomes in the capital cities such as Sydney, Melbourne, Brisbane and Perth have meant higher personal consumption of food and material goods in those cities. Accordingly, the waste generation rate has risen by approximately 7% per annum, outstripping population growth during this period, which was of the order of 1.6% per annum. This is illustrated in Table 1.

There were significant improvements in levels of waste recovery (13.6% per annum) over this period. This resulted in the overall level of waste disposal only increasing by about 3.2% per annum on average between 1999-2000 and 2004-5. The annual growth in waste generation is expected to have slowed due to the effects of the economic downturn, although no data is yet available to verify this.

Table 1 - Growth of waste generation and recovery in Australia

	1999-2000	**2004-2005**	**Increase (%)**	**Ave annual increase (%)**
Tonnes generated (millions)	28.4	38.4	35%	7.0%
Tonnes recovered (millions)	10.5	17.6	68%	13.6%
Tonnes disposed to landfill (millions)	17.9	20.7	16%	3.2%

Source: WCS, 2008

Over the years, there have been slow improvements in the percentage of waste diverted from landfill, although the overall tonnages to landfill have increased. In 1999-2000, about 28 million tonnes of waste were generated, with 39% of this recovered and 61% disposed of to landfill. In 2002-3, approximately 32 million tonnes of waste was generated across the country, of which approximately 46% was recovered, and 54% was landfilled, as shown in Table 2. By 2004-5, more than 38 million tonnes of waste were being generated in Australia each year, with approximately 48% recovered, and 52% of this disposed of to landfill.

According to the Productivity Commission (2006), the quality of Australian waste management data has traditionally been quite poor. Each State and Territory collects and reports data differently, and there are gaps in the coverage of regions, waste streams and materials. Caution must therefore be used when comparing Australian waste generation, landfill and recycling rates with those of other countries. There is currently no national approach to sustainable waste management, as the Federal Government has traditionally left the management of non-hazardous wastes to the States and Territories.

1.2 Waste strategies

Most States and Territories have some form of waste management and recycling strategy. The New South Wales (NSW) Waste Avoidance and Resource Recovery Strategy set targets for Councils and businesses, as shown below in Table 3.

Table 3 - Targets from the NSW Waste Avoidance and Resource Recovery Strategy (2003)

Outcome area	Target
Preventing and avoiding waste	To hold constant the total waste generated for the next 5 years.
Increasing recovery and use of secondary resources	By 2014, to: Increase recovery and utilisation of materials from the municipal sector from the current 26% to 66% Increase recovery and utilisation of materials from the commercial & industrial sector from the current 28% to 63% Increase recovery and utilisation of materials from the construction & demolition sector from the current 65% to 76%

Source: DECC (2003)

1.3 Waste levies

To provide additional incentives for diverting materials from landfill and recovering resources, some States have introduced landfill levies, although these levies vary considerably between States. Some of the revenue collected is used to fund government waste minimisation programs.

A waste levy rate of A$47/tonne applies in the Sydney, Australia's largest city. (In contrast, a waste levy of A$15/tonne applies in Melbourne, Australia's second largest city). The State Government of NSW has stated that this levy will increase at a rate of A$7/tonne each year until it reaches A$57/tonne. Thereafter, annual increases will depend upon inflation.

2 Alternative Waste Technologies

2.1 Development

Mixed waste composting systems (such as Bedminster) were the first types of alternative waste technologies to be introduced to Australia. However, marketing of mixed waste derived compost for agricultural applications proved to be difficult, because of concerns about product contamination.

In 2001, a tunnel composting plant to process separately collected garden waste into high grade compost products was commissioned by the waste company Rethmann (now Remondis) at Port Macquarie, on the North Coast of NSW. Later, food waste was also separately collected, and composted at this plant, with good results. The compost product from this plant is successfully marketed to residential and commercial customers.

This same plant also used its tunnel composting technology to treat the residual waste from the residential collections, with an intention of producing a refuse-derived fuel (RDF). However, this initiative was never commercially viable, since there were no obvious customers for the RDF, and the treated residual waste is simply landfilled.

Anaerobic digestion of separately collected commercial food wastes had been undertaken since approximately 2001, at the Earthpower plant in Western Sydney. However this plant struggled to attract commercial wastes, due to low costs of landfilling (at the time) and much of the material that the customers delivered was highly contaminated with non-organic wastes. The processing costs were therefore quite high, and the plant did not ever reach design capacity.

The largest AWT facility to be built in Australia to date has been the Global Renewables plant at Eastern Creek. This is an anaerobic digestion plant with a mixed municipal waste feedstock. This plant was highly engineered, and very sophisticated, but there were issues with large quantities of lead acid car batteries received in municipal waste deliveries. While the plant produces green energy to feed into the electricity grid, the mixed waste compost it produces has proved difficult to market.

The most recent AWT facility to be commissioned in Australia is the Ecolibrium facility at the Macarthur Resource Recovery Park in Southwestern Sydney. This uses the Arrow Bio technology from Israel. Another AWT facility, the SITA Advanced Waste Treatment (SAWT) facility at Kemps Creek, in Sydney's west is now being commissioned. The ArrowBio plant uses anaerobic digestion for organics processing, while the SITA plant uses mixed waste composting technology to produce a mixed waste compost for rehabilitation of the Elizabeth Drive landfill site, where it is located.

Table 4 - Summary of alternative waste facilities in Australia to 2009

AWT Facility operator	Location	Approximate annual throughput (tonnes)	Type of technology	Year in operation
SITA (formerly Bedminster)	Port Stephens (NSW)	30,000	MWC	1999
Atlas	Stirling (WA)	100,000	MWC	2000
Earthpower	Camellia (NSW)	80,000	AD	2001
Remondis	Port Macquarie (NSW)	30,000	SOC/MWC	2001
SITA (formerly Bedminster)	Cairns (Qld)	50,000	MWC	2003
Global Renewables	Eastern Creek (NSW)	180,000	AD/MWC	2004
SMRC (formerly Bedminster)	Canning Vale (WA)	120,000	MWC	2004
WSN	Macarthur (NSW)	90,000	AD/SOC	2008
BioMass Solutions	Coffs Harbour (NSW)	40,000	SOC/other	2008
SITA (SAWT)	Kemps Creek (NSW)	120,000	MWC	2009
Conporec	Mindarie (WA)	100,000	MWC	2009
Anaeco	Shenton Park (WA)	30,000	AD	2009
TOTAL		970,000		

AD = anaerobic digestion, MWC = mixed waste composting, SOC = organics composting

It is widely believed that the NSW Waste levy has provided a significant driver for wider adoption of alternative waste technologies in Sydney, as there are more AWT plants operating in the Sydney area than in any other capital city. (There are no plants in Melbourne where landfilling prices have been very low and the waste levy is only A$15/tonne).

Recently, the gate fees for Sydney's major putrescible waste landfill sites reached a level of A$150/tonne for the first time (including A$47/tonne levy). This makes the treatment of waste (estimated cost A$100-$140/tonne) much more cost effective than landfilling of mixed waste, which should result in an increased number of new AWT plants built in Sydney over the next few years.

However it is clear from current data that there are unlikely to be enough AWT facilities commissioned and operating in NSW before 2014 for the NSW Waste Strategy targets for municipal waste (refer Table 3) to be achieved. Also there are insufficient economic drivers to force commercial wastes to be diverted to AWT facilities, so it is unlikely that the commercial waste targets will be met either.

Even in Sydney, where landfill charges are the highest in the country, the cost of waste disposal for businesses is still relatively low compared with other more significant operating costs, such as labour and rent.

Private consortiums and existing waste companies responding to tenders from Local Government have built most of the AWT plants in Australia to date. Generally Councils have entered into contracts with these service providers for periods ranging from 10-20 years. The contracts are for financing, construction and operation of the AWT facility, with the Council (s) agreeing to direct all municipal waste that they or their contractors collect from residential areas to the plant for this contract period, and often to pay an availability fee to cover the financing costs of the plant, plus an agreed rate per tonne of waste received. In some cases, Councils have also provided the land and environmental approvals for the successful tenderers.

There are no AWT facilities currently operating in other capital cities, such as Brisbane and Melbourne. However, the Victorian State Government is currently examining the best way of introducing AWT into Melbourne, through its Victorian Advanced Resource Recovery Initiative (VAARI) scheme. This may eventually result in State Government assistance or incentives for establishing three such plants in the Melbourne metropolitan area within the next 5-10 years.

2.2 Other drivers for reducing waste to landfill

One of the most significant drivers for encouraging AWT processing of municipal and commercial wastes in Australia will be the proposed introduction of the Federal Government's Carbon Pollution Reduction Scheme (CPRS). From July 2010, the introduction of the CPRS will mean that there will be a price placed on carbon dioxide and five other greenhouse gas emissions including methane.

This is the first time in the world that waste has been included in an emissions trading scheme. The European system does not include waste, however in Europe there are other drivers that are not in place in Australia, such as the European Landfill Directives, that reduce the amount of untreated waste going to landfill.

The cost of carbon pollution permits is projected to be around $23 per tonne in 2010/11 when the CPRS is due to commence. An emissions price cap will be set at $40 per tonne in 2010/11 and will rise by 5 per cent above CPI each year for the first five years thereafter. The scheme is designed to link with international markets and other trading schemes that generate Kyoto compliance permits. Liable parties will not be subject to any quantitative limitations on the number of Kyoto compliant permits that they use.

Specific implications of the CPRS for waste sector operators include direct liability for fugitive emissions and therefore a requirement to purchase and acquit permits. Waste operators may also have a direct liability for fugitive emissions.

Features of the scheme that affect waste facilities include:

- Landfill facilities that emit 25,000 tonnes CO2-e a year or more will be required to purchase and acquit permits for each tonne of CO2-e emitted;
- A participation threshold of 10,000 tonnes CO2-e or more will apply to landfill facilities that are operating in proximity to another operating landfill (criteria to be determined);
- Emissions from landfill sites closed prior to 30 June 2008 will not be covered;
- Liability for emissions from past waste streams (legacy waste) will be excluded from the Scheme until 2018;
- Legacy emissions will need to be reported and counted towards a facilities' Scheme participation threshold; and
- Methane that is captured will be allocated proportionally between legacy and new emissions.

The introduction of the CPRS will increase the cost of operating landfill facilities, by an estimated A$5 -A$15/tonne, depending upon the throughput and whether the sites have existing landfill gas management systems. This cost increase is not significant in Sydney, where a landfill levy of A$47/tonne already applies, and overall gate fees are approximately A$150/tonne.

However, in many rural areas where landfill gate fees are still relatively low ($30-$50/tonne), the CPRS liability could have a dramatic impact on the costs of operating waste management systems. This may encourage greater source separation of wastes, and adoption of lower cost AWT systems such as food and garden waste enclosed composting.

2.3 The Future of AWT in Australia

Despite AWT facilities becoming more common in Australia, there is still a high degree of scepticism about the claims made by many technology providers about the performance of AWT facilities generally. The technical and commercial failure of technically complex plants such as the SWERF gasification plant in Wollongong has created a lack of trust in AWT facilities. Even plants using relatively mature technologies such as the Bedminster process have had technical issues. Local Councils are conservative by nature and therefore wary of new technologies of any type.

Therefore they are inclined to select technologies that are either well proven in Australia, or overseas. Any technology provider seeking to market waste technologies in Australia must be aware of this. However, there is a general lack of awareness in Australia of more than the handful of technologies that are currently used in this country. There are opportunities for European technology providers with a strong track record of many years of successful operations in Germany or other countries with a large number of operating facilities to enter the Australian market, especially if they partner with a local waste company.

Due to issues faced by plant operators who are trying to market mixed waste compost, the likely future trend is towards energy production, rather than composting technologies. Therefore there are likely to be more anaerobic digestion plants built to serve the major cities. In regional centres, it is more likely that food and garden waste composting plants will be adopted, because of their simplicity and lower costs, and reliable local markets for high grade agricultural compost.

As mentioned previously, there have been difficulties in directing commercial wastes to AWT facilities without laws in place to make this happen, and this is a big challenge in trying to meet State waste strategy targets. One possible solution that has been canvassed is for operators of municipal waste facilities to “top up” their plant throughputs, with commercial waste. Some facility agreements with Councils already allow this, with Councils receiving royalties or a share of the profit associated with commercial customers using their facilities. Businesses with corporate sustainability objectives are interested in diverting a high percentage of their waste from landfill, and maximising their recycling achievements, so there are a number of potential customers in the market.

In Europe, a large number of the waste processing plants produce refuse derived fuels (RDF) from waste, for energy production. None of the current AWT plants in Australia do this. There are commercial reasons, such as lack of markets for the material and lack of purpose built facilities for these fuels.

It should be mentioned that there is considerable reluctance to build and operate any type of thermal waste treatment plant in Australia. There are concerns that dioxins and other pollutants could increase health risks to surrounding populations. Hence siting of such a facility would be problematic. Hence it seems most likely that co-firing of RDF in cement kilns and power stations on a small scale will be the main application for RDF from waste facilities in future.

3 Summary

This paper has examined the current progress, drivers and possible trends in alternative waste technologies in Australia. Whilst there are many AWT plants being built, it is likely that rate of completion of new facilities will be slower than required to meet State waste strategy targets, and that commercial wastes will continue to be difficult to attract to these facilities.

4 Literature

DECC (2003),	Waste Avoidance and Resource Recovery Strategy 2003, Department of Environment and Climate Change NSW
Productivity Commission 2006	*Waste Management*, Report no. 38, Canberra. ISBN 1 74037 208 5
WCS (2008)	The Blue Book – Australian Waste Industry 2007-8 Industry and Market Report , WCS Market Intelligence 2008
WSN Environmental Solutions	Waste Services and Charges, Issued 2 Jan 2009

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The management process in development of the secondary resources market on a regional level in Russian Federation

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Abstract

In the Russian situation of forming the market relations the urgent problem concerning the waste treatment can be resolved for the expense of guiding the development of process of the wastage capitalization and consumption. The resolve of this problem implies the introduction of the market infrastructure elements into the sphere of waste treatment on a territorial level subject to principles of the governmental environmental protection policy, the strategy of socio-economic development and territorial and geographical features of a region[1].

Keywords

The wastage, the waste capitalization, the regional government, a market of secondary resources, the business-infrastructure, the geo-informational system (GIS), the ecological management.

Over last years of reforms following the economical growth and rise of the population's incomes the situation in the sphere of wastage treatment has become more acute because of an increase of waste' sizes and their accumulation. The precedents to resolve of the waste problems in market conditions have become possible through the waste capitalization process without the legal provision. The waste containing valuable components in the form of chemical elements and substances obtained the real cost and changed into claiming commodity resource. In fact the competition in the sphere of waste treatment in regions has developed according to rules of a spontaneous market on the basis of "the fast money" principle.

Activity in the sphere of waste treatment have become attractive for commercial and municipal structures because of inexhaustible secondary resources, their specific variety and guaranteed financial provision. The nomenclature of the waste taking place at enterprises of Russia includes more that 200 denominations appointed by the Federal Classification Catalogue of Waste (2002). However sizes of collected and reprocessed secondary resources in Russian Federation are small. The market of macklepaper is

[1] In this working the totality of wastage and consumption are analyzed as a secondary material resources suitable for further usage (capitalization).

opened up on 30%, the cullet market – on 15–20%, the aluminum package – on 5–10%, the polymeric package – on 5%.

The man-caused resources represent the unused reserve material base that is a source for ecological ill-being at a territory. As a whole these resources are not estimated, calculated and managed by regional and municipal levels of government. The situation is conditioned by imperfection of Russian legislation and its normative-legal base, long-term reorganization of governmental services on the environmental protection and the ecology. On the other hand this situation is conditioned by insufficient competence, sluggishness and poor understanding of the reforms in socio-economic life for a part of many State and municipal employees.

The verge between terms “waste” and “the secondary resources” is relative. It changed depending on a level of technique-economic potential of a society, the economic expediency and technological opportunities in the treatment and usage of the waste. Taking into consideration a rate of influence of governmental structures to the economy and a rate of technological development, the verge “waste” – “secondary resources” are defined by proprieties that a society has in the person of legislative and executive power bodies.

In modern Russia the qualitative change of functions at regional and municipal levels (dependent on territories) occurs. Step-by-step an attention is concentrated on the resources’ capitalization at a territory that is on an increase of the capitalization‘s assets cost. Actions are concentrated not only on the steady raising of the rate of production plant when functions of economically free subject have been changed but also on the creation of conditions for opening the personal initiative and attracting the market mechanisms to opening up the waste treatment and consumption.

Republic of Karelia as an independent subject of Russian Federation has preconditions to the socio-economic development such as advantageous geographical and geopolitical location, an essential natural- resources potential, an industrial orientation in the structure of the Karelian Republic’s economy, the dynamical development of priority-driven natural-exploited branches and accompanied productions, a developing transport infrastructure, an experience in the international activity realization (a statistics, the Customs, banks, etc.), high-skilled workers presence, a favourable ecological environment. At the same time Republic of Karelia has problems in the sphere of an intensive increase of waste’s sizes, a necessity to organization of infrastructure for the economic activities associated with keeping, collecting, neutralization, transportation, allocation and treatment of waste of all five ranks of danger.

A rise of the business activity in the Karelian Republic is accompanied by a process of an intensive waste formation. For example a size of shipped production has increased in 2007 in comparison to 2004 in 1,8 times whereas a growth of a waste's formation was 1,6 times (from 70026,775 thousand of tons in 2004 to 106379,220 thousand of tons in 2007). The negative trend is confirmed by an increase of the waste's size on one Ruble in the Gross Regional Product – since 4,9 kg of the waste in 2004 to 6,4 kg in 2007. In addition a specific stability of factory waste remains. The modern technologies in budgetary and municipal enterprises specializing on use and skin-deep treatment of local natural resources are slowly introduced. A growth of the waste's size at enterprises of the key natural-exploited branches of Republic is conditioned by an external economic activity characterizing by a structural unbalanced correlation between streams of goods and services. In 2004 the export size exceeded the import one to 4,3 times. The export structure in Republic consisted in most cases from raw materials and production with low level of recycling. The import of the Republic in 2004 was characterized a number 19% in foreign trade turnover; the machine-building production was characterized by a number 61% in the goods structure. Until 2008th year the situation hasn't changed significantly.

According to statistical data for the last three years, there is more than 100 millions tons of waste generated by enterprises of the Karelian Republic annually. In 2007 there were 740 enterprises at the territory of Karelia (Table 1).

Table 1 The dynamics of the waste's formation and consumption in the Karelian Republic for the period since 2004 to 2007 years, thousand of tons

Ranks of danger	A size of the waste's formation			
	2004	**2005**	**2006**	**2007**
The rank 1	0,071	0,041	0,051	0,039
The rank 2	0,236	0,178	0,136	0,091
The rank 3	39,49	28,912	25,183	19,099
The rank 4	554,096	573,061	2014,161	693,553
The rank 5	69432,883	100916,498	99689,118	105666,437
Sum total	70026,775	101518,690	101728,648	106379,220

There are such extremely dangerous wastes as worked-out quicksilver-containing lamps and apparatuses, condensers with trichlorobenzene, transformer oil leavings containing polychloride diphenyls in the group of "the 1 rank". Almost 90% of the 1st rank's wastes are removed to Saint-Petersburg and Scherepovetc with the aim for reprocessing because there are no special plants on treatment of quicksilver-containing waste in the Republic.

The high dangerous waste of the 2nd rank is characterized as worked-out accumulator acid and alkali, accumulators with electrolyte. Generating waste of the given rank of danger (almost 95%) as a usual are used again (as well as the secondary raw materials in the form of non-ferrous metals) or are neutralized by means of a neutralization of electrolyte.

A medium dangerous waste of the 3rd rank is characterized as worked-out railroad sleepers, oils, emulsions and petroleum product mixtures, contaminated mazut and firm soil, bird’s dung. These wastes (a size to 75%) are neutralized and used again. There is a strong tendency to bury a medium dangerous waste in a size 9% from the overall mass of annual formation.

A less-dangerous waste of the 4th rank is characterized as a mineral waste forming in the process of extraction and reprocessing of the non-metallic minerals, the rind waste, and domestic waste form an enterprise’s activity. Almost 98% from the rind is used as fuel resources for heat-recovery boiler pulp and paper plants in the Republic. A level of a less-dangerous waste’s use rises for the expense of extension of stone-working waste sizes.

The non-dangerous waste of the 5th rank consist a bigger part from the overall volume of waste in the Karelian Republic (to 99%). For the most part there are such non-dangerous waste as the mining’s waste and the ore minerals reprocessing waste at enterprises of the mining production – 98%. In this case use of waste consists only 6%. These wastes are used for a quarry’s covering, a dam’s quarry, roads’ ballasting and the building materials’ production. The main mass of waste (95%), the stripping rock and the concentration tails, is located into a dumpnation and tails-storage. There are more than 1100 millions of tons in the depths. The main problem for nature-exploiting enterprises is a rise of level and an economic effectiveness from the complex use of multi-component raw minerals. The waste from the mining branches are characterized as large-capacity ones. This circumstance leads to a situation when large territories of land resources are allotted for organization of firing ranges, dumpnations and storages for the deposition and the burial of the waste. Following enterprises are classified as large pollutants: public corporations – “Karelsky okatysh”, “Kondopoga”, “Segezhsky CBK”, ”CZ Pitkyaranta”, “LFK Bumeks”, “NAZ-SUAL” and the private corporation “Petrozavodskmash”.

The waste forming it the sphere of housing and communal services are characterized by the waste form the mechanical and biological cleaning of sewage (to 50%) and solid domestic waste (to 50%). Only 3% of the waste form the mechanical and biological cleaning of sewage is used. Other wastes are allocated on dumps of solid domestic waste (to 60%) or are kept on the sit areas (more than 100 thousand of tons are accumulated).

Almost all volume of the solid domestic waste from industrial enterprises and population are buried on the waste allocation objects sited at territories of municipal formations in the Republic (130 dumps, 1 firing range – 380 hectares). Having being a factor of the environment pollution, dumps of the solid domestic waste contain valuable components: the mackle-paper, the polymeric materials, the ferrous and non-ferrous metals, and the glass. During the process of warehousing these materials are lost for the further use as the resources.

The waste allocation objects' screening allowing to estimate availability and opportunity for utilization of the waste as a secondary resource hasn't been carried out. The system of collection and allocation of the solid domestic waste and some kinds of industrial waste existing in municipal formations requires a cardinal reconstruction.

The pollution of the Karelia's territory by the waste of all ranks of danger has a strongly pronounced local character. In general the waste accumulation occurs on the waste allocation objects: at enterprises of Kostomuksha, the Kondopoga district, Petrozavodsk, Segezha, Pitkyaranta and Sortavala, as well as on dumps of the solid domestic waste within the bounds of functional zones of settlements.

The Department on the Technological and Ecological Control in Republic of Karelia functioning as a subdivision of the Federal Service on the Ecological, Technological and Atomic Control in Russia carries out a control in the sphere of regulation of permissible influence on the environment at a territory of Republic. The Department determines the administrative regulations defining a procedure, rules of the licenses for the waste allocation, the methodical rules on the standards elaboration, a procedure of the work organization on the dangerous waste certification.

One of the main conditions for getting a license is a leaving of a copy of a license on the activity for collection, usage, neutralization, transportation and allocation of the dangerous waste.

In the Karelian Republic 490 nature-consumers have the license for the waste allocation. A limit for allocation is defined as 108821,535 thousand of tons. At the same time 25 specialized organizations and enterprises (private corporations "Interkamen", "Nord Inter House", the public corporation "EckoLint") carry out a collection, utilization and reprocessing of such waste as a plastic, a mackle-paper, a polymeric waste, a scrap metal, auto bodies, exhaust accumulators, a rubber waste, a quicksilver-containing waste at a territory of Karelia.

Reprocessing a waste having features of a specific rank of danger is specified by the maintenance of requirements on the ecological safety. As a result an entrepreneurial aim is defined by not only a maximization of profits. A growth of a profits' rate in firms specializing in the sphere of the waste circulation depends on a rate of satisfaction of the consumers' needs and the users, a public responsibility and formed image, the technical effectiveness and rate of labour productivity, use of innovations in the secondary resources' reprocessing. Nevertheless an entrepreneurial aim is achieved for the expense of the business adaptation to the environment. In this case an essential rate of risk (from the positions of market demand and supply, he price determination) can be eliminated by the regional power bodies potentially interested in the waste capitalization and consumption. An advantage for the regional power bodies is essential because the inexhaustible resources are involved into the production and the ecological statement of the environment is improved, the employment of the population also increased.

According to the legislative norms, the costs on the waste allocation and consumption in within the bounds of the fixed limits are related to the cost price of the products commodities. The cost price is defined according to permissible standards of the waste formation, technical indicators and the limits of allocation according to a rank of danger. If an exceeding of established norms and limits occurs, enterprises make payments from the available profits. As a result the principle "a pollutant pays" is realized. Payments must execute a stimulating function and must orient enterprises to implementation and organization of closed cycles of production, to the recycling of the industrial wastes. However at the modern stage of socio-economic development the given economic instrument doesn't stimulate a secondary use of the waste.

Based on the analysis and prognosis of situation in the sphere of the waste reprocessing and consumption, the forming system of the institutional management in the sphere of nature-usage in the Karelian Republic and overall tendencies in the socio-economic market development, the effective method allowing resolving the problem «the waste» is development of the waste capitalization process. The capitalization is a process of the waste transformation into the required material resources for the expense of creation of conditions for the business sphere. In this case it is possible to organize the waste commercialization in the form of transfer of some transaction costs form the business sphere to the regional administrations' competence. The market is conditioned by the demand and supply for goods and services. On a level of a region, it is necessary to form supply and demand on the basis of guiding the economic agents' behavior through a change of their motivation to usage of the waste. This guiding is possible on the basis of principles of economic interest, industrial and territorial cooperation, the market infrastructure development and institutional frames in municipal and regional government. The given position allow to "transfer" the waste from the category of factors having negative influence upon natural and social capital of a territory into the factors contributing a growth and development of the secondary resources' market in a region. Thus the waste capitalization is analyzed as a process of the waste transformation to the real actives. The capital in the form of material resources is used for an innovative activity. As a result the waste in the form of an economic loss is transformed into the secondary resources realized for a new production creation in the future.

A mechanism of the waste capitalization on a regional level is analyzed as a process anticipating a realization of complex of arrangements in the two-level system (the regional level and level of independent economic subjects). The given arrangements allow involving the waste into the market turnover. The given mechanism is based on a use of methods, tools and the impact controls to the process of the secondary resources market development and brining in innovations to this sphere of activity.

A preparation of the waste to the realization is carried out on a micro level. The conditions to the maximum profitable realization of the waste are created on a meso level for the expense of the regional business-infrastructure development.

A basis for the waste involving into the exchange process is the geo-informational system (GIS) "The Waste" that is an innovative instrument of regional government by the waste capitalization process development.

The GIS is oriented to the complex and systematic monitoring of the process in the sphere of the waste recycling and activity occurring on a level of a region, municipal formations and other subjects of the North-West Federal District for informing interested users of GIS. GIS will provide the automatized registration of data on the waste formation on a regional level and the registration of all components of the regional list of the waste, the regional list of the waste allocation objects, and the data bank of the waste, the bank of technologies in use and neutralization of the waste.

The GIS having integrated with existing data bases and systems of production control will be able to give out an analytical information concerning formation, accumulation and allocation of the waste on the basis of a cartographical material of municipal formations of Karelia subject to transport schemes of Karelia and information concerning an estimation of a pollution rate at territories.

The GIS will also allow to use an information according to lists of the waste with address-geographical fixation, to resolve logistic problems (a search and analysis of optimal routes for transport movements of the waste, to execute analysis of spatial distribution of industrial dumps and firing areas in a region, to define sanitary-protective zone in territories and zones of responsibility of dependent organizations. The given scheme will become an instrument of regional and municipal government in process of recycling and capitalization of the waste on the basis of expert-analytical estimation concerning the sanitary-ecological situation in the Republic. The GIS will provide an opportunity to have analytical information for an effective realization of business tasks. First of all this system will be interested for users carrying out the main and additional activity at various stages of the waste recycling.

The mechanism of the waste capitalization includes arrangements associated with the business development in the sphere of the waste recycling and realization of production received from the secondary resources; with preferences in the form of non-repayable services on a search of investors, potential consumers and pre-investment planning; with organization and development of territorial co-operation on the waste recycling and reutilization; with creation of the republican portal as an electronic exchange of the waste transfer in the Internet.

As enlarged form it is possible to embody the waste capitalization process in the form of the algorithm (Figure 1).

The main elements of the algorithm are arrangements contributing the waste market development in the Republic.

The system of the waste recycling at a territory defining a behavior of the waste's owners is formed during the process of the algorithm's realization. On level economic subjects an obligatory preliminary ecological analysis with the aim of the waste certification and an enterprise's waste eco-balance (organization of calculation and control in the sphere of waste's formation) is carried out. Real standards of the waste's formation and limits concerning their allocation (a control of the waste's recycling) are elaborated. Simultaneously the elaboration of project of the waste recycling and a training of a stuff working with the waste are executed. An enterprise has got a license on the given type of activity and disposes of the waste according to a commercial expediency.

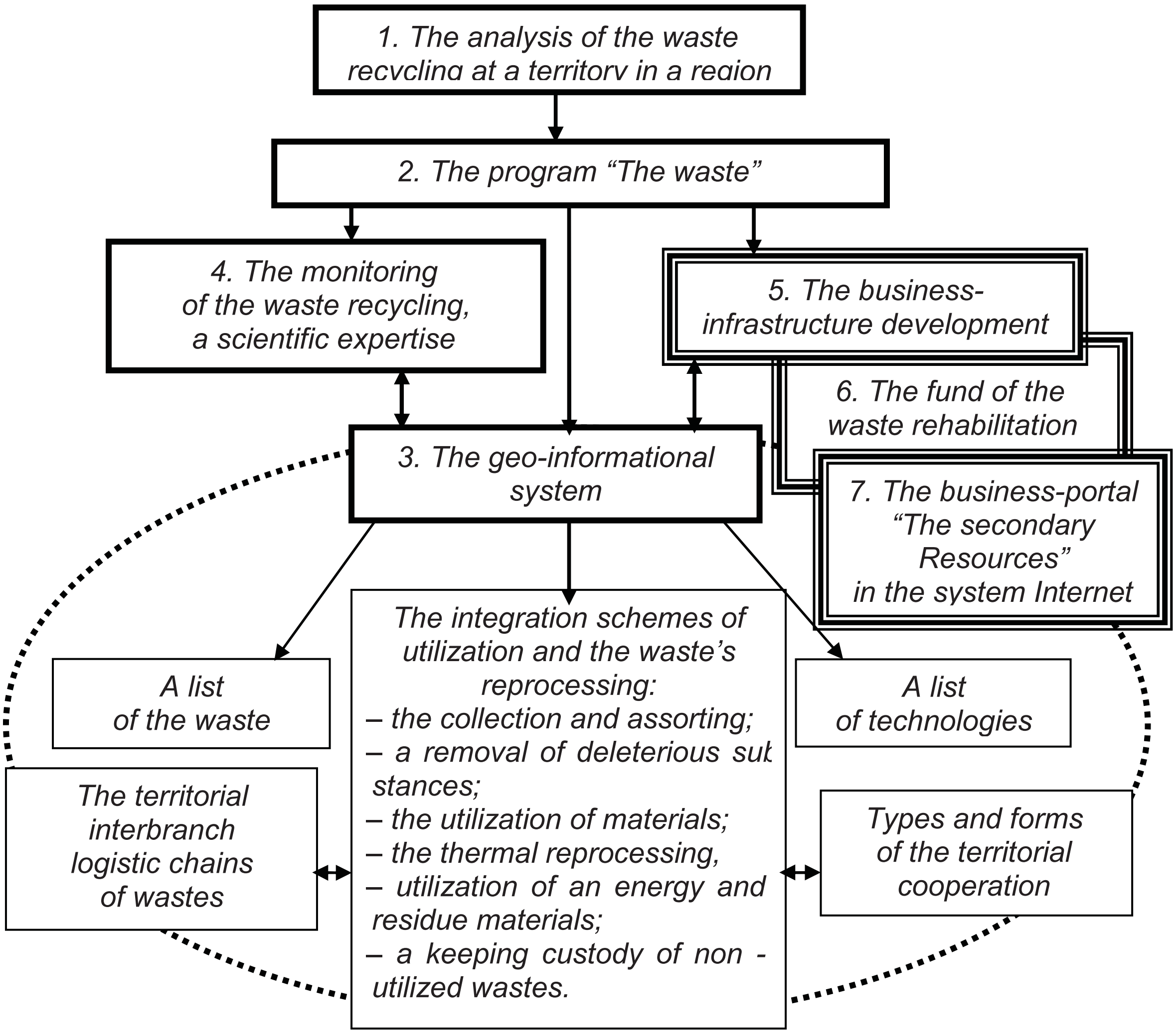

Figure 1 The algorithm of the industrial waste capitalization and consumption in a region

The monitoring of the industrial waste's recycling, the eco-controlling of industrial processes and further activity concerning the waste, an internal ecological audit of the waste stimulate an enterprise to decrease a production costs. The proposed system of arrangements contributes an application of principles of "the clean production" and implementation of the ecological management system at an enterprise. A subject of economical activity having effectively solved problems with the waste and having gotten an international certification, has strengthened his competitive advantages at international markets and has become an active participator at a regional market of the waste as a secondary resources.

For realization of the conceptual regulations on the secondary resources market development "the instruments" of regional management in the sphere of the waste recycling have been systematized on a level of subjects of an economic activity in the Republic (Table 2).

Table 2 The classification of instruments of the waste recycling regulation on a level of subjects of economic activity in a region

Administrative			Economic	
Legal	**Control**	**Legal**	**Control**	**Legal**
The law rules	The inventarization	The monitoring	Grants	Taxes
-	Eco-balance	The ecological registration – №2-TP (the waste); №18-KS; №4-OS	Deferred interest rate on investments	Payments
Eco-standards		Eco-effectiveness or MIPS-analysis	Subsidies, subventions	Penalties
Eco-licencing		Education	In payment	Compensation
Ecological certification		Eco-advertisement	Low-interest loan	-
Plans	-	Prognostication	Speeded up amortization	-
Eco-audition		GIS-technologies	Leasing	-
-	-	Information-program package	Insurance of ecological and other risks	-
Eco-marking			Out-sorting	-
-	Eco-controlling		Tax priviledges	-
-	Ecological control		Franchising	-

Use of the given methods on a regional level implies not only adaptation of flexible policy in agreement of economic subjects' activity but also appropriate financing.

The main instrument of management by the process of the secondary resources market development is the Republican Specific Program "The Waste". The preferable variant to resolve of the territorial problem "the waste" is suggested in the context of the strategic conception of socio-economic development of the Karelian Republic till 2020th year.

The specific programming has an indicative character. At the same time the methodological base allow to use the whole set of supposed methods defining a complexity of the specific program. This complexity is realized through a synergetic effect of the program's execution effectiveness.

The elaborated scheme of functioning of the Republican Program "The Waste" gives an opportunity to carry out the monitoring on the program's execution, to estimate an effectiveness of the program's arrangements realization for achievement of a strategic aim, to make a correction of arrangements, to estimate a work of regional and municipal management of the program.

Thus there are both objective and subjective preconditions for the development of the secondary resources market at a regional level in Russian Federation. Realization of these preconditions in many ways is predetermined by creation of a market infrastructure in the sphere of the industrial waste recycling and consumption. National and municipal power bodies play a defining role in the guiding the process of the waste capitalization. Use of elaborated methodological recommendations on the secondary resources market development in the Republic on the basis of the program method with the use of modern instrumentation will partly allow resolving socio-economic, ecological problems, to perfect the institutional structure in a region, to contribute development of the small business sector and upbringing of citizens.

Literature

A National Report on the Environment Statement in the Karelian Republic (2007)	2008	The Ministry for the Rural, the Fish Industry and Ecology in the Karelian Republic. – Petrozavodsk, Karelia, ISBN 978-5-75445-1571-0
Kodolova T.	2006	A Project Approach as an Instrument of the Strategy's Realization of the Regional Ecological-Resources Specific Programs / The Economics of the North-West Russia: the Problems and the Development Perspectives, № 4 (30), Saint-Petersburg, 2006. P. 98-105.
Kodolova T., Polin A.	2007	GIS and the Internet-Technologies – Elements of Innovations in Guiding the Waste Capitalization Process in a Region / The Ecology of the Industrial Production: The Interbranch Scientific and Practical Journal / FGUP "VIMI", Moscow, Volume 2. P. 6-14.

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From waste to resource management
Do we still need incineration?

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Abstract

With regard to the shortage and price increase of resources it is important to break new ground in waste management to support sustainable methods of waste treatment in the future.

The following article gives an overview of the availability and the use of raw materials (fossil fuels, metallic and non-metallic) in some important countries in the world. Also, it is shown how CO_2-emissions can be reduced by recycling and valuable resources can be saved for future generations.

Today's methods of waste treatment (mechanical-biological-treatment or waste incineration) are evaluated concerning their feasibility for sustainable waste management.

Finally recommendations on how to reach a sustainable waste management are presented.

Keywords

waste management, resources, raw materials, waste treatment, MBT, incineration

1 Introduction

The approaching exhaustion of many raw materials and expanding demand for resources due to fast growth of word population and increasing prosperity in many developing countries are a challenge for the world economy and will become a driving factor for enhanced waste treatment / material recovery technology. Quantity and quality of recovered resources from residual waste depend on the kind of waste treatment. Mechanical-biological treatment (MBT) and incineration are the dominant treatment technologies for residual waste and have to prove their feasibility for sustainable waste and resource management.

2 Population growth, consumption of raw materials and available resources

2.1 Population development and consumption of raw materials

The world population will grow from 6.7 billons now (data 2007) to round about 9.1 billon in 2050 (UN, 2009). That corresponds to an average anual growth of 56 millons.

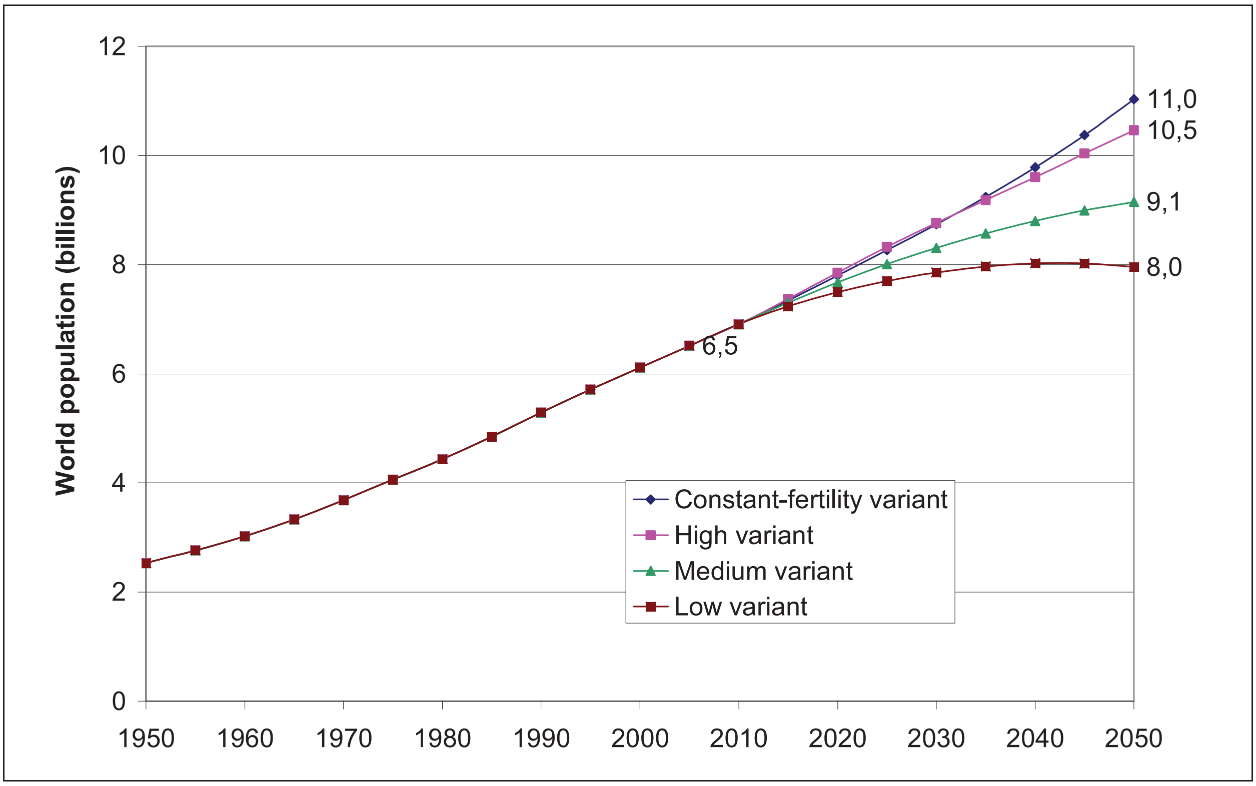

Figure 1: Different scenarios of world population growth (data source: UN, 2009)

The German Foundation for World Population (DSW) reports on their web site a current world population growth of about 81 million people per year. This is nearly as much as the total number of Germany's inhabitants.

Developing and emerging countries show the highest rates of population growth but there are huge differences between the countries. Figure 2 shows the prediction (medium variant) for China and India compared to Germany. Due to their high number of inhabitants and high economic growth, China and India have a high relevance for the topics discussed in this paper.

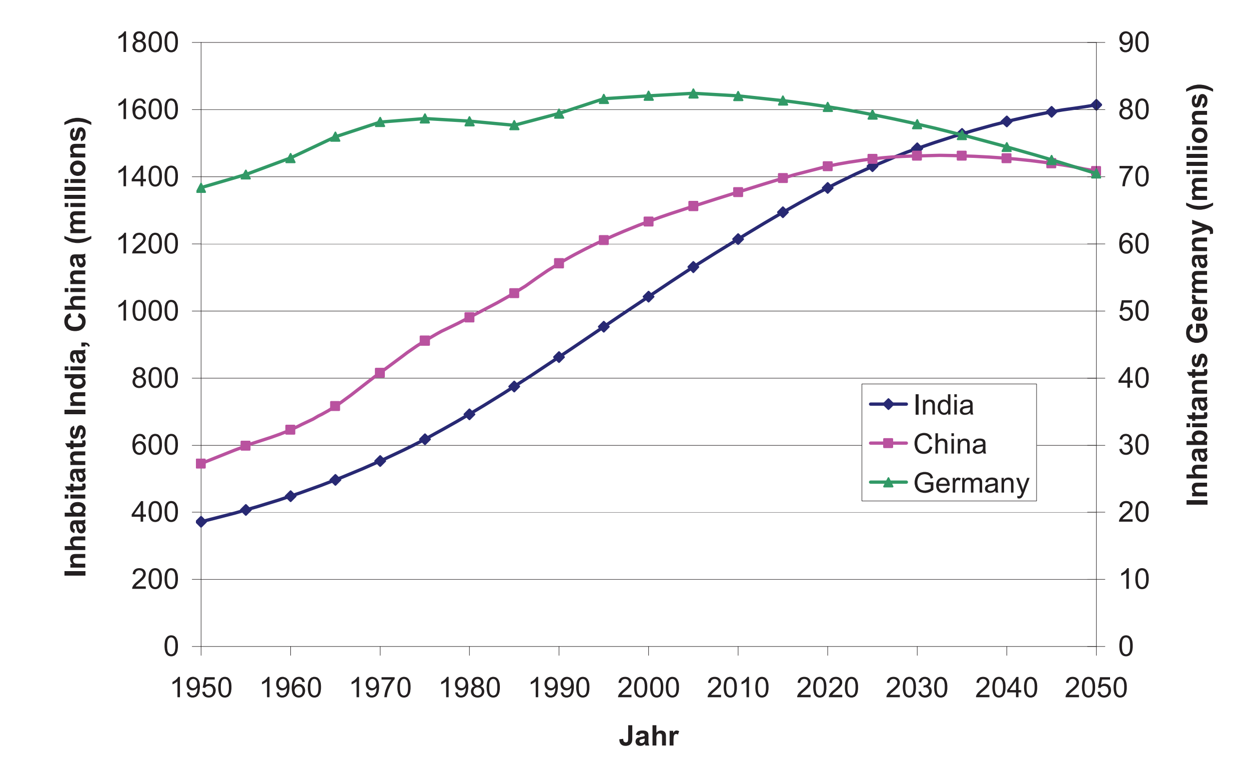

Figure 2: Population development in India, China and Germany, med. variant (data: UN, 2009)

Figure 3 presents the per capita consumption of selected and all resources in different countries. The total includes Biomass. China is already going to approach the average per capita consumption of fossil fuels of the European Union.

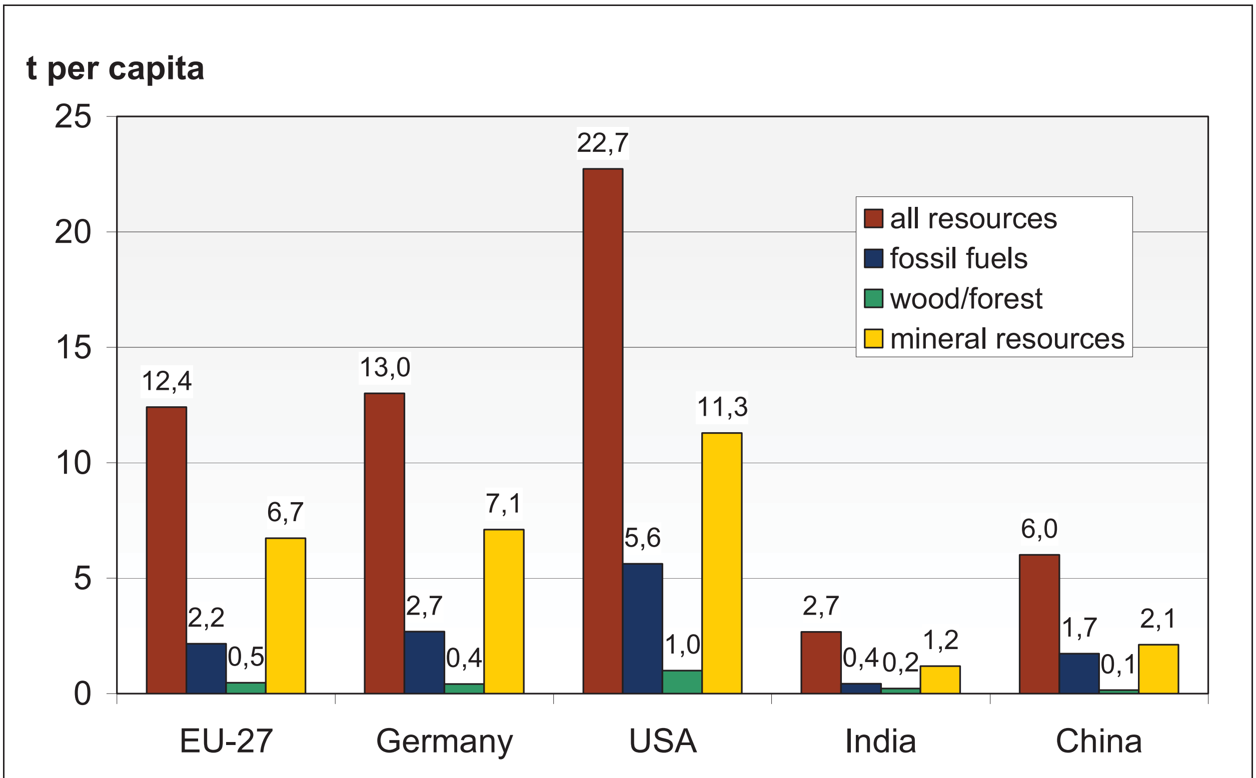

Figure 3: Per capita consumption of resources in different countries (data source: SERI, 2009)

2.2 Important definitions on material reach

For a proper description of the reach of materials (remaining time of availability), some terms need to be defined to avoid misunderstandings due to a different use of these terms in colloquial language. Definitions are according to BARTHEL (1999). These definitions are applied in chapter 2.3 and **Fehler! Verweisquelle konnte nicht gefunden werden.** of this article.

Reserve: Those known raw material sources (e.g. ore) that can be economically produced under current market price conditions.

Resource: Proven (natural) material sources were production effort is too high for an economical material production. When the market price increases or cheaper production technologies are developed, resources can become reserves.

Static reach: Time that reserves last (reach of reserves) at a constant production rate

Reach data in chapter 2.3 and **Fehler! Verweisquelle konnte nicht gefunden werden.** is based on a constant production rate. An increase of the production rate would shorten the reach.

2.3 Reach of fossil fuels and Uranium

The reach of the non renewable energy resources is important to consider in long term waste management concepts as it will influence the value of refuse derived fuels (RDF) and recovered plastics because oil is the basic raw material for plastics. Oil reserves just last 42 years even under constant production.

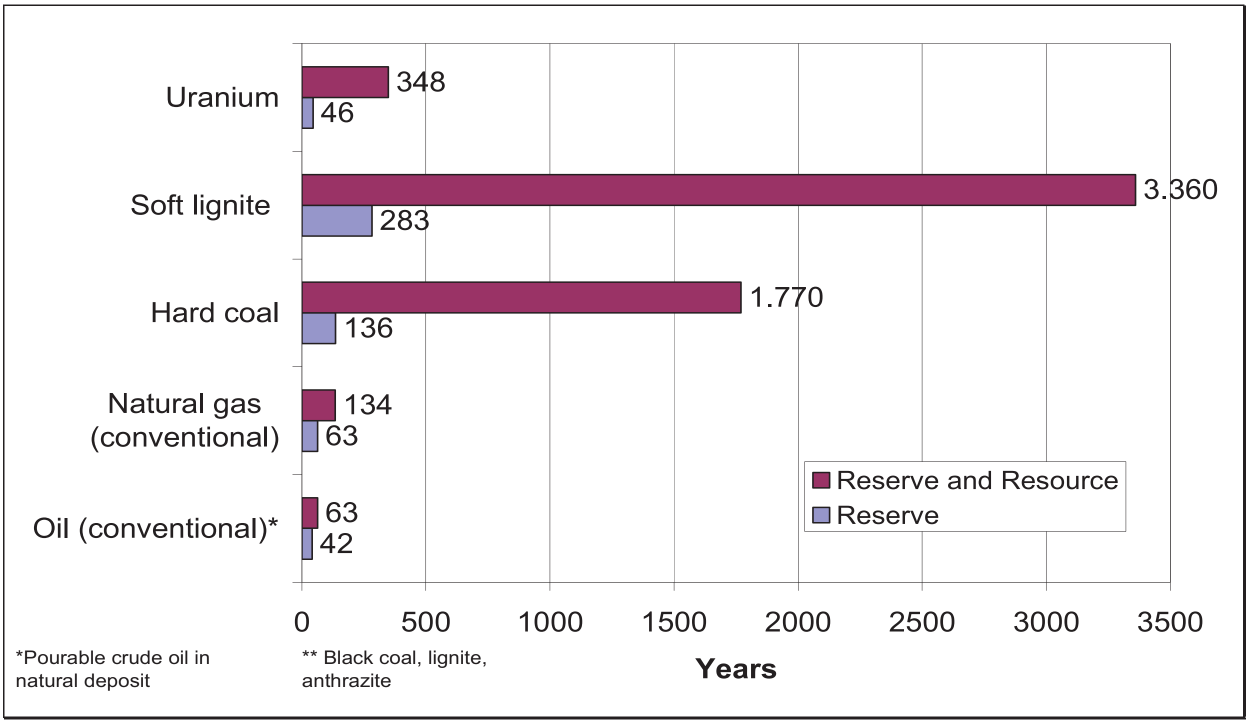

Figure 4: Reach of energy raw materials (data source: BGR 2007)

2.4 Reach of metals and minerals

The reach of metallic and mineral raw materials is not as present as fossil fuels in the public discussion although the reach of many of those irreplaceable materials is even shorter than the reach of oil.

Besides materials that are used for the production of goods, the reach of Phosphate, that is essential for the industrial agriculture and hence for the alimentation of the rapidly growing earth population is only 122 years (BARDT 2008).

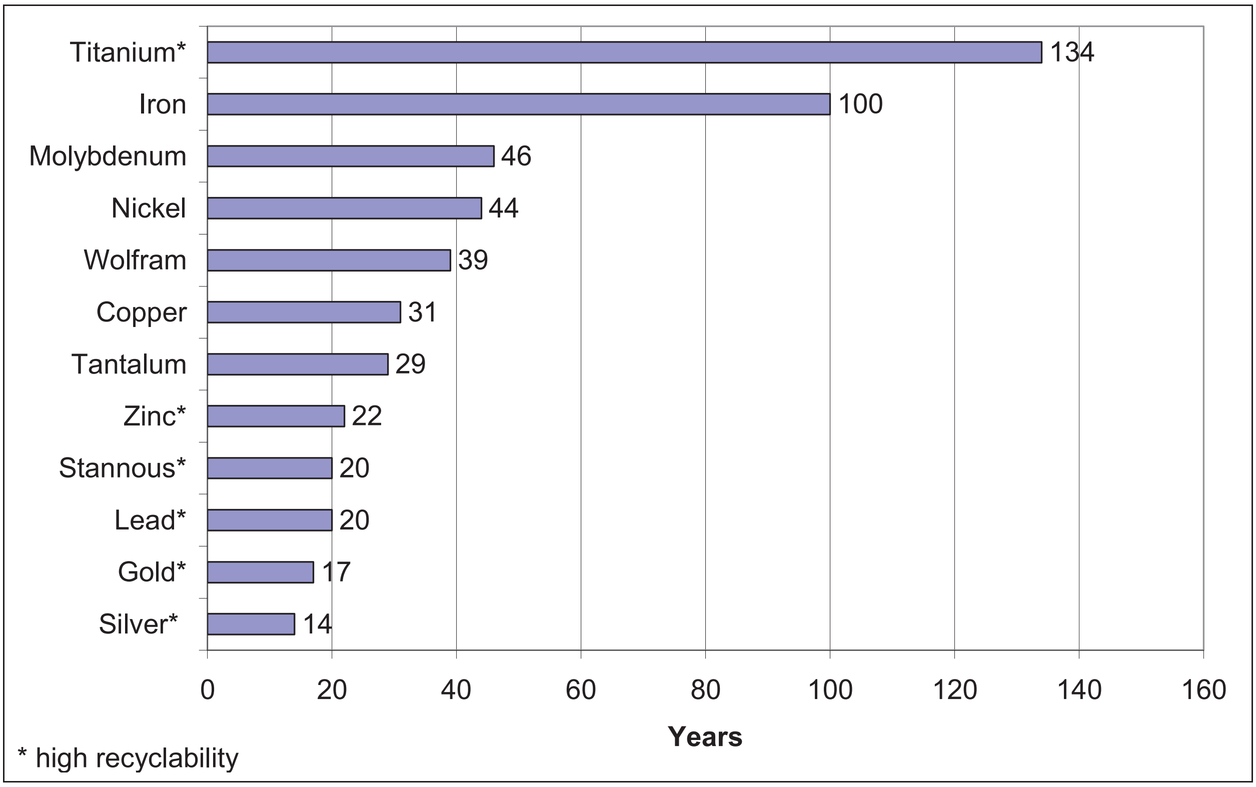

Figure 5: Reach of metallic reserves (DATA SOURCE: BARDT 2008)

The institute of German economy (Institut für Wirtschaft, IW) in Cologne (Köln) published a raw material supply risk list of materials that have a reach of less than 30 years. In spite of their short reach, gold, silver, zinc, stannous and lead do not appear in this list because of their high recyclability. The supply with chrome, molybdenum, columbium (niobium) and metals from the platinum group is classified as very critical in the list. This considers not just the reach but also the situation, that the supply with those metals depends on only 3 countries and 3 companies (BARDT, 2008).

The situation in metal supply is reflected by price development for metallic raw materials that increased by 235% from 2005 to 2008. The price increase of iron ore and steel scrap was even 385% (BARDT 2008). The current massive price drop can be assumed as a temporary event.

2.5 Price development of secondary raw materials

The prices of plastic reclaim (re-granulate) increased significantly in the last years too. With the beginning economical crisis in the second term of 2008 massively declined. This endangers the recycling industry seriously.

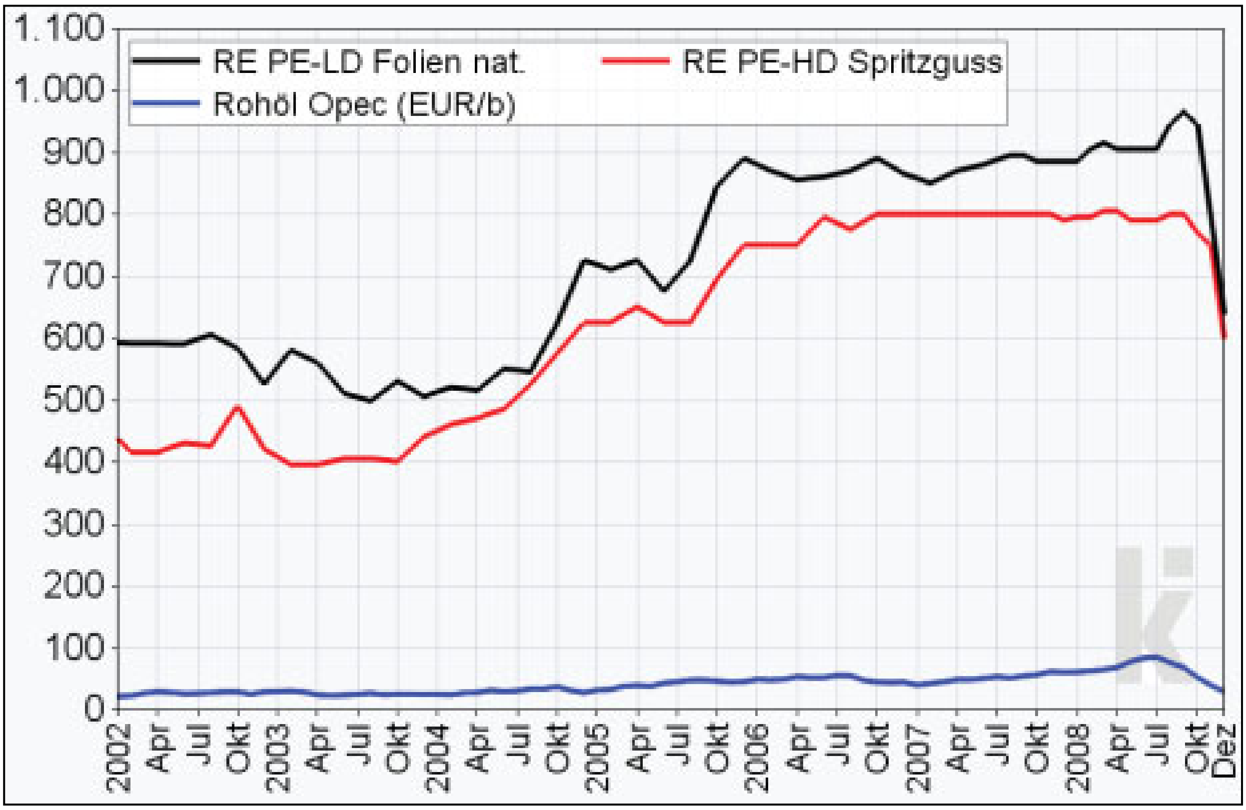

Figure 6: Prices (Euro) for plastic reclaim and crude oil [Rohöl] (kiweb, 2009)

The situation of trading prices for used paper is similar:

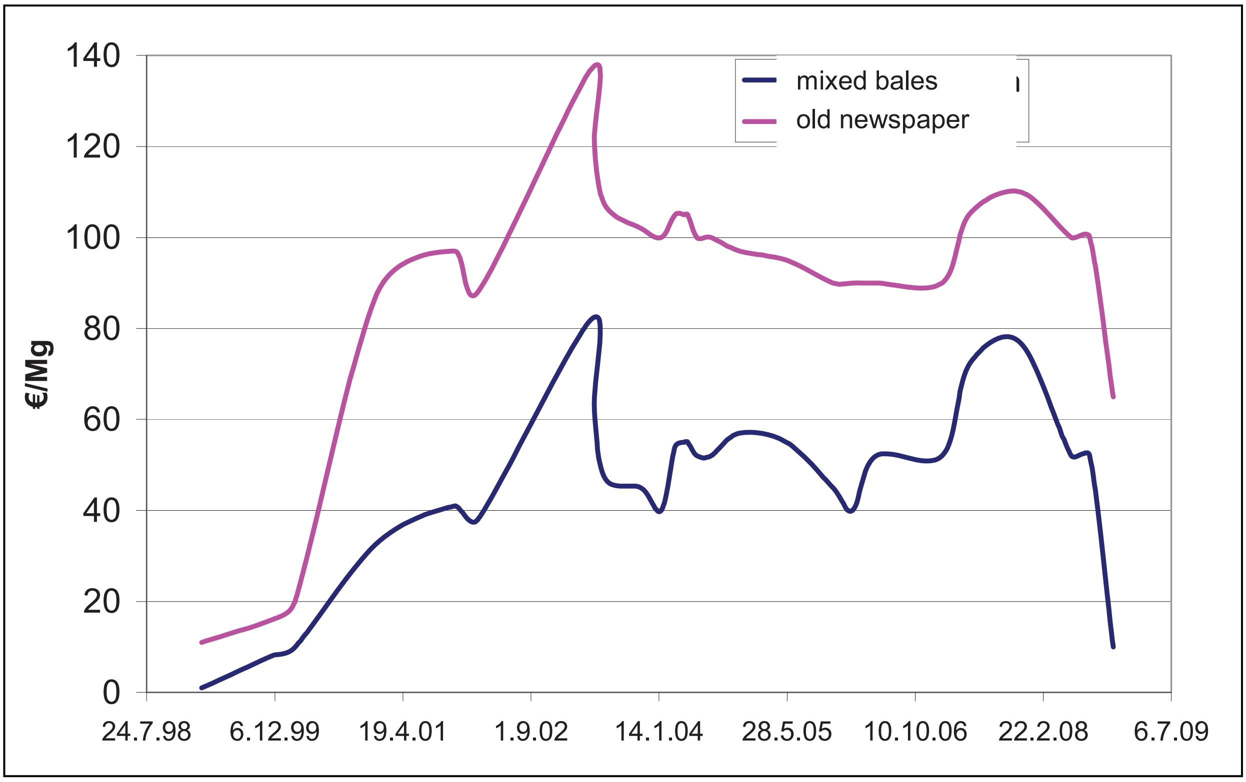

Figure 7: Prices of 2 used paper qualities (data: numerous issues of EUWID Recycling und Entsorgung)

2.6 Reduction of CO_2- emissions by recycling

Recycling is important for climate protection too. By order of INTERSEROH, a German recycling company, Fraunhofer-Institute UMSICHT compared CO_2-emissions caused by the production of primary and secondary materials.

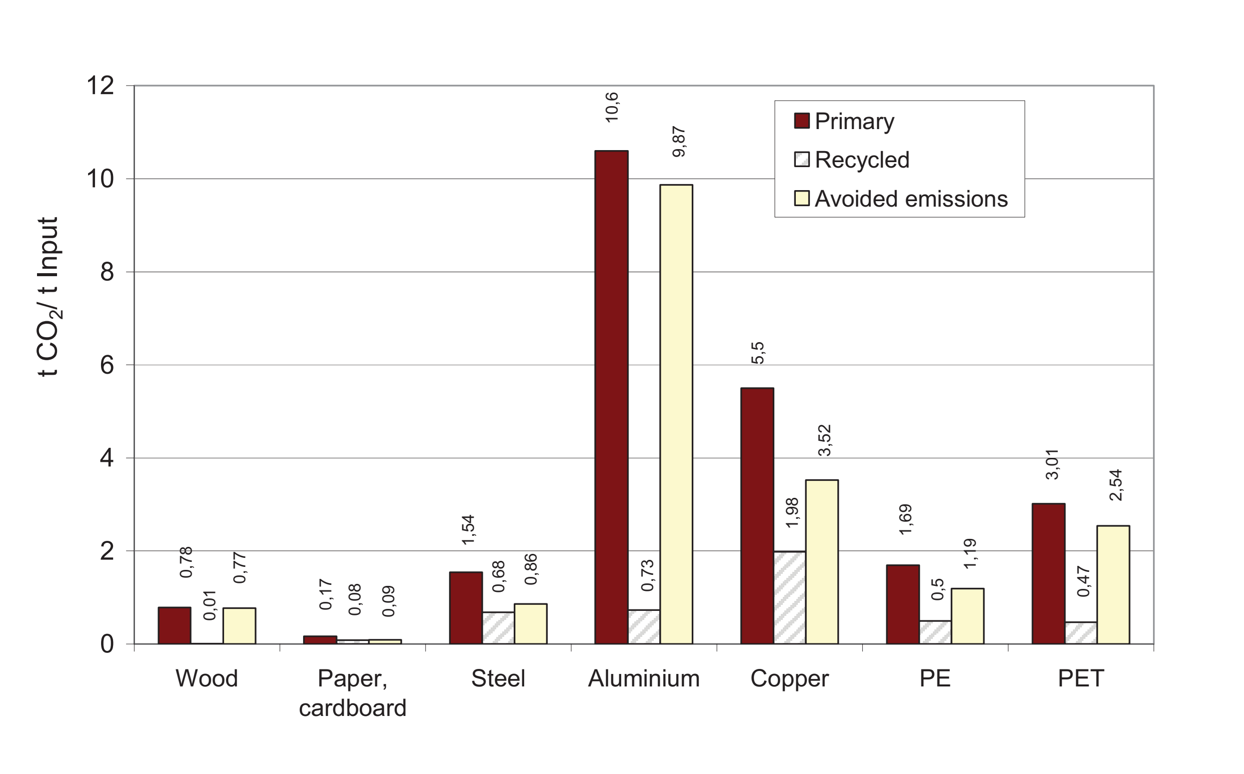

Figure 8: CO_2-emissions by primary and secondary material production and avoided emissions by recycling (data: Interseroh, Umsicht, 2008)

Figure 8 shows that recycling saves an enormous amount of CO2 emissions and thus energy. For example, copper recycling saves 36%, steel recycling 56%, PE recycling 70%, PET recycling 85% and aluminium recycling even 95% compared to primary material production.

The calculated emissions of the recycling process consider collection, transport and the recycling process itself. Considered transport distances to the recycling facilities are based on the true situation. In case of PET this is the transport to south east Asia. It has to be mentioned, that plastics, paper and wood are only feasible for a small number of recycling cycles. Paper fibres can be re-used 5 - 7 times.

3 Feasibility of waste treatment technologies for the requirements of sustainable waste management

3.1 Treatment of residual waste in Germany

Landfilling of non inert waste is not permitted in Germany. Packages and native organic waste are separately collected and recycled. The remaining residual waste is treated by incineration (about 80%) and about 20% mass-% by mechanical-biological treatment (KÜHLE-WEIDEMEIER, 2005).

3.2 Thermal waste treatment (incineration)

3.2.1 „Classic“ incineration of residual waste

Conventional waste incinerators are an approved and very reliable technology for waste treatment. If they are combined with a state of the art exhaust gas treatment system, there is not much reason to be concerned about their toxic emissions.

Depending on it’s quality (leaching test) incinerator bottom ash is used as construction material (mainly for roads) or landfilled. The long term behaviour of incinerator bottom ash is subject of a controversial discussion. The main concern is that possibly a real long term stability (immobilisation of heavy metals) is possibly not given. That is why some opponents call roads constructed with incinerator bottom ash “line landfills”.

A part of the exhaust gas cleaning residues is highly toxic and gets stored in subsurface hazardous waste landfills.

Ferrous metals are removed from incinerator residues by magnetic separation. These metals are heavily oxidised. Non-ferrous metals are inrecoverably lost in the bottom ash.

Another product of incineration is energy. That is why incinerators are sometimes called waste to energy plants (sounds nicer). Municipal solid waste [MSW] (with or without source separated collection) has many components with a low calorific value like water (humidity) soil and much more. Hence, the yield of energy is low. Some incinerators are badly located in areas without demand for the produced heat. In some countries the calorific value of the waste is so low that oil is needed to support the combustion process. In this case, waste to energy converts to energy to waste.

3.2.2 Co-generation plants for refuse derived fuel (RDF)

Co-generation pants that are operated with (pre-treated) high calorific waste (RDF) are real power stations that can be truly called waste to energy plants. They are usually connected to industrial plants that allow using the produced heat (steam) and the electricity too.

3.2.3 Evaluation and future relevance for sustainable waste management

Concerning the conservation of resources, waste incinerators are energy and resource destruction plants. Table 1 reveals how much energy is lost if only the energy represented by the calorific value is recovered.

Table 1: Calorific value and energy equivalent (cal. value + energy effort for production) of some plastic materials (Reimann 1988)

Material	Calorific value [kJ/kg]	Energy equivalent [kJ/kg]
Polyethylen (PE)	43,000	70,000
Polypropylen (PP)	44,000	73,000
Polystrol (PS)	40,000	80,000
PVC hard	18,000	53,000

Only ferrous metals can be recovered from the incineration process. Hence, in a sustainable waste and resource management concept, incineration is feasible only for the treatment of those waste components that can not be recycled or when recycling effort (e.g. energy consumption) exceeds the benefit of recycling. That has been the case with the majority of the MSW in the past. That is why incineration as an expensive but reliable technique is so widespread in Germany.

Innovations and significant cost reductions in waste processing and sensor based waste sorting has changed this situation as well as the approaching shortage of raw materials. After the current economical and raw material price crisis more and more waste components will be picked out by sorting machines. Besides the ecological benefit, this saves cost for expensive treatment like incineration and often even creates a positive income. Some waste management societies have already voluntarily installed sensor based sorting units because they it pays off. Step by step there will be less waste that will be incinerated in Germany, resulting in increasing incinerator over capacities. This development might be delayed by price dumping of incinerator operators.

3.3 Mechanical-biologial treatment (MBT)

3.3.1 Current situation

Figure 9 shows the average mass-balance of the German MBTs. The amount of material recovery in these plants is not very high. From the total of 4.9 million Mg (tons) per year 127,000 Mg ferrous metal and 9,000 Mg non ferrous metals are recycled. The vast majority (2 million Mg) of MBT output goes to energy recovery (incineration) and 1 million Mg are landfilled.

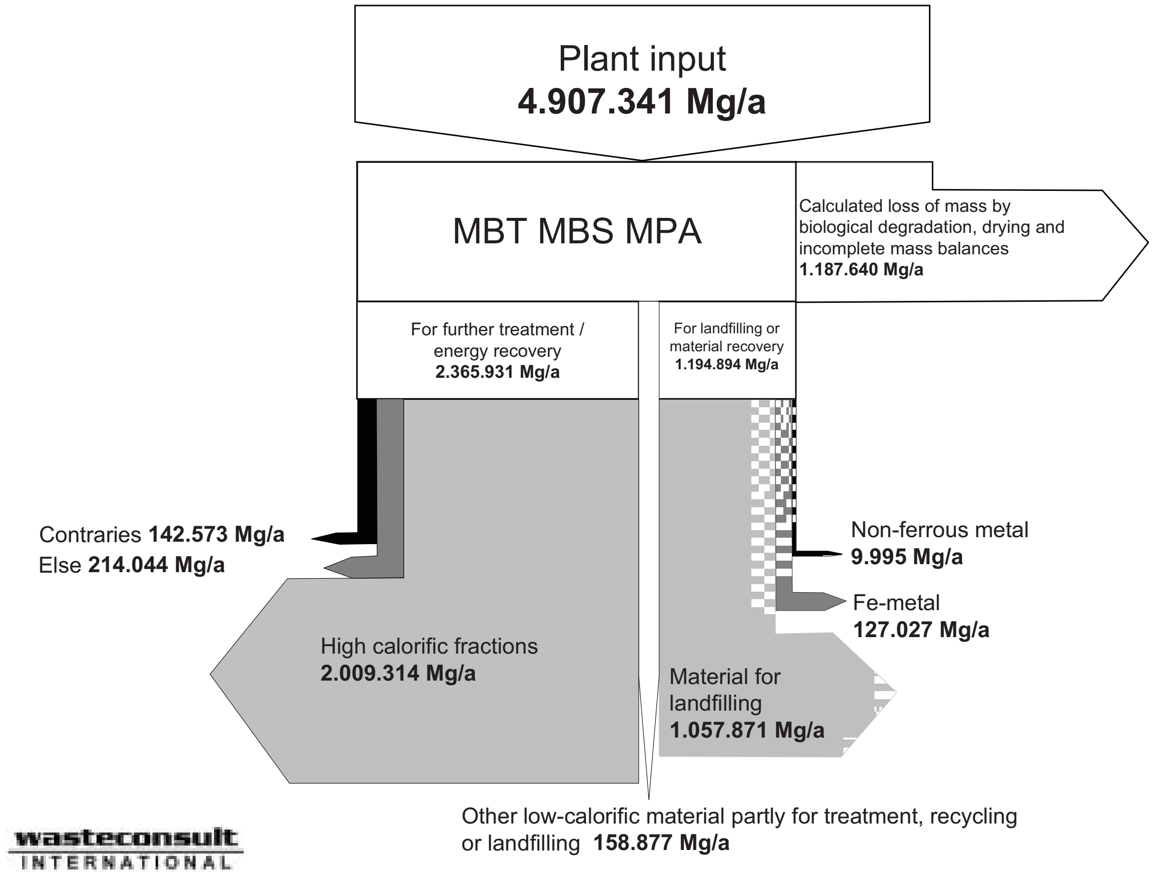

Figure 9: Mass-balance of the German MBTs (Kühle-Weidemeier et al., 2007)

Only anaerobic MBT processes produce energy that covers at least their own energy demand. The other MBT processes just consume energy.

3.3.2 Evaluation

Currently, MBT wastes energy and resources although the material and energy recovery potential is already higher than with conventional incinerators. Even the input of the biological treatment step contains valuable resources that could be picked out (paper, wood, plastics, minerals …), like it is already done in a very few plants.

3.3.3 Enhancement and future potencial of MBT

Big progresses in sensor based sorting makes installation of such units in MBT plants attractive. They are applicable to the coarse fraction as well as to the fine fraction. Best conditions for such applications exist at plants with wet mechanical treatment steps or biological / physical drying. MBT will develop to MRFs with integrated biological treatment.

Figure 10: Various fractions from a biological and wet mechanical treatment step of an MBT

The (former) landfill fraction of MBTs with wet mechanical treatment steps of wet anaerobic treatment does not necessarily has to be landfilled. Figure 10 shows that useable mineral and organic fractions could easily be extracted.

The conception of MBT as a material specific waste treatment technology offers best requirements for a sustainable, resource optimised waste management but it needs to be consequently improved with the focus on material separation and recovery.

4 Resource recovery from landfills

Concepts for material recovery from landfills have come back on the agenda, for example VISVANATHAN ET AL., 2007.

Currently, landfill mining is still to expensive in Europe but with increasing prices of raw materials this might change in a medium range of time. Faulstich (2008) compiled data about recoverable resources in German landfills:

Table 2: Resources in German landfills (Data from Faulstich, 2008)

Deutschland	Deponierte Siedlungsabfälle	Deponierte Massenabfälle	Deponierter Klärschlamm	
Gesamtmenge	960	50	>> 10	Mio. Mg
Fe- + NE-Metalle	32			
Zink		70.000		Mg
Blei		25.000		Mg
Phosphat			1	Mio. Mg

5 Summary and recommendations

Shrinking natural resources, fast growth of the world population and increasing prosperity in emerging and developing countries requires consequently resource optimised acting in general and especially in waste management. A massive increase of the share of materials recovered from waste is necessary. This would enhance material supply and save lots of energy (CO_2-emissions) too. Resource recovery means climate protection.

Enhanced MBTs and sensor based waste sorting plants must become the heart of a sustainable, material specific waste management system. Current MBTs are the first step on this very promising way. MBT will develop to MRF with integrated biological treatment or pure material separation.

Incineration does not meet the requirements of a sustainable, resource optimised waste management concept, because the energy that was spent for the production of the materials that are used as fuels is completely lost in the incineration process. Precious waste components like non-ferrous metals are irrecoverably lost in the incinerator ash. A significant share of the waste that is expensively incinerated at the moment will be cheaper recovered in the future. Hence, there will be less input for incinerators. Incineration will step by step lose it’s importance, although there will always be demand for some incineration capacity because total recovery and recycling is not possible. Countries that are going to design their waste treatment concept should consider this development.

6 Literature

ASA-Beirat	2006	MBA und das Ziel 2020. Arbeitsgemeinschaft Stoffspezifische Abfallbehandlung (ASA e.V.), pdf-Dokument.
Bardt, H.	2008	Sichere Energie- und Rohstoffversorgung. Herausforderung für Politik und Wirtschaft? Deutscher Instituts-Verlag, Köln, ISBN 978-3-602-24133-0.
Barthel, F.	1999	See the world from a wider perspective. Commodity top news. Fakten, Analysen, wirtschaftliche Hintergrundinformationen. No. 6. Bundesamstalt für Geowissenschaften und Rohstoffe (BGR).
Biebeler, H., Mahammadzadeh, M. und Selke, J.-W.	2008	Globaler Wandel aus Sicht der Wirtschaft. Chancen und Risiken, Forschungsbedarf und Innovationshemmnisse. Deutscher Instituts-Verlag, Köln, ISBN 978-3-602-14791-5
Brammer, F.	1997	Rückbau von Siedlungsabfalldeponien. Schrittfolge und Entscheidungskriterien bei Planung und Ausführung. Dissertation am Fachbereich für Bauingenieur- und Vermessungswesen der TU Braunschweig.
Bundesanstalt für Geowissenschaften und Rohstoffe (Hrsg.);	2008	Reserven, Ressourcen und Verfügbarkeit von Energierohstoffen 2007. Jahresbericht 2007. pdf-Dokument, www,bgr-bund.de
Deutsche Stiftung Weltbevölkerung	2009	http://www.weltbevoelkerung.de/info-ser-vice/weltbevoelkerungsuhr.php?navanchor=1010037
Faulstich, M.	2008	Abfallwirtschaft und Ressourcenschutz. Welchen Beitrag leistet Recycling zur Nachhaltigkeit? Präsentation zum Rohstoffkongress 2008, Berlin.
Fraunhofer Institut UMSICHT, INTERSEROH AG (Hrsg.)	2008	Recycling für den Klimaschutz. Ergebnisse der Studie von Fraunhofer UMSICHT und INTERSEROH zur CO_2-Einsparung durch den Einsatz von Sekundärrohstoffen, Broschüre.

Kühle-Weidemeier, M.	2005	Bedarf, Konstruktionsgrundlagen und Betrieb von Deponien für mechanisch-biologisch behandelte Restabfälle in Deutschland. Veröffentlichungen des Institutes für Siedlungswasserwirtschaft und Abfalltechnik der Universität Hannover, Heft 127. ISBN 3-921-421-57-8
Kühle-Weidemeier, M.; Langer, U.; Hohmann, F.	2007	Anlagen zur mechanisch-biologischen Restabfallbehandlung. Schlussbericht. By order of the German Environment Agency (Umweltbundesamt) UFOPLAN 206 33 301
SERI (Sustainable Europe Research Institute)	2009	http://www.materialflows.net/mfa/ Visited 10.03.2009
UN (United Nations)	2009	World Population Prospects: The 2008 Revision. Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, http://esa.un.org/unpp
Visvanathan, C.; Norbu, T.; Chiemchaisri, C.; Charnnok, B.	2007	Applying Mechanical Pre-Treatment and Landfill Mining. Approach in Recovering Refuse Derived Fuel (RDF) from Dumpsite Waste: Thailand Case Study. In: Kühle-Weidemeier, M. (Hrsg.): International Symposium MBT 2009. Proceedings.
Wuttke, J. Dr.	2005	Grundzüge der Abfallwirtschaft in Deutschland. In: Hösel, Bilitewski, Schenkel and Schnurer (Hrsg.) Müllhandbuch, Bd. 1, 0169, Erich Schmidt Verlag, Berlin.

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How is MBT-technology in 20 years?

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Abstract

Due to considerable changes in landfilling strategies in Germany and Austria during the last decade MBT technology has become one of the most important treatment procedures for municipal solid waste besides incineration. Reduction of environmentally relevant emissions has been in the focus of interest. After some years of experience this request is proved to be accessible. The future challenge in waste management will be the use of resources from waste in a proper way. The objective is not only the avoidance of negative effects, but the improvement of positive effects by material recovery, energy production and carbon sequestration. The carbon cycle and the effect on climate will be a crucial issue. In this paper data of four sorting analyses are presented. Input materials of four MBT plants were investigated and assessed in terms of the intended purpose. About 5 to 10 % were sorted for material recovery. Improved sorting technologies can provide about 30 % for heat production. Data of carbon sequestration in landfilled MBT material are presented and compared to municipal solid waste incinerator (MSWI) bottom ash. The total organic carbon (TOC) content differs from MBT material (average ~ 17 % DM) to MSWI bottom ash (average ~ 2 % DM). Finally incineration of municipal solid waste containing biogenic materials and food waste with high water contents is discussed.

Inhaltsangabe

Im Zuge der Änderungen der Ablagerungsstrategien in Deutschland und Österreich wurde die MBA Technologie neben der Verbrennung zu einer der Hauptbehandlungsarten von Siedlungsabfällen. Das Hauptaugenmerk lag auf der Vermeidung negativer Auswirkungen auf die Umwelt. Nach einigen Jahren ist mittlerweile klar, dass dieses Ziel erreicht werden kann. In den nächsten Jahrzehnten wird die größte Herausforderung der Abfallwirtschaft darin bestehen, die Ressourcen des Abfalls zu nutzen. Nicht nur negative Effekte verhindern, sondern positive lukrieren, muss zum Ziel werden. Der Blickpunkt muss auf den Kohlenstoffkreislauf und Klimarelevanz gelegt werden. In der vorliegenden Arbeit werden beispielhaft Daten aus vier Sortieranalysen präsentiert. In vier verschiedenen MBA Anlagen wurde das Inputmaterial bewertet. Zwischen 5 und 10 % könnten zur stofflichen Verwertung genutzt werden. Durch bessere Sortierung wären zusätzlich bis zu 30 % des Materials für die Energieerzeugung geeignet. Außerdem werden Daten zur Kohlenstoffsequestrierung von MBA Deponien im Vergleich zu Verbrennungsschlacke präsentiert. Der organische Kohlenstoffgehalt (C_{org}) liegt bei MBA Deponiegut im Mittel bei 17 % TM, während Schlacke nur einen Kohlenstoffgehalt von 1 – 2 % TM aufweist. Die Verbrennung von organischer Substanz mit hohem Wassergehalt wird diskutiert.

Keywords

MBT technology, material recovery, sorting analyses, carbon sequestration

MBA Technologie, Recycling, Sortieranalysen, Kohlenstoffsequestrierung

1 Introduction

During the last decades waste management has mutated from prevention of negative environmental impacts by waste reactivity and end of pipe strategies into improvement of provident measures to minimize emissions by the landfilled materials in advance. This purpose has resulted in the landfill ordinances for the compulsory pretreatment before landfilling. Mechanical-biological treatment (MBT) and municipal solid waste incineration (MSWI) are the most relevant procedures to reach this goal. In addition resource recovery and the use of waste have increasingly gained in importance the last years. In this context sorting technologies have become an indispensable integral part of current strategies. Biological and thermal treatment moved from competitive technologies to complementary measures within a comprehensive waste management concept. The efficient use of resources including materials and energy is aimed for. The markets for these resources have developed at different quality levels and economical reasons are in most cases the determining factor. Because all measures affect the global carbon cycle we have to consider the impact and the consequences of all waste management activities in this context. The task for politicians will be to adjust the markets for waste resources and to take into account ecological aspects in a holistic approach. This paper focuses on two main points:

- Determination of potential resource recovery based on sorting analyses
- Benefits by carbon sequestration and discussion on energy efficiency

2 Materials and Methods

2.1 Sorting analyses

Four examples of sorting analyses with different purposes and methods are presented. Analyses A – C focused on the quantification of different fractions, analysis D on the assessment of thermally usable materials. The material composition was consistent in all cases with the usual input intended for the biological treatment in a MBT plant.

Example A: residual waste (37,700 kg comprising 10 charges) was manually sorted. The material was not shredded or treated anyway else. The following fractions were separated:

Agrofoils, aluminum tins, batteries, coloured foils, electronic scrap, stained glass, clear glass, untreated wood, treated wood, cables, crate wood, magnetic separator, medicaments, engine oil bottles, nail polisher, non-packaging plastics, paper, PET-bottles, plastic pipes, PS, X-ray photographs, carpets, transparent foils and packaging materials.

Example B: Residual waste (79,900 kg) was sorted automatically. The material was not shredded. The selected fractions were metals and contraries.

Example C: Residual waste (40,380 kg) was manually sorted with the focus on two charges. The material was not shredded or treated anyway else. The sorted fractions were green, blue and transparent PET-bottles, other hollowware, foils, ferrous metals and non-ferrous metals.

Example D: Residual waste (180,000 kg) was sorted automatically. The material was shredded and dried using the heat that is generated by the biological treatment. Metals and wood, however, were sorted for material recovery. The thermal fraction was divided into a fraction from 6 to 40 mm and a fraction from 40 to 70 mm.

2.2 Determination of carbon contents in MBT landfills

Carbon contents were determined by investigation of 34 MBT landfills and MBT materials intended for landfilling. They covered the variety of Austrian MBT materials.

Total carbon and inorganic carbon were measured using the CNS analyzer (VarioMax). The total organic carbon (TOC) content was calculated by subtracting the inorganic carbon from the total carbon.

2.3 Determination of carbon contents in MSWI bottom ash and water evaporation in combusted MBT materials using thermal analysis

Quantification of carbon contents in MSWI bottom ash was carried out using an instrument for simultaneous thermal analysis (STA 409 CD, Netzsch GmbH).

Twenty-four samples of MSWI bottom ash ready for landfilling or already landfilled were analyzed. The samples originated from different plants and landfills respectively and covered the range of Austrian MSWI bottom ashes. The samples were subjected to the heating program from 30°C to 950°C with a heating rate of 10 K min^{-1}. By means of thermogravimetry the weight loss is measured. The CO_2 ion current (mass 44) caused by combustion of organic matter and carbonate decay > 650 °C is recorded by the mass spectrometer. It enables to distinguish weight losses by CO_2 release or water (mass 18) evaporation.

3 Results

3.1 Sorting analyses

Results of sorting analyses are compiled in tables. The material recovery potential of sorting analysis A was found to be 7 ± 1.9 % (w/w). A detailed list of different fractions and the portion of the total residual waste charges is presented in Table 1.

Table 1: The fractions of the material sorted for recovery in example A.

fraction	percentage	fraction	percentage
magnetic separator	14.3	treated wood	1.6
agrofoils	13.7	PET-bottles	1.3
paper	12.4	aluminum tins	0.9
packaging materials	11.9	batteries	0.4
carpets	9.2	PS	0.4
non-packaging plastics	7.6	stained glass	0.3
transparent foils	6.9	clear glass	0.3
colored foils	6.6	crate wood	0.3
untreated wood	3.8	medicaments	0.1
cables	3.7	engine oil bottles	0.1
electronic scrap	3.3	nail polisher	0.1
plastic pipes	2.3	X-ray photographs	0.1

According to sorting analysis B the total potential for material recovery was assessed by 4.0 % (w/w).

According to sorting analysis C the potential for material recovery amounted to 9 ± 3.3 % (w/w). Details on composition and percentage are compiled in Table 2.

Table 2: The fractions of the material sorted for recovery in example C.

fraction	percentage	fraction	percentage
foils	44.1	non-ferrous metals	6.4
ferrous metals	23.7	PET blue	3.1
hollowware	10.5	PET green	1.9
PET transparent	10.3		

Sorting analysis D led to following results displayed in Table 3.

Table 3: The fractions of the input material in example D.

fraction	percentage	fraction	percentage
6 – 40 mm	30	wood	5
40 – 70 mm	20	metals	2

The rest amounted to about 40 %.

3.2 Organic carbon contents in MBT materials and MSWI bottom ash

Figure 1 displays the different carbon contents of MBT and MSWI output materials for landfilling. The mean TOC content of the MBT materials was about 17 ± 2.5 % DM. The MSWI output reached a mean content of about 2 ± 1.4 % DM. The average difference between carbon contents in MBT waste and MSWI bottom ash is about 15 % organic carbon DM.

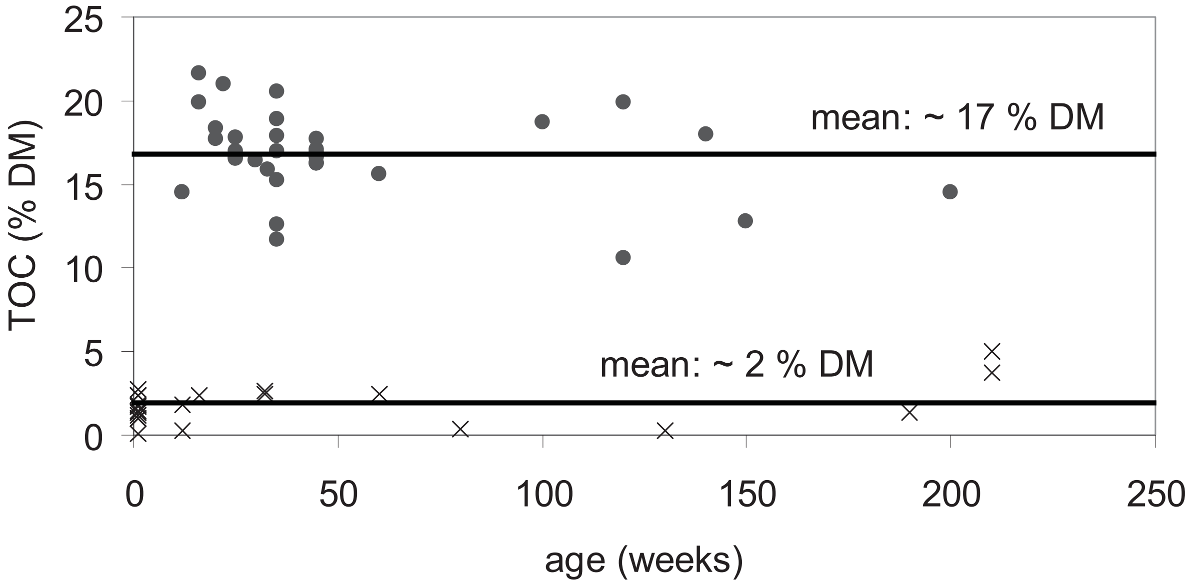

Figure 1: The TOC values of material from landfilled MBT material (●) and slag from MSWI bottom ash (×)

During MSW incineration two effects occur that reduce the efficiency of thermal utilization and should be taken into account: evaporation of water and the decay of carbonates. Carbonates are deteriorated at temperatures > 650 °C, leading to CO_2 release (Smidt et al., 2009). In addition the decay is an endothermic reaction with energy uptake which lowers the energy efficiency. In the MBT process a considerable amount of "stable" carbon remains in the matrix and is not released into the atmosphere. Figure 2 illustrates the exothermic processes of organic matter combustion and the endothermic reaction of the carbonate decay.

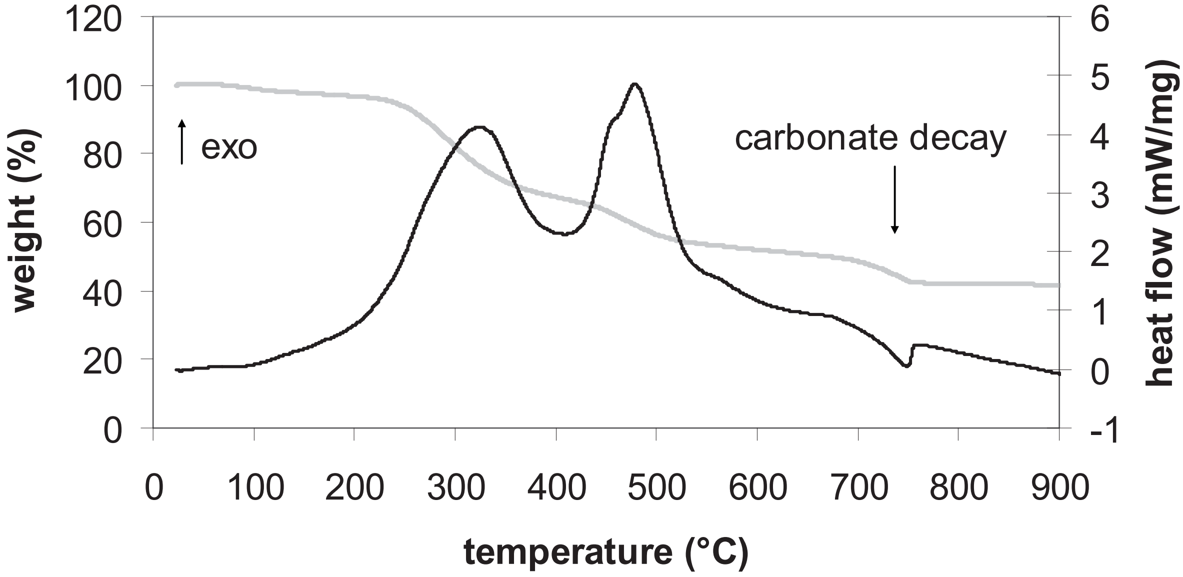

Figure 2: Weight loss and heat flow curve of MSW indicating the decay of carbonates by the weight loss and the endothermic reaction

Evaporation of water as well takes energy and diminishes the energy efficiency of MSW incineration. Materials (e.g. biogenic waste and food waste) with high water contents should be separated carefully and subjected to biological aerobic or anaerobic processes. Figure 3 displays the endothermic reaction of water evaporation at about 100 °C.

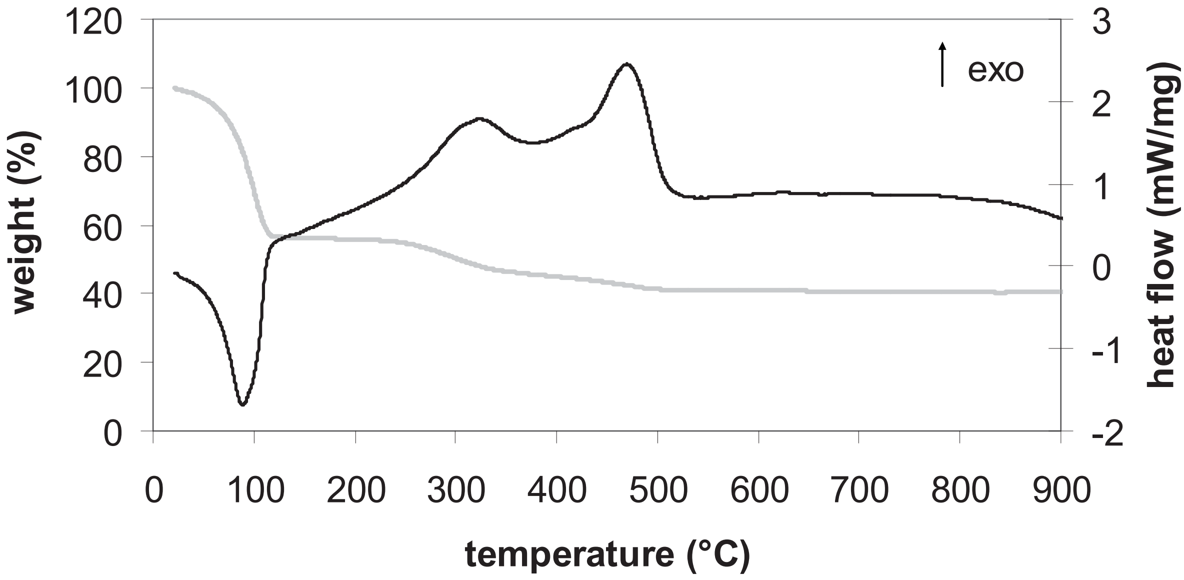

Figure 3: The mass loss and the heat flow (enthalpy) of biogenic waste with an original water content

The calorific value of the dry material is indicated by the exothermic reaction up to 550 °C indicated by the heat flow curve, respectively by the area below the heat flow curve.

4 Discussion

The next 20 years MBT technology will have to focus more on the one hand on the improvement of the material recovery and on the other hand on the maximization of carbon sequestration of all materials that cannot be used for energy production in MSWI plants.

The results of the sorting analyses display a potential for material recovery of about 5 to 10 % of the input of the biological treatment of MBT plants. Only in example A the recovery of the sorted fractions is actually realized. In examples B and C the sorted materials usually end up in the MBT process without sorting. In example D about 20 % of the input material is actually separated instead of the assessed 60 %. The additional amount for material recovery was about 7 %; for energy recovery about 30 %. Even though the results are not transferable one to one, the potential implies the improvement of sorting technologies. In all cases of the sorting analyses investigated the improved recovery was recognized as an economically interesting step even when low and strongly fluctuating prices of raw materials seem to alienate the runners of the plants.

The biological treatment of MBT plants must become compulsory for all fractions of the residual waste, which cannot be used for energy production in MSWI plants. The heavy fraction with a usually high content of wet, biogenic material is improper for energy production (by means of incineration). Moreover, the inorganic fraction with a high content of carbonates is not just useless but problematic, as the decay of carbonates at temperatures > 650 °C is an endothermic reaction and leads to additional release of CO_2 to the atmosphere with loss of energy.

The carbon storage in MBT landfills seems also to be a crucial challenge for the MBT technology in the future. In the context of climate change the benefit of MSWI is energy production, the positive impact of MBT waste is carbon sequestration. The difference in the carbon content of about 15 % DM between landfilled MBT and MSWI output seems to be a veritable result.

A crucial research topic which is in the focus of interest targets the quality of organic compounds indicated by the TOC. The determined content of 17 % DM in MBT materials cannot be considered as the long-term stable carbon pool. The amount of carbon, which is stored in the landfill over centuries, will be a percentage of this value. Investigations of degradation rates under different conditions, stabilization effects by mineral compounds, more details about microbial processes and adequate testing methods will be future research projects.

Despite many open questions it can be assumed that MBT landfills develop towards real carbon sinks. This aspect has to be taken into consideration in the discussion about balances, benefits and carbon credits.

Waste management in 20 years will concentrate on the fate of carbon and on the efficiency of measures to slow down the turnover rates. Therefore the processes of material recovery, energy production and carbon sequestration should be optimized. In this context MBT technology ranks in a key position as an interface of material recovery, energy production and carbon sequestration.

5 Literature

Smidt E., Meissl K., Tintner J., Ottner F.	2009	Interferences of carbonate quantification in municipal solid waste incinerator bottom ash: evaluation of different methods. Environ Chem Lett, in press, Springer

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Evaluation of system costs for the use of plastics with regard to disposal costs

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Abstract

In this paper we evaluate the real costs for the use of plastics regarding costs for disposal. These costs are until now not sufficiently reflected in the consumer prices. This causes massive competitive disadvantages for renewable raw materials, even though these are produced with significantly lower energy consumption and disposal costs. Plastics waste has no recycling potential and should be regarded as waste for disposal.

Keywords

Plastics, Recycling, Disposal, System costs, Antimony

1 Introduction

Plastics are increasingly present in our everyday world. People, who are concerned with waste in some way, will see these plastics again when they are no longer usable - as waste. Our motivation for this paper springs from some observations about plastics during our dealings with waste.

The company EcoEnergy has been operating the demonstration plant for the SCHU-BIO®-Process for wet mechanical separation of waste since 2005.

In the process biogenic, native organic matter is separated from the fossil organics, the plastics.

Chemical analysis of these fractions shows a definite decrease of pollution in the native organics fraction and increased pollution in the fractions containing plastics.

A second clue, indicating the pollution of plastics, appeared when we investigated possible RDF fuels, applicable for co-combustion until up to 25 % of the thermal output in a coal fired power plant. We established suitable input criteria for co-combustion, not only regarding plant emission but also quality of desulphogypsum and fly ash. In the end, only material blends with little or no plastics could meet the input criteria.

These findings lead us to investigate further and analyze the system costs for the use of plastics with regard to disposal costs.

2 Production of Plastics

Naphtha is produced from crude oil and is the raw material for production of plastics.

Until the Fifties nahptha was used directly as fuel. The development of higher compression for combustion engines lead to the need for more knock-proof fuel with higher octane number. Naphtha became a by-product from crude oil distillation.

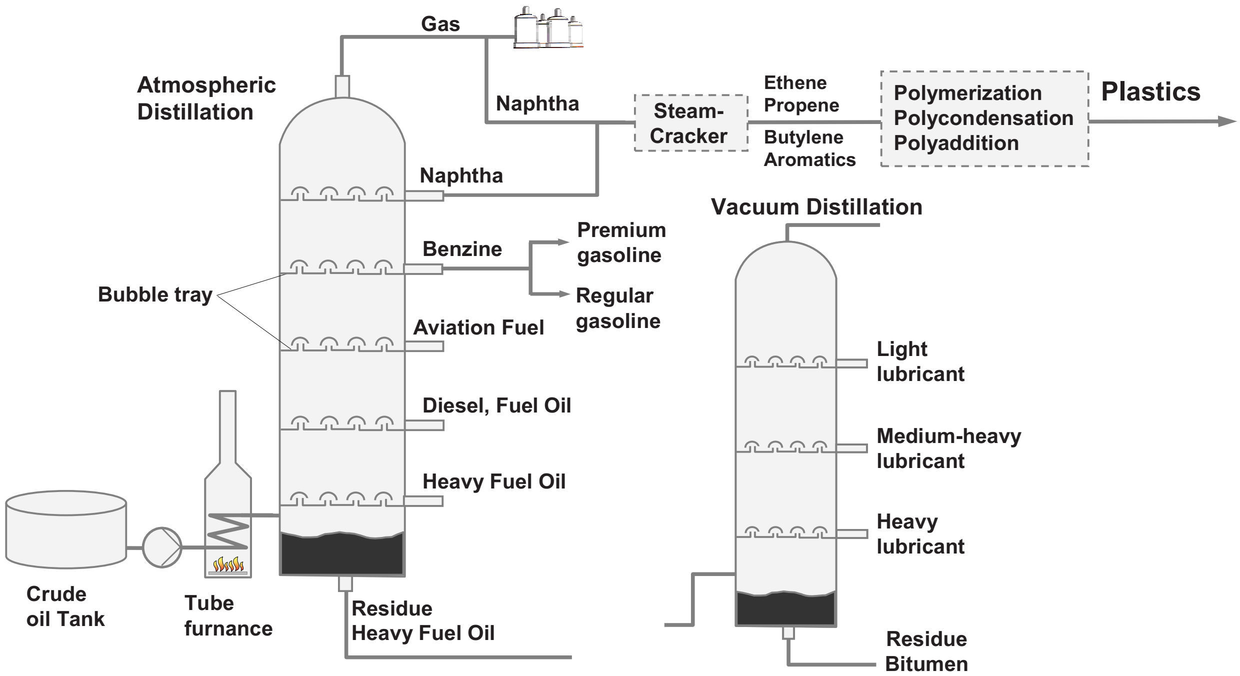

Figure 1: Distillation of crude oil and plastics production

Modern refineries produce about 9 % Naphtha from crude oil. When the production is aimed more at benzine and diesel instead of heavy fuel oil, naphtha yield is at about 12 %.

In Germany crude oil consumption is at about 120 million t per year and 20 million t plastics are produced. Additionally needed naphtha is imported via product pipeline from Rotterdam. The precursors for plastics, especially ethane, are produced from naphtha using a steamcracker (see figure 2).

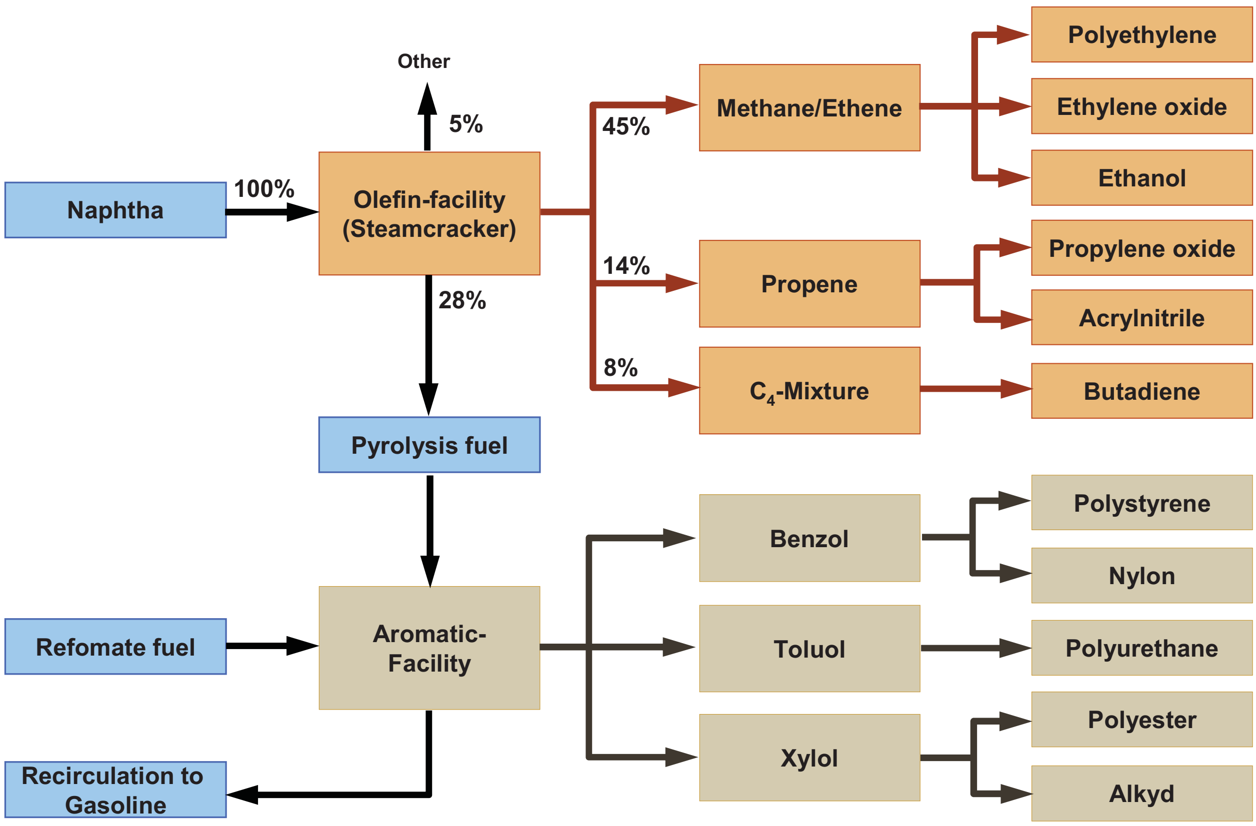

Figure 2: Products from Naphtha-steamcracker

Percentage distribution of the produced fractions depends on the crude oil properties. The precursors for plastics production are therefore not produced on demand from the consumer market for plastics but according to crude oil quality and to the technical conditions of the refinery.

Consequently refineries can only run when the produced naphtha is processed to plastics. Recently, in March 2009, the steamcracker of BASF in Ludwigshafen, Germany, was shut down because of the drop in demand for plastics.

Crude oil tanks in the USA are full, but the stored gasoline is decreasing because of the decreased demand for plastics. Demand for plastics dropped by 20 % to 70 %, depending on the sort. Logistics of the by-products are crucial for operating a refinery since these, like f. ex. naphtha, are generated in a substantial amount. For example, benzene storage capacity can not be increased easily, because it is a hazardous substance. If there is not enough demand for benzene, the refinery has to shut down. Therefore, production of polystyrene from benzene can not be stopped. To secure the demand for the produced plastics, the price can be adapted until they are cheaper than the corresponding natural material.

Another example is PVC, already much discussed in waste industry. PVC contains 57 % chlorine and is produced from chlorine gas and hydrochloric acid. Formerly there was a surplus of chlorine gas from sodium electrolysis in the chemical industry because sodium hydroxide was needed for production processes. PVC production consumed chlorine gas as well as naphtha and provided a way out of a disposal problem. Today, the situation is reversed because of the increased demand and acceptance of PVC.

3 Costs of raw plastics production

Many refineries are still burning off naphtha. For production of plastics precursors, naphtha is split via steamcracker into different short-chain hydrocarbons.

Naphtha is difficult to combust, because it is a very heterogeneous material. Gas turbines for naphtha need external combustion chambers and have to be equipped with explosion protection. In addition, they have a short lifetime and need to be replaced after 3 to 5 years. Naphtha is easily inflammable and transportation is a logistic challenge. Consequently, plastics production plants are often installed near a refinery.

Table 1: Up-to-date fuel costs in comparison with naphtha

Fuel	Procurement Costs (customary units)	Energy content	Energy-based Procurement Costs
Naphtha	332,00 €/t	43,50 MJ/kg	27,48 €/MWh
Crude Oil	49,60 US$/bbl	42,80 MJ/kg	22,26 €/MWh
Heavy Fuel Oil Power plant	167,00 €/t CE	41,80 MJ/kg	20,50 €/MWh
Light Fuel Oil Industry	303,00 €/t CE	41,80 MJ/kg	37,20 €/MWh
Natural Gas Industry	22,33 €/MWh	-	22,33 €/MWh
Natural Gas Power Plant	21,84 €/MWh	-	21,84 €/MWh
Anthracite	112,50 €/t	29,32 MJ/kg	13,81 €/MWh
Pulverized Lignite	112,00 €/t CE	21,00 MJ/kg	13,75 €/MWh
Waste Wood	-1,00 €/t	15,00 MJ/kg	-0,24 €/MWh
Wood, dry, finlely chopped	30,00 €/fm	15,00 MJ/kg	11,08 €/MWh
Straw, dry	60,00 €/t	17,00 MJ/kg	14,95 €/MWh
Grain, whole Plant	90,00 €/t	17,00 MJ/kg	22,42 €/MWh
Grain	120,00 €/t	17,00 MJ/kg	29,90 €/MWh
Vegetable Oil	500 €/m³	37,00 MJ/kg	52,88 €/MWh
Biogas from corn silage (Basis: Biogas recovery)	22,00 €/t	-	23,20 €/MWh

* CE = coal equivalent (anthracite)

The use of naphtha for plastics production is more profitable than using naphtha for power generation. During the last few years naphtha prices have been between 150 €/t and 400 €/t. Table 2 shows the costs for different fuels compared to naphtha.

The naphtha price is lower than benzene, diesel and light fuel. For processing naphtha to plastics precursors, the same amount of energy as the energy content of naphtha is needed again.

Table 2: Production energy as accumulated energy requirements (AEE) compared to procurement costs and disposal costs for plastics and other materials

Material	AEE MJ/kg	Procurement costs		Heating Value MJ/kg
		€/t	€/MWh AEE	
Naphtha	55	332	21,7	43,5
LDPE plastic film	91,8	800	31,4	46
HDPE plastic film	99,8	800	28,9	46
PP die casting	118,8	850	25,7	44
PVC plastic film	66,3	820	44,6	20
PS (high impact)	91,8	860	33,7	46
PET bottle	101,4	1060	37,6	46
PET plastic film	109,2	1020	33,6	46
Steel	35,8	247	24,8	0
Aluminium	193,3	1450	27,0	0
Clear glass	12,7	140	39,6	0
Corrugated card board, Carton	19,8	160	29,1	15
Paper (graphic etc.)	44,8	500	40,2	17
Chipped wood f. hard-boards	17,0	55	11,6	16
Wood trunk, green	14,0	150	38,6	10
Wood trunk, dried	19,0	220	41,7	15

About 20 million t plastics per year are produced in Germany. Assuming an average AEE of 90 MJ/kg, these 20 million tons would equate about 62 Gigawatt thermal output capacity, if not produced. Taking 50 % electrical efficiency as a basis, this equals a base load power plant with an electrical capacity of 30 Gigawatt. The installed capacity of all nuclear power plant in Germany is 21.5 Gigawatt, the total average yearly performance is 80 Gigawatt.

Combustion of all those plastics in a waste-to-energy plant with an electrical efficiency of 24 % would only equal a base load power plant with a thermal output of 29.5 Gigawatt and electrical capacity of 7 Gigawatt.

Consequently, only a quarter of the production energy (AEE) can be recovered from plastic waste as electrical power equivalent.

4 Replacement of renewable resources by plastics

Refining of crude oil yields the fractions naphtha, benzene, diesel/light fuel oil, heavy fuel oil and bitumen in a certain ratio. The sale of the products has to follow this ratio.

In the following example it is shown, how the political system is used to influence the fuel market to ensure demand.

In Germany, there has been a trend for private households and industry to replace oil with natural gas as heating fuel. The decreased demand for heating oil/diesel caused a surplus supply. With a lower tax on diesel the demand increased, until today Germany is one of the countries with the highest percentage of diesel sales.

Since the Fifties mineral oil tax or other fees on plastics have never been raised. This is also true for plastics, used for energy generation in coal fired power plants, cement kilns, for reduction in steelworks or for methanol production in the “Schwarze Pumpe” plant. Mineral oil tax is raised on all other mineral oil products for energy generation.

The material use of renewables, for example cotton, is not supported by the government in any way. Textile sellers like IKEA, OTTO, C&A and H&M have taken the initiative and support cotton farmers in Africa, whose survival on the market is threatened by cheap synthetic textiles, partly produced from PET-recycling material.

The German Renewable Energy Sources Act benefits energy recovery from wood as a renewable energy source. Consequently, the wood price is rising, also for material use of wood, which is not supported in any way. Therefore, plastics have a good chance to replace wood in many applications, for example thick-walled products like garden benches, fences or terrace paving.

Natural fibrous insulating material consumes only one tenth of the production energy of plastics based insulation, but even so, they cannot compete on the market with polyurethane or polystyrene materials. Insulation is state-aided in Germany without regard to the production energy of the insulation material.

Because of the high production energy and the high disposal costs, insulating with plastics should be watched critically, considering the ecological and economical impact. Politics are called to act and compensate this inequity.

5 Disposal of plastic waste

Today, plastic waste is mostly considered as recyclable material even though about 50 % of plastic waste is burned in waste incineration plants and recycling of mixed industrial waste is questionable too. The separate collection of plastic waste from households has also come under public criticism.

5.1 Energy Recovery of Plastic Waste

Pure polyethylene and polypropylene production waste with a low pollution level can be used for energy recovery in coal fired power plants and cement kilns.

In general however, plastics contain several critical pollutants such as chloride, bromide and especially heavy metals like mercury, lead, cadmium and antimony. Besides emission control, the product cement and the residues from the power plant should be taken into consideration.

5.1.1 Cadmium pollution

Cadmium is a waste product from tin smelting and has been used a pigment in plastics in general and especially as stabilizer in PVC. According to our evaluation of pollutant distribution in a coal firing power plant with co-combustion up to 25 % of thermal capacity, the limit value for cadmium is < 0.4 mg/kg fuel. Only then the required quality of the desulphogypsum can be maintained.

Biogenic waste material, not containing plastics, can meet this requirement. The limit value for cadmium of the “Bundesgütegemeinschaft Sekundärbrennstoffe e.V.”, an association of RDF producers, is 4 mg/kg RDF and is aimed at lower co-combustion rates. Waste containing plastics can barely keep this new, low limit.

According to the EU Directive 76/769/EWG, the limit value for plastics is 100 mg/kg. Germany imports more than half of the plastics for internal demand, even though all in all there is an excess of exports. The cadmium content of the imported plastics is nearly impossible to monitor. Some plastics contain up to 200 mg/kg cadmium.

5.1.2 Antimony pollution

The corrosion catalytic properties of antimony during combustion are still unknown and, until now, have also not been investigated. Antimony concentration in plastics is 1’000 to 2’000 times higher than in coal. In natural products antimony concentration is < 0.01 mg/kg. PET contains 300 mg/kg and Polyester 150 mg/kg due to the production process conditions. Flame retardants, also containing antimony, are used in electronic products in cars and in building. In the back cover of a TV set for example, 4’400 mg/kg antimony were measured.

Migration of toxic antimony from PET bottles into the liquid has been verified in 2006. Doctors are warning against wearing PET textiles, which are produced partly from PET recycling material, because of sweat releasing antimony and possibly causing skin irritation and neurodermatitis.

Replacement of antimony by titanium and phosphate in PET-production was tested in Japan. However, due to an unavoidable yellow tinge of the product, the new process could not take hold. Currently there are no alternatives to the use of antimony.

Antimony limit value in waste for combustion in cement kilns in Switzerland, was originally at 5 mg/kg and has since been adjusted to 300 mg/kg for „plastic waste“ and to 800 mg/kg especially for PET-waste. In Germany, the limit value for antimony in RDF has been raised to 50 mg/kg by the „Bundesgütegemeinschaft Sekundärbrennstoffe e.V.“. Until today there has been no long term study on the migration of antimony from concrete containing antimony polluted cement. So far, there exist no binding declarations by the plastics industry concerning a restricted use of antimony. Technically there is no alternative for antimony, neither as a stabilizer in PET and polyester nor as a synergist in bromide containing plastics.

5.1.3 Lead Pollution

Lead is used as stabilizer for the PVC production and as pigment. PVC in today's waste contains about 2'000 mg/kg lead, the limit value for co-combustion is at 70 mg/kg.

According to a voluntary declaration of PVC producers (Vinyl 2010), the use of lead in PVC production shall be reduced from 2015 on.

5.1.4 Mercury pollution

Hydrochloric acid is used for PVC production. Two thirds of hydrochloric acid is produced with chlorine-alkali-electrolysis and the amalgam process. In this process, contamination of the hydrochloric acid with mercury is unavoidable. In consequence the mercury is also incorporated into the PVC. Around 1973, 58 mg mercury per kg chlorine was used in PVC production. PVC products have a lifetime of 2 to 50 years. The limit value for co-combustion is 0.6 mg/kg.

5.1.5 Chlorine pollution

The chlorine content of waste containing plastics stems to 60 % to 95 % from the plastics. Best known example is crude PVC with a chlorine content of 57 %. The final PVC products contain about 30 % to 80 % of crude PVC; resulting in 12 % to 30 % chlorine content in the PVC based plastics. Separation by automatic sorting is therefore difficult. The reject material is not recyclable as PVC and the operators of waste-to-energy plants do not accept this mixed PVC waste, containing > 10 % of chlorine. Chlorine is further used in many other plastics as flame retardant.

Energy recovery in suitably designed waste-to-energy plants with combined heat and power is possible for nearly all plastic waste. Nonetheless, thermal treatment in waste incineration plants is generally classified as disposal. Discrimination between energy recovery and disposal in waste incinerators is determined in Germany by the German Life-Cycle Resource Management Act (KrW-/AbfG).

Chlorine, together with chloride-forming heavy metals and alkaline, is responsible for high temperature corrosion in the boiler. Many waste-to-energy plants have a permit for burning material with maximum of only 1 % chlorine. Not all flue gas cleaning systems of currently operating waste incineration plants or waste-to-energy plants allow for chlorine content higher than 2.5 %. On top of the costs caused by boiler corrosion, f. ex. higher maintenance costs, less availability and shorter run time, chlorine causes also higher utilities consumption for chlorine binding and higher costs for disposal of residues.

The total extra costs because of the chlorine load are 400 to 700 €/t PVC, basic costs for waste incineration not included. These extra costs are included into price escalation clauses of waste-to-energy plants by the operators. It is evident, that the presence of PVC in a mixed waste, declared for energy recovery, is not any indication for the suitability of PVC for energy recovery.

5.2 Raw material recycling

Raw material recycling of plastics is irrelevant at present, since the coal-oil-plant in Bottrop, Germany, was closed in 1999; the gasification plant for methanol synthesis SVZ shut down in 2005 and the steelworks do not use plastic waste as reduction material since 2005. Antimony content is important for steel production because antimony causes grain boundary segregation and, even more so, surface segregation of steel and iron based alloys. This causes embrittlement and higher corrosion risk of the steel. Commercial steel contains about 10 mg/kg antimony. Due to the increasing use of low quality scrap metal from car recycling, electronics scrap metal and ferrous scrap metal from waste incineration slag, it is likely that the antimony content of steel will increase. We do not expect a “revival” of the use of plastic waste in the steel industry.

5.3 Material recycling

We also investigated material recycling of waste, containing plastics. The term “recycling” of plastics implies that the same product can be produced again from the recyclate granulates. Up to now, this is regrettably not the case.

Even in plastics of the same sort, plasticizers evaporate and are present in different concentrations, depending on the age of the material. Different additives are uses according to the different applications of the material. Post consumer waste is therefore not recyclable even if separated into uni-type fractions and is only usable for down cycling.

The term „bottle-to-bottle“ in PET- bottle recycling does only mean a 15 % addition of recycling PET to the raw material for production of new bottles. The highest recycling quality to date is reached by blending regranulates from production waste with new raw material. This application for high quality products however, is not possible from post consumer waste without an inappropriate sorting effort and by mixing more than 10 % into the product.

Material recycling of plastics usually means production of thick-walled products. These can not be recycled after use and have to be disposed of by thermal treatment. So the incineration of the original plastic material is delayed, but ecologically and economically it is still the better alternative compared to land filling.

However, there is not enough waste incineration capacity in Germany today for disposal of all plastics waste in any case. 15 million tons of plastics have been consumed in Germany in 2007. Standardized to average heating value for waste incineration, this equals a waste incineration capacity of 60 million t/a, if the plastic waste would be treated in waste incineration plants. The waste incineration plant capacity can not be increased at the same rate as the plastics production of the last few years and also take into account the average lifetime of the material.

5.4 Society Landfill

The term “society landfill” is implying the intermediate storage of polluted plastics in society in the form of thick-walled plastic recycling products, such as garden benches, fences or even bicycle stands, prior to their final disposal. The society landfill secures the plastic waste for a subsequent controlled disposal.

5.5 Thermal Disposal by Waste Incineration

The most accepted and best way for the disposal of plastics waste is waste incineration. Plastics are responsible for 50 % to 80 % of incineration costs even though their proportion in the waste is only 15 % to 40 %. Because of their high heating value they account for 50 % to 90 % of the thermal output of the waste incineration plant.

Costs depend mainly on the waste volume, determining logistics, bunker and feeding costs as well as on pollution of the waste and on the thermal output of the plant.

The mass throughput is only a minor factor for the costs of waste incineration. One ton industrial waste with a high plastics content and 16’000 kJ/kg heating value is displacing two tons household waste with 8'000 kJ/kg heating value. Consequently, the plant operator earns only half when processing this industrial waste.

Average costs for waste incineration have been about 150 €/t in Germany during the last 3 years relating to an average heating value of 10'000 kJ/kg. One ton of plastic waste with 40'000 kJ/kg heating value consequently displaces four tons of household waste. The theoretical costs for disposal of plastic waste are therefore about 600 €/t, in case it were possible, to operate a plant only with this plastic waste. With exception of the circulating fluidized bed combustion (CFB), no waste incineration plant in operation today can tolerate heating values of 16'000 kJ/kg in the long run.

5.6 Landfill

Plastic waste from car recycling and plastics in the MBT landfill fraction are still land filled legally in Germany. In other countries, with few exceptions, disposal of plastic waste on landfills is still the main disposal method.

5.7 Export for pseudo recycling

Officially, plastic waste goes mainly into material recycling in foreign countries. In 2008 the "Bundeskriminalamt" (Federal Criminal Police Office) has published a report about „Waste management cross-border crime in connection with the EU enlargement to the East". Quotation: „On the European waste market there is a large dark field of illegal transport, especially of so-called pseudo recycling. The 2002 ecological report of the German Council of Environmental advisors states, that this is usual practice and calls this development a perversion of waste management. Compulsory use of the public disposal system for recycling was abolished and consequently the national and international waste transport increased…"

In our opinion plastic waste has to be regarded as hazardous waste. The danger to the environment is only perceivable in the long term. The point is not an alleged acute toxic effect but the extremely high persistence of plastics in the environment.

In 2004 it has been discovered, that several million tons of plastic waste are drifting in the Pacific Ocean between California and Hawaii. These plastic are slowly crushed mechanically and raise the plastic content of the plankton. This has been monitored. Degradation and therefore release of the toxic pollutants however, is estimated to take more than 500 years.

Air and water pollution can be remedied in a few years time. For example the air pollution in the "Ruhrgebiet", an industrialized area in the west of Germany, could be quickly reduced by installation of filter units. In contrast the pollution of the environment by plastics can last over 1'000 years.

The most obvious problem with using oil is carbon dioxide emission. This problem applies to 90 % of the oil application an can – at least in theory – be solved in a time frame of fifty to hundred years by switching to renewable resources. The other 10 % are used for production of plastics. The consequences by irresponsible disposal of plastics are not reversible during the next millennium.

6 Conclusion

Plastic waste is not recyclable. The real system costs of plastics production are principally higher than the use of basic material like glass, paper, wood, natural fibres, stone, metal etc. for the same application.

The system costs of oil based plastic production will increase along with the increasing shortage of crude oil. Less plastics production is consequently leading to fewer possibilities for the material recycling of plastics. The pressure for pseudo recycling can only be reduced if the compulsory use of public disposal systems is re-established for waste containing plastics.

7 Literature

Achternbosch, M. et al.	2004	Auswirkungen des Einsatzes von Abfällen bei der Zementherstellung auf die Spurenelementgehalte von Zement und Beton. In: NACHRICHTEN - Forschungszentrum Karlsruhe Jahrg. 36 4/2004 S. 213-218
Association of Cities and Regions for Recycling	2004	Empfehlenswerte Verfahren zum Recycling von Kunststoffabfall - Ein Wegweiser von und für lokale und regionale Behörden. Verlag : Jean-Pierre Hannequart. Download: http://www.pvch.ch/docs/PDF/VINYLGER.pdf
Brahms, E.; Eder, G.; Greiner, B.	1988	Papier • Kunststoff • Verpackungen - Eine Mengen- und Schadstoffbetrachtung. Technische Universität Berlin, Berlin.
Bundeskriminalamt (Hrsg.)	2008	Abfallwirtschaftskriminalität im Zusammenhang mit der EU-Osterweiterung. Wolters Kluwer Deutschland GmbH, Köln, ISBN 978-3-472-07156-3.
Eder, G.	1992	Wohin mit dem Kunststoffmüll? Werner-Verlag

		GmbH, Düsseldorf, ISBN 3-8041-14-33-4.
Westerhoff, P. et al.	2008	Antimony leaching from polyethylene terephthalate (PET) plastic used for bottled drinking water. In: Water Research, 2008 Feb;42(3):551-556

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Alternative Fuels from Waste

Pathways of interest & key challenges

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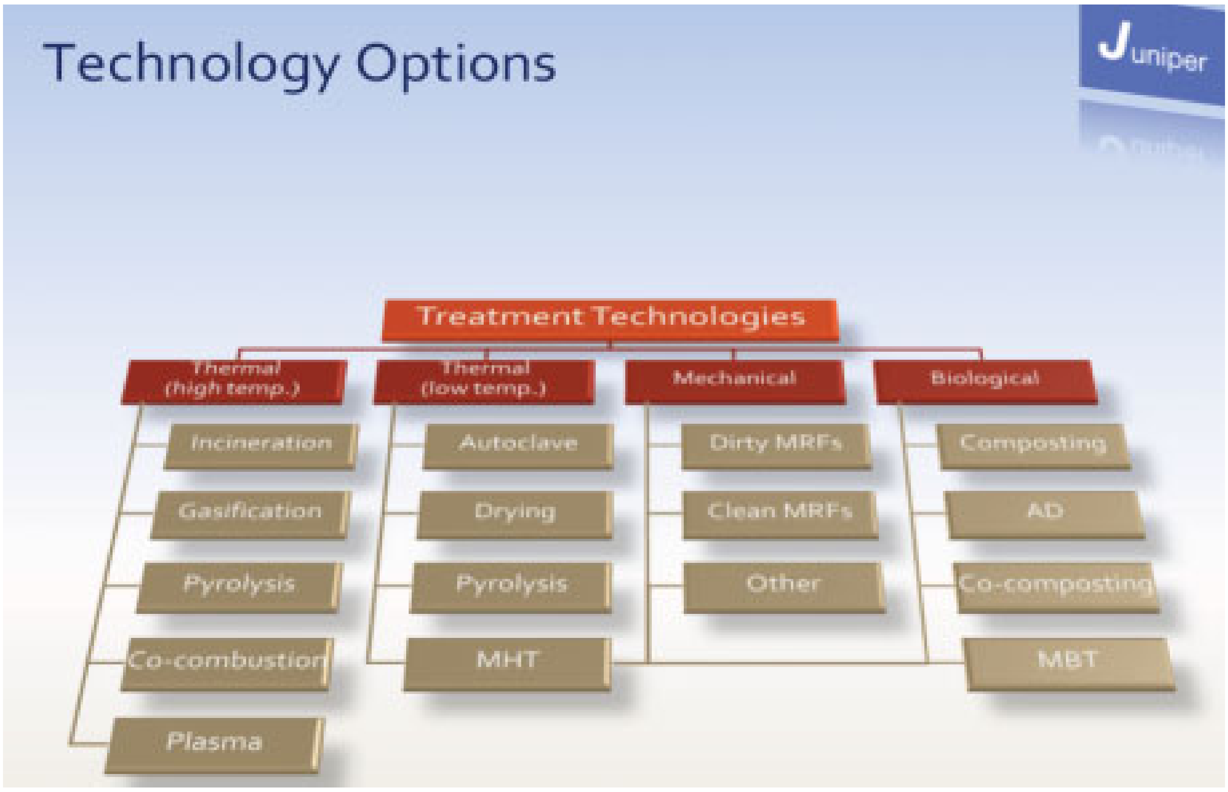
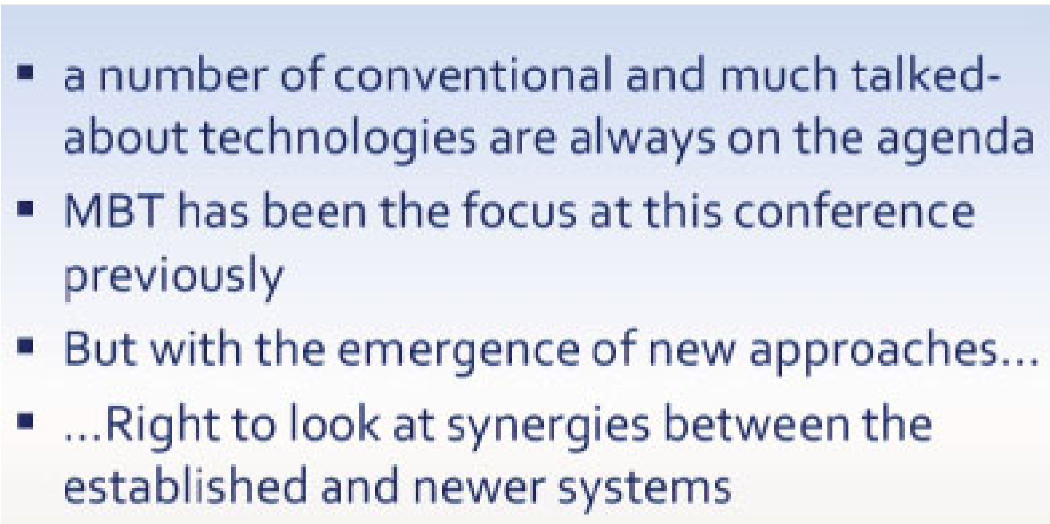
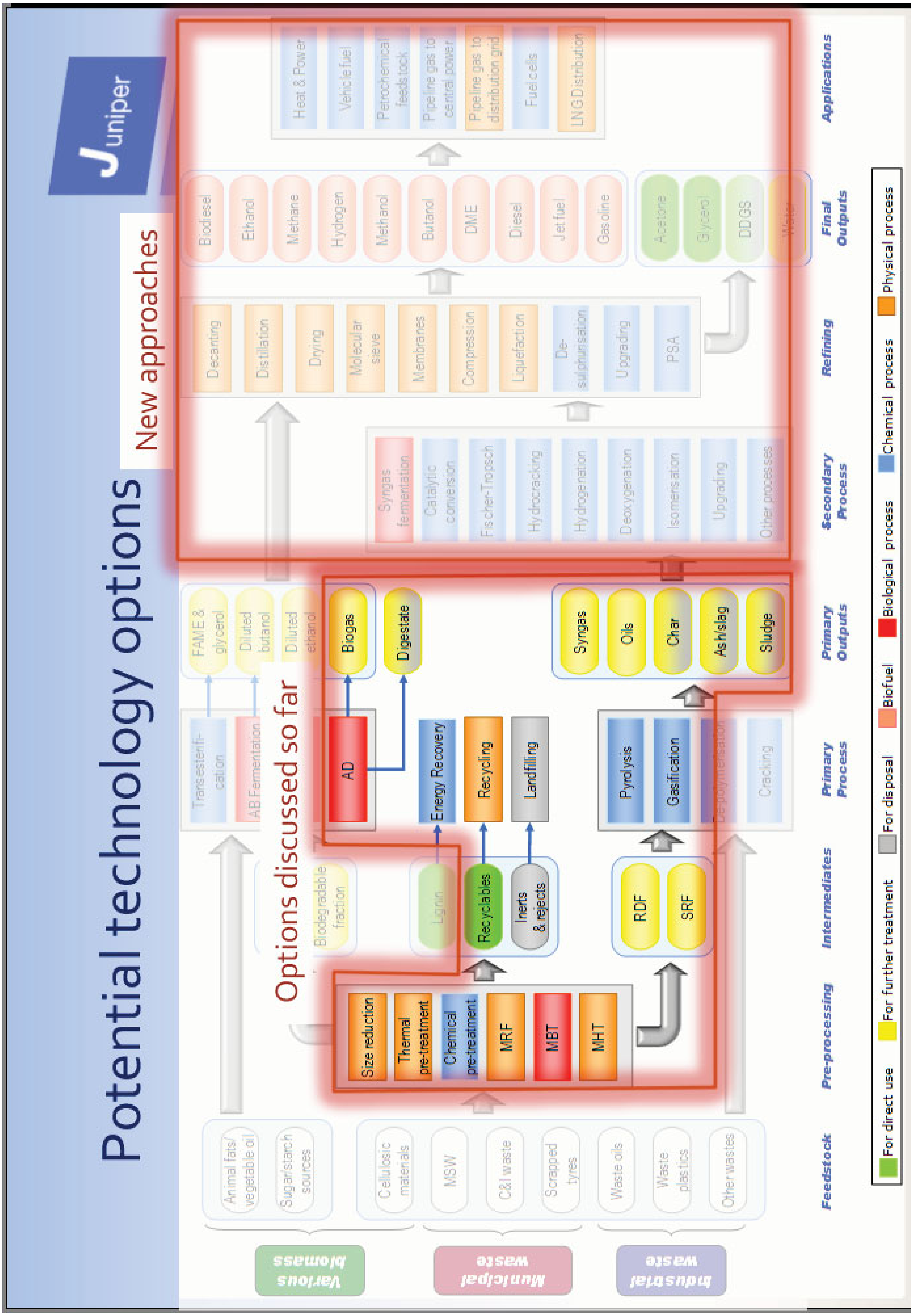
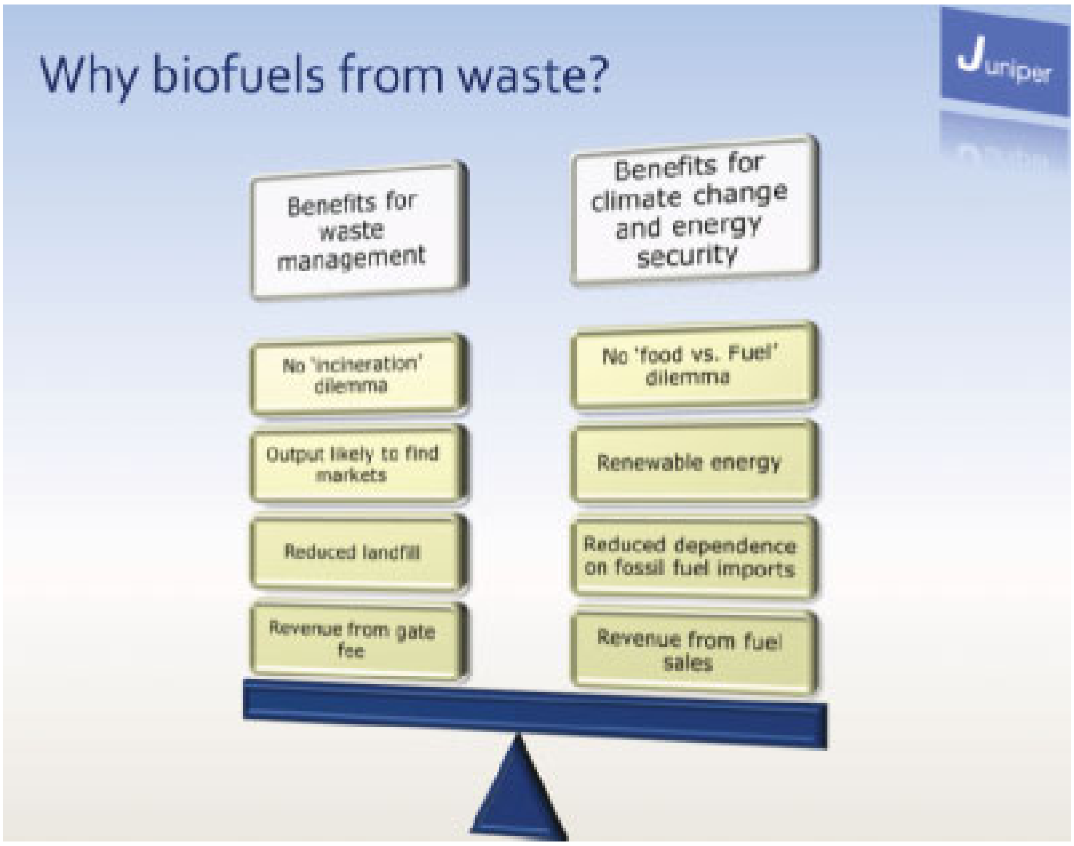
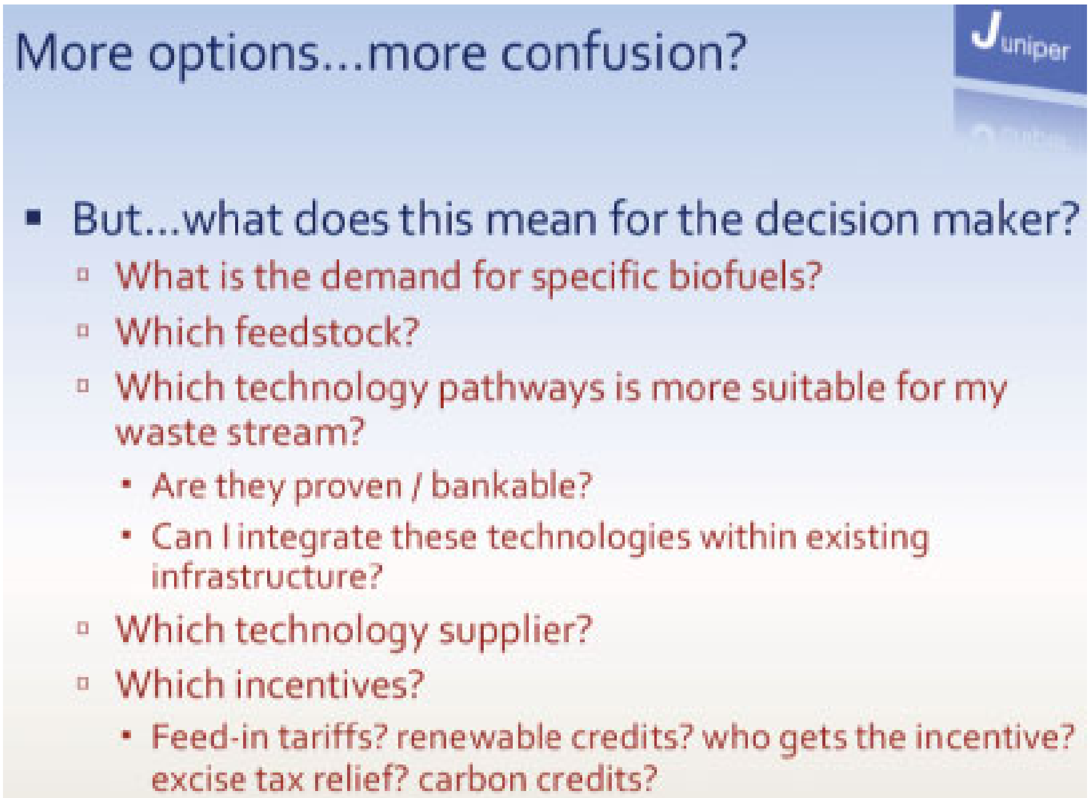


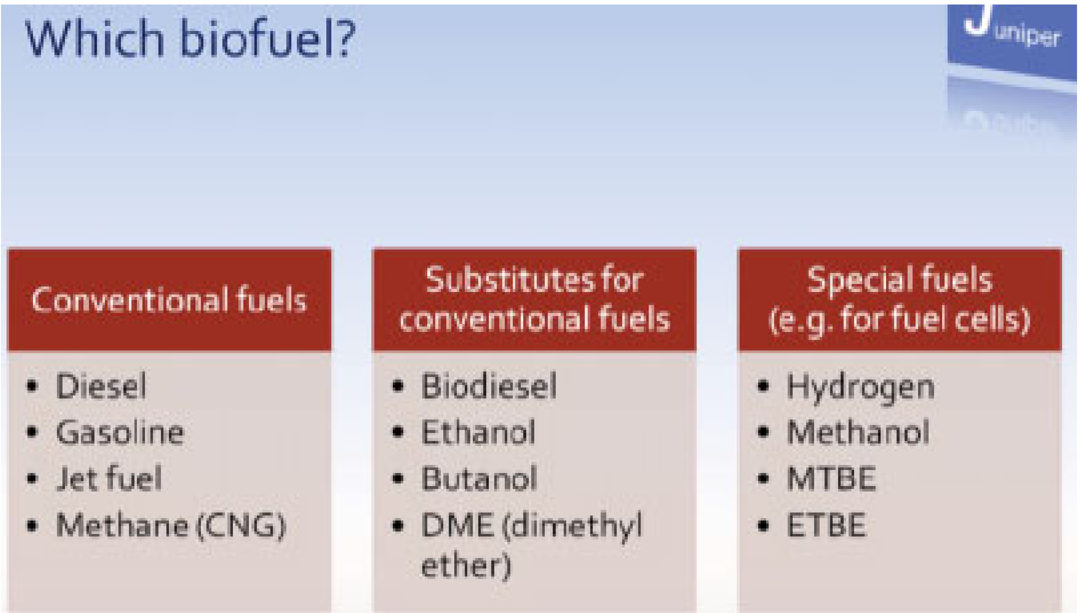

Whenever we talk about waste...
Juniper
▪ a number of conventional and much talked-about technologies are always on the agenda
▪ MBT has been the focus at this conference previously
▪ Discussing issues like
▫ adequately stabilising the input waste for landfilling
▫ finding sustainable markets for MBT outputs: RDF, SRF, CLO, digestate, etc.

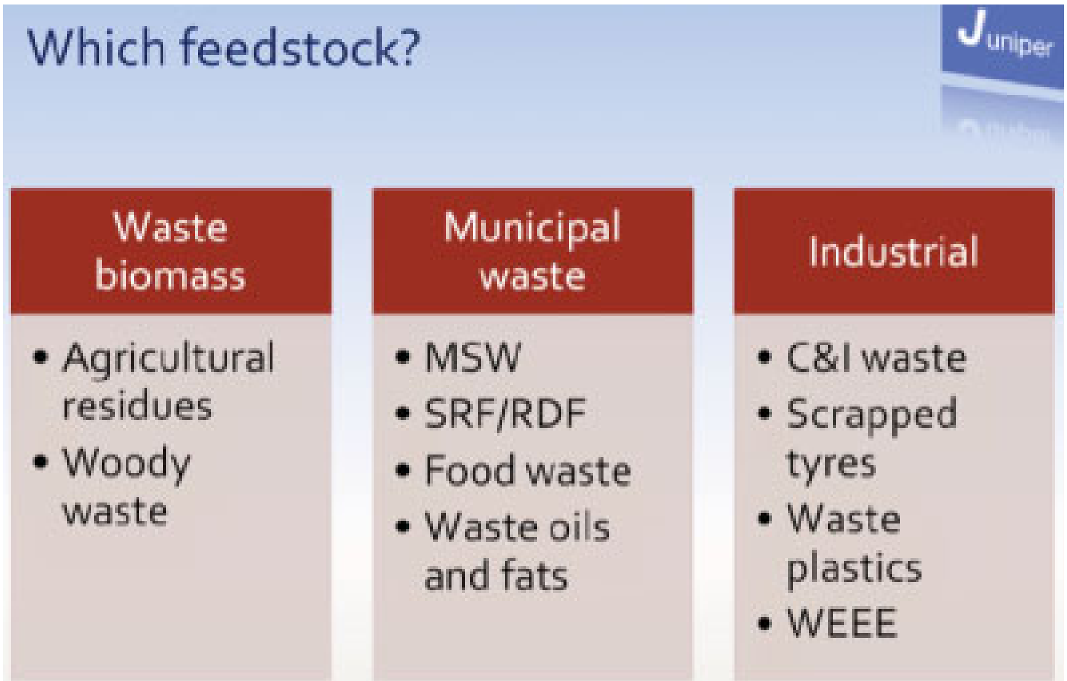

▪ a number of conventional and much talked-about technologies are always on the agenda
▪ MBT has been the focus at this conference previously
▪ But with the emergence of new approaches...
▪ ...Right to look at synergies between the established and newer systems


Potential technology options
New approaches
Options discussed so far
Juniper
Various biomass
Municipal waste
Industrial waste
Feedstock
Pre-processing
Intermediates
Primary Process
Primary Outputs
Secondary Process
Refining
Final Outputs
Applications
Animal fats/ vegetable oil
Sugar/starch sources
Cellulosic materials
MSW
C&I waste
Scrapped tyres
Waste oils
Waste plastics
Other wastes
Size reduction
Thermal pre-treatment
Chemical pre-treatment
MRF
MBT
MHT
Biodegradable fraction
Lignin
Recyclables
Inerts & rejects
RDF
SRF
Transesterification
AB Fermentation
AD
Energy Recovery
Recycling
Landfilling
Pyrolysis
Gasification
Depolymerisation
Cracking
FAME & glycerol
Diluted butanol
Diluted ethanol
Biogas
Digestate
Syngas
Oils
Char
Ash/slag
Sludge
Syngas fermentation
Catalytic conversion
Fischer-Tropsch
Hydrocracking
Hydrogenation
Deoxygenation
Isomerisation
Upgrading
Other processes
Decanting
Distillation
Drying
Molecular sieve
Membranes
Compression
Liquefaction
De-sulphurisation
Upgrading
PSA
Biodiesel
Ethanol
Methane
Hydrogen
Methanol
Butanol
DME
Diesel
Jet fuel
Gasoline
Acetone
Glycerol
DDGS
Water
Heat & Power
Vehicle fuel
Petrochemical feedstock
Pipeline gas to central power
Pipeline gas to distribution grid
Fuel cells
LNG Distribution
For direct use
For further treatment
For disposal
Biofuel
Biological process
Chemical process
Physical process


Why biofuels from waste?
Juniper
Benefits for waste management
Benefits for climate change and energy security
No 'incineration' dilemma
No 'food vs. Fuel' dilemma
Output likely to find markets
Renewable energy
Reduced landfill
Reduced dependence on fossil fuel imports
Revenue from gate fee
Revenue from fuel sales


More options…more confusion?
Juniper
But…what does this mean for the decision maker?
What is the demand for specific biofuels?
Which feedstock?
Which technology pathways is more suitable for my waste stream?
Are they proven / bankable?
Can I integrate these technologies within existing infrastructure?
Which technology supplier?
Which incentives?
Feed-in tariffs? renewable credits? who gets the incentive? excise tax relief? carbon credits?


Which biofuel?
Juniper
Conventional fuels
• Diesel
• Gasoline
• Jet fuel
• Methane (CNG)
Substitutes for conventional fuels
• Biodiesel
• Ethanol
• Butanol
• DME (dimethyl ether)
Special fuels (e.g. for fuel cells)
• Hydrogen
• Methanol
• MTBE
• ETBE

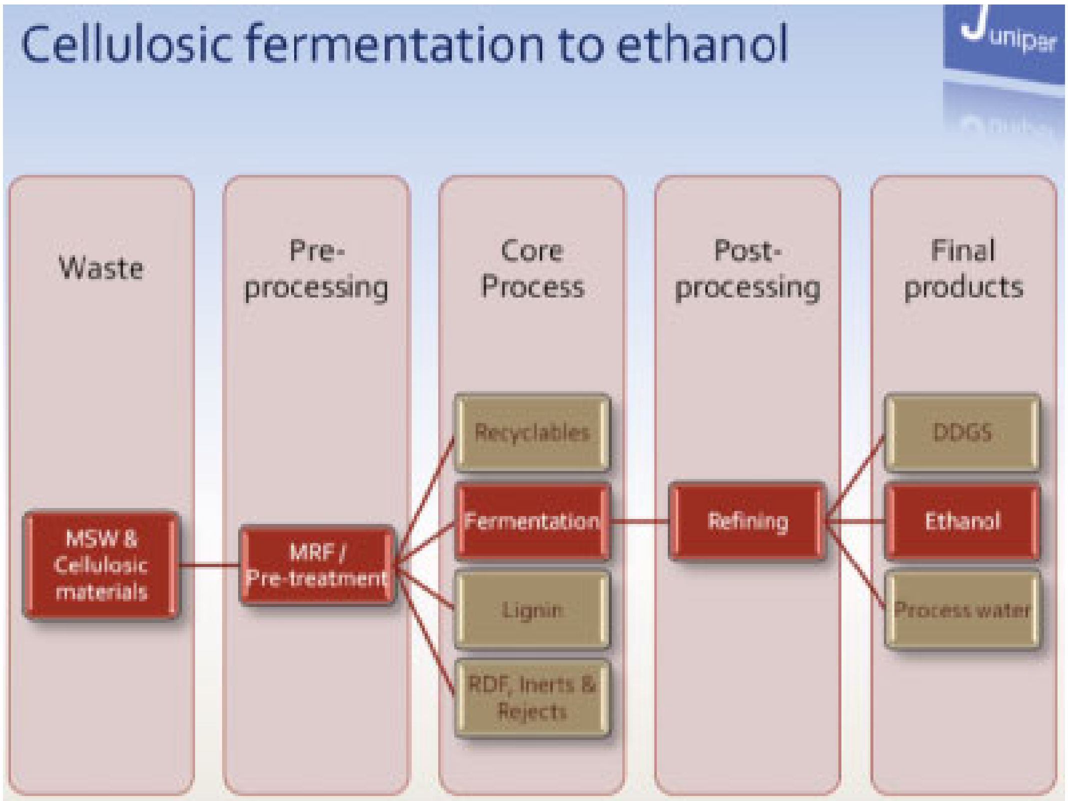

Which feedstock?
Juniper
Waste biomass
• Agricultural residues
• Woody waste
Municipal waste
• MSW
• SRF/RDF
• Food waste
• Waste oils and fats
Industrial
• C&I waste
• Scrapped tyres
• Waste plastics
• WEEE

Which technology pathway?

- Juniper has identified 75 pathways considered as commercially relevant
  - 20 of these use MSW and/or MSW-derived wastes
  - 23 use special wastes: food waste, manures, C&I waste, etc.
- Because of time ...I will discuss only a few
  - Benefits and challenges
  - Potential for integration with MBT

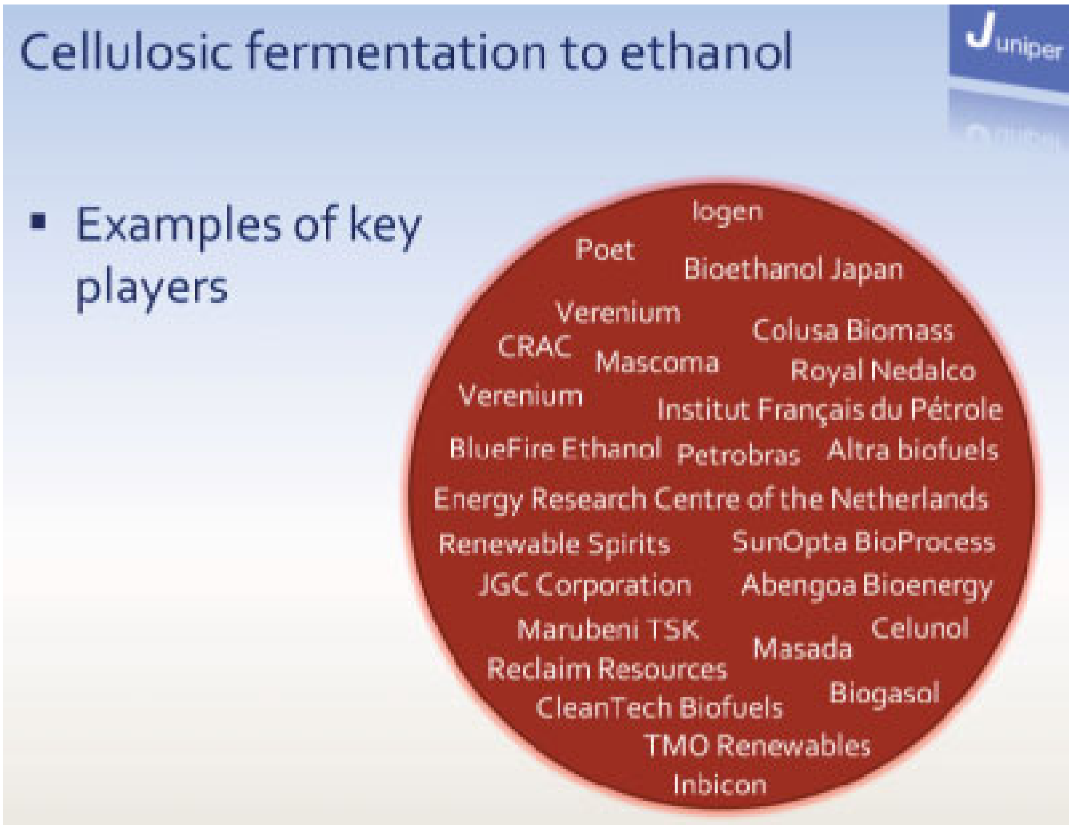
Selected pathways of interest

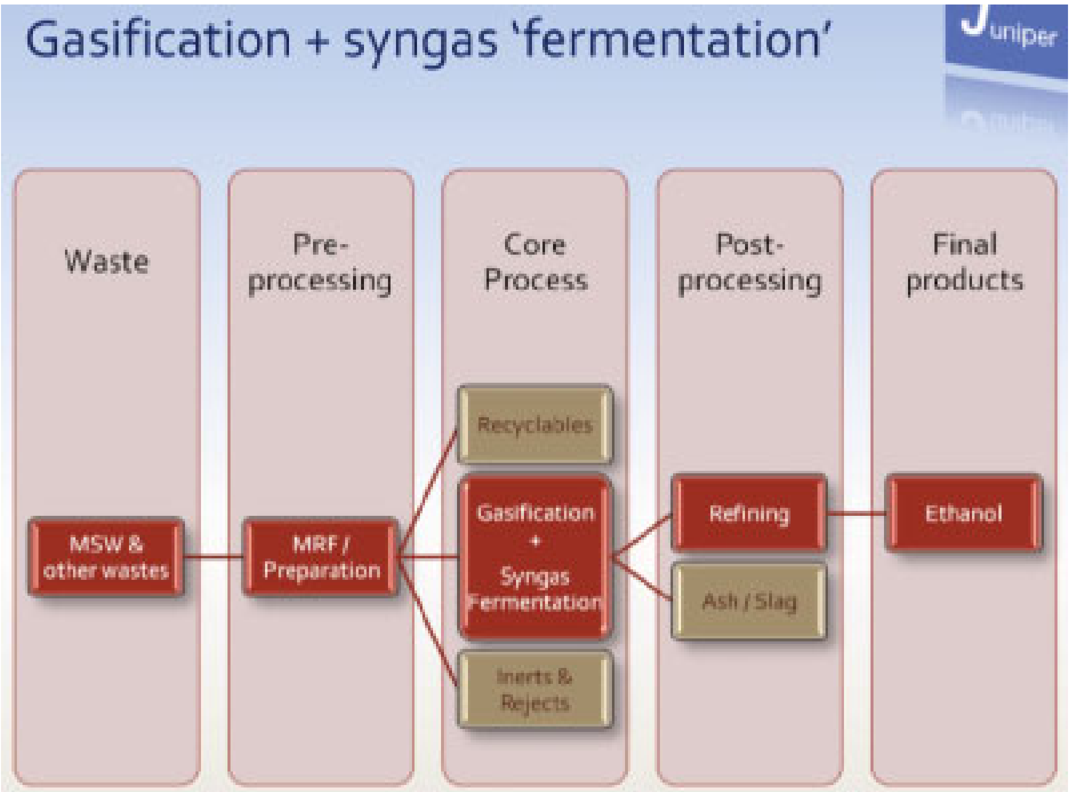
- Cellulosic Fermentation to *Ethanol*
- Gasification + Catalytic Conversion to *Alcohols & DME*
- Gasification + Syngas 'Fermentation' to *Ethanol*
- Gasification + Fischer-Tropsch to *Diesel, Jet Fuel & Gasoline*
- Depolymerisation to *Diesel*
- AD + Biogas Upgrading to *Biomethane*
- Fast Pyrolysis to *bio-oil*



Cellulosic fermentation to ethanol

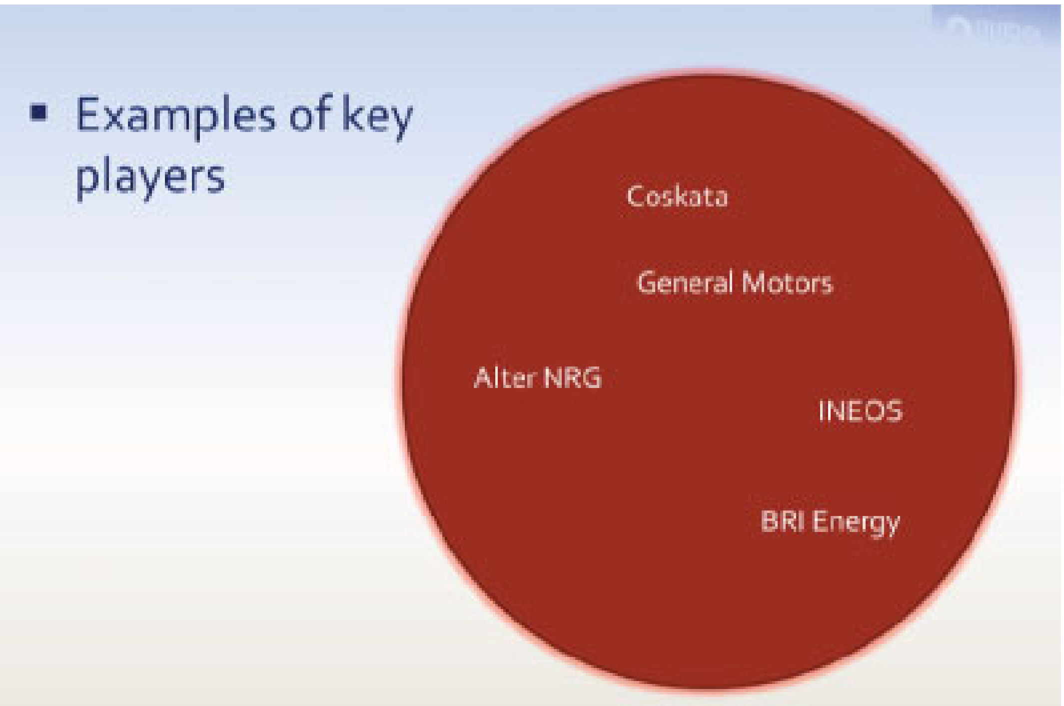
Criteria	Potential Advantages and Issues
Waste types	✓ Biodegradable, food and green wastes ✓ Cellulosic materials (e.g. waste wood, crop residues)
Technical	✓ Can handle wet and low CV materials ✗ Pre-treatment of cellulosic materials still being developed
Economic	✗ Opex may be high (enzymes, pre-treatment agents, energy requirements)
Environmental	✓ Likely to be perceived as avoiding incineration ✗ ...but need to manage residues: lignin, DDGS, off-gases
Provenness	✗ No longstanding commercial reference projects
Synergies with MBT	✓ MBT can assist in feed preparation ✓ Developments in pretreatment of cellulosic materials could provide opportunities for MBT

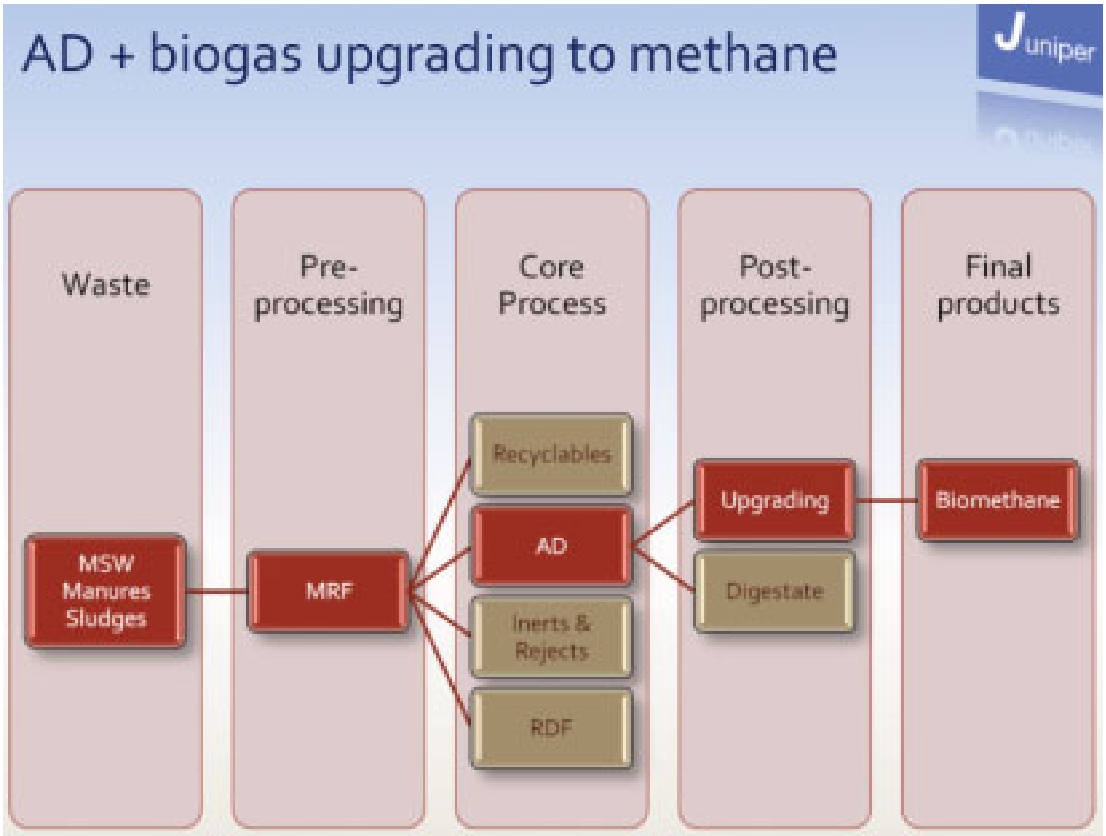

Cellulosic fermentation to ethanol
Juniper
Examples of key players
Iogen
Poet
Bioethanol Japan
Verenium
Colusa Biomass
CRAC
Mascoma
Royal Nedalco
Verenium
Institut Français du Pétrole
BlueFire Ethanol
Petrobras
Altra biofuels
Energy Research Centre of the Netherlands
Renewable Spirits
SunOpta BioProcess
JGC Corporation
Abengoa Bioenergy
Marubeni TSK
Masada
Celunol
Reclaim Resources
Biogasol
CleanTech Biofuels
TMO Renewables
Inbicon


Gasification + syngas 'fermentation'
Juniper
Waste
Pre-processing
Core Process
Post-processing
Final products
MSW & other wastes
MRF / Preparation
Recyclables
Gasification + Syngas Fermentation
Inerts & Rejects
Refining
Ash / Slag
Ethanol

Gasification + syngas 'fermentation'

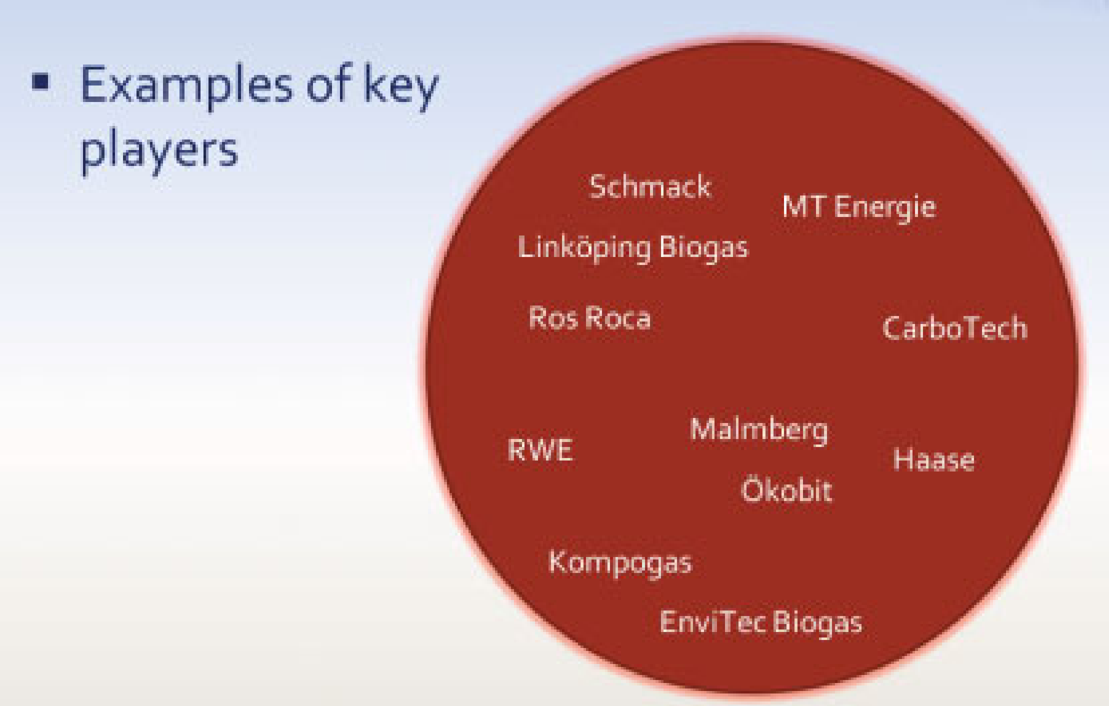
Criteria	Potential Advantages and Issues
Waste types	✓ Biodegradable, food and green wastes ✓ Cellulosic materials ✓ Special wastes: plastics, tyres, residual MSW
Technical	✓ Syngas 'fermentation' step operates at low temp & pressure ✗ System complexity potentially high ✗ Not good with wet and low CV materials
Economic	✗ Potentially high capex
Environmental	✓ Does not produce lignin-rich or DDGS-like residues ? Need to manage an ash or slag
Provenness	? Only proven at pilot scale
Synergies with MBT	✓ MBT can play critical role in ensuring that feedstock is suitable for gasification

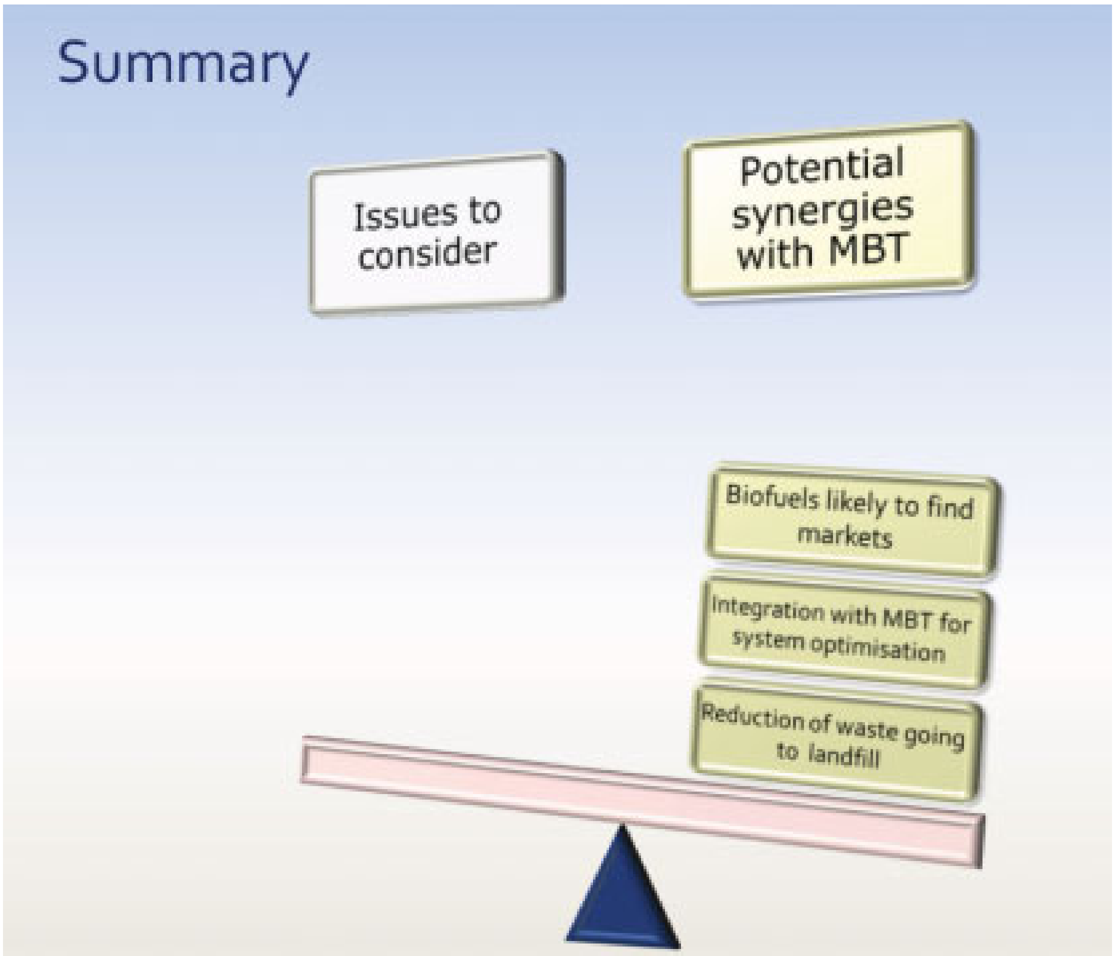


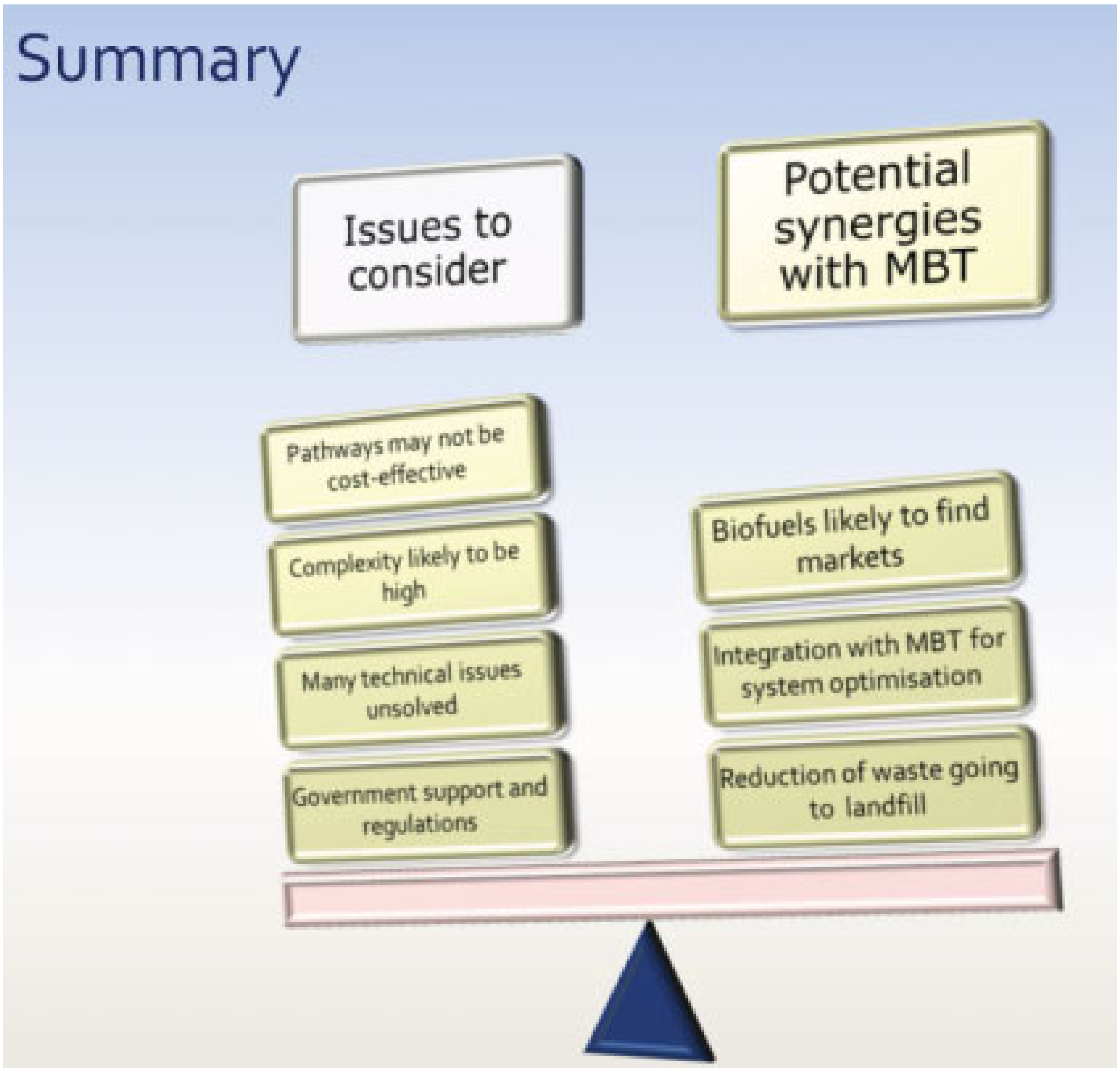


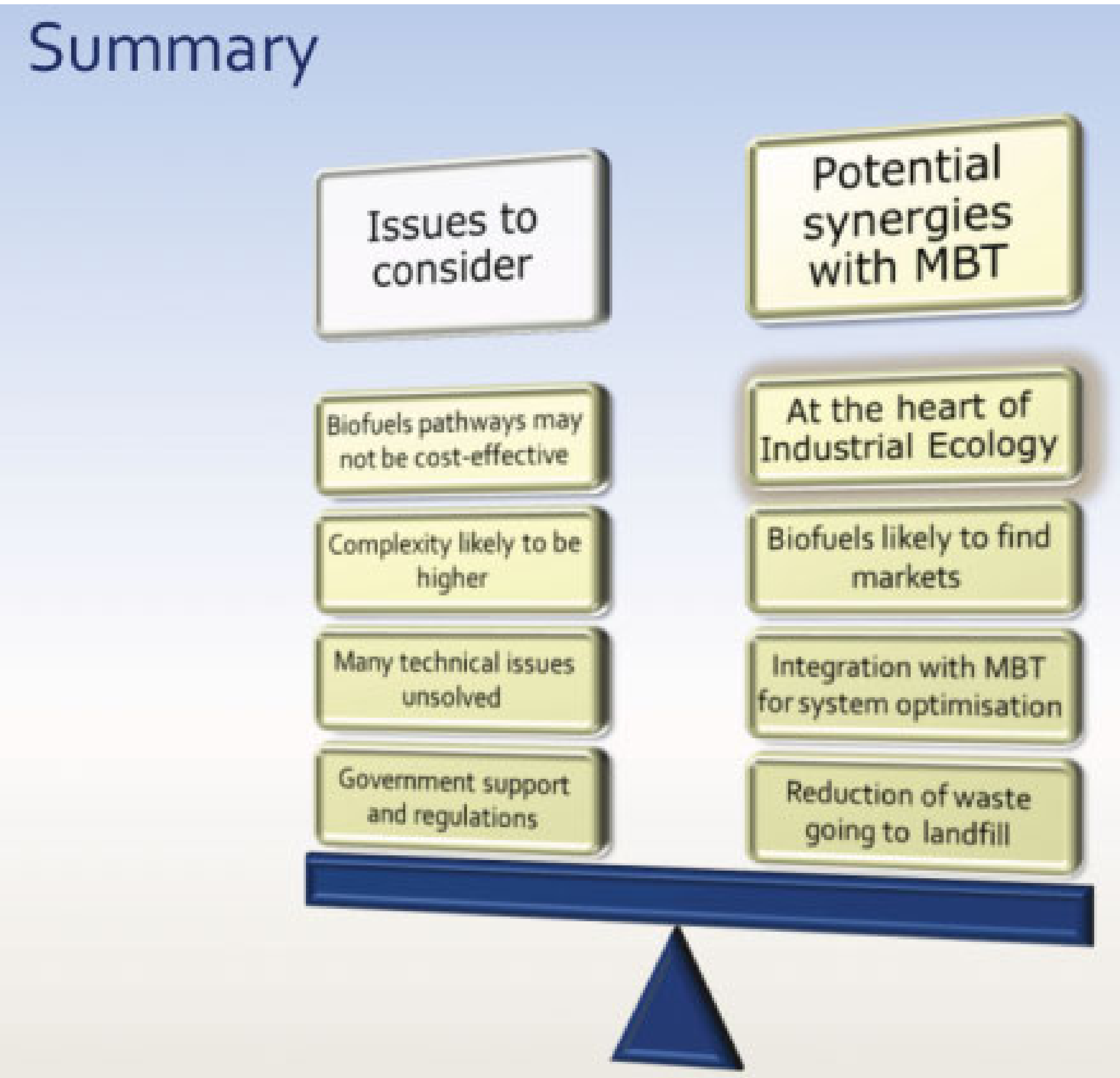
AD + biogas upgrading to methane

Criteria	Potential Advantages and Issues
Waste types	✓ Biodegradable, food and green wastes
Technical	✓ Can handle wet and low CV materials
Economic	– Very case specific
Environmental	✓ Can avoid incineration as desirable in some countries ✗ ...but need to treat off-gases from process and manage CO_2-rich gas stream from biogas upgrading ✗ Need to manage digestate, water effluent
Provenness	– Fully proven but with certain feedstock
Synergies with MBT	✓ Relatively straightforward to integrate in some MBT systems


Examples of key players
Schmack
MT Energie
Linköping Biogas
Ros Roca
CarboTech
RWE
Malmberg
Haase
Ökobit
Kompogas
EnviTec Biogas


Summary
Issues to consider
Potential synergies with MBT
Biofuels likely to find markets
Integration with MBT for system optimisation
Reduction of waste going to landfill


Summary
Issues to consider
Potential synergies with MBT
Pathways may not be cost-effective
Complexity likely to be high
Many technical issues unsolved
Government support and regulations
Biofuels likely to find markets
Integration with MBT for system optimisation
Reduction of waste going to landfill



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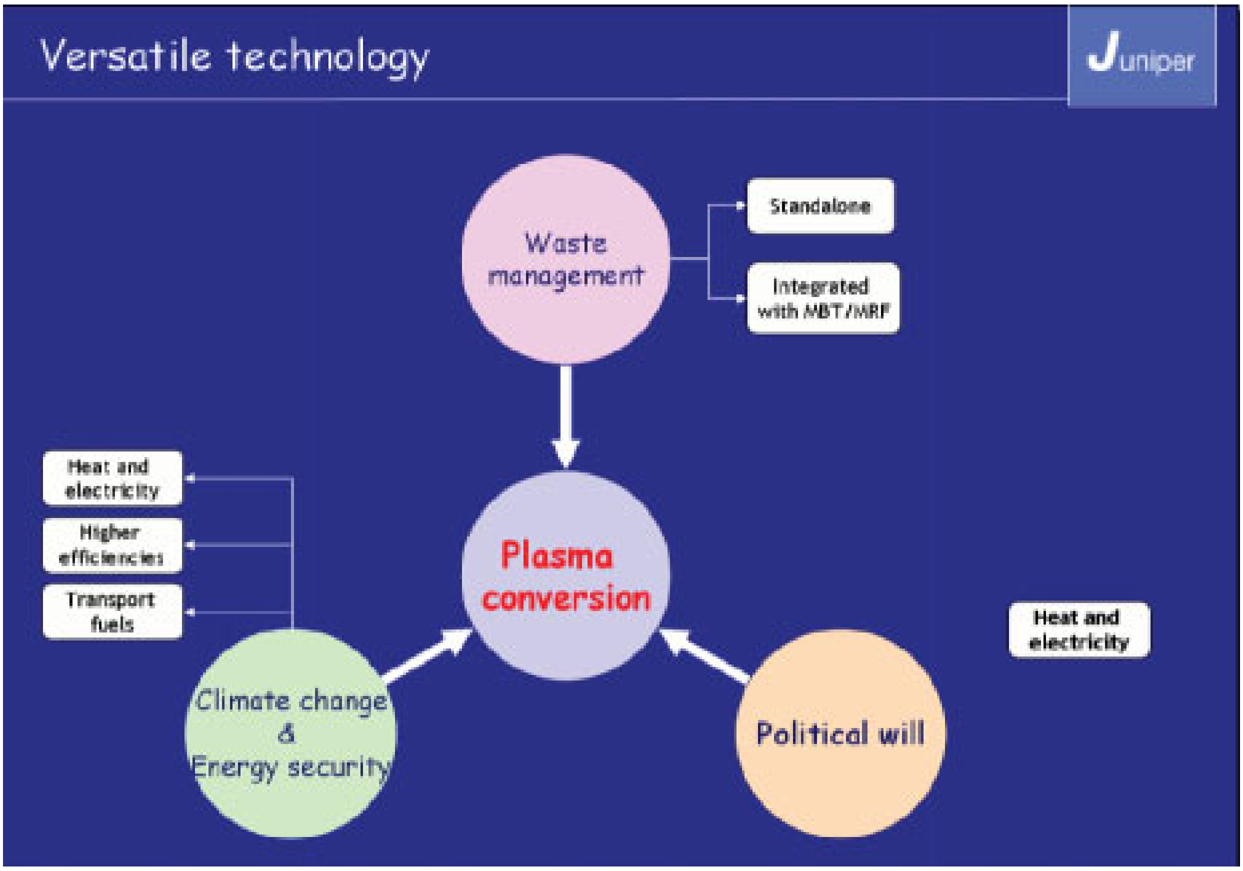
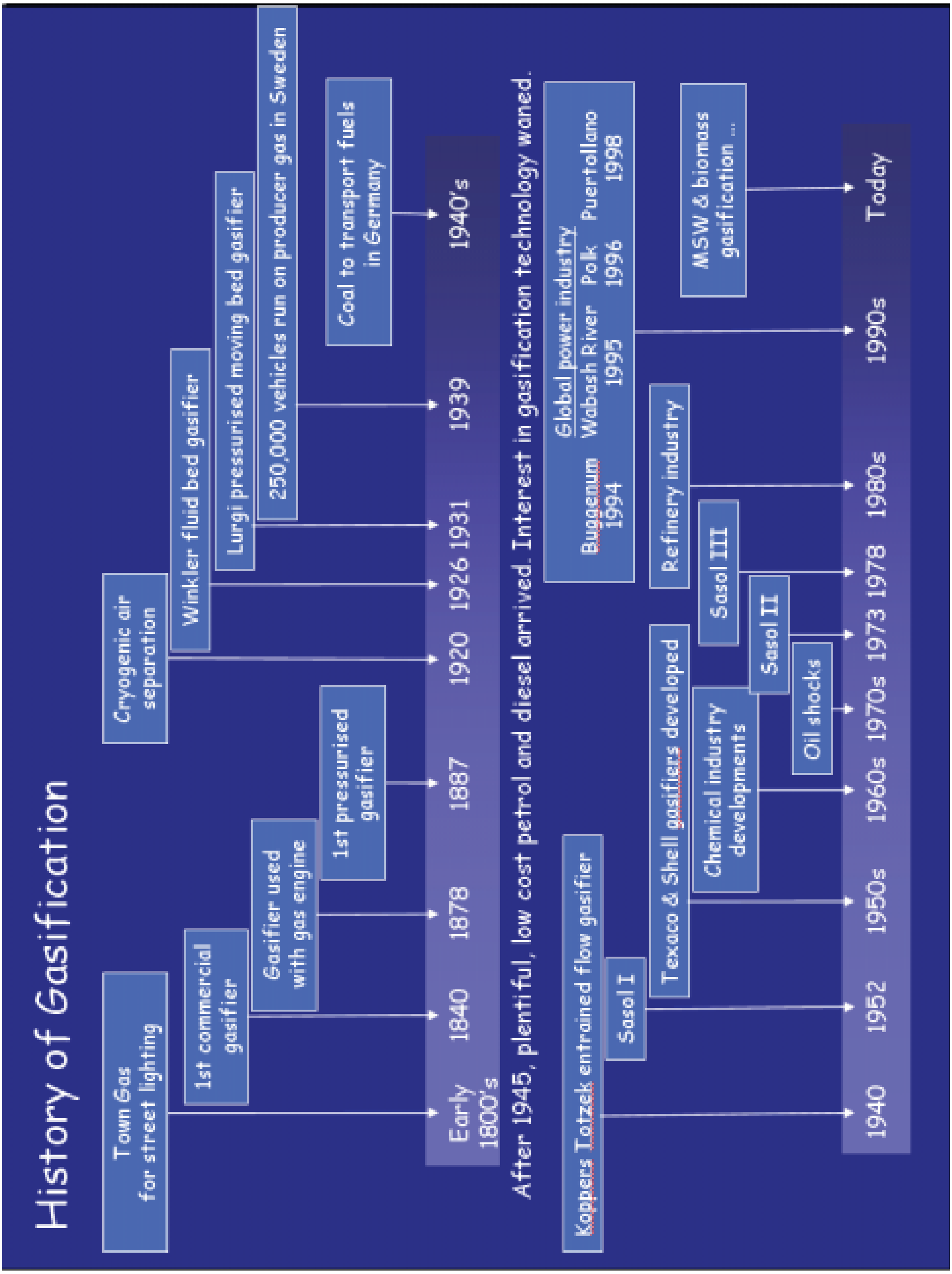
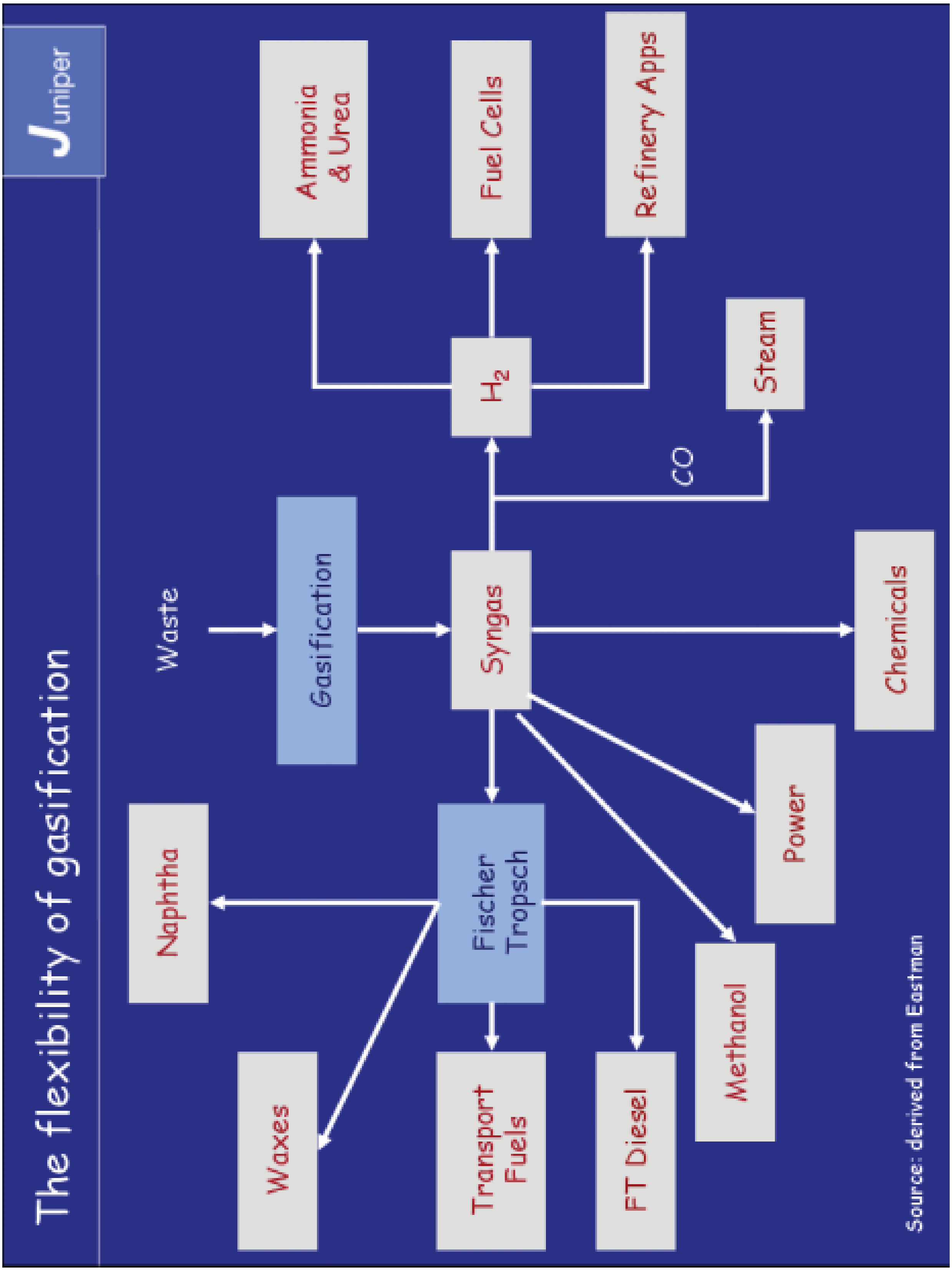
Plasma conversion of waste and biomass - a new solution?

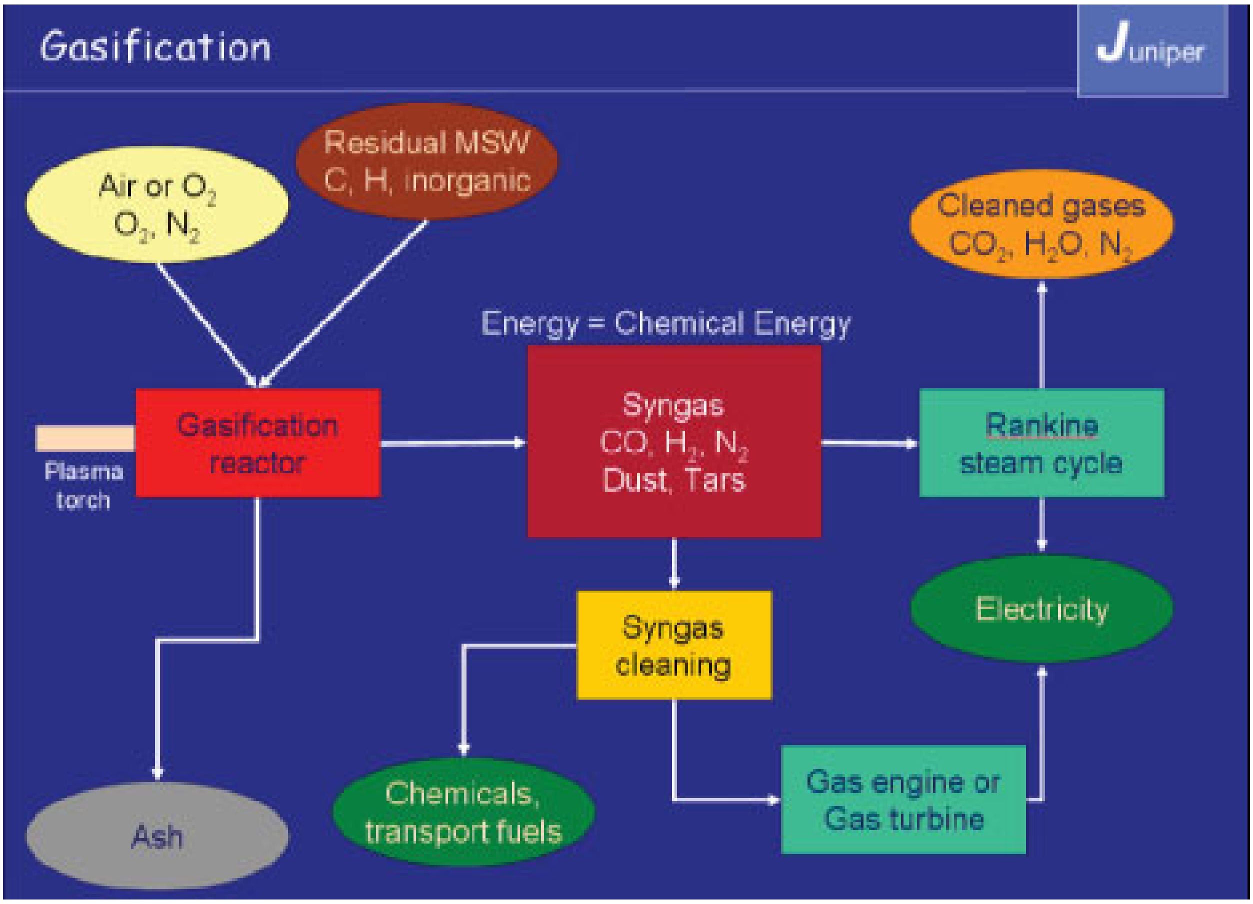
Dr. Egan Archer

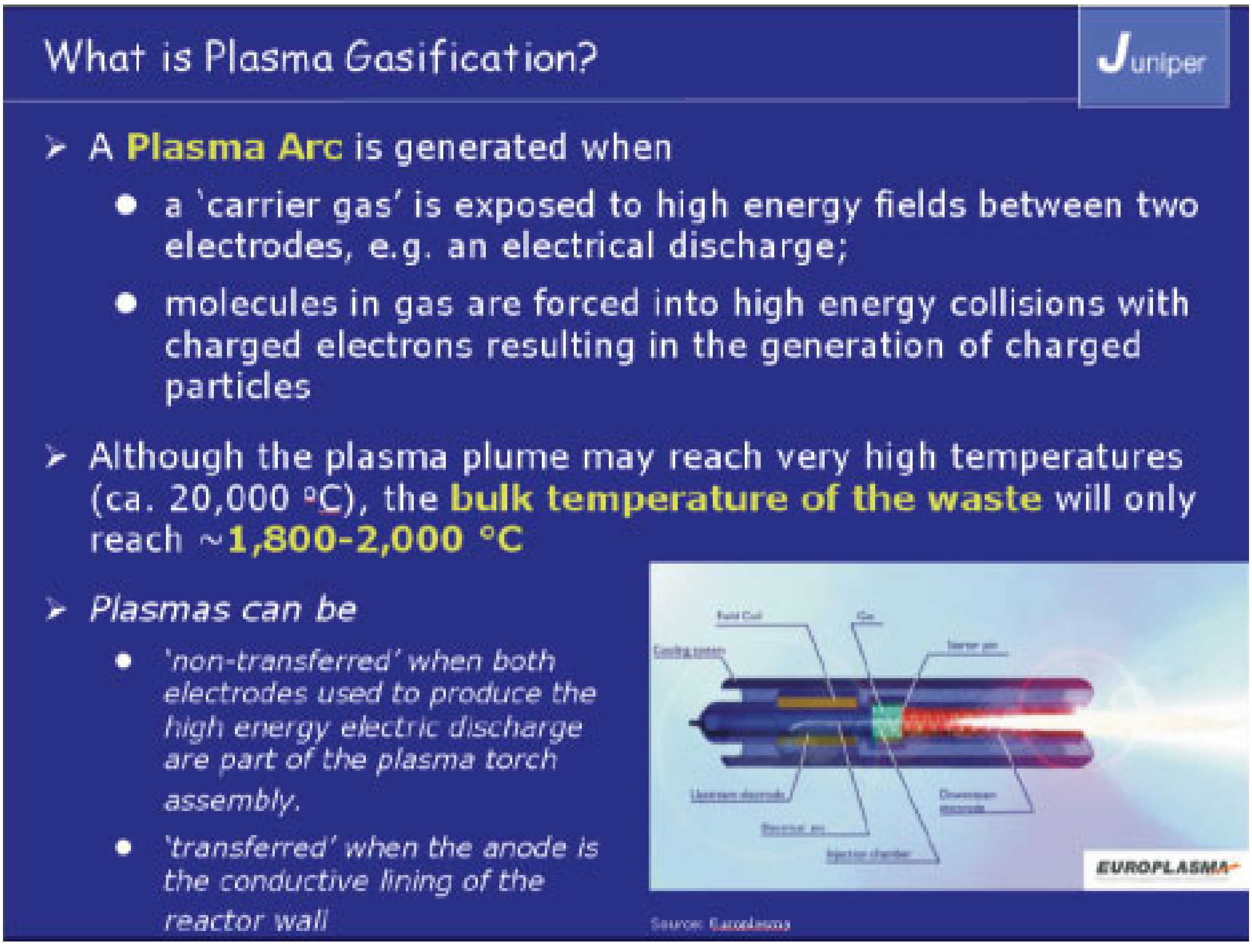
Director, Juniper Consultancy Services Ltd.

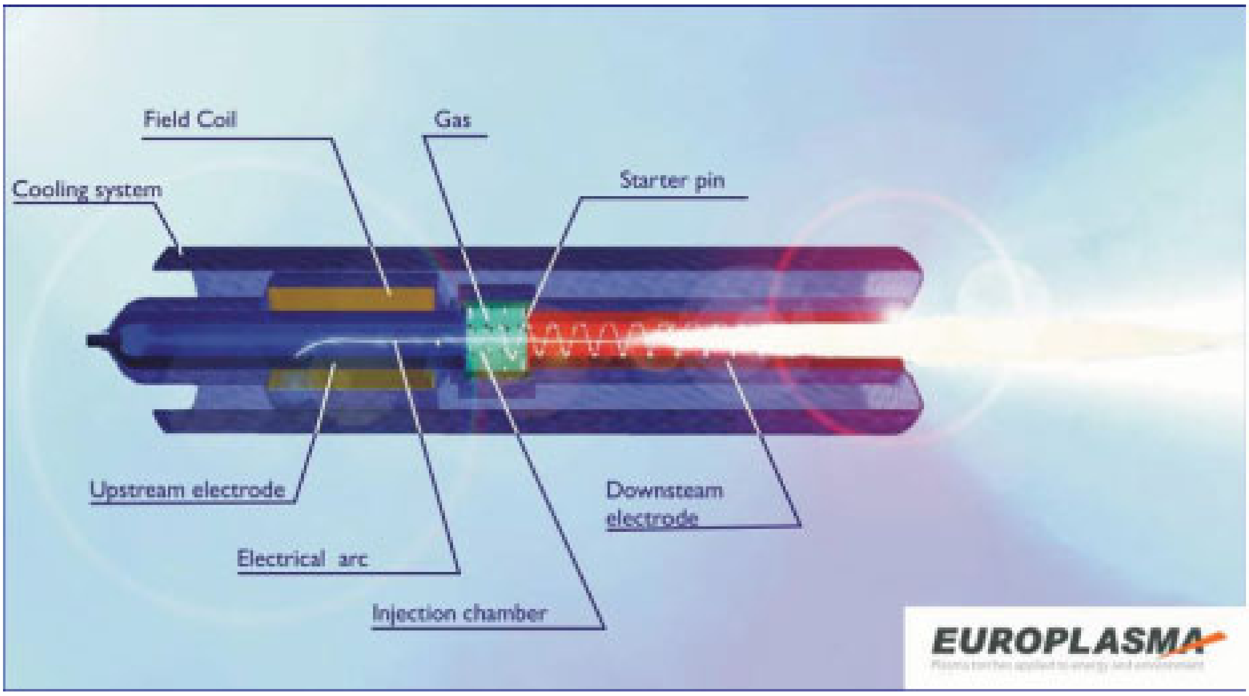



History of Gasification
Town Gas for street lighting
1st commercial gasifier
Gasifier used with gas engine
1st pressurised gasifier
Cryogenic air separation
Winkler fluid bed gasifier
Lurgi pressurised moving bed gasifier
250,000 vehicles run on producer gas in Sweden
Coal to transport fuels in Germany
Early 1800's
1840
1878
1887
1920
1926
1931
1939
1940's
After 1945, plentiful, low cost petrol and diesel arrived. Interest in gasification technology waned.
Koppers Totzek entrained flow gasifier
Sasol I
Texaco & Shell gasifiers developed
Chemical industry developments
Oil shocks
Sasol II
Sasol III
Refinery industry
Global power industry
Buggenum 1994
Wabash River 1995
Polk 1996
Puertollano 1998
MSW & biomass gasification ...
1940
1952
1950s
1960s
1970s
1973
1978
1980s
1990s
Today

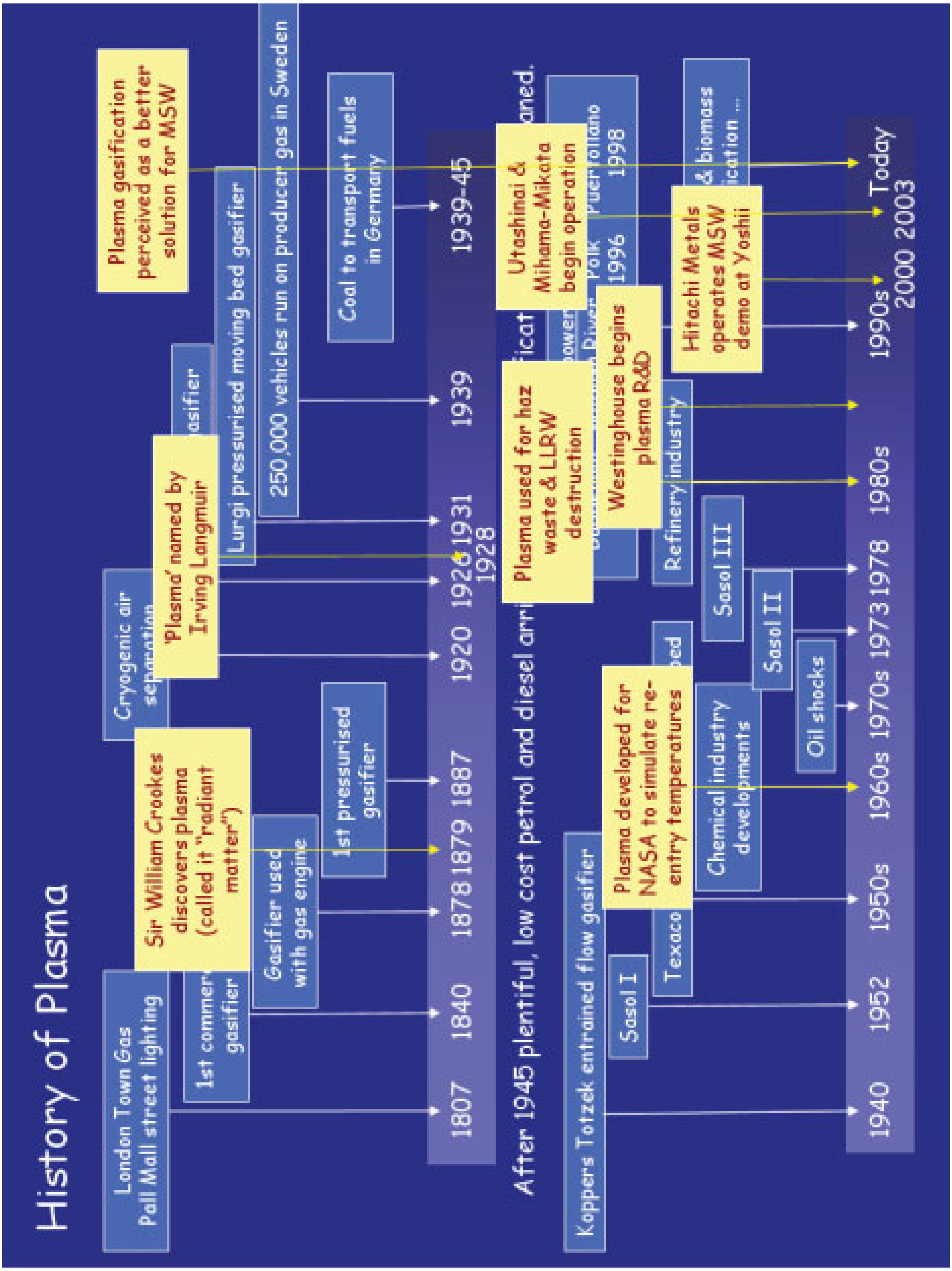

The flexibility of gasification
Juniper
Waste
Gasification
Syngas
H2
CO
Steam
Ammonia & Urea
Fuel Cells
Refinery Apps
Chemicals
Power
Methanol
Fischer Tropsch
Naphtha
Waxes
Transport Fuels
FT Diesel
Source: derived from Eastman

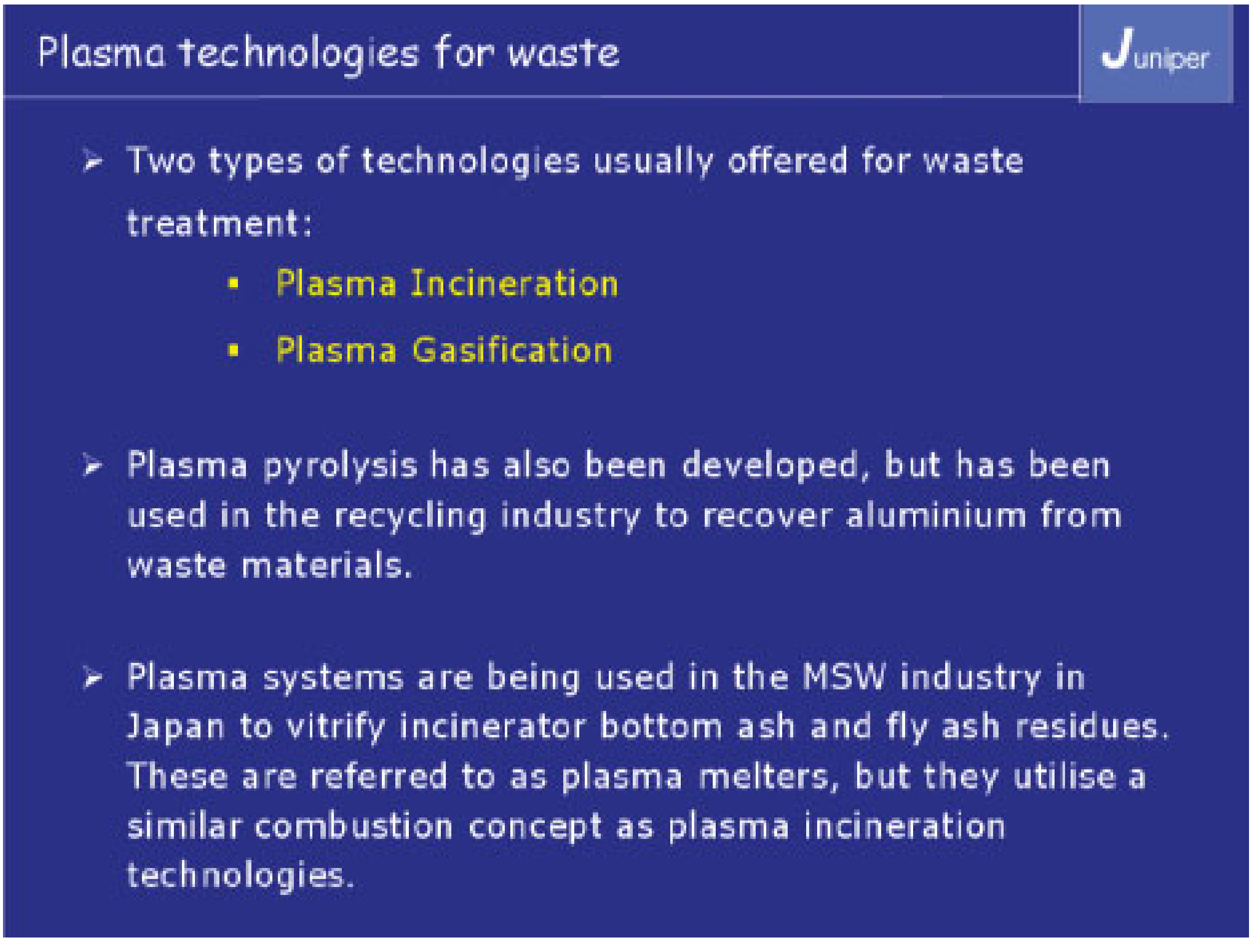

Gasification
Juniper
Air or O_2
O_2, N_2
Residual MSW
C, H, inorganic
Cleaned gases
CO_2, H_2O, N_2
Energy = Chemical Energy
Plasma torch
Gasification reactor
Syngas
CO, H_2, N_2
Dust, Tars
Rankine steam cycle
Electricity
Syngas cleaning
Chemicals, transport fuels
Gas engine or Gas turbine
Ash

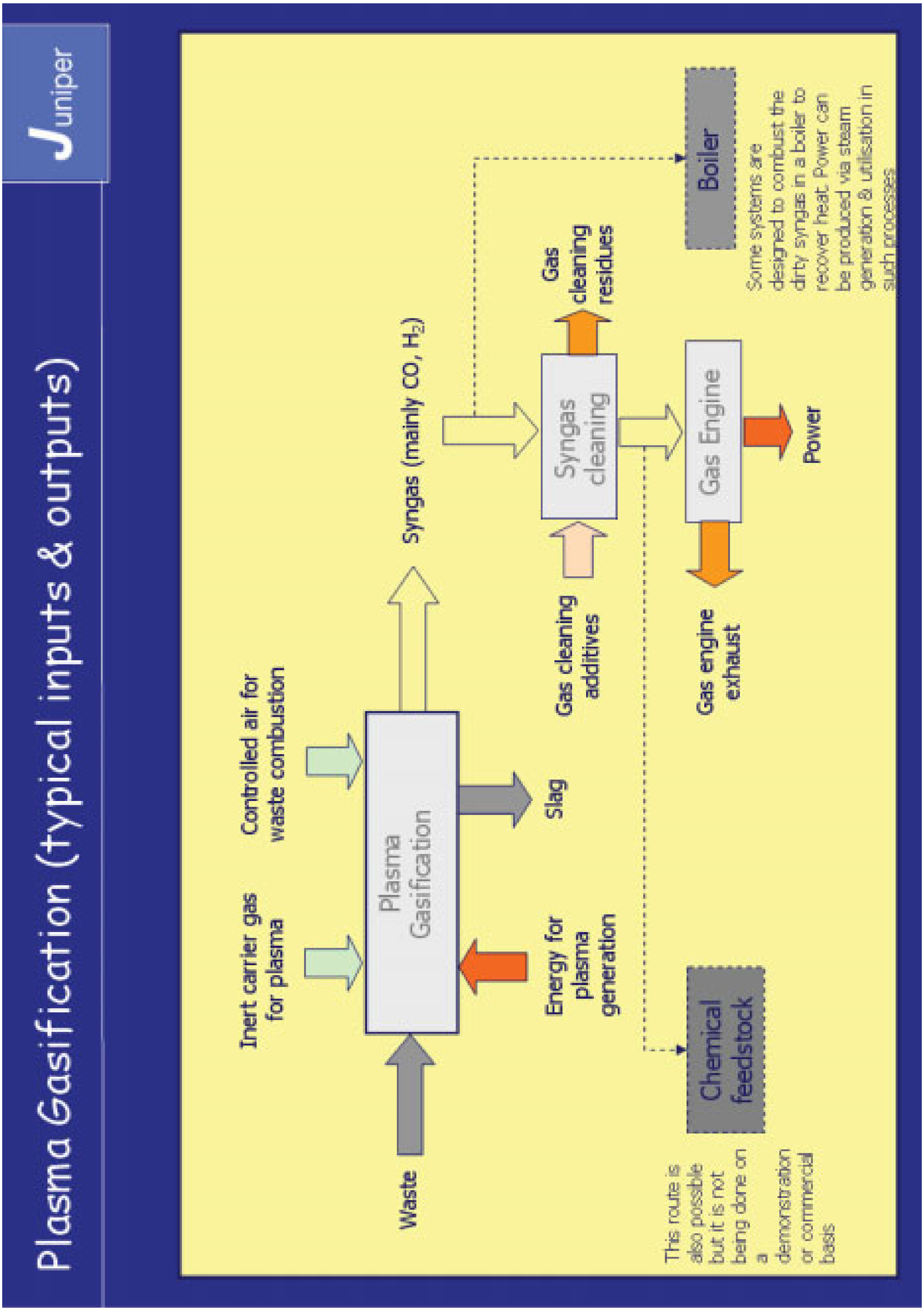


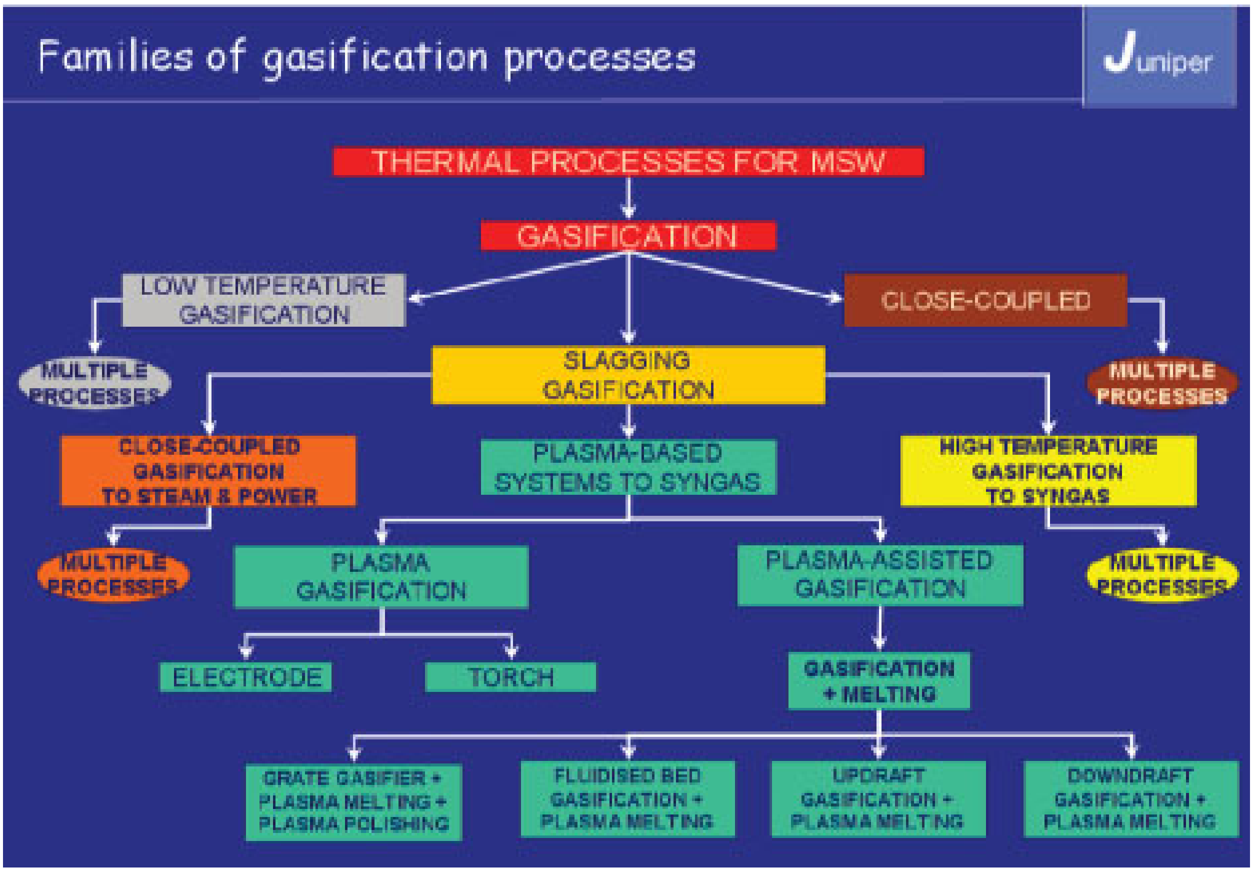


Source Europlasma


History of Plasma
London Town Gas Pall Mall street lighting
Gasifier used with gas engine
1st pressurised gasifier
Lurgi pressurised moving bed gasifier
250,000 vehicles run on producer gas in Sweden
Coal to transport fuels in Germany
Plasma gasification perceived as a better solution for MSW
Sir William Crookes discovers plasma (called it "radiant matter")
'Plasma' named by Irving Langmuir
1807
1840
1878
1879
1887
1920
1926
1928
1931
1939
1939-45
Koppers Totzek entrained flow gasifier
Sasol I
Texaco
Plasma developed for NASA to simulate re-entry temperatures
Chemical industry developments
Sasol II
Oil shocks
Sasol III
Refinery industry
Plasma used for haz waste & LLRW destruction
Westinghouse begins plasma R&D
Utashinai & Mihama-Mikata begin operation
Hitachi Metals operates MSW demo at Yoshii
Polk 1996
Puertollano 1998
1940
1952
1950s
1960s
1970s
1973
1978
1980s
1990s
2000
2003
Today


Plasma technologies for waste
Juniper
Two types of technologies usually offered for waste treatment:
Plasma Incineration
Plasma Gasification
Plasma pyrolysis has also been developed, but has been used in the recycling industry to recover aluminium from waste materials.
Plasma systems are being used in the MSW industry in Japan to vitrify incinerator bottom ash and fly ash residues. These are referred to as plasma melters, but they utilise a similar combustion concept as plasma incineration technologies.


Plasma Gasification (typical inputs & outputs)
Waste
Inert carrier gas for plasma
Controlled air for waste combustion
Plasma Gasification
Energy for plasma generation
Slag
Syngas (mainly CO, H$_2$)
Gas cleaning additives
Syngas cleaning
Gas cleaning residues
Gas Engine
Gas engine exhaust
Power
Boiler
Chemical feedstock
This route is also possible but it is not being done on a demonstration or commercial basis
Some systems are designed to combust the dirty syngas in a boiler to recover heat. Power can be produced via steam generation & utilisation in such processes



Leading plasma processes targeting MSW

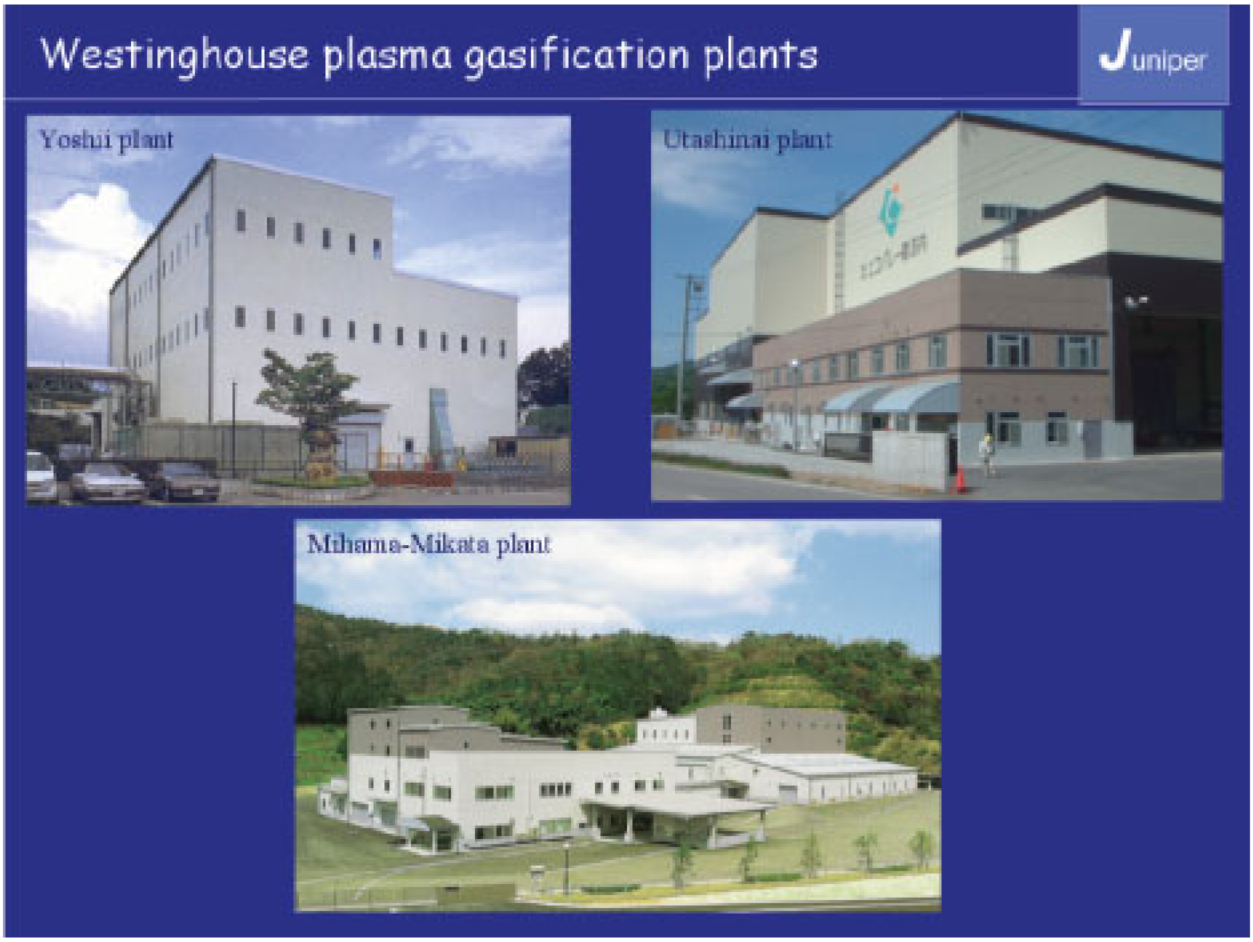
Juniper

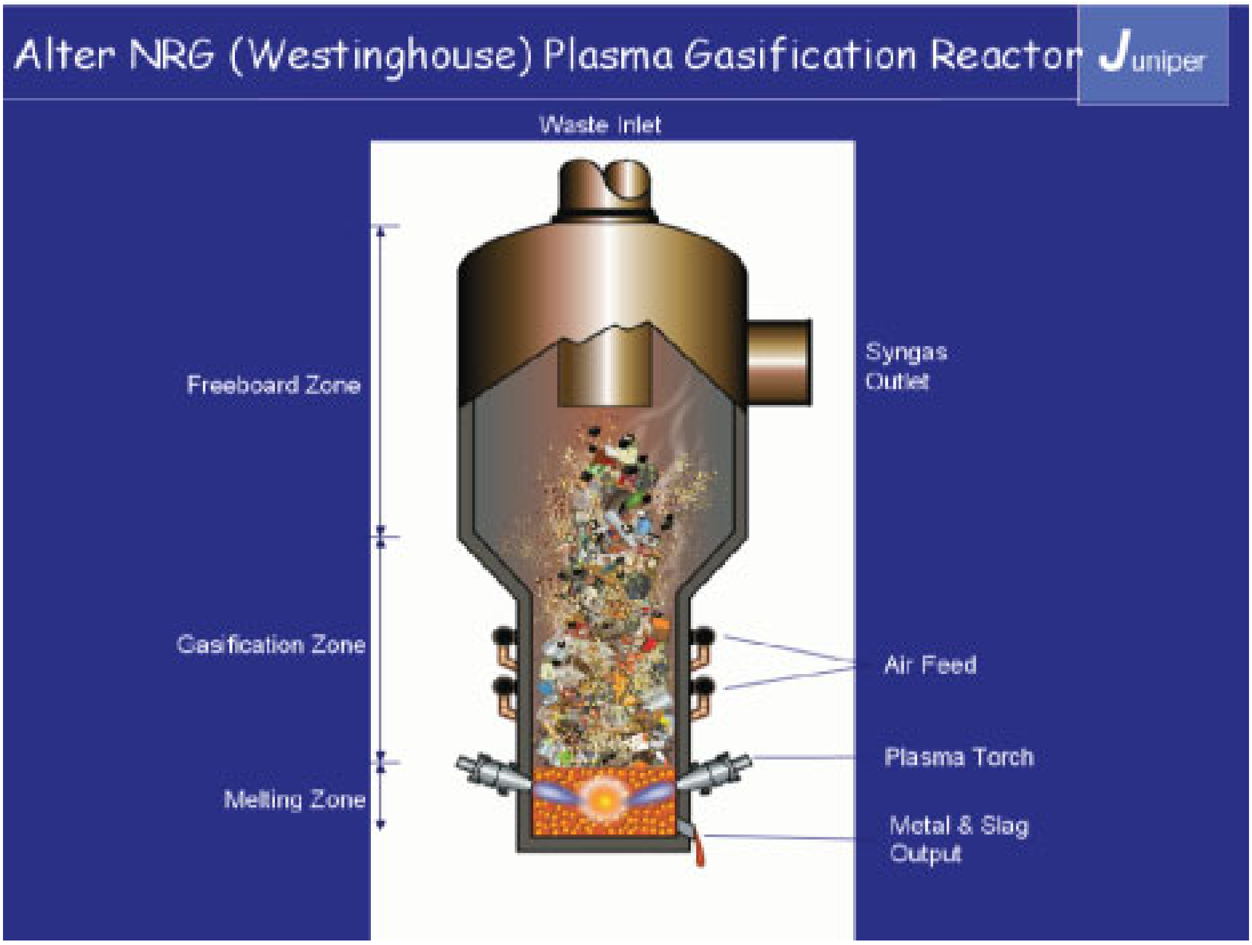
Company	Process Status	
	Hazwaste	MSW/RDF
Advanced Plasma Power (GasPlasma)	N/A	Pilot
Alterfirg (Westinghouse)	N/A	Commercial
EER	N/A	Demonstration
Europlasma	Commercial	Concept (projects announced)
Geoplasma	N/A	Concept
InEnTec (formerly IET)	Commercial	Concept (project announced)
Plasco	N/A	Demonstration
Pyrogenesis	N/A	Pilot
Solena	N/A	Concept
Startech	Pilot	Pilot

Source: Juniper database

The leading suppliers targeting MSW applications


Alter NRG / Westinghouse - Technology Status
Juniper
➢ Two commercial plants built in Japan by Hitachi Metals using the WPC technology
● Arguably the only commercial reference plants for plasma gasification of MSW
➢ Owns long-standing pilot plant (Waltz Mill) in Pennsylvania, USA
➢ Alter NRG relevant projects:
● ~150kTpa MSW-to-syngas in St. Lucie, Florida, USA
● MSW-to-syngas-to-ethanol (with Coskata and, hence, GM)
● Other projects with MSW, biomass, coal, petcoke and haz. waste processing
Waltz Mill pilot plant
WPC Plasma torch being test fired


Westinghouse plasma gasification plants
Juniper
Yoshii plant
Utashinai plant
Mihama-Mikata plant



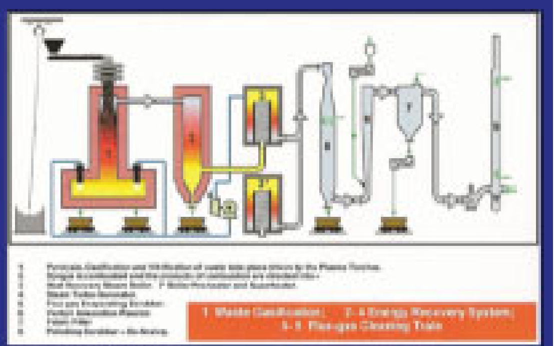
EER - Technology Status

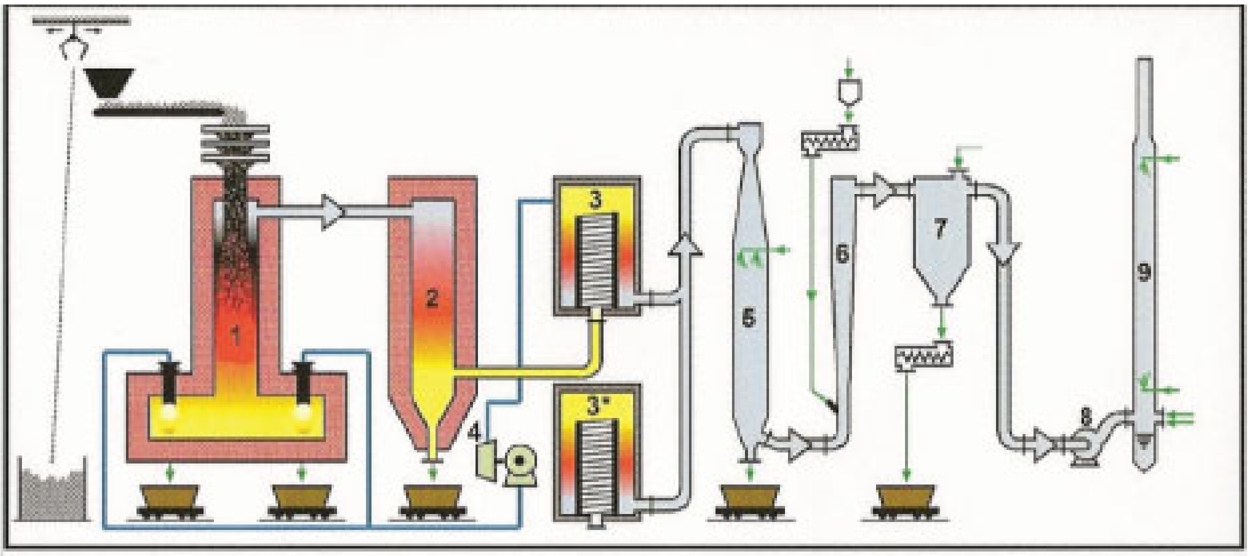
Juniper

- Technology derived from process developed by SIA Radon (in Russia) for destruction of LLRW
- **Built and operated demo plant** at the Yblin landfill site in Israel
  - Only operated a few times since built in 2003
  - Used simulated MSW so far, though real MSW planned to be used in 2008
  - Facility is a close-coupled design due to small throughput capacity
  - 1st commercial plant would clean the syngas and produce electricity via gas engines

Demo Plant in Yblin, Israel

Schematic of Demo Plant





1. Pyrolysis, Gasification and Vitrification of waste take place driven by the Plasma Torches.
2. Syngas is combusted and the products of combustion are directed into –
3. Heat Recovery Steam Boiler. 3* Boiler Pre-heater and Superheater.
4. Steam Turbo-Generator.
5. Flue-gas Evaporating Scrubber.
6. Venturi Adsorption Reactor.
7. Fabric Filter
9. Polishing Scrubber – De-Noxing.

1 Waste Gasification; 2- 4 Energy Recovery System; 5- 9 Flue-gas Cleaning Train

Plasco - Technology Status

Juniper

- Plasco owns the IPR
- **First commercial scale project built in Ottawa, Canada**
  - operates as a demonstration plant
  - designed to process about 30,000 Tpa of MSW
  - plant has had issues during commissioning, some of which are still to be resolved
- **Operates a test facility in Castellgali, Spain**
- MSW projects were announced in Europe over many years, but none of these ever went ahead
- Relevant projects announced:
  - 400 Tpd (c. 120kTpa) plant in Ottawa
  - *300 Tpd plant in Red Deer County*

Plasco's pilot installation, Canada

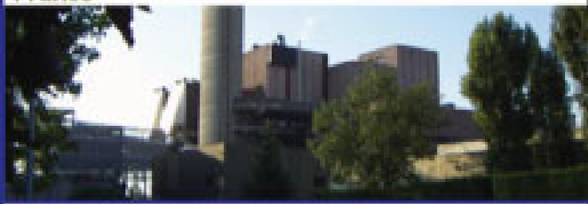
Demo plant, Canada

Europlasma - Technology Status

Juniper

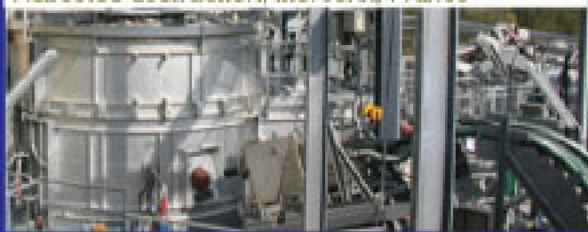
- Europlasma specialises in the use of plasma technology for industrial applications, most notable for haz. waste destruction (vitrification)
- **32 Europlasma torches delivered** for various applications in metal industry and hazardous waste destruction
- Currently expanding its business to
  - CHO-Power: Electricity from waste
  - Galacsy: Diesel from biomass
- CHO-Power will be integrated with gas engines in announced projects...
- ...with long-term plans for liquid fuels production

Vitrification of Incineration residues, Cenon, France



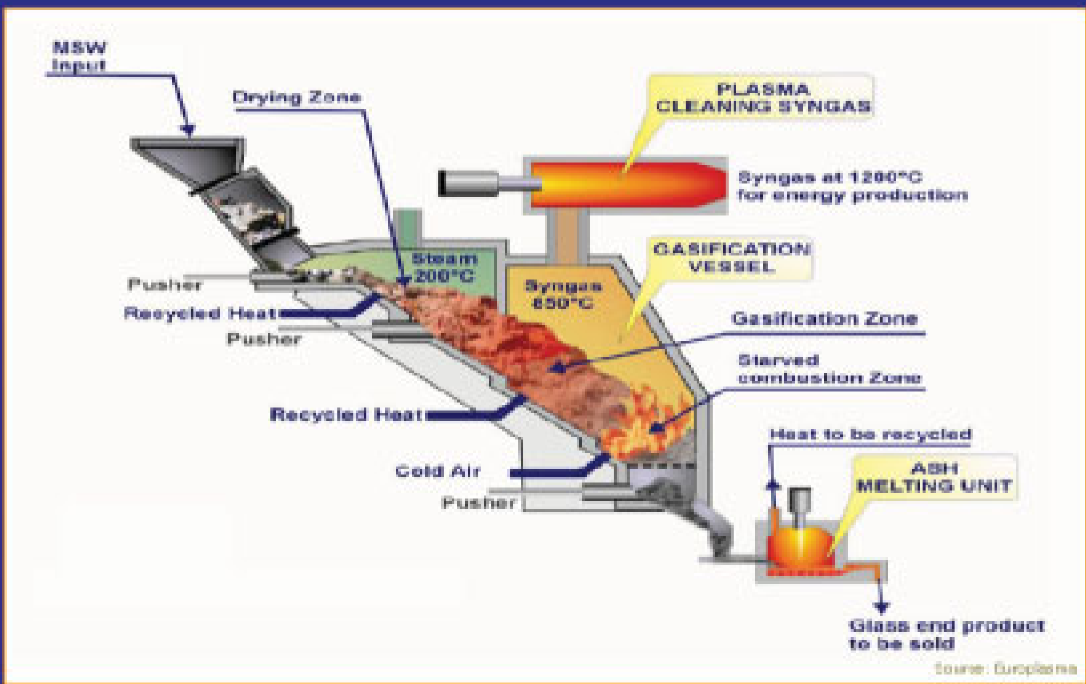
Fly ash melting, Imuzu, Japan

Asbestos destruction, Morcenx, France



Europlasma - CHO-Power Process

Juniper



InEnTec - Technology Status

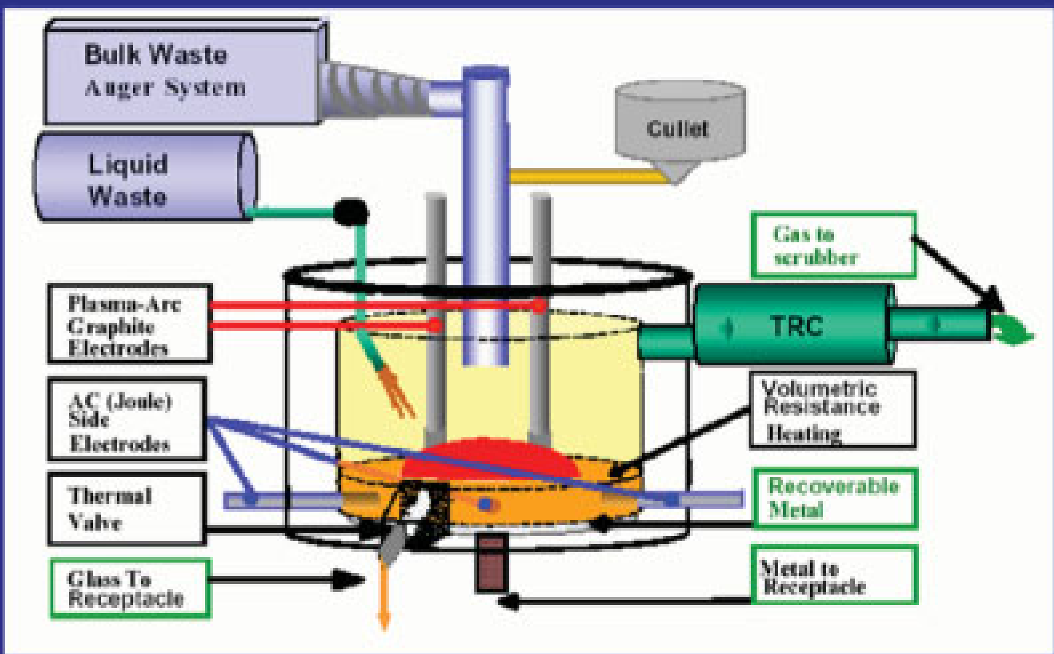
Juniper

- Plasma gasification technology developed in the mid 1990's on the back of DOE sponsored research at MIT and Battelle Labs. IP owned by Oregon based, InEnTec
- Exclusive licence agreement Kawasaki Heavy Ind. to market and operate in Japan
- **3 commercial plants** in the USA, Japan & Taiwan treating various hazardous wastes.
- Plant under construction at Dow Midland for chlorinated haz wastes
- Are diversifying into the production of ethanol from syngas

Source: InEnTec

Plasma electrode process

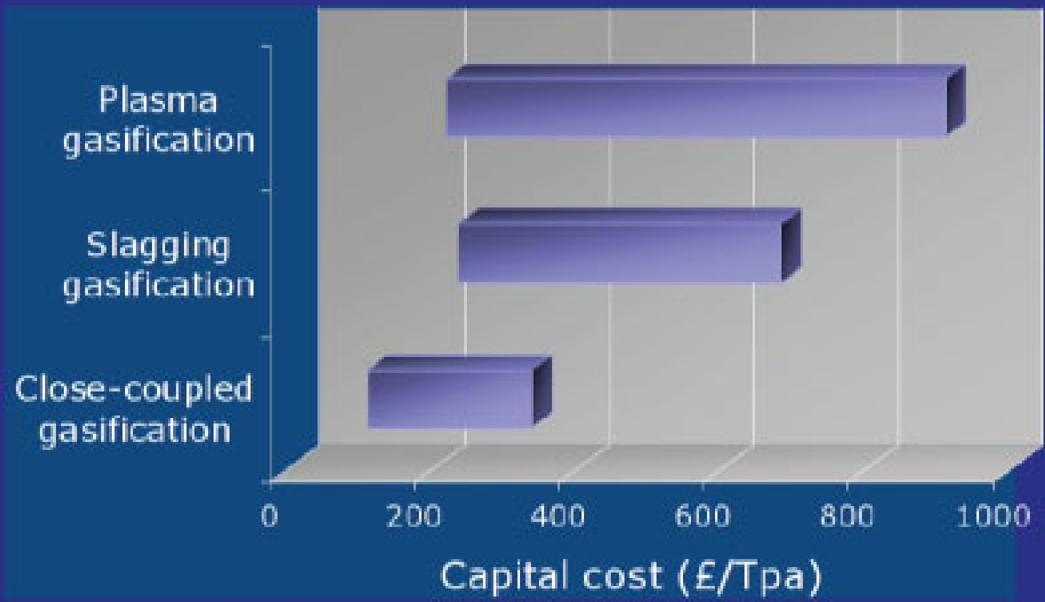
Juniper



Source: InEnTec (formerly IET LLC)

Range of capital cost data

Juniper

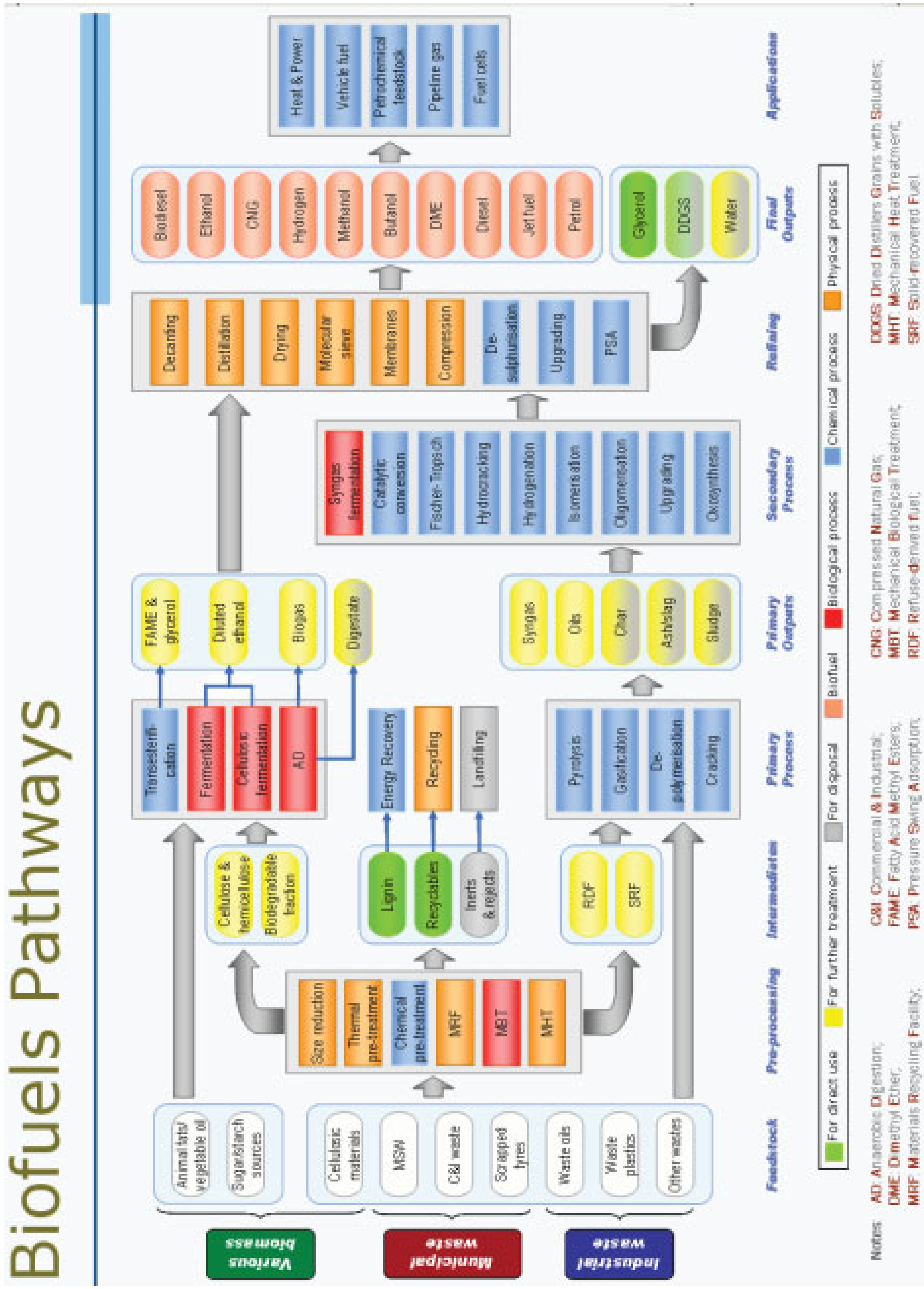


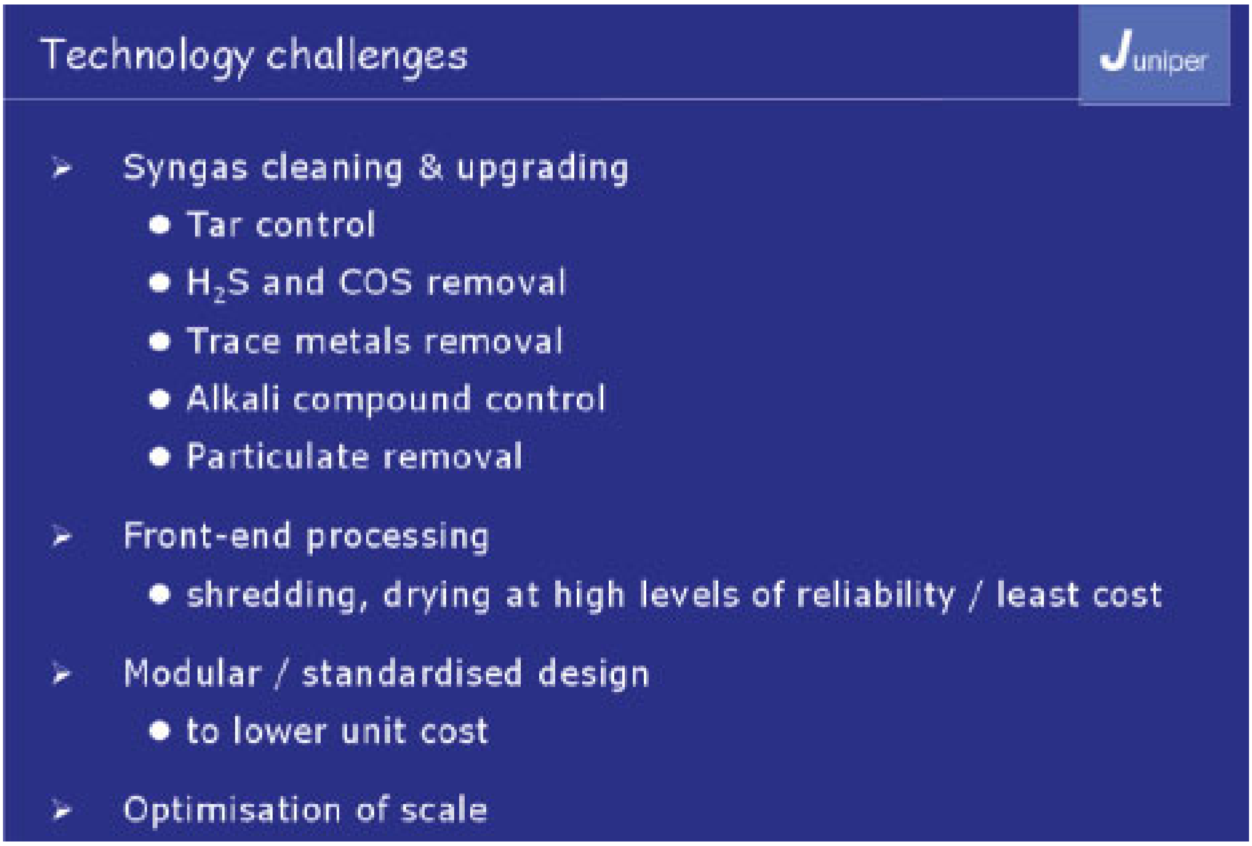
Source: Juniper database

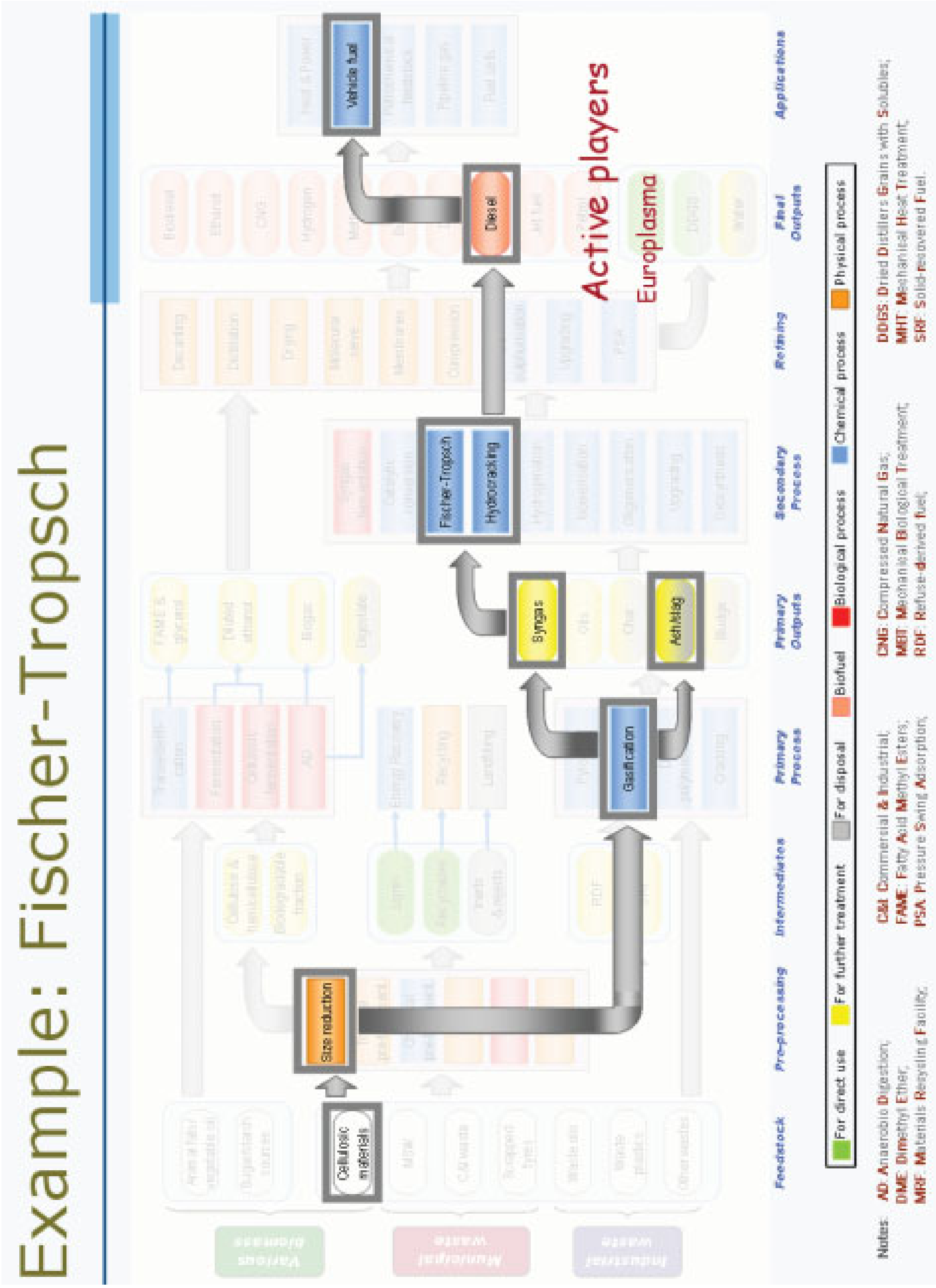
Newer roles for plasma technology

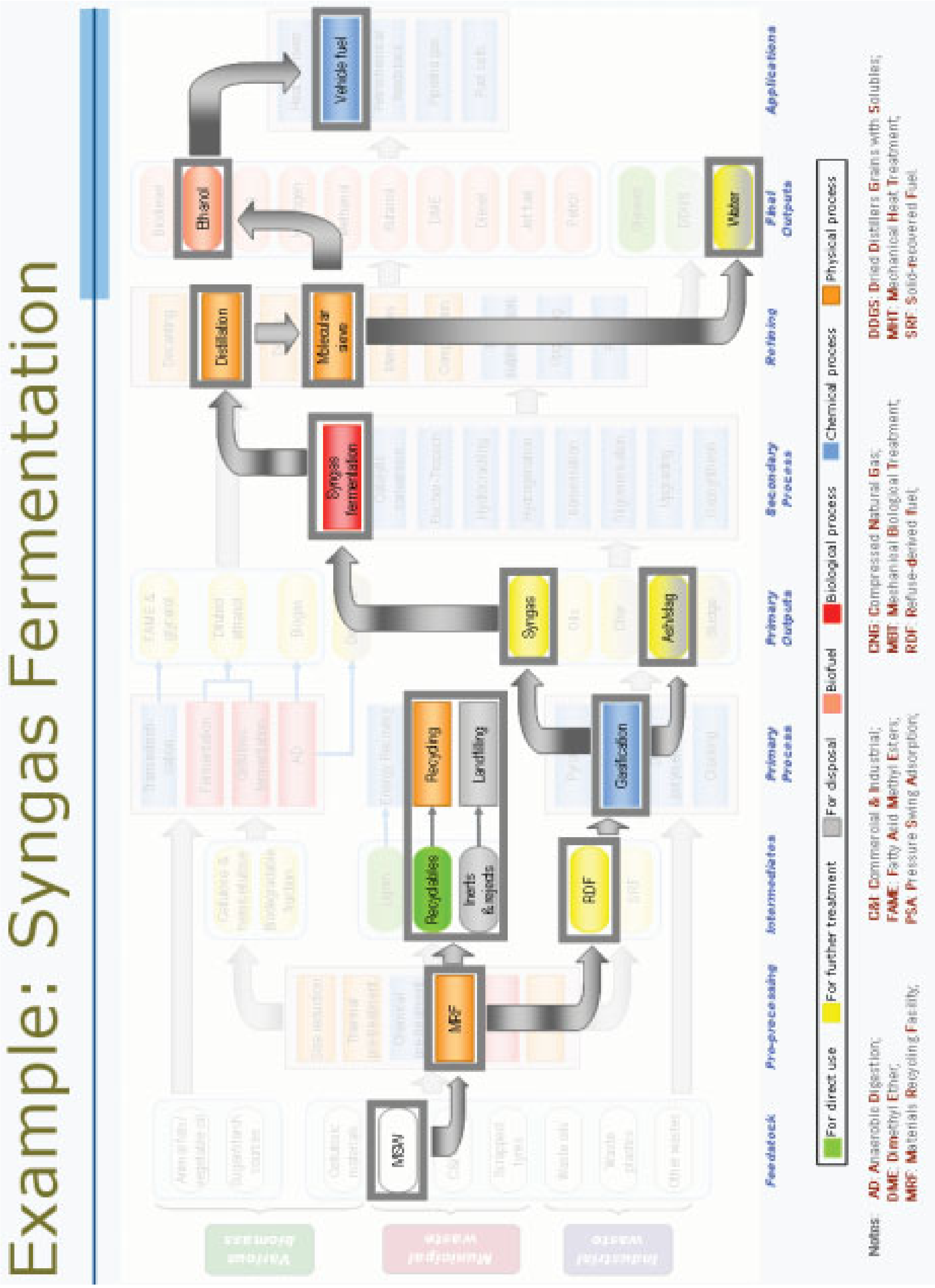
Juniper

- sustainability objectives include the reduction of CO_2 emissions by:
  - displacement of fossil fuels
  - increase in thermal efficiency
  - conservation of exergy
- biomass utilisation:
  - forestry residue
  - agri-wastes
  - food wastes
  - energy crops
- waste utilisation as a resource (fuel):
  - residual MSW
  - SRF
  - commercial waste


Biofuels Pathways
Various biomass
Municipal waste
Industrial waste
Feedstock
Pre-processing
Intermediates
Primary Process
Primary Outputs
Secondary Process
Refining
Final Outputs
Applications
Animal fats/ vegetable oil
Sugar/starch sources
Cellulosic materials
MSW
C&I waste
Scrapped tyres
Waste oils
Waste plastics
Other wastes
Size reduction
Thermal pre-treatment
Chemical pre-treatment
MRF
MBT
MHT
Cellulose & hemicellulose
Biodegradable fraction
Lignin
Recyclables
Inerts & rejects
RDF
SRF
Transesterification
Fermentation
Cellulosic fermentation
AD
Energy Recovery
Recycling
Landfilling
Pyrolysis
Gasification
De-polymerisation
Cracking
FAME & glycerol
Diluted ethanol
Biogas
Digestate
Syngas
Oils
Char
Ash/slag
Sludge
Syngas fermentation
Catalytic conversion
Fischer-Tropsch
Hydrocracking
Hydrogenation
Isomerisation
Oligomerisation
Upgrading
Oxosynthesis
Decanting
Distillation
Drying
Molecular sieve
Membranes
Compression
De-sulphurisation
Upgrading
PSA
Biodiesel
Ethanol
CNG
Hydrogen
Methanol
Butanol
DME
Diesel
Jet fuel
Petrol
Glycerol
DDGS
Water
Heat & Power
Vehicle fuel
Petrochemical feedstock
Pipeline gas
Fuel cells


Technology challenges
Juniper
Syngas cleaning & upgrading
Tar control
H2S and COS removal
Trace metals removal
Alkali compound control
Particulate removal
Front-end processing
shredding, drying at high levels of reliability / least cost
Modular / standardised design
to lower unit cost
Optimisation of scale


Example: Fischer-Tropsch
Active players
Europlasma
Feedstock
Pre-processing
Intermediates
Primary Process
Primary Outputs
Secondary Process
Refining
Final Outputs
Applications
Cellulosic materials
Size reduction
Gasification
Syngas
Ash/slag
Fischer-Tropsch
Hydrocracking
Diesel
Vehicle fuel
For direct use
For further treatment
For disposal
Biofuel
Biological process
Chemical process
Physical process
Notes:
AD: Anaerobic Digestion; DME: Dimethyl Ether; MRF: Materials Recycling Facility;
C&I: Commercial & Industrial; FAME: Fatty Acid Methyl Esters; PSA: Pressure Swing Adsorption;
CNG: Compressed Natural Gas; MBT: Mechanical Biological Treatment; RDF: Refuse-derived Fuel;
DDGS: Dried Distillers Grains with Solubles; MHT: Mechanical Heat Treatment; SRF: Solid-recovered Fuel.


Example: Syngas Fermentation
Feedstock
Pre-processing
Intermediates
Primary Process
Primary Outputs
Secondary Process
Refining
Final Outputs
Applications
MSW
MRF
Recyclables
Inerts & rejects
Recycling
Landfilling
RDF
Gasification
Syngas
Ash/slag
Syngas fermentation
Distillation
Molecular sieve
Ethanol
Vehicle fuel
Water
For direct use
For further treatment
For disposal
Biofuel
Biological process
Chemical process
Physical process
Notes:
AD: Anaerobic Digestion; DME: Dimethyl Ether; MRF: Materials Recycling Facility;
C&I: Commercial & Industrial; FAME: Fatty Acid Methyl Esters; PSA: Pressure Swing Adsorption;
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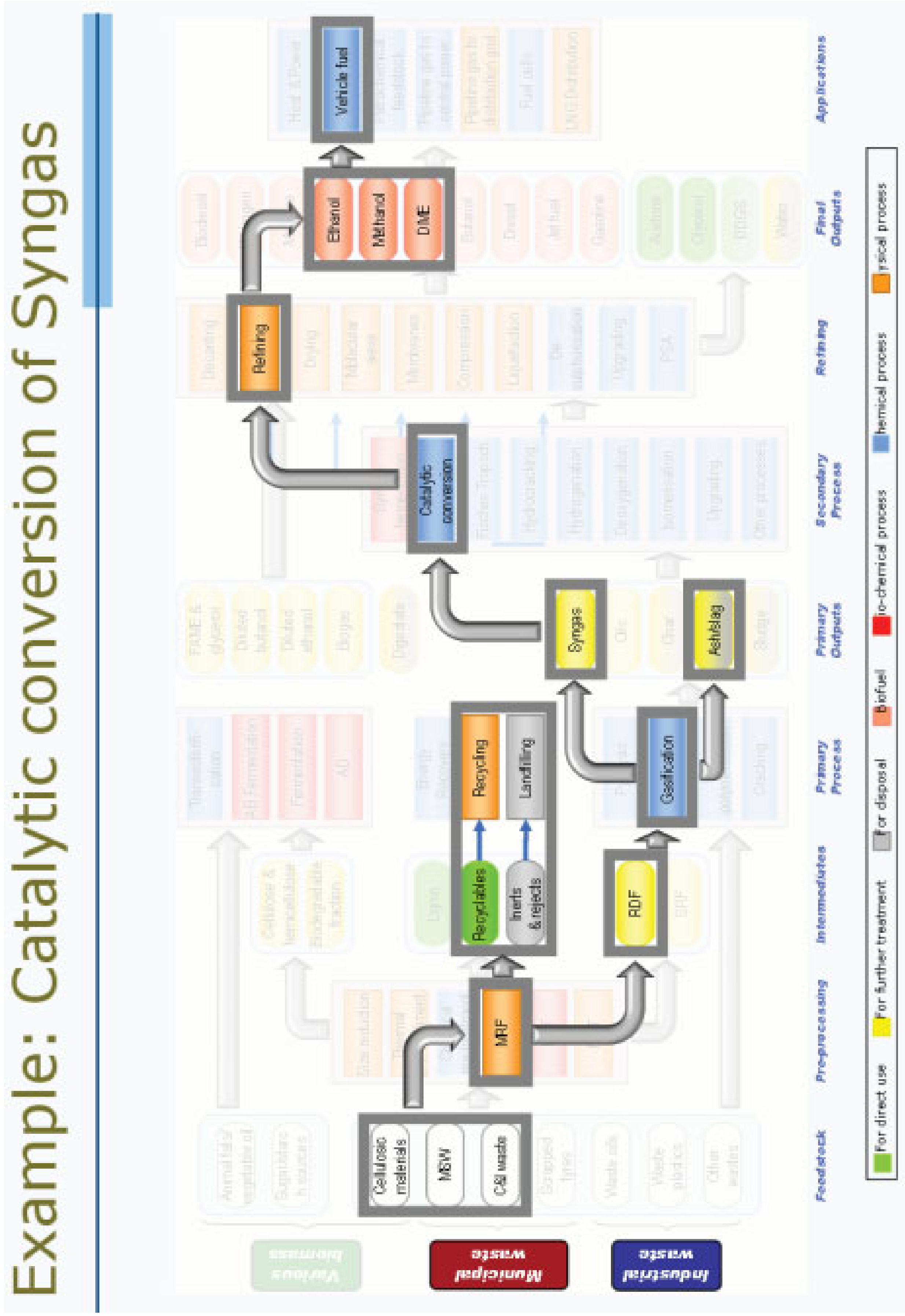
DDGS: Dried Distillers Grains with Solubles; MHT: Mechanical Heat Treatment; SRF: Solid-recovered Fuel.


Example: Catalytic conversion of Syngas
Various biomass
Municipal waste
Industrial waste
Cellulosic materials
MSW
C&I waste
MRF
Recyclables
Inerts & rejects
RDF
Recycling
Landfilling
Gasification
Syngas
Ash/slag
Catalytic conversion
Refining
Ethanol
Methanol
DME
Vehicle fuel
Feedstock
Pre-processing
Intermediates
Primary Process
Primary Outputs
Secondary Process
Refining
Final Outputs
Applications
For direct use
For further treatment
For disposal
Biofuel

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Recovering biowastes from municipal waste to land: maintaining public confidence through regulation

Dave Purchase

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Abstract

This paper explains how the Environment Agency is developing its approach regulating the recovery of compost-like output (CLO) derived from the mechanical, biological treatment (MBT) of mixed municipal solid waste. This is currently the focus of our attention on the recovery of a range of organic wastes. The paper gives the author's current answers and views on the following questions[1]:

What is MBT CLO and how can it be used?

What are the problems with its use and the restrictions that are imposed?

What is the position of the Environment Agency on sustainable use of biowastes and the use of MBT CLO on agricultural land?

What is the demand, and how much CLO is there?

What are the risks and how are we regulating them?

How will we improve the evidence?

This approach is driven by the belief that we can only increase public confidence in the recycling of biowastes if we actively maintain public confidence in how we regulate those risks.

Keywords

MBT, CLO, mechanical-biological treatment, compost-like output, bioresources, MSW, mixed municipal solid waste

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[1] The reader is assumed to be familiar with MBT technologies and their outputs and uses, and the various permits that may be needed at each stage. Information on permits is available on the Environment Agency website: http:/www.environment-agency.gov.uk>business and industry >Environmental topics>Environmental permitting.

1 The resource: MBT CLO

1.1 What is MBT CLO?

We use the umbrella term compost-like output (CLO) or grey compost to describe the separated and treated biowaste from mixed municipal solid waste (MSW) after it has been biologically treated and stabilised (using anaerobic digestion and/or aerobic composting) through a mechanical-biological treatment (MBT) process.

This differentiates these biowastes from source-segregated organic waste streams such as green compost and anaerobic digestates. These are regulated under the lighter touch approach of exemptions and are defined as resources when they are certified under approved quality protocols.

There are a variety of components in mixed MSW and different processes of mechanical-biological treatment (MBT) resulting in the variable composition and quality of compost-like outputs (CLO) from the range of MBT plants in England and Wales. For this reason, the Environment Agency regards CLO from MBT of mixed MSW as a recovered waste that poses higher risks than other biowastes spread on land.

The environmental permitting regulations in England and Wales, excludes the use on agricultural land of compost like output (CLO) derived from non-source segregated wastes from the lighter touch approach of exemptions. They can be used on non-agricultural land that has been previously developed for the purposes of providing either an agricultural benefit or an ecological improvement.

The Association for Organic Recycling published its report ‘The State of Composting and Biological Waste Treatment in the UK 2006/7’ in February 2009. From this we know that: In 2006/7 about 77,500 tonnes of mixed MSW went to biological treatment in the UK. As a proportion of the total mixed wastes going to biological treatment (MSW and non-MSW) this has reduced from almost 100% to about 56%. It is estimated that about 86% of this mixed MSW is the biodegradable waste that MBTs sort, separate and treat (about 66,900 tonnes in 2006/7).

From the information we have, there are about 28 MBT plant we can identify as operating, under construction or planned. Of these, about 11 produce or are planned to produce CLO. This is currently going (or is planned to go) to landfill, land recovery or as a refuse-derived fuel.

There are many different processes that may be combined in different ways to recover CLO from mixed MSW. These are under ongoing innovation and development. They include physical processes (trommels, mechanical and magnetic screens, air knives, percolators, filters, presses); heat treatment (autoclaves, pyrolysis) and biological treatment (anaerobic digestion, in-vessel composting and aerobic composting). The mixed waste that goes through these processes and the resulting biowastes, are also sensitive to changes in collection strategies and practices. These biowastes vary over time, depending on the content of MSW, the MBT processes.

1.2 How much CLO is there?

The amount of mixed MSW being processed through MBT plant and the amount of CLO being produced is due to rise sharply as new plants come on line. These will tend to be larger, more complex plant with a wide range of physical and biological treatment processes, in the capacity range of 150,000 to 200,000 tonnes MSW per year producing CLO in the range of 90,000 to 120,000 tonnes per year. We estimate that in 2010 there will be a ten-fold increase in the amount of CLO produced in England and Wales over the amount for 2006-7, to about 650,000 tonnes. We believe that this is likely to rise to between 900,000 and 1,800,000 tonnes of CLO per year by 2020.

Some local authorities in England and Wales, and operators who have MBT and CLO's as a significant part of their waste strategies, are investing heavily in improving their processes. This is not only by developing complex or more sophisticated technologies, but also through simpler approaches. These include; source separation of batteries to reduce lead content, handpicking and other soft segregation at the front end and introduction of aerobic processing at the backend to break down chemicals such as triclosan.

1.3 How can it be used?

The current options are:

- Landfill disposal as stabilised waste
- Soil conditioner and nutrient source for landfill recovery, the recovery of previously developed non-agricultural land, and (subject to the restrictions discussed later) agricultural land
- Refuse-derived fuel

Landfill disposal as stabilised waste is not strictly a use so much as a means of satisfying the criteria for landfill under the Landfill Directive. It may be an option for reducing carbon dioxide and methane emissions, since the carbon content of the waste may have been reduced through generation and capture of biogas during anaerobic biological treatment and stabilisation. However, it does not satisfy the current criteria for a reduced rate of Landfill Tax. It is the lowest in the hierarchy of waste options, but it may be where most is currently going in England and Wales.

The most commonly chosen options appear to be the use of CLO as a soil conditioner and nutrient source for landfill recovery, for the recovery of previously developed land, and as a refuse-derived fuel. Biogas is recovered from the anaerobic biological treatment processes and used as a fuel. Another option that is used in Europe and being developed in the UK is the integration of MBT and CLO into a wider Combined Heat and Power (CHP) option for a cradle to grave strategy.

No CLO is currently being used on agricultural land in England or Wales, although in principle it could be under an appropriate permit. I discuss this later.

1.4 What are the benefits of using CLO on land?

They are advocated as its value in:

1. Improving soil condition
2. Increasing soil nutrients
3. Diverting biodegradable wastes from landfill
4. Reducing use of fertilisers
5. Contributing to soil organic matter

Producers of CLO call their products by a variety of terms, intended to remove the negative connotation of waste; for example, organic matter amendment (OMA), stabilised organic fraction (SOF) and organic growth medium (OGM). Operators of higher end MBT plant state their CLO is similar in composition to treated sewage sludge (biosolids) and green compost, with comparative metal content.

2 Potential risks of using MBT CLO on land

2.1 What are the problems?

We don’t know enough about the quality and variability of the waste that goes into MBT and the biowaste that comes out of MBT. This means the risks to the environment and human health are also unknown. This includes direct and indirect risks to soil quality and sustainability, ecology (including plant and animal health) the food chain, water quality and the quality of life.

It is commonly observed that: ‘anything can go into municipal solid waste’. As discussed earlier, numerous variables can also affect biowaste quality from an individual plant over time.

We need improved data and evidence, but industry research tends to focus on the benefits of CLO, while as regulators we are more concerned with the potential contaminants and their risks. There are things we need to know about CLO before we can develop our knowledge of the risks when spread on land. These include the contaminants that are currently addressed for sewage sludges recovered to land and under the quality protocols for green composts and anaerobic digestates; that is, levels of specified nutrients, physical contaminants (glass and plastic), metals and metalloids and pathogens. Our analysis suite for MBT CLO also includes organic pollutants that are likely to be part of the mixed MSW composition and of the resulting CLO.

Our evidence is that levels of some contaminants can be highly variable in a given CLO, and that there are potential risks, for example from Zn, Cr, Cd and some micro-pollutants, triclosan, benzo-a-pyrene and several phthalates. We are paying particular attention to these.

2.2 What are the restrictions?

Land spreading of wastes is carried out under exemptions in England and Wales, and has to be for agricultural benefit or ecological improvement. Exemptions are available for low risk land spreading, with standard permits for low to medium risk activities and bespoke permits for medium to high risk activities.

Exemptions are being reviewed by the UK government. From later this year they will only be available for a restricted range of low risk operations including small amounts of landspreading of certain wastes. Standard permits will be used for low to medium risk activities. MBT CLO is not source-segregated, so it is excluded by the regulations from the option to spread it to *agricultural land* under the proposed new exemptions. It could only be used for spreading on agricultural land if a permit were to be issued. Since we regard CLO as a higher risk waste for use where contaminants could enter the foodchain or water, it would have to be a bespoke permit.

We are proposing a standard permit for spreading certain wastes to *non-agricultural land*, since we consider the risks to be lower. These wastes will include CLO.

3 What is our position on the use of MBT CLO on land?

Our overarching position on biowastes is given on our website at
http://www.environment-agency.gov.uk/research/library/position/41227.aspx.

The key elements are that:

1. We believe biowastes should be treated and recovered to maximise their benefit as a resource, while minimising their impact on the environment.
2. We want a more coherent and integrated approach to management and disposal of biowastes, linked to waste strategy and land use planning.

3. We prefer separation at source. This has clear advantages over mixing of wastes.
4. We recognise that source segregation of MSW is not always practicable, but local authorities and operators should bear in mind that lack of separation will limit their options for re-use of the outputs.

We have published a more specific position on the use of MBT CLO for agricultural land, at http://www.environment-agency.gov.uk/research/library/position/41227.aspx. (This is the same url as above)

This states that we do not believe CLO should be applied to agricultural land used for growing food or fodder crops, or any land that is likely to grow food or fodder crops in the future. We are concerned with minimising and managing the risks of:

1. Chemical contamination
2. Physical contamination
3. Longer term, cumulative risks to environment and sustainable use of land
4. Unreliability of the quality of CLO (and/or data on that quality) coming out of MBT processes
5. Our current lack of good, necessary and sufficient evidence on those risks

4 What is the demand to spread MBT CLO on agricultural land?

4.1 Who wants to do it and why?

The UK government has specifically excluded non-source segregated wastes from the remit of exemptions for spreading on agricultural land, because of the relatively higher risks. The government (and the EU) are reviewing the evidence on current standards for sewage sludge, which have been the basis in England and Wales for regulating standards for other biowastes and for PAS100 and PAS110 protocols. Some limits may become more restrictive, and the available land could be considerably restricted.

MBT is a key feature of a number of local authority waste management strategies; mainly for use as a refuse derived fuel. CLO is of interest in land use, development and planning and represents a business opportunity for operators. But the waste management industry and local government should take into account the costs and burdens of pursuing this option for the use of their MBT CLO.

Although any future increased use of CLO on agricultural land may please local authorities who have invested in MBT plant or who have included MBT plant construction in their waste strategy, other stakeholders may not be as happy and may see it as direct competition for their product.

For example, land owners and developers have been using MBT CLO for the recovery of previously developed or brown field land for some years, generally as single or limited applications under exemptions, to establish an ecology or land suitable for planned use.

Farmers generally apply organics in repeat applications, on an annual or biannual basis, under exemptions.

No farmers or operators have yet applied for a permit to spread MBT CLO on land and a demand from farmers has yet to be demonstrated. The size of such a market against that for all the organic resources spread to land is relatively very small (less than 1%) and the proportion of available agricultural land that could be affected is small (hypothetical maximum of 0.4% rising to 1.1% by 2020).

Such a market will be sensitive to market prices for soil conditioners and fertilisers, and the farmers' needs for agricultural benefits or ecological improvements, balanced against their desire to protect and enhance their land and the marketability of their produce. They will need to be convinced about the quality of CLO before using it.

They may also think it is unnecessary to produce an additional source of nitrates when a large proportion of farmland lies in Nitrate Vulnerable Zones and farmers have to store sewage sludge due to spreading restrictions.

Retailers are the missing link in the creation of a market for CLO for agricultural land. They will be critical to the demand for CLO by farmers, and rigorous on the potential contamination of food. The grocery and food production sectors will also question the quality and standards of animal fodder and food grown on agricultural land in England and Wales where CLO has been used. There may be extra sensitivity in the light of issues in 2008 in Ireland and NI with dioxin contaminated cattle and pig feed.

One of the hats we wear is as members of the public. However, that hat comes in many colours, styles and sizes. As members of the public our confidence and attitudes regarding MBT CLO on land will be sensitive to our particular situations and interests, and to how we perceive and understand the risks. Those concerns will often be modified or mediated by interest groups and, critically, media reports.

Our position has been (and remains) that CLO should not be spread on agricultural land. As I shall describe below, we are prepared to consider applications for strictly controlled trials for a specific operator spreading a specific CLO at a specific site on specific soil. However, the media may see this as opening the floodgates to CLO use on agricultural land.

Consequently, they may take issue with any of the following:

1. Contaminants – like metals and organic pollutants;
2. Odour, bioaerosols, and methane emissions;
3. Soil quality – now and in the longer term – and the suitability of land that has been spread with MBT CLO in the past for growing food for human consumption;
4. Health of animals grazing the land;
5. Health of humans consuming food grown on the land; and
6. Other risks to the environment.

4.2 How much is there and how is it being used?

MBT CLO is currently a very small proportion of the market. The 650,000 tonnes of MBT CLO that we estimate will be produced in 2010 would constitute only about 0.6% of the approximately 100 million tonnes of biowastes estimated currently spread to land (the greater proportion of which are biosolids from sewage sludge treatment). By comparison, in 2006-07, 1.15M tonnes (53%) of source-segregated compost products went to agricultural use. This had doubled in four years. [Association For Organic Recycling, 2009]

Land availability is a key issue. We estimate there are about 5.5 million hectares of agricultural land available. No CLO is currently going to agricultural land, but hypothetically, if all the CLO produced were to go to agricultural land (assuming a rate of 30 tonnes of CLO per hectare per year) then this would cover about 0.4% of the total available land in 2010, rising to between 0.5% and 1.1% in 2020.

5 Improving the evidence on the risks of MBT CLO

5.1 Do we know what we need to know?

We do not yet know enough. The Environment Agency is a modern, better regulator, risk and evidence-based, but firm, fair, flexible and proportionate. We want to work with industry to develop the evidence needed to determine where this waste stream should be spread. But we are also mindful of the risk to public confidence in the recovery of biowastes and its regulation if we are perceived to have got it wrong on MBT CLO. While scientific trials are underway, we will continue to maintain a protective approach.

It is our aim to ensure that operations are permitted and carried out on the basis of the best available evidence.

5.2 How will we improve the evidence?

We are an evidence-based regulator. But the best evidence we have is too general, non-specific, unclear and unreliable to merit a review of our position on the use of MBT CLO on agricultural land.

We recognise that technology is developing and in recent years, the quality of CLO from some MBT has improved as regulation has driven better processes. There is evidence that processes can be developed to reduce the risks so that (in certain circumstances) they can be managed to an acceptable level. We are working with the operators producing CLO to derive a better understanding of the use of these materials.

We have been developing and improving our risk assessment models. A review of human health and environmental risks associated with the land application of mechanical-biological treatment biowastes (ENVIRONMENT AGENCY, APRIL 2009). This will be published on our website.

We have given permission for a small scale time-limited research study to spread small amounts of CLO from a specific, high end MBT plant on farmland in Leicestershire, England. This trial is the first to take advantage of an Environment Agency lighter touch approach to regulating trials of waste management activities. The small-scale, time-limited trial will quantify nitrogen release from the organic fraction of MBT residues to show it has a beneficial effect on crop yield. Up to six tonnes of CLO from the Biffa MBT plant in Leicestershire will be spread on 0.2 hectares of land during the two- year trial.

We have decided that where there is a genuine trial of a previously untested process and it would be disproportionate to require an environmental permit, we will permit land spreading. We are not inclined to issue permits for use of an area of land for spreading MBT CLO, where this land is or is likely to be used for food or fodder crops. But we are exploring a middle way with industry and government.

On this basis, we will consider applications for large-scale trials subject to defined limits on capacity and rate of application of a defined CLO to a defined area of land. (Our requirements are described later). There will be costs, risks, and burdens to be borne by the operator and potentially by the farmer or landowner that need to be recognised. We do not guarantee the success of an application, but we will consider each application on its merits. Good assessments and good, reliable and applicable evidence will be key.

5.3 Research

Defra is contracting research into levels and limits for metals in soils, and into attitudes towards biowaste recovery to land. WRAP (Waste Resource Action Programme) provides useful data and reviews and reports on the reduction, recovery and use of biowastes, as well as (with ourselves) the Quality Protocols for composts and anaerobic digestates. The Environment Agency is continuing its research into risks and risk assessments. This includes a sampling and analysis programme involving a number of operators producing MBT CLO.

The waste management industry is generating research and collecting evidence through organisations such as the Sustainable Organic Resources Partnership (SORP), the Association for Organic Recycling (AFOR), and the BioCompost Alliance.

5.4 Europe

We have published a review of the use and application to land of MBT compost-like output and current European practice in relation to environmental protection (Environment Agency, March 2009). This presents a confusing picture, and it is difficult to draw any conclusions.

CLO from non-source segregated MSW has been applied to agricultural land in a number of EU countries, but we have found that there is no uniform system for setting compost standards and these can vary significantly from one country to another. So far it has not been possible to obtain useful data to apply to such applications in England and Wales. The composition of MSW and CLO, soil conditions and qualities and environmental factors vary geographically and there is no large-scale field evidence directly applicable.

5.5 How will we regulate large-scale trials?

We are in discussion with an MBT operator and are expecting an application for a permit to carry out a trial of a large-scale application of the CLO from their plant to a farm. The scale of the operation is under discussion. As for all applications we receive, applications for such trials will be considered on their merits. They will have to be specific to the CLO, the site, the parameters of use of the CLO and the crop type and use. The permits will be bespoke and the operator’s assessments will need to be detailed and specific. We will require rigorous management and detailed quality assured sampling, monitoring and analysis. We will require submission of data and defined reports on the progress and outcomes of the trial, to inform a review of that permit and of our approach.

It is not a simple task for operators to apply for a permit to trial use of their CLO for agricultural purposes. It will incur significant time and resources, without the guarantee of a favourable outcome. We will use the information from such permitted trials to improve the evidence base, our strategic advice and our regulatory approach for MBT CLO.

5.6 Why limit the amount and area?

We do not have enough good evidence to permit any operational spreading on a commercial scale on land where potential contaminants could enter the food chain. We need a defined and enforceable line where the EA and the operator can take stock, and we can weigh the evidence openly and transparently before taking the next step. We are currently developing the detail of how we will apply these limitations through the permit conditions.

5.7 What will we require from the operator?

The permit conditions and guidance will provide equal opportunities for operators. Our standards are high but proportionate to the need to improve the evidence, while protecting the environment, animal and human health and maintaining public confidence.

The permit will require the operator to:

1. Closely manage the operation
2. Provide extensive and detailed information and assessments
3. Protect human health and the environment, ensuring long term sustainability of the soil is not compromised.
4. Restrict use of the crops to prevent harm to animal or human health
5. Monitor and assess the soil and crops until the permit is surrendered, against appropriate criteria and assessments
6. Report on defined outcomes

We will use the information from trials to improve the evidence base, our strategic advice and our regulatory approach for MBT CLO and other higher risk recovered biowastes.

6 Key messages

We are working with industry, but we are working for the environment, the public and the government of England and Wales.

We believe that MBT is an area where regulation is having a positive effect in driving improvement of the technology and processes, but also, more fundamentally, in reviewing options for resource use and recovery.

We are a modern regulator and a better regulator. We support and observe the Regulators' Code of Practice. We are working to improve the way we regulate the recovery of biowastes (like CLO) and organic resources (like green compost). MBT CLO is a key example of the options for biowaste recovery. Our regulation needs to be robust and flexible to protect the environment. Our level of knowledge is growing but until we know what is safe and what is not, we are taking a protective, evidence-based approach.

We acknowledge it is not an easy task for operators to apply for a permit to trial their CLO for agricultural purposes. It will incur significant time and resources, without the guarantee of a favourable outcome. But it will also take Environment Agency resources to regulate trials.

The burden of proof is on the operator to provide evidence regarding their CLO and each site and use. That burden is not light, nor should it be at this stage, but it will have to be borne if we are to maintain public confidence in the use on land of biowastes in general and MBT CLO in particular.

We can only increase public confidence in the recycling of biowastes if we maintain the confidence of the public in how we regulate.

7 Literature referenced

Association for Organic Recycling	2009	'The State of Composting and Biological Waste Treatment in the UK 2006/7'
Environment Agency	March 2009	The use and application to land of MBTcompost-like output - review of current European practice in relation to environmental protection (Science Report – SC030144)
Environment Agency	April 2009	A review of human health and environmental risks associated with the land application of mechanical-biological treatment outputs (Science Report – SC030144)

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Risk assessment for the use of mixed waste composts on previously developed land in the UK

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Abstract

One possible output from a Mechanical Biologiocal Treatment (MBT) process is an organic fraction referred to as MBT compost, which is distinctive from source segregated green waste compost and may either be landfilled as a biostabilised material or potentially used in a number of applications on land. Within the current regulatory framework in the UK the most significant land-based outlet for MBT compost in the UK is likely to be previously developed land (PDL). If MBT compost is to be successfully and sustainably applied to PDL over time, there is a need to assess the potential environmental and human health risks of such an activity in a proportionate and robust manner. Such an assessment would provide a clear framework through which informed decisions could be made by both environmental regulators and the regulated community alike. This paper will describe the potential scale of future MBT compost production in the UK and potential applications for the material on PDL, as well as approaches to the assessment of the degree of risk involved in doing so.

Keywords

MBT, compost, Previously Developed Land (PDL), risk assessment, market opportunities

1 Introduction

Mechanical Biological Treatment is an umbrella term that applies to many processes for the treatment of residual waste that use some form of mechanical separation to refine the feedstock either before or after some form of biological treatment, such as composting or anaerobic digestion. There are several possible biological outputs from such processes, one of which is an organic fraction referred to within this paper as MBT compost. This is predominantly organic material derived from mixed waste feedstock and subjected to biological treatment (composting, in-vessel composting, anaerobic digestion, or possibly a combination of these) as part of an MBT process. The resulting organic fraction may either be landfilled as a biostabilised material or used in a number of potential applications, such as landfill engineering (daily cover or capping for example) or the management of previously developed land (PDL). The use of MBT compost (or any other organic material) on PDL could be for two principal end goals. First, it could be used to reduce the risk of any physical loss of contaminants present within a site migrating beyond its boundaries by improving soil quality, making it more stable and potentially improving the short to medium term sorption capacity of the soil. Alternatively, in cases where PDL is less contaminated and/or is situated in a suitable location, MBT compost could be used to restore the land to a beneficial end use, which might include a recreational facility such as a country park, or a commercial activity such as non-food crop production, or a combined site with commercial and recreational areas.

While other recreational land uses, such as parks and golf courses, or new infrastructure such as earthworks for roads, railway lines and airports, agricultural and horticultural applications, or biological applications such as plant pathogen control *may* provide an outlet for MBT compost in the future, previously developed land remains the most significant and most realistic outlet for MBT compost. While MBT compost would provide a cheap and plentiful source of organic carbon for soil of generally poor quality (in most potential applications), concerns exist over its quality and consistency, particularly in relation to physical and chemical contaminants in the material.

If MBT compost is to be successfully and sustainably applied to PDL over an extended period of time, thereby providing a reliable alternative to landfill for this material and a source of organic matter for the land, there is a need to assess the potential environmental and human health risks of such an activity. Such an assessment would provide a clear framework through which informed decisions could be made by both environmental regulators and the regulated community alike.

This paper will describe the potential scale of future MBT compost production in the UK and potential applications for the material on previously developed land, as well as approaches to the assessment of the degree of risk involved in doing so. It will collate information on potential hazards in MBT composts, along with possible pathways and receptors and suggest how these might be applied in deriving generic risk based criteria for the use of MBT composts on PDL. A practical and proportionate screening risk assessment methodology for the identification of potential risk for several exposure scenarios and receptors will be discussed. This methodology moves beyond the limited historic view in the UK that only considers a few trace metals detailed in sewage sludge regulations. Uncertainties, assumptions and information gaps will be highlighted.

2 What is MBT compost and how much of it is there?

The term MBT compost describes organic materials that have been derived from mixed municipal solid waste (MSW) feedstock and processed by some form of Mechanical Biological Treatment (MBT) to produce an organic-rich fraction. MBT is a term that can be used to describe numerous processes, or combinations of processes. The only common factors between all of them are:

- They treat mixed waste.
- They contain some form of mechanical separation of unwanted inorganic elements, like fragments of metal, glass and plastic, such as screening, ballistic separation and magnets, for example
- Mechanical separation takes place either before and/or after treating the organic-rich fraction using a biological treatment such as composting or digestion.

The feedstock used in these processes is largely household waste, with a small proportion coming from commercial and industrial units; due to urban and rural locations, different seasons and the efficiency of recycling schemes within the area this feedstock can be widely variable throughout the year. As a result of the variation in the initial feedstock and the range of processes classed as MBT, there is considerable variation in quality both within and between the organic amendments collectively known as MBT compost.

MBT composts should not be confused with green waste composts produced from source segregated material. Green waste composts that comply with PAS100 or the compost Quality Protocol (WRAP 2006) can be used as garden-based growing media and soil improvers, and for commercial horticulture and agriculture (WRAP, 2007a,b). Such opportunities are not realistically open to MBT composts but finding alternative end uses for these materials, that are genuinely sustainable in the long term and do not compromise environmental quality would allow for the diversion of significant quanities of material from landfill, aiding compliance with the Landfill Directive (EU, 1999).

In order to place MBT compost into a wider context of land and waste management solutions, it is necessary to have an estimate of the likely quantity of material that will be produced in the future. Two estimates have been derived; one based on the capacity of operational and planned MBT plant in the UK, the other based on national data on municipal waste arisings and waste management.

In the last five years MBT has gone from being a potential waste management solution to an actual solution in the UK. Several plants are now operational, others have been commissioned and yet more are in the earlier stages of development such as PFI negotiations (references). The total estimated input capacity of MBT plants either in operation or under construction by local authorities at the end of 2008 was in excess of 3.1 million tonnes per year by 2010, assuming all projects come to fruition. This may be a conservative estimate, as further plants are now under consideration. However it may also overestimate MBT compost production, as there is increasing production of Solid Recovered Fuel (SRF) rather than MBT-compost due to greater market security for the otput and uncertainty over the development of future markets (Bardos & Chapman, 2008; Environment Agency, 2008).

Previous research has suggested that around 35% of a typical input waste stream for a MBT plant would be processed by composting, if most of the paper content were treated by energy from waste (Bardos 2005). The composting process typically reduces the volume of material to 60% of the input weight, which leads to an estimated MBT-compost yield of 21% of the input volume. On this basis an input of 3.1million tpa of residual waste to the MBT process would result in MBT-compost production of 650,000 tonnes per year by 2010 (Bardos & Chapman, 2009). However, the highly variable configurations of MBT plant, the principal outputs produced (i.e the plant could be configured for Solid Recovered Fuel or stabilised biowaste production, rather than MBT compost), and natural variation in feedstock mean that the figure of 650,000 tonnes per year is probably an overestimate.

In comparison, WRAP (2006b) suggested in a recent meeting report that 3.6 million tpa of compost from source segregated sources could be being produced by 2010. In fact the 2006/7 survey of composting in the UK (Afor, 2008) reported that this figure had been reached. In the same year approximately 87,000 tonnes of anaerobic digestate was produced from source segregated feedstock, while the amount of mixed waste composted by MBT was estimated at 140,000 tonnes for 2006/7 (Afor, 2008). This material was either distributed at no cost, used on site or on sites owned by the producer, or disposed of to landfill. Thus although MBT-compost will be produced in significant quantities in the near future, the scale of production will be comparable to or less than the production of other forms of waste-derived organic matter.

3 The extent of Previously Developed Land in the UK

The term Previously Developed Land (PDL) has been defined as ‘land that was developed but is now vacant or derelict, or land currently in use with known potential for redevelopment (DCLG, 2007). Previously Developed Land encompasses sites that have been affected by former uses of the site or surrounding land and are derelict or underused. Generally they are urban or semi-urban areas and would require intervention to bring them back to beneficial use; in addition they *may* have real or perceived contamination problems. Some sites may have remained unused for long periods because they occupy a very large area or they are relatively inaccessible by road or are inappropriate for a hard development or otherwise unsuitable. There may be little economic incentive to regenerate the areas affected. In the UK a proportion of this marginal land has been managed with “soft” restoration, for example for amenity use such as “country parks” (recreational areas in rural or semi-rural locations). The amount of land that remains degraded over the long term is a matter of concern as the degradation continues to blight local populations, and there are strong quality-of-life, social and political arguments for some form of action.

Redevelopment of PDL is usually categorised as “hard” or “soft”. Hard end-use refers to built redevelopment. Soft end-use describes non-built end-use. Soft end uses can either non-commercial (e.g. in the amenity, landscaping and habitat sectors) or commercial (e.g. non-food crops). The Department of Communities and Local Government produced a survey of previously developed land in 2006 (DCLG, 2007). The main conclusion was that there were 62,700ha of previously developed land, of which 34,900ha (55%) were vacant or derelict (as opposed to in use with scope for rehabilitation). Note that this figure includes more than just long-term derelict land: a survey by English Partnerships (2003) estimated the scale of long-term (i.e. longer than ten years) derelict sites greater than 2ha in size at 16,523 hectares. There is no dataset to estimate the total area of long-term derelict sites that are less than two hectares. However, anecdotal evidence from Local Authorities suggests that the unrecorded land area occupied by such sites could be up to ten percent of that occupied by those above two hectares. This would indicate approximately 1,700 hectares in this category, making an estimated total of 18-20,000ha of long-term derelict land in England. In a European context it is forecast that the number of brownfield and potentially contaminated sites across Europe is expected to grow, making brownfield land a significant and ongoing land management issue for the foreseeable future. This represents a significant financial burden that will largely be the responsibility of Local Authorities in which these areas exist.

4 Existing guidance on the application of MBT compost in the UK

Existing guidance supports a risk based use of MBT composts on PDL. There are two environmental frameworks to be considered: the application of MBT compost to land under the Environmental Permitting regime and the management of land affected by contamination:

1. The Environmental Permitting (EP) programme, introduced in 2008, streamlines and combines Waste Management Licensing (WML) and Pollution Prevention and Control (PPC) legislation under a single environmental permit (Defra, 2008). A waste management operation (including recovery operations, such as use on land) may take place under a standard permit, with an exemption or with a bespoke permit depending on the degree of risk in each case. A standard permit has standard rules, with which the permit holder must comply. Bespoke permits have conditions that are set specifically for an individual facility or activity. The use of MBT composts on land would require either a standard or bespoke permit.

2. PDL may also be land affected by contamination, in which case the suspected quality of the land itself will trigger a risk assessment. Typically the initial risk assessment

is generic, with site investigation and quantitative risk assessment being carried out if the initial appraisal indicates a need. Good practice is described in the Model Procedures for the Management of Land Contamination Contaminated Land (Defra & Environment Agency, 2004).

Hence for previously developed land, MBT compost applications need to be considered in a risk assessment framework. In this context it would seem appropriate that criteria used for generic risk assessment for organic waste applications are linked to risk assessment tools developed for land affected by contamination, such as the Soil Guideline Values (SGVs), rather than the current approach which is related to guidelines for the use of sewage sludge on agricultural land. A significant step forward in deciding how to tackle risks to the environment from compost addition might be to reach a consensus on what constitutes “harm” or “damage”, along with guidance on how sources, pathways and receptors can be appraised. It is possible that such a consensus might enable a broader range of applications of MBT composts than is currently available.

5 The potential hazards in MBT compost

In common with other waste derived organic materials, the use of MBT-compost may cause undesirable impacts which *may* affect human health, the intended application and/or the wider environment. Principal concerns relate to risks from chemical and visual contaminants, plant nutrients, impacts on soil (pH, conductivity and redox conditions), partially degraded (immature) composts and the effects caused to plants growing in them. The severity of any impact is related to the composition of the organic matter added, the requirements of the soil and its application and the sensitivity of the land, for example its proximity to water resources and its capacity to buffer inputs such as nitrogen and phosphorous.

5.1 Potential biological hazards

Many plant pathogens are destroyed during the composting process although some parasitic organisms may persist (Noble & Roberts 2003). Human and animal pathogens are likely to be rare or absent in properly made and matured composts derived from MSW, produced in accordance with the Animal By-product Regulations (Defra 2006a). Work by Dimambro *et al* (2007) showed that levels of fecal coliforms and *E. coli* in two types of MBT-OM were comparable with those in composts made from source segregated organic materials and better than many. In both cases the level of E. coli was lower than the PAS 100 criterion (there is no PAS100 criterion for fecal coliforms and salmonellae were absent from all samples tested).

5.2 Potential chemical hazards

Levels of many trace elements, in particular arsenic, cadmium, copper, lead, and especially zinc, tend to be elevated in MBT-compost compared with soils. There are several reports that regular application of MBT-compost to land leads to accumulation of trace elements in the topsoil (e.g. Jobbágy & Jackson, 2004, Zhang *et al.,* 2006), although findings about the potential effects of these trace elements to plants, soil and animal health are not consistent. Due to the source mateial MBT composts may also have elevated concentrations of a range of pthalates, PFOS and biocides such as triclosan (unpublished data).

Some authors believe that such pollutants do not pose a significant risk, while others suggest that MBT-compost should not be used as a precautionary measure (Groenveld & Hébert, 2003). Amlinger *et al* (2004) recommend restricting the use of mixed waste compost to limited non-food areas such as land reclamation of brownfields and surface layers on landfill sites or on noise protecting walls beside roads or railways. Conversely, Smith (2009) argues that the application of source segregated and MBT composts to soil does not necesarily increase the availability of heavy metals or lead to phytotoxic effects.

The content of plant nutrients in MBT-OM, as well as the effect it has on pH, redox and soil conductivity from the content of cations such as potassium, sodium and calcium and anions such as nitrate and chloride, can have negative as well as beneficial impacts. Its content of nitrogen and phosphorous may migrate to surface and groundwater depending on their environmental availability. This is a particular issue in sensitive areas such as Nitrate Vulnerable Zones (NVZs) and Groundwater Protection Zones (GWPZs). The significance of the discharge will depend on the river ecology, its capacity to withstand discharges and the scale of the discharge. Organic matter addition is seen as the overriding benefit of MBT-compost and compost addition for soil improvement. However, the organic matter addition itself may carry a risk of undesirable impacts, including the generation of gas from MBT-compost used as fill material, reduction in soil oxygen by decomposition processes (Inbar *et al.,* 1990), phytotoxic effects from immature composts (Ozores-Hampton *et al,* 1998) and the removal of plant available nitrogen during the decomposition of high C:N ratio MBT-compost in soil (Janssen, 1996)

As well as the concept of risk to the environment from the potential contamination in all composts and sludges, closer consideration will also have to be given in the future to a broad range of potential impacts on soil, groundwater and water as a result of:

- The expanded scope of the Nitrate Directive
- The implementation in the UK of the Water Framework Directive and the Groundwater Daughter Directive

- Developments in soil protection policy
- Concerns over potential impacts from organic pollutants (e.g. endocrine disrupting substances)

5.3 Potential physical hazards

Depending on the substance in question, inert materials such as stones, glass, metal and plastic pose a variety of problems in compost; in particular the visual appearance of treated soils may be affected (Mamo *et al*., 1998) and the potential for harm to wildlife or domestic animals (via the ingestion of plastics for example (Mays *et al.,* 1973). Other issues include the presence of sharp items, including shards of metal, glass and ceramics, splinters of wood and plastic, needles, pins and blades. These pose a risk of cuts and grazes during handling (Kendle, 1990) and may also pose a risk to humans and animals once applied. The elimination of sharps is often a major goal of MBT refining and processing.

6 Risk assessment

Risk is distinct from hazard. A hazard is an inherent property of a material, such as the level of contamination it contains: risks relate to the possible impact of those properties on a receptor such as human health or the environment and is a function of both the scale of any such potential impact and the likelihood of the impact happening. It may be possible for risk to be minimised by appropriate management and use.

Risk assessment provides an objective, technical evaluation of the likelihood of unacceptable impacts to human health and the environment. Considerations of risk can also be used to how best to minimise risk. This process of decision making and its consequent actions are called risk management. Risk management is a process of deciding how pollutant linkages might be most effectively and efficiently broken, and then undertaking the actions which have been agreed as necessary. There are three basic ways in which pollutant linkages can be broken for CLO applications:

- Source reduction, (minimising the content of hazardous materials in CLOs)
- Pathway management (for example using a barrier to restrict the migration of contaminants from an applied CLO, say in an engineered highway embankment), and
- Modifying exposure (for example by choosing a future land use where opportunities for exposure are reduced).

Should a risk be demonstrated the next question is whether it has a significant impact or not. What constitutes harm to receptors like human health, soil ecology, ground and surface water is controlled in large part by political considerations about what it is reasonable to expect to achieve, balancing environmental considerations against social and economic constraints. What is acceptable depends on whether the regulator takes a multi-functional approach to how soil is used (i.e. that any soil can be used for any purpose) or a view related to its use. For example, fear of damage to soil function may be a greater concern for agricultural land than for the restoration and remediation of a brownfield site. If a site already carries a heavy burden of trace elements, the possible harm from incremental increases due to CLO addition may not be high compared to the potential benefits of the CLO use for restoration and remediation (Defra 2006c).

6.1 Risk to Humans

Humans potentially exposed to harmful constituents of CLO include those employed in production and individuals using, visiting or living on CLO treated land. It is also conceivable that pathways such as wind-blown dust might affect humans on surrounding sites. The principal human health impacts that need to be considered for any soil improver have already been elaborated in some detail by CEN TC 223 (BSI, 1999) and include toxic substances, pathogens, dust, odour and bioaerosols and/or allergens (particularly during processing and application) and sharps. These hazards can potentially apply to any organic materials whatever the feedstock.

Human exposure to soil contaminants can occur via many pathways (Defra & Environment Agency 2002a, 2002b, 2002c). Direct human exposure pathways of importance include dermal absorption, inhalation of soil/dust, inhalation of volatilized compounds and inadvertent soil ingestion (or, in the case of some children, deliberate soil ingestion). Indirect pathways include plant uptake of contaminants followed by ingestion, contaminant presence in groundwater/surface water followed by ingestion, and pathways involving transfers through the food chain. A similar set of pathways can be envisaged for contaminants in CLOs, and also for exposures to pathogens, and some pathways could also apply for exposure to allergens. Exposure pathways for sharps are likely to be those related to direct contact.

6.2 Risks to the Environment

Inappropriate use of organic material on land may have detrimental effects ono soil and water, to ecosystems and to plants and animals. These risks may be posed by one or more hazards, such as chemical contamination, plant and/or animal pathogens, inerts, changes in pH or redox conditions, nutrient loadings (particularly nitrogen and phosphorous) and conductivity and the effects of organic matter addition (including immature composts).

Transport and migration of certain chemicals including nitrates, phosphates and heavy metals to water bodies have been widely reviewed (Defra, 2004d; Foster & Charlesworth, 1996). The pathways are related to the movement of air, water (including entrained sediment) or dust. These pathways also spread contaminants through soil, and to plants and soil dwelling organisms. The effects of burrowing animals (Smallwood *et al.,* 1998) and also of plant accumulation followed by leaf litter fall also can spread contamination (Jobbágy, & Jackson, 2004). Animal exposure pathways are likely to be similar to pathways of exposure for humans, described above, but are not generally well accounted for in exiosting regulatory frameworks for sewage sludge. In particular it is important to account for the environmental risks of secondary poisoning from metals and organic contaminants.

6.3 Approaches to risk assessment

Modern risk assessment needs to consider the sources, pathways and receptors descirbed, but also has to reflect developments in knowledge and understanding related to contaminants and contaminant behaviour. Traditional approaches to risk assessment, focused on heavy metals, do not reflect modern understanding of the range and complexity of contamination that can be found in waste-derived organic materials, nor do they consider the wider impacts of organic contaminants such as PAHs, PFOS, triclosan and some flame retardants. Modern risk assessment must reflect modern knowledge and provide a practical, precautionary approach to the application of organic material to land that reflects the correct balance between the benefits of added organic matter and the hazards of introducing potential contaminants into the environment.

From a wider management perspective, such risk assessments must fit into broader considerations of how brownfield land is to be managed in the most practical, sustainable manner. In part this reflects the environmental risk discussed, but should also take into account the suitability of the proposed land use, the land to be used, the wider added value of undertaking the project and the long term environmental and financial sustainability of doing so. This is the approach proposed within the Rejuvenate project[1], applied to the assessment of the suitability of brownfield land to the cultivation of biomass. While this is a specific end goal, it illustrates one apprach to investigating the sustainability of land management practices, which incorporates environmental risk assessment as a key stage in the process.

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[1] Rejuvenate includes partners from Germany, the UK, the Netherlands and Sweden and began in October 2008. It is funded, under the umbrella of an ERA-Net (SNOWMAN), by the Department for Environment Food and Rural Affaires and the Environment Agency (England), FORMAS (Sweden) and Bioclear BV (Netherlands). The EU ERA-Net SNOWMAN is a network of national funding organisations and administrations providing research funding for soil and groundwater bridging the gap between knowledge demand and supply (http://www.snowman-era.net). It is one of more than 70 ERA-Nets (European Research Area-Networks) funded by the EC's 6th Framework Programme for Research and Technological Development.

7 Conclusions

MBT is now an established method if waste treatment in the UK and the number of plants is expanding. Many of these plants produce MBT compost as an output and this is likely to become a significant source of organic matter in the near future. The application of CLO to land is a realistic outlet for this material and is increasingly likely given the Environmental Permitting regime and the pressure to divert biostabilised material from landfill. In this context it is important that the material applied to land is fit for purpose and an appropriate form of risk assessment is required to ensure regulators and users that it is so.

A particular consideration for all forms of waste-derived organic material will be to move toward a risk assessment approach that reflects improvements in the understanding of both the range of contaminants present in waste-derived organic materials and the behaviour of chemicals. This increased understanding, including knowledge realating to chemicals that have not been routinely monitored in the past, suggests that a practical, precautionary approach to the use of organic wastes to land is required. A secure, honest, yet flexible form of risk assessment will be a valuable tool for the future. Risk assessment is iterative and provides a powerful methodology to target resources and deliver commercially and environmentally beneficial solutions. Such risk assessments should fit into a wider planning and management process that considers the suitability of the proposed land use and the proposed site for the end purpose, as well as the value added by the change in use and the financial stability of the project as a whole. Land management and risk assessment starategies have to evolve and historical approaches to risk assessment

8 References

Amlinger, F., Favoino, E. and Pollak, M.	2004	Heavy metals and organic compounds from wastes used as organic fertilizers. On behalf of the EU Commission DG ENV.
Association for Organics recycling, Afor	2008	The state of composting and biological waste treatment in the UK, 2006/7, ISBN 0-95477797-9-7
Bardos, R.P.	2005	Composting of Mechanically Segregated Fractions of Municipal Solid Waste – A Review. SITA Environmental Trust Ltd. www.compost info.info
Bardos, R. P. & Chapman, A. S.	2008	Towards certainty in the use of MBT organic outputs: a workshop report, May 19th 2008. Available at www.r3environmental.co.uk

Bardos, R. P. & Chapman, A.S.	2009	The market potential for organic matter derived from MBT processes. Available at www.r3environmental.co.uk
British Standards Institution, BSI	1999	PD CR 13455:1999: Soil improvers and growing media. Guidelines for the safety of users, the environment and plants, British Standards Institute, London, UK
Department for Communities and Local Government, DCLG	2007	Previously-Developed land that may be available for Development: England 2006 - Results from the National Land Use Database of Previously-Developed Land (NLUD) June 2007 Product Code 07HC04713
Department for the Environment, Food and Rural Affairs, Defra and the Environment Agency	2002a	Potential contaminants for the assessment of land. R&D Publication CLR8 ISBN 1 857 05733
Department for the Environment, Food and Rural Affairs, Defra and the Environment Agency	2002b	Contaminants in soil: Collation of toxicological data and intake values for humans. R&D Publication CLR9 ISBN 1 857 05734 1.
Department for the Environment, Food and Rural Affairs, Defra and the Environment Agency	2002c	The Contaminated Land Exposure Assessment (CLEA) model: Technical basis and algorithms. R&D Publication CLR10 ISBN 1 857 05749 X.
Department for the Environment, Food and Rural Affairs, Defra and the Environment Agency	2004	Model Procedures for the Management of Land Contamination Contaminated Land Report . 11 ISBN: 1844322955
Department for Environment, Food and Rural Affairs - Defra	2006a	Animal by-products: Treatment in approved composting or biogas plants of animal by-products and catering waste - Q&A.
Department for Environment Food and Rural Affairs, Defra	2007a	Waste Strategy for England 2007 PB12596 CM 7086.

Department for the Environment, Food and Rural Affairs, Defra	2007b	Municipal waste management statistics 2006/7. Statistical release 404/07,
Department for Environment Food and Rural Affairs, Defra.	2008	Environmental Permitting: core guidance for the Environmental Permitting Regulations (2007).
Dimambro, M.E. Lillywhite, R.D. and Rahn, C.R.	2007	The physical, chemical and microbial characteristics of Biodegradable Municipal Waste derived composts. *Compost Science and Utilisation,* 15; 243-252
English Partnerships	2003	Towards a National Brownfields Strategy; Research findings for the Deputy Prime Minister.
European Union	1999	Council Directive EC/31/1999 on the landfill of waste
Foster, I.D.L. & Charlesworth, S.M.	1996	Heavy metals in the hydrological cycle, trends and explanation. *Hydrological Processes*, 10 pp227-261
Groeneveld, E. and Hébert, M.	2003	Dioxins, furans, PCBs and PAHs in eastern Canada compost. Prepared on behalf of Ministère de l'environnement de Québec
House of Commons Environment, Food and Rural Affairs Committee	2005	Waste Policy and the Landfill Directive: Fourth Report of Session, 2004-2005. Report HC 102 (incorporating HC 1256-i & -ii, Session 03/04)
Inbar, Y., Chen, Y., Hadar, Y. and Hoitink,	1990	H.A.J. (1990) New approaches to compost maturity. BioCycle, December 1990.
Janssen, B. H.	1996	Nitrogen mineralization in relation to C:N ratio and decomposability of organic materials. Plant and Soil, 181 (1) 39-45
Jobbágy, E. G. and Jackson, R. B.	2004	The uplift of soil nutrients by plants: biogeochemical consequences across scales. Ecology, 85: 2380–2389.
Kendle, A.	1990	Soil ameliorants for landscape planting, Plant user specification No 3, Part 1, July 1990, pp 3-7
Mamo, M. Halbach, T. R. and Rosen, C. J.	1998	Utilization of Municipal Solid Waste Compost for Crop Production. Online factsheet, University of Minnesota, US.

Mays, D.A., Terman, G.L. and Duggan, J.C.	1973	Municipal Compost: Effects on Crop Yields and Soil Properties. Journal of Environmental Quality. 2 (1), pp. 89-92.
National Audit Office, NAO	2006	Reducing the reliance on landfill in England REPORT BY THE COMPTROLLER AND AUDITOR GENERAL, HC 1177 Session 2005-2006 | 26 July 2006
Noble R. and Roberts S.J.	2003	A review of the literature on eradication of plant pathogens and nematodes during composting, disease suppression and detection of plant pathogens in compost. WRAP, Banbury, Oxon, UK
Ozores-Hampton, M.P., and T.A. Obreza.	1998	Use of composts in Florida's vegetable crops. pp. 39-42. In: Florida Department Environmental Protection (ed.). Compost use in Florida.
Smallwood, S.K., Morrison, M.L. & Beyea, J.	1998	Animal Burrowing Attributes Affecting Hazardous Waste Management *Environmental Management* 22 (6) pp831-847
Smith, S. R.	2009	A critical review of the bioavailability and impacts of heavy metals in municipal solid waste composts compared to sewage sludge, Environment International, 35 142-156, ISSN: 0160-4120
The Waste and Resources Action Programme, WRAP	2002	Research Analysis of the market potential for CLOed materials in the UK. ISBN 1 84405 034 3
Waste and Resources Action Programme, WRAP	2007a	Quality Protocol Compost. The quality protocol for the production and use of quality compost from source-segregated biodegradable waste.
Waste Resources Action Programme, WRAP	2007b	Quality compost opens up new uses for brownfield land on Teesside: The case for greener brownfield regeneration
Waste Resources Action Programme, WRAP	2007c	The Lambton Cokeworks reclamation scheme: The case for greener brownfield regeneration
Zhang, M. Heaney, D. Henriquez, B. Solberg, E. and Bittner, E.	2006	A four-year study on influence of biosolids/MSW compost application in less productive soils in Alberta: Nutrient dynamics. Compost Science and Utilisation, 14 68-80

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'Mechanical-Biological Treatment: the French approach to agronomic compost quality'

How to generate soil conditioners from RHR* in order to optimise the recovery of organic matter

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*ASTEE French Association of Environmental; **UNIA French Association of Agronomists; ***FNADE French Association of Private Industries for Waste Management & Treatment

Summary

The French Urban Waste Treatment Market is characterised today by the growing development of Mechanical-Biological Treatment (MBT) plants producing premium quality compost recycled to land. In that scheme, Urban Domestic waste collected at the kerbside (after selective collection of glass, tin and aluminium cans, batteries, etc.) either undergoes aerobic composting or anaerobic digestion (followed by secondary composting in accordance with French Standard NFU 44051 for organic fertiliser substances) to produce top quality compost for agricultural recycling.

In 2008, over 10% of the 50 million tons of urban waste were transformed in 30 MBT plants into approximately 3 million tons of standardised compost currently being recycled in agricultural fields.

This paper will describe and analyse the current status of French MBT plants on a technical basis, providing the regulatory framework for compost management. Various issues will be addressed (partnership between waste processors and downstream compost users, the type of MBT technology implemented, flow sheets, etc.) and special emphasis will be placed on the environmental benefits of the MBT approach.

* *Residual Household Refuse*

1 Introduction: the French background to the mechanical-biological treatment of waste

1.1 Terminology

While, at present, there is no statutory definition relating to the mechanical-biological treatment of urban domestic waste in France, the concept of MBT is now frequently used to denote the new generation of aerobic composting plants, with or without methanogenesis (anaerobic digestion, AD), which converts residual household refuse (RHR) into fertiliser substances, plus a potential renewable energy outcome with biogas produced under AD conditions.

As far as technicians are concerned, the MBT plants – ranging from small composting units to large factories such as Lille or Montpellier, which produce electricity and soon vehicle fuels - are a measure of the continuous advancement in the fermentation of refuse, reflected in more than 3 centuries of technological progress.

The concept of residual household refuse (RHR) relates to domestic waste considered without selective collection of biowaste on a door-to-door basis (kitchen waste, vegetable waste) and in conjunction with the collection of toxic waste in diverse quantities (batteries, chemical products, etc,) via a dedicated network (waste collection centres, voluntary deposit points, etc.).

This last condition is not the less important one as it represents a major guaranty for compost quality and toxic contamination by heavy metal, dangerous chemicals etc.

1.2 The French statutory framework governing the treatment & recycling to land of organic waste

Major driving force of the waste management market, the statutory framework governing the management of recycled organic waste in agriculture applies at two main levels:

- on the one hand, the level of Classified Installations for Protection of the Environment (CIPE), with technical constraints and requirements developed in order to restrict their nuisance impact (mainly odours emissions)
- and, on the other hand, in terms of the quality of the organic soil conditioning products, under application of the provisions of the Code Rural which, by means of industrial standards, imposes thresholds for various analytical parameters.

Under pressure from the European Community in particular, this national framework is subject to periodic change.

Thus, the recent revised French Standard NFU 44-051 relating to organic soil conditioners, put into force by the Decree dated 21 August 2007 (Official Journal dated 28 August 2007), is to be applied to all domestic waste composting plants with effect from 1st March 2009.

Moreover, the 50 or so older sorting/composting plants, with upstream crushing, constructed or refurbished[1] during the 1980s, no longer comply with the regulations and, in

[1] Les Résidus ménagers : Composition, collecte et traitement, André Saurin Ed. Eyrolles (1967), 80p

turn, are no longer capable of producing standardised soil conditioner for use in agriculture[2].

1.3 The impact of the revised Standard NFU 44-051 on MBT plants

While the revised Standard NFU 44-051 does not exclude the production of organic soil conditioner from RHR[3], it nonetheless stipulates **obligations regarding results** (and not methods) with regard to:

- agronomic parameters
- the content and throughput of metallic trace elements (MTE) and polyaromatic hydrocarbons (PAH)
- and the maximum content of undesirable/inert substances and pathogenic agents (salmonella, whipworms).

It appears that this *'French form of MBT'*, operated on RHR, constitutes an exception within the Community landscape, together with Spain and the United Kingdom (not mentioning Canada).

As a matter of interest, in spite of some opposition exclusively in favour of the selective door-to-door collection of biowaste, French regulations permit the production of fertiliser products derived from RHR.

Indeed, various trial investigations conducted on an industrial scale (for example the Launay Lantic plant in Brittany) have demonstrated the technical feasibility of the standardised production of compost from RHR.

Finally, by applying Community objectives to the recycling of waste, France has declared its intention to maximise the rate of collection of organic matter[4] (OM) in the RHR in order to favour organic recycling.

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[2] The Circular dated 27/02/09 only authorises interim manure spreading plans and – in the final analysis – depositing in landfill at a storage centre.

[3] The term 'RHR' relates to residual waste (grey rubbish bin) after the collection(s) of dry recyclable materials (iron and steel, aluminium, plastic bottles, packaging) and special domestic waste (dry cell batteries, vehicle batteries, medicines, etc.) and, in some cases, green waste.

[4] 'Biodegradable organic matter' comprises the non-synthetic organic matter contained in the waste. 90% of the non-biodegradable or synthetic matter is plastics, which represents a 10% ash content (source: CEMAGREF).

At the moment, the mechanical-biological treatment of RHR with the production of soil conditioner is experiencing a significant revival of interest on the part of numerous French contracting authorities.

At the end of 2008, the ADEME (Agence de l'Environnement et de la Maitrise de l'Energie *[the French Environment and Energy Conservation Agency]*) listed some 40 projects (50-50 for new sites and upgraded facilities) between now and 2012, totalling an annual flux of 3 million tonnes of waste.

2 Recycling organic matter and typology of the mechanical-biological treatment systems

2.1 Strategies for recycling residual organic matter

Management of the organic content of residual refuse, which may contain up to 50% biodegradable organic matter, is based on 2 separate approaches:

- Approach 1: selective collection of biowaste with the implementation of two specific treatment processes, one applied to the biowaste in order to produce a soil conditioner (aerobic composting or anaerobic digestion) and the other applied to the residual portion of the RHR in order to 'economise on landfill capacity'
- Approach 2: Non-selective collection of biowaste with the implementation of Mechanical-Biological Treatment of the RHR, together with the production of an organic soil conditioner (aerobic or anaerobic treatment)

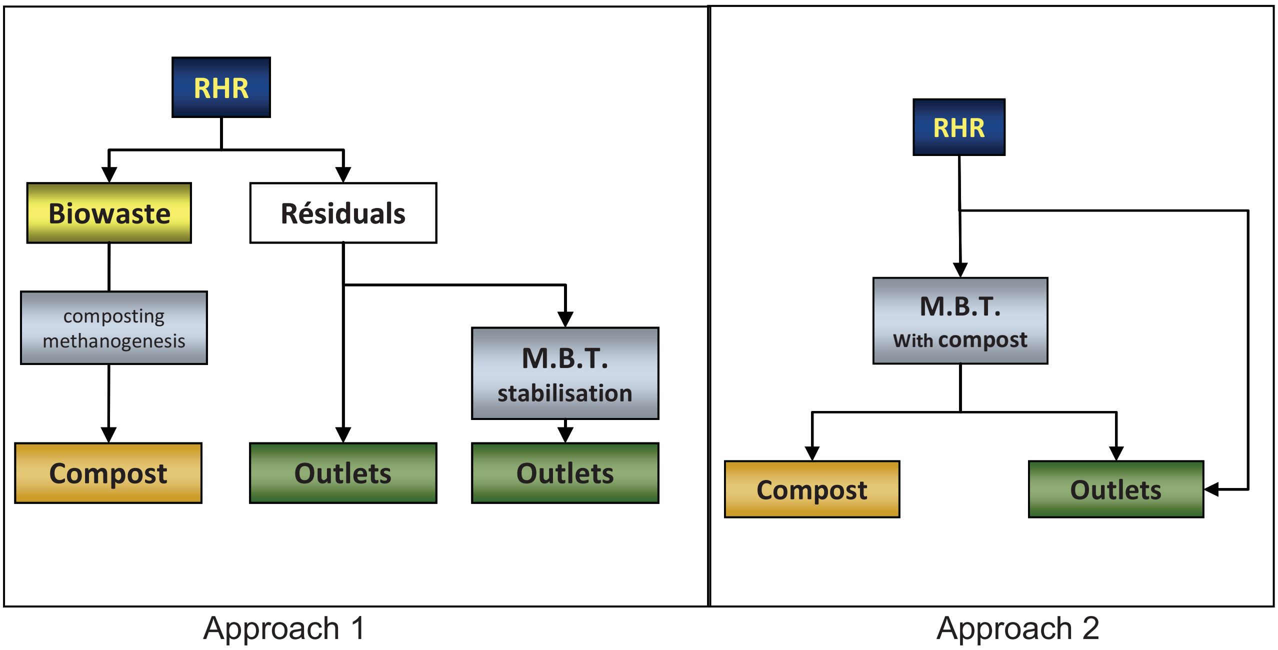

Figure 1: Typology of managing pathways of the organic matter of RHR

The outlets consist of landfill installations for non-hazardous waste (ISDND) or incinerators, which also generate a proportion of final and hazardous waste which must be buried as landfill.

In the case of Approach 2, which is the subject of this analysis, Figure 2 (below) illustrates the sequence of treatment operations, including an optional anaerobic stage.

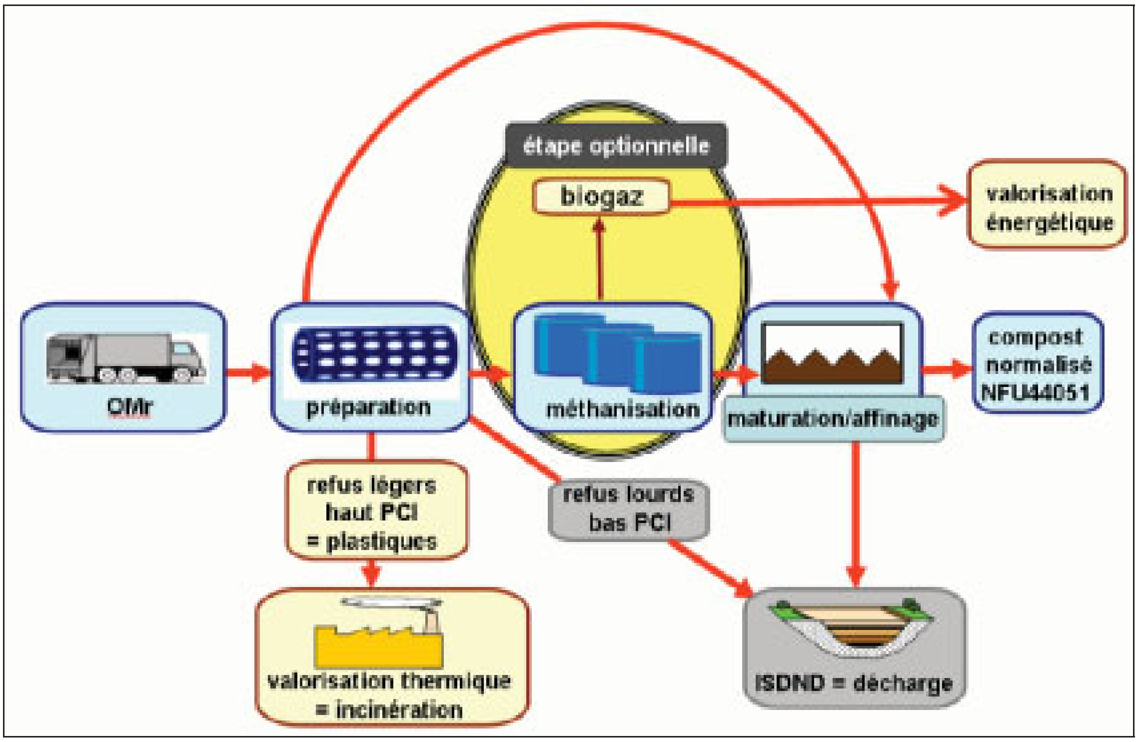

Figure 2: Schematic diagram of the MBT process applied to RHR (with optional methanogenesis)

2.2 Performance of selective collection of organic matter schemes

Based on a recent study for the ADEME (2008) conducted on 65 operations involving the selective collection of fermentable substances in France[5], the returns appeared to be relatively mixed, with low collected throughput characterised by, among other factors, an average quality since, to a major extent, they consisted of garden waste.

[5] Technical-economic analysis of the operations involving the biological management of waste, ADEME, May 2008. A summary can be viewed at: http://www2.ademe.fr/servlet/getBin?name=44CE7B751FC5359964C4B3A7358672E61232632467701.pdf

Indeed, as shown in Table 1 (below), this study highlighted collection rates for biowaste of between 44 kg/occupant/year[6] and 94 kg gross/occupant/year[7].

Table 1 : Summary of the results of the rate of collection of biowaste in France (2008 – ADEME)

	Type of collection analysed		**Total**
	Type 1	**Type 2**	
No. of operations	30	35	65
Type of biowaste	Kitchen waste	Kitchen waste + Garden waste	
Tonnage 2005	30,898	136,153	167,051
Average quantity	44 kg/occupant/year	94 kg/occupant/year	78 kg/occupant/year

It should be noted that, in France, due to the number of operational composting plants[8], the treatment of garden waste does not present any particular problem.

Furthermore, there is evidence of significant sensitivity on the part of methanogenesis processes to the seasonal variations of garden waste, with impacts on the quantity as well as the quality of the source materials.

Since they usually operate on a continuous basis (whereas composting is generally performed in batches), methanogenesis plants are subjected to variations in the quality of source materials being fed to the reactor.

Because stability is required for the process, those fluctuations in quality with not readily compatible waste are more than likely to face operational difficulties.

In view of the 65% humidity content, the volume of biodegradable organic matter 'recovered' by the observed selective collection procedures is therefore of the order of **15 kg dry matter/inhabitant/year** (excluding garden waste); this is very low and calls into question the economic viability of this type of arrangement in France.

2.3 Effectiveness of MBT plants

In view of the disappointing results obtained from the selective collection of organic matter in France, the opportunity of producing soil conditioners derived from RHR repre-

[6] Ratio obtained for the sole specific collection of kitchen waste

[7] Ratio obtained during the combined collection of kitchen waste and garden waste

[8] http://www.orgaterre.org/presentation-audit-compostage-6-pages.pdf

sents a solution for developing the rate of recovery of biodegradable organic matter in RHR, in terms of both kitchen waste and paper/cardboard.

The operational units and the currently-planned MBT units with the production of soil conditioner are intended, on average, to guarantee a rate of recovery of biodegradable organic matter of the order of 90 kg gross/occupant/year[9], compared with 44 kg gross/occupant/year for the collection of biowaste (excluding garden waste).

However, it should be emphasised that compliance with the threshold imposed by the Standard NFU 44-051 requires the implementation of a series of stages of mechanical-biological treatment which are relatively complex and cumbersome, particularly in view of the multiplicity of non-synthetic organic matter in the RHR and the undesirable substances which have to be removed.

3 The type of biodegradable organic matter in residual household refuse and the potential for recovery

3.1 Fractional analysis of the average residual rubbish in France

Recent analyses of grey (residual) rubbish bins have highlighted the significant uniformity of the materials in the rubbish, associated with major variations in terms of the size (granulometry) of the 'constituent categories'.

[9] In relation to dry matter, the recovery values for organic matter derived from RHR are even more favourable for MBT projects.

Table 2: Example of the composition of a typical batch of RHR

Categories	Typical composition (as % dry)
Fermentable substances	11.0
Paper	18.0
Cardboard	8.8
Composites	2.3
Textiles	2.3
Sanitary textiles	6.6
Plastic films	5.4
Plastics	8.7
Unclassified combustible substances	4.3
Glass	7.8
Ferrous metals	4.0
Other metals	0.8
Unclassified non-combustible substances	4.7
Special waste	0.9
Fine particles <8 mm	14.4
	100.0

Table 2 shows, for a series of communities, the average typical composition of the residual rubbish, drawn up on the basis of 15 designations of the MODECOM® method developed by the ADEME in France:

Illustrating the variability of the characteristics of the aforementioned categories, Figure 2 represents a typical granulometric distribution of the various constituent categories of RHR (with the exception of fine particles <8 mm):

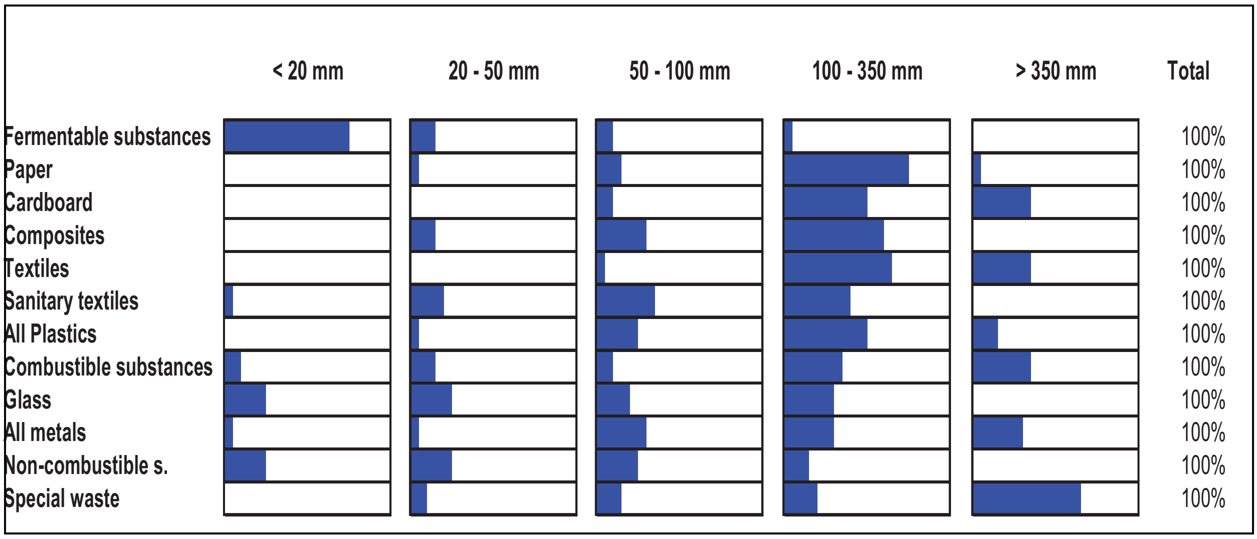

Figure 2: Granulometric distribution of the 12 categories of typical RHR

In summarised form, the bibliography shows that biodegradable organic matter basically comprises the following categories:

Table 3: Distribution of biodegradable organic matter in various categories

	Dry material % MB	**Total Organic Matter (TOM)**[10] % MS	**Biodegradable organic matter** % TOM
Fermentable substances	**35%**	**92%**	**98%**
Paper	**80%**	**80%**	**95%**
Cardboard	**85%**	**82%**	**98%**
Sanitary textiles	**39%**	**91%**	**90%**
Fine particles (<8 mm)	**55%**	**52%**	**96%**

In the case of biodegradable organic matter, these factors highlight a granulometric predominance, on the one hand in the 'coarse' fraction of 100 to 350 mm and, on the other hand, in terms of the fine particles.

Thus, the biodegradable organic matter in the RHR is primarily concentrated in the following 5 granulometric bands:

- category of fermentable substances: granulometric band <20 mm
- category of paper: granulometric band 100 – 350 mm
- category of cardboard: granulometric band >100 mm
- category of sanitary textiles: granulometric band 50 – 350 mm
- category of fine particles (<8 mm)

The relative distribution of the principal sources of biodegradable organic matter present in RHR can be shown in the form of a pie chart (below):

[10] TOM measured by loss in a flame at 550 °C

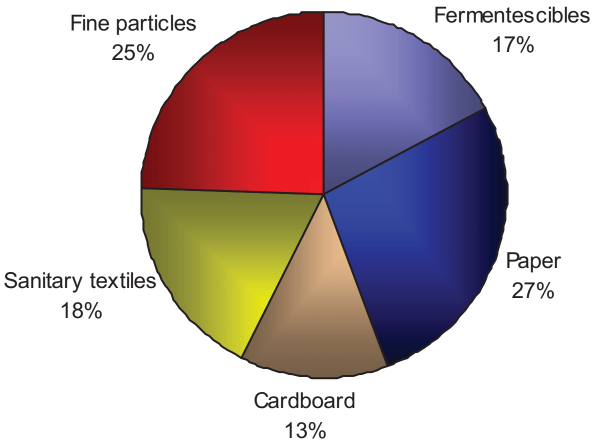

Figure 3 : Distribution of the biodegradable organic matter (as % of the gross) in a typical batch of RHR

From this it is possible to deduce a strategy for recovering this fraction of fermentable particles.

Based on the ratios shown above, the total biodegradable fractions contained in one tonne of gross RHR represents a potential of the order of 450 to 500 kg (gross) of total biodegradable fraction.

Reduced to the level of each occupant (on the basis of 300 kg gross/occupant/year of collected RHR), the biodegradable fractions represent a potential of the order of 140 kg untreated/occupant/year – excluding garden waste)., with paper and cardboard, which could represent up to 25 to 30% of the content of the residual rubbish.

4 Examples of MBT in France

4.1 Typology of operations

There is no typical preparation sequence. Each of the solutions consists of a combination of various types of equipment of varying complexity and diversified on the basis of the required degree of separation and, in turn, on the quality of the fertiliser substances produced in this way.

In this changing context, in which industrial performance is aimed at fulfilling the statutory requirements, some treatment organisations stand out from the rest.

Thus, the units which are experiencing growth in France are deploying:

- **upstream** of the biological process in its strict sense, biomechanical treatment using a rotating tube to prepare the substrate and to facilitate subsequent recovery of the biodegradable organic matter present in the larger granulometric particles, such as paper, cardboard and sanitary textiles
- at the heart of the process, aerobic or anaerobic biological treatment techniques
- a succession of negative and positive sorting techniques, by utilising the different properties of the constituent elements of the RHR

Thus, the operations involved include sorting the waste by its optical, mechanical, electrical, magnetic and electromagnetic properties, by its properties associated with its size and morphology and, finally, its surface properties.

4.2 Composting RHR

The characteristics of a current project involving an MBT plant to be set up in Western France, designed to produce 26,000 tonnes per annum from RHR, together with the production of an organic soil conditioner, are shown on the next page.

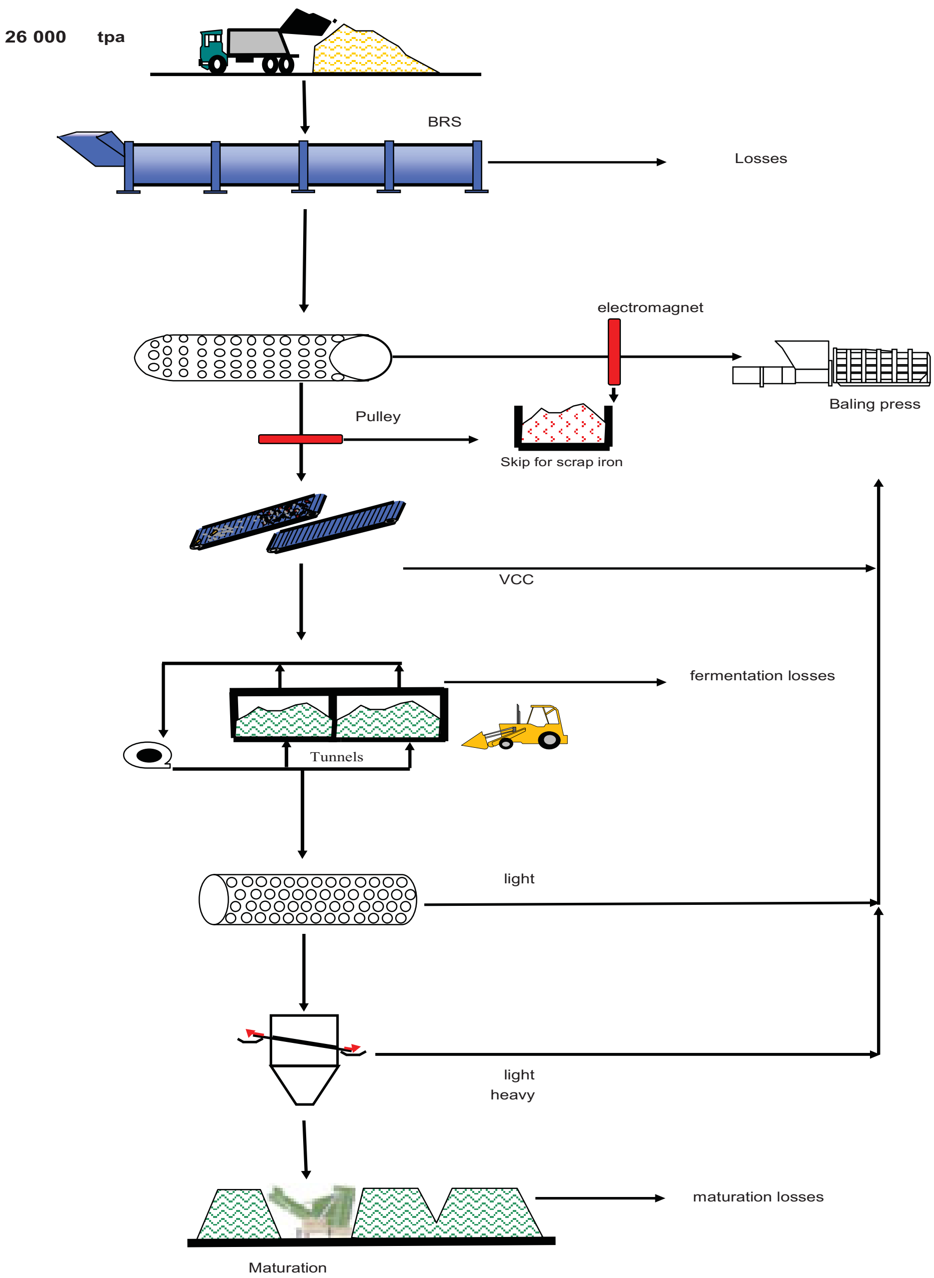

Figure 3: Schematic diagram of the MBT project (26,000 tonnes per annum)

The table below summarises the throughput of dry matter and biodegradable organic matter associated with the proposed main treatment levels:

Table 4: Throughput of dry matter and biodegradable organic matter

Workstations	Roles	Throughput of dry matter (kg DMS)	Throughput of dry biodegradable organic matter (kg DMS)
Receipt	Sort voluminous undesirable substances	1,000	500
Rotating tube	Granulometric reduction Homogenisation Biological decay Preparation of the substrate	900	410
Screen	Removal of plastics	600	320
DTS	Removal of heavy VCC	480	280
Composting	Biological decay Stabilisation Homogenisation, drying	400	210
Refining in the drum	Removal of small plastic items	270	170
Refining on the densimetric table	Removal of small plastic items Removal of small heavy items	250	160
Maturation	Stabilisation	210	140

The final rate of recovery (that is to say in terms of compost) of the biodegradable organic matter is estimated to be around 28%.

By incorporating the losses associated with biological treatment processes (biological treatment using the rotating tube for 4 days and biological treatment by composting for 4 weeks, followed by a 3-week period of maturation); the anticipated rate of recovery is of the order of 64%.

This is equivalent to a rate of recovery estimated at:

- 300 kg gross of biodegradable organic matter per tonne of treated RHR
- 85 kg gross of biodegradable organic matter per occupier and per annum (based on the production of 300 kg gross of RHR/occupant/year).

4.3 Digesting RHR

4.3.1 Dynamics of the methanogenesis process applied to residual household refuse

The French mechanical-biological treatment of residual household refuse, with methanogenesis of the organic fraction with a view to the production of a soil conditioner, is in a state of rapid growth:

- with 4 units in service (Amiens, Varennes Jarcy, Le Robert, Montpellier) and 2 units treating biowaste (Calais and Lille), with a total theoretical capacity of 560,000 tonnes per annum
- and with 4 allocated contracts (surveys in progress or construction in progress) in Marseilles, Romainville, Angers, Bourg-en-Bresse, Vannes and Forbach.

For the ADEME, responsible for monitoring the management of domestic waste, the rate of growth is of the order of 2 to 3 units per year, mainly involving Residual Household Refuse, with a few examples of biowaste collection having been identified (Forbach).

With regard to the technical approaches, two major choices are vying for approval:

- to introduce a ‘clean’ product into the digesters, which demands a fine sorting operation upstream and the use of a screen mesh of 0-10 mm for the separation process or
- to retain the maximum amount of organic matter at the input side of the digesters by carrying out a ‘coarse’ sorting operation, followed by a fine sorting operation on the digestate (using a hydraulic process for example)

In both cases, the majority of operators prepare the raw material using mixer tubes, with the aim of ‘unsticking’ the organic matter, that is to say rendering it ‘easy’ to hydrolyse and separate from the other constituents.

This is the objective driving the granulometric reduction operations.

4.3.2 Example of a methanogenesis plant treating residual household refuse (Bourg-en-Bresse, France)

This project (which is at the ‘manufacturer’s survey’ stage: OWS – DRANCO + SORD-ISEP processes) is designed to treat an annual throughput of 90,000 tonnes of residual household refuse and 15,000 tonnes of green waste.

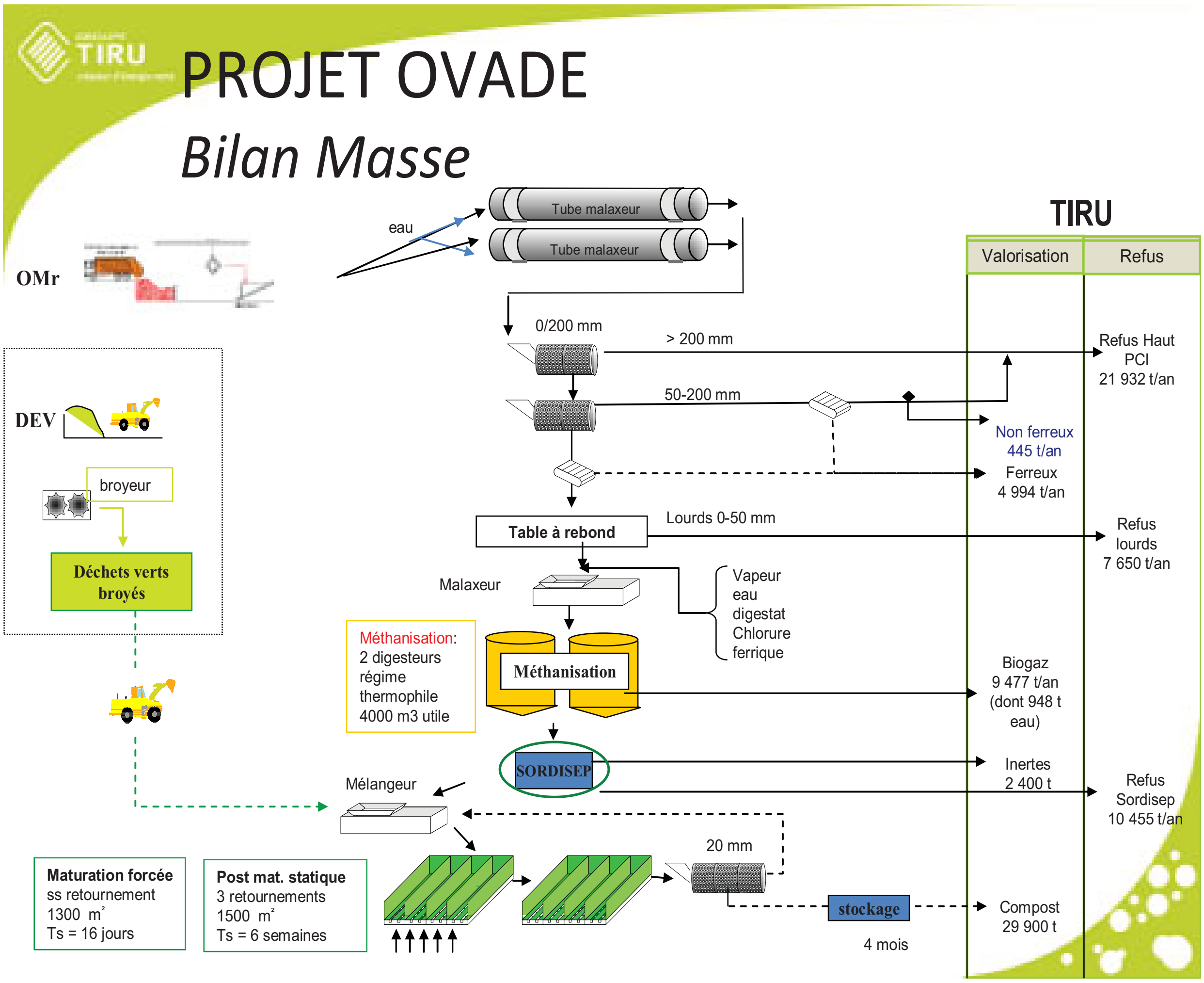

Figure 5: Schematic diagram of the MBT project at Bourg en Bresse

The contract has been placed on the basis of:

- digesters which are suitable for medium-sorted products (fraction 0 – 50 mm), without an agitation system and with an increased dry matter content (Dranco/OWS)
- a proven system for hydraulically sorting the inert substances (Sordisep/OWS)
- the absence of upstream crushing (mixing to facilitate separation of the constituents)
- and, finally, the production of compost which ensures total compliance with the ratio of inert substances stipulated by Standard NFU 44-051.

The principal ratios are as follows:

Biogas: 120 Nm3 / entry tonne, i.e. 250 kW/hr/tonne entering the digester

Diversion ratio: 54.6 %

Biogas: 10.5 %

Compost: 22.4 %

Clean inert substances: 2.7 %

Scrap iron: 5.5 %

Non-ferrous metals: 0.5 %

Evaporator: 13.0 %

Total : 54.6 %

In a subsequent stage, refuse with a high NCV - which constitutes 25.7% of the total mass - will be thermally recycled in a thermal treatment unit; this illustrates the complementary nature of the biological process with the energy recycling of refuse with a high NCV.

To summarise, the process involving methanogenesis of RHR demonstrates a high overall level of recovery of organic matter (optimisation of the production of biogas and compost) and methods to reduce the amount of refuse should be implemented.

4.3.3 Methanogenesis applied to household biowaste (Calais, 62)

Commissioned at the end of March 2007, during 2007 the unit treated a throughput of 6,350 tonnes, rising in 2008 to 12,000 tonnes.

The operation is characterised by a high proportion of green waste in the entry waste, with a ratio of 2/3 green waste after treatment.

Experience has shown that over and above a 30% proportion of grass cuttings at the entry to the digester, operation in thermophilic mode is no longer guaranteed and yet the volume of grass cuttings was as high as 80 to 90% of the green waste in spring and the start of the summer.

Therefore, during 2008, it became necessary to limit the volume of green waste to 50% in order to ensure that the digester operated satisfactorily.

In terms of operation, the ratio of production of biogas is 150 Nm^3/treated tonne. Furthermore, since the throughput of household biowaste was lower than the forecasts by the communities, the production of biogas was insufficiently high to power the generating set. The table

Table 8: Comparison factors between methanogenesis applied to RHR and to biowaste

	BIOWASTE	**RHR**
Treated organic waste	15 to 40 kg/ occupant/year	60 to 90 kg/ occupant/year
Production of biogas per tonne entering the digester	150 Nm^3/tonne	120 Nm^3/tonne
Assessed potential of biodegradable organic matter	≅ 30 %	≅ 70 %

5 Quality of the compost produced by MBT in France

The sanitary quality represents the major limiting factor in the production of organic soil conditioner derived from RHR.

For a typical batch of RHR, Figure 5 shows a breakdown of the 9 metals[11] stipulated by Standard NFU 44-051 for the principal categories and granulometric fractions of a typical batch of RHR:

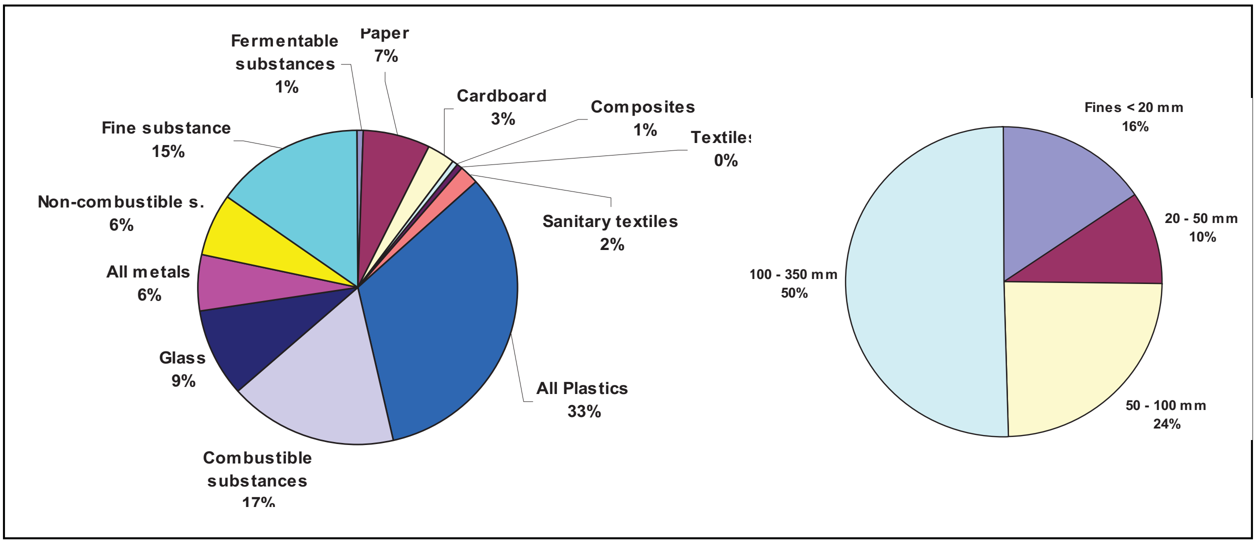

Figure 6: Breakdown of the 9 metals in RHR

[11] Total of the parameters As, Cd, Cr, Cu, Hg, Ni, Pb, Se and Zn

The following tables summarise the limiting thresholds and throughputs stipulated by French and German regulations:

Table 9: Limiting thresholds for metals, as stipulated by French and German Standards

	Maximum contents, in mg/kg MS		
	D		Fr
	20 TWM	30 TWM	
As	-	-	18
Cd	1.5	1	3
Cr	100	70	120
Hg	1	0.7	2
Pb	150	100	180
Se			12
Ni	50	35	60
Cu	100	70	300
Zn	400	300	600
Fluoranthene	-	-	60
Benzo(b)fluoranthese	-	-	300
Benzo(a)pyrene	-	-	600

Table 10: Limiting throughputs of metals, as stipulated by French and German Standards

	Limiting throughputs g/ha over 1 year					
	D		F	D		F
	Maximum average throughputs*		Flux maximaux moyens**	Maximum throughputs at any given time*		Maximum throughputs at any given time**
	basis 20 T WM	basis 30 T WM		basis 20 T WM	basis 30 T WM	
As	-	-	90	-	-	270
Cd	10	10	15	30	30	45
Cr	667	700	600	2 000	2 100	1 800
Hg	7	7	10	20	21	30
Pb	1 000	1 000	900	3 000	3 000	2 700
Se	-	-	60	-	-	180
Ni	333	350	300	1 000	1 050	900
Cu	667	700	1 000	2 000	2 100	3 000
Zn	2 667	3 000	3 000	8 000	9 000	6 000

* Throughput calculated by comparison with the preceding table

** Stipulated throughputs

Current feedback shows that the content of metals and polyaromatic hydrocarbons does not represent a limiting factor regarding the compost produced by MBT.

Moreover, a number of studies have highlighted the significant presence of metals among the fine particles, particularly in heavily urbanised sectors. Large-scale recovery of the paper and cardboard contained in RHR in the MBT plants represents an important factor, enabling the compost to be enriched with organic compounds with a low metal content.

The most problematic point under consideration is the ratio of inert/undesirable substances. The overriding problem is achieving a satisfactory compromise between the production of a soil conditioner and the quality of the said soil condi-

tioner via the choice of a judiciously conceived refining process incorporated into the treatment sequence.

The final table (on the next page) highlights approaches which are totally incompatible with the one adopted by France and by Germany; these approaches do not employ the same parameters to characterise the inert substances in the compost and, in turn, their aesthetic quality.

Table 11: Threshold for inert substances specified by French and German regulations for urban compost

	Limiting values	
	Germany	France
Physical contaminants: glass, plastics, metal >2 mm	<0.5% MS	-
Stones >5 mm	<5% MS	-
Films + EPS >5 mm	-	<0.3% / MS
Other plastics >5 mm	-	<0.8 % / MS
Glass + metals >2 mm	-	<2.0 % / MS

6 Conclusion

The product of an organic soil conditioner from RHR ensures the optimum rate of recovery (and, in turn, recycling) of residual biodegradable organic matter.

However, this solution is only in its early stages in France.

Of the fifty or so MBT plants for RHR currently in operation, only 4 units are equipped with rehabilitated treatment lines suitable for the production of compost which complies with the new Standard NFU 44-051.

There is no question that the fifty or so projects in the course of development will confirm the long-term viability of the industry and, in particular, reconcile a high rate of recovery of biodegradable organic matter and satisfactory final quality for the types of compost produced, whose final destination is a return to the soil.

7 Bibliography

- Le compostage entre dans une nouvelle ère, TSM n°11 (nov 2008) – E. Adler
- Report of the survey of the municipal solid waste composting plant (2003) - B. Morvan, S. Aboulam, JP Blanquart CEMARGREF - M. Baptista, M. Gonçales LQARS
- Anaerobic digestion of residual municipal solid waste using biological-mechanical pre-treatment: the Varennes Jarcy plant (2008) - H. Fruteau, E. Thiebaut VALORGA
- Composting of household waste: from the problematic to the technical choice at the Launay Lantic plant (2007) - TSM No. 5
- Analyse technico-économique des opérations de gestion biologique des déchets (2008) - ADEME
- Expertise du procédé Comporec de l'installation de Sorel Tracy - Québec (2003) - P. Thauvin - ADEME, B. Morvan, E. Le Saos CEMAGREF
- Recherche d'une méthode d'analyse du fonctionnement des usines de tri-compostage des déchets ménagers. Fiabilité des bilans matière (2005) - Thèse de S. Aboulam - ENSAT
- Influence des pré-traitement mécaniques et biologiques des OMr sur leur comportement bio-physico-chimique en Installation de Stockage de Déchets (ISD) (2006) - Thèse de J. De Araujo Morais - INSA Lyon
- Caractérisation de la matière organique dans les ordures ménagères : analyse sur produit sec (2004) Rapport de DEA de F. Achour - INSA Lyon
- Méthode de caractérisation des déchets ménagers (2000) - B. Morvan- TSM vol. 20
- Composting municipal solid waste or biowaste? The same quality of compost is possible (2004) - B. Morvan - Conference 14-17 November, Wakefield

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Addition of an Anaerobic Treatment Stage to MBT Plants – Based on the Example of Rostock

Michael Nelles, Joachim Westphal and Gert Morscheck

Since 1 June 2005, it has been mandatory to treat municipal waste before landfilling. This pre-treatment aims to render the waste inert in order to avoid reactions in the landfill. Two pre-treatment technologies have become established in Germany: the thermal treatment of refuse in waste incineration plants and mechanical-biological treatment (MBT).

In Germany, a large number of MBT and waste incineration plants are available for the pre-treatment of municipal waste. 25% of the residual municipal waste is treated in 46 waste incineration plants (DOEDENS et al., 2007).

Waste incineration plants destroy organic substances as well as other combustible components of waste and use their energy content.

MBT plants usually separate waste into combustible fractions, mainly plastics, which can be thermally used in specific plants, and another fraction, which mainly consists of natural organic components and is treated aerobically in most cases.

In principle, mechanical(-biological) treatment processes have proven their functionality. Technical difficulties which arose during operation of such plants have meanwhile been solved to a considerable extent. However, there remains a need for optimisation in some plants and regarding certain parts of the MBT-technology (THOMÉ-KOZMIENSKY and THIEL, 2008).

At the beginning of the 1990s, the city of Rostock started thinking about the future of its waste management. 1993 saw the introduction of the German TASi regulation [Technical Instructions on Waste from Human Settlements] which stipulated the construction of pre-treatment plants by 31 May 2005. In May 1994, the EVG [Entsorgungs- und Verwertungsgesellschaft mbH Rostock – waste disposal and recycling company Rostock] was founded.

A board of consultants from various backgrounds (economy, associations, administration, environmental associations and the University of Rostock) works for the EVG and discussed possible solutions. The main question was whether to build a waste incineration plant or a MBT plant.

In May 1996, a call for proposals for the treatment of the residual waste of the city of Rostock and surrounding districts was published, addressed at technology providers all over Europe.

In June 1997, the city parliament decided on the construction of a residual waste treatment plant comprising mechanical-biological and thermal treatment at Rostock-Seehafen.

In September 1998, a waste disposal agreement was concluded between the EVG mbH Rostock and the Hanseatic city of Rostock.

The approval procedure started in December 1998 and the permit pursuant to BImSchG [German Federal Immision Control Act] for the construction and operation of the RABA [residual waste disposal plant] Rostock was granted in September 2000.

In January 2004, the city parliament of Rostock decided on a major change in the concept: the MBT plant was still to be built, but plans for an incineration facility under the responsibility of the EVG were cancelled. The **Vattenfall** Europe New Energy GmbH is currently building an RDF-fired thermal power station next to the MBT plant.

The foundation stone for the MBT Rostock was laid on 27 May 2004; operations commenced on 1 June 2005.

A fermentation facility as an addition to the MBT plant was commissioned in July 2008.

Plant Technology

The mechanical-biological waste treatment plant Rostock has been operated by the EVG since 1 June 2005. Domestic refuse from the Hanseatic city of Rostock and the districts Bad Doberan, Güstrow and Nordvorpommern is treated there. Approximately 120,000 Mg of waste are delivered and treated per annum.

In a first step, the domestic waste is treated mechanically (screening, classifying, sorting out of ferrous and non-ferrous metals, separation of plastics). Recyclable material is separated and the processed, organic fine fraction is then treated biologically.

So far, two types of final products have been derived from the refuse. Firstly, refuse derived fuel (RDF - approx. 40% of the total output), and secondly, disposable landfill material (approx. 50%) as a result of composting processes. RDF is produced in different sizes and is used as a substitute for coal in cement and power plants. One of the buyers is the Nehlsen thermal power station in Stavenhagen, which uses high-quality RDF to produce energy for the adjoining Pfanni factory. From the 2nd quarter of the year 2009, all RDFs will be delivered to the Vattenfall RDF-fired thermal power station which is being built right beside the MBT plant.

The organic refuse components are stabilised within 10 weeks, using a combination of intensive decomposition and post-maturation. The material resulting from this process is then deposited on landfills. The decomposition process requires a constant aeration of the material in the decomposition reactors. A cooling system is needed to control temperatures during the decomposition process. Furthermore, all exhaust air must be cleaned through post-oxidation before emission into the environment. Each of the three components is highly energy- and thus cost-intensive. In addition, the organic fraction still contains unused energy after the aerobic treatment.

The high energy costs and the so-far unused remaining energy of the biogenic material led to the decision to introduce a future-oriented and environmentally acceptable additional stage in waste treatment: energy generation through fermentation, this in the wake of a reassessment of the waste flows.

The new additional fermentation facility uses technology by KOMPOGAS and increased the input capacity from 120,000 tons to the now permitted 135,000 tons of refuse per annum. This was made possible by the fact that through the fermentation process, biological degradation already takes place before intensive decomposition and thus reduces the pollution to be treated with RTO (Regenerative Thermal Oxidation, used for exhaust air cleaning), the weak point of the process so far. After comprehensive tests, the facility was commissioned in the 1st quarter of 2008.

The feeding of the fermentation facility requires a change of the material flow in the separation process of the MBT plant. Half of the biomass which used to be fed into the intensive decomposition reactors before the introduction of the new facility now has to be fed into fermentation. This can be done by feeding the organic material into a catch bin after the separation of hard material. On the other hand, sedimenting material is fed directly into the rotting tunnel after the separation of non-ferrous metals.

Automatically controlled conveyor belts carry the highly organic material - in evenly distributed cycles - from the catch bin into the three horizontal fermenters. An automatic agitator mixes the material in the fermenters, which comprise a volume of 1,200 m^3 each. The fermenters provide an anaerobic environment with an average water content of 75% and a relatively constant temperature of 53.5°C (128.3°F), thus offering optimum conditions for the production of biogas. The material remains in the fermenter for 10 to 12 days.

The desulphurised biogas is then used by two gas engine-operated CHP stations (2 x 625 kW electric) to generate energy and heat. This way, 12,000 MWh/a electrical energy are fed into the public grid by the EVG.

The waste heat of the CHP stations is used to heat the fermenters and adjoining building parts. A complete use of thermal energy, both of the CHP stations and the waste gas heat, will be achieved with the commissioning of the Vattenfall thermal power station where it is fed into the steam cycle.

Fermentation residues are carried off via a combined wet/dry-discharge and are subsequently united with the other organic components for rotting. This process optimises the subsequent decomposition.

In addition to the treatment of the biological part of domestic waste, food that has passed its shelf life and leftovers may also be added. The yearly input of leftovers from meals amounts to 4,000 tons.

The overall concept of the plant at the seaport is completed by the RDF-fired thermal power station which is expected to be commissioned by Vattenfall Europe New Energy Ecopower Gmbh in the 1st quarter of 2009. Exhaust air, which so far had to be cleaned and burnt (RTO) at the EVG's expense, and RDFs will be delivered to this station in the future. This also enables the recovery of energy of methane (approx. 0.1% of exhaust air) produced in the aerobic stage.

The EVG uses state-of-the-art technology to generate energy from waste in an environmentally friendly way and recovers energy from RDFs without creating further pollution through transportation. This makes the EVG a pioneer well beyond the borders of Mecklenburg-Western Pomerania. MBT, fermentation and the thermal power station allow for a complete energy recovery and together constitute one of the most modern waste management sites in Germany.

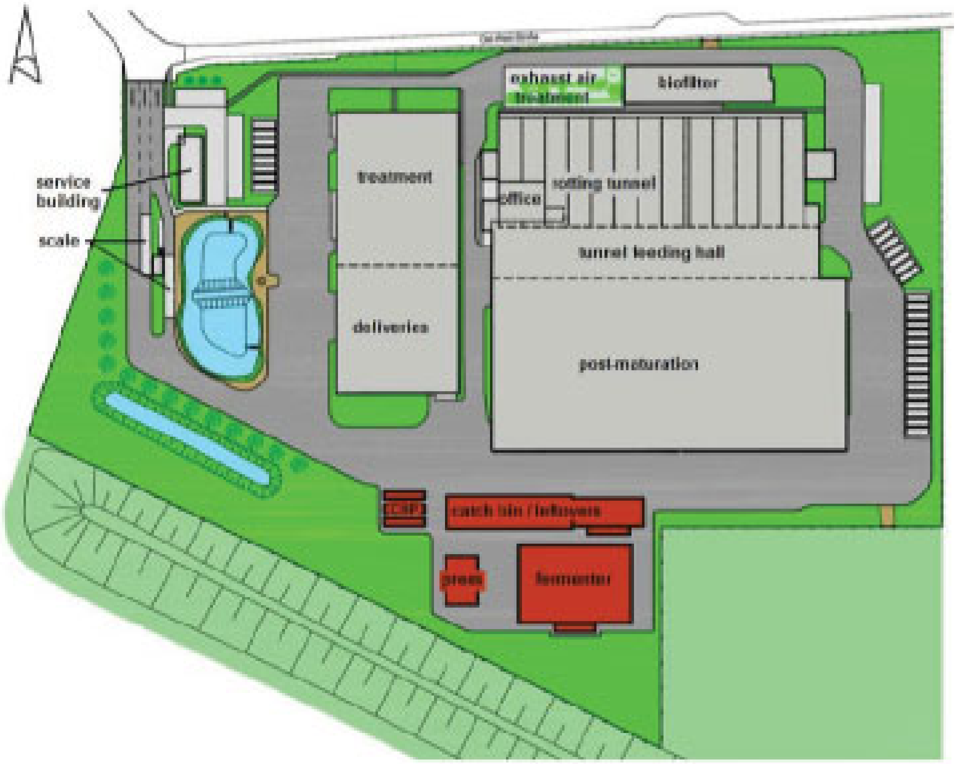

Figure 1: Layout plan of the MBT plant with aerobic and anaerobic treatment facilities

The functional principles of the MBT plan are outlined in the following flow chart (figure 2):

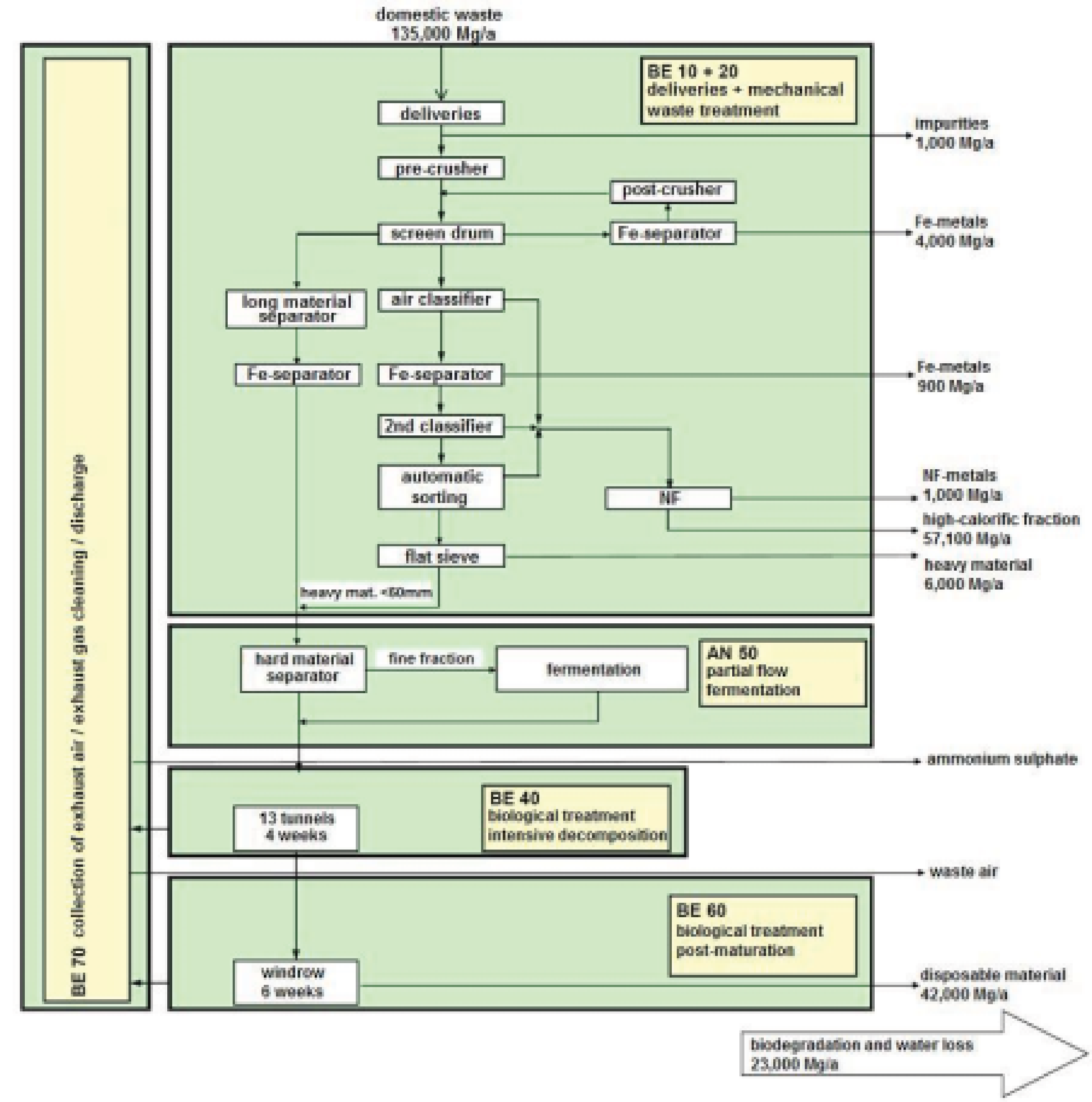

Figure 2: Process flow chart of the MBT plant Rostock

The operating units (BE) shown in figure 2 are explained below:

BE 10 + 20 delivery + mechanical waste treatment

- encapsulated delivery and preparation hall
- single-line layout: organic line
- crushing aggregates
- classification of the waste flows
- use of air classifiers and AutoSort systems

AN 50 partial flow fermentation

- hard material separator

- fermentation

BE 40 biological treatment – intensive decomposition

- encapsulated rotting tunnel (13 tunnel modules, air circulation with cooling, rotting period 4 weeks)

BE 60 biological treatment – post-maturation

- closed windrow (rotting period 6 weeks); objective: observation of storage criteria pursuant to AbfAblV [German Waste Storage Ordinance]

BE 70 collection of exhaust air / exhaust gas cleaning / discharge

- separated collection and redirection of exhaust air from hall areas and highly or lightly polluted process exhaust air from areas of biological treatment
- use of air circulation as far as possible to reduce volumes
- treatment of highly polluted process exhaust air with a combination of acid scrubber and RTO
- treatment of lightly polluted process exhaust air with a combination of air humidifier and encapsulated biofilter
- discharge of exhaust air via stack; objective: observation of emission limit values pursuant to 30th BImSchV [German Federal Immission Control Ordinance]

What is the point of adding fermentation to the MBT plant?

Between 1990 and 2003, the waste management industry succeeded in reducing CO_2-equivalent emissions by approximately 45 million tons per year. This makes up almost 20% of the total reduction in Germany (TROGE, 2007). The federal government is planning to raise the share of renewable energies in Germany to 16% by 2020. The waste industry's biogas plants will and must make their contribution too. Switching from aerobic to anaerobic treatment or respectively adding anaerobic stages to existing plants is supposed to play an increasing role in the generation of electric power. From the authors' point of view, this only makes sense with regard to ecological aspects if the waste heat of electricity generation is used as well.

As regards the addition of anaerobic treatment to MBT plants, the following possibilities are conceivable. However, operational experience differed considerably.

- with partial flow dry fermentation (reliable in operation)
- with full flow dry fermentation (process water treatment after dewatering of fermentation residues)
- with full flow wet fermentation (percolation, demanding, facilities in Heilbronn and Buchen decommissioned) (DOEDENS et al., 2007)

In its Environmental Report 2008 “Environmental protection in the shadow of climate change”, the German Advisory Council on the Environment (SRU, 2008) underlines the benefits of adding anaerobic treatment to MBT plants.

In aerobic processes, the energy content of organic material is fully converted into unusable heat. The different possible combinations with anaerobic partial or full flow concepts, however, allow for a recovery of energy. Fermentation can thus contribute to an improved economic and ecological situation of MBT plants (SRU, 2008).

Subsidisation pursuant to the EEG [German Renewable Energy Sources Act] is not earmarked for mixed municipal waste. § 8 of the EEG refers to ‘recognised biomass’ according to the German Biomass Ordinance; mixed municipal waste does not belong to this category (BiomasseV § 3 no. 3). According to § 3 (1), the EEG promotes energy generation from biomass. The use of biomass in the context of fermentation as a part of MBT is now being subsidised increasingly. The MBT plant Rostock receives aid, too.

Following the separation of native organic material, individual waste code numbers can be allocated. Due to the separation, the refuse fed into fermentation no longer falls into the category ‘mixed municipal waste’. The native organic fraction is allocated the waste code number (AVV-Nr.) 191212, no mixed municipal waste is involved here (TISCHER and GASSNER, 2006).

§ 2 (3) no. 5 of the German Biomass Ordinance stipulates: “Without prejudice to paragraph 1, the following are biomass [...] Biogas produced through anaerobic fermentation [...].” This enables subsidies.

§ 3 of the act on granting priority to renewable energy sources (EEG) gives another definition of ‘renewable energies’: “[...] energy from biomass, including biogas, landfill gas and sewage treatment gas, as well as the biodegradable fraction of municipal waste and industrial waste.”

§ 64 of the new EEG furthermore states “that the entitlement to payment of a tariff for electricity from biomass shall only apply where proof can be furnished that [...] when generating the electricity from the utilised biomass, a certain reduction in greenhouse gases is achieved.” This reduction is subject to proof.

In the statement of reasons for the new EEG, the future general entitlement of MBT plants to remuneration is explained as follows:

“The term ‘biomass’ is not conclusively defined in the legal text. [...] The general term ‘biomass’ as used at this point includes biogenic energy sources in solid, liquid or gas state of matter. In general, these are biodegradable products, residues and waste from vegetable or animal origin from agriculture, forestry and related industries.

[...] The explicit statement that biomass in this context also includes biogas originates from Directive 2001/77/EC of the European Parliament and of the Council on the promotion of electricity from renewable energy sources where biogas figures as a separate renewable energy. [...] In further implementation of Directive 2001/77/EC, the biodegradable share of industrial and municipal waste is also defined as ‘renewable energy’. Additionally, it must be taken into consideration that only the part of electricity generated from the defined material is subject to the enlarged scope of application of the law. Furthermore, it must be noted that the principle of exclusiveness still applies to the payment of a tariff and that electricity generated from mixed industrial and municipal waste will not be remunerated in the future either.”

The EVG’s Fermentation Stage

In recent years, the general ecological conditions for anaerobic technologies have improved decisively due to technological developments and the Renewable Energy Sources Act [EEG] (TURK et al., 2008).

In Rostock, a partial flow fermentation facility and a CHP station were added to the existing MBT plant. This enabled an increase of its input capacity from 120,000 t/a to 135,000 t/a. Reserves for seasonal fluctuation and additional processing options for organic waste are set up. The fermentation stage is aimed at recovering the energy of biogenic mass. Therefore, half of the biomass which used to be fed into the intensive decomposition reactors is now treated in the fermentation facility.

The generated biogas is then used by a gas engine-operated CHP station to produce electricity and heat. The electricity generated in the CHP plant (12,000 MWh/a) is fed into the grid. The residual heat is used for preheating and drying on the site. The fermentation stage reduces the effort for exhaust air cleaning in the following rotting process.

The EVG’s MBT plant in Mecklenburg-Western Pomerania is the first to use municipal waste for biomass fermentation and to recover energy in this environmentally friendly way. In combination with the RDF-fired thermal power station, which is operated by the Vattenfall Europe New Energy GmbH, a comprehensive energy recovery is achieved through fermentation at Rostock-Überseehafen. Even the plant’s exhaust air, which so far had to be cleaned and burnt using regenerative thermal oxidation, will soon be burnt together with the refuse derived fuels produced on site. The proximity of MBT plant and thermal recovery adds further ecological and economical advantages.

The investment volume for the fermentation facility was 8 million euros. This investment formed the basis for stable costs and reliable waste disposal.

In this way, the EVG covers its own energy consumption and additionally feeds 3,700 MWh/a into the public grid. The waste heat of the CHP stations is used to heat the fermenters and adjoining building parts. The complete use of the thermal energy is covered by a contract starting in 2009.

Fermentation residues are carried off via a combined wet/dry-discharge to the rot.

The Fermentation Unit - KOMPOGAS Dry Fermentation

Existing aggregates like screens, shredders and magnetic separators can be used for the preparation of the material. They crush the delivered material, free it from magnetic matter and screen it down to a particle size of less than approx. 60 mm. The screened material is fed into the catch bin. Oversize material can be crushed again or be fed into another recycling line (e.g. RDF...). The treatment is supposed to only crush material if necessary. If possible, leftovers from meals, biowaste etc. should exclusively be screened in order to maintain the actual material structure.

The basic principle always remains the same: the horizontal plug-flow fermenter that guarantees a very high energy efficiency and maximum reliability of operation. It can be fitted into MBT and composting plants as a standardised module construction (ZEIFANG, 2008).

The process temperature is 55°C (131°F), i.e. within the thermophilic range. Waste heat from the CHP station delivers the heat required for the treatment.

The digested material is pressed for further conditioning and thus separated into a liquid fraction (re-circulated material) and a solid fraction (raw compost). In most cases, the re-circulated material is used for mashing the new material so that no supplementary extern liquids are required.

The continuous mode of operation enables a stable generation of biogas (Universität Rostock et al., 2007).

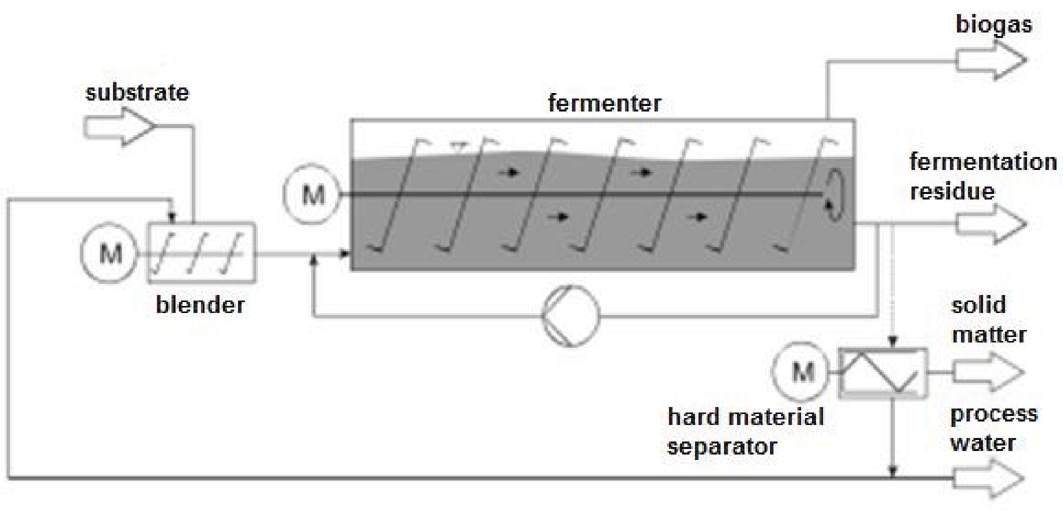

Figure 3: Continuous dry fermentation with plug-flow fermenter (KOMPOGAS) (Gülzower Fachgespräche, 2006)

Benefits of the Retrofitting of the MBT plant Rostock

Provisional calculations indicate today already that the retrofitting creates an ecological benefit for the Hanseatic city of Rostock (EVERS, 2008).

The EVG's CHP station will have produced approximately 8 million cubic metres of biogas by the year 2008. With a methane content of 58%, a calorific value of approx. 46 GWh can be expected. This energy will be used to generate 11 GWh electricity (net) and 25 GWh waste heat for auxiliary cooling or respectively district heating.

This reduces carbon emissions as follows:

- electricity: 6.8 Gg related to the electricity mix of Germany
- district heat: 5.5 Gg related to natural gas heating or 2.3 Gg related to CHP district heating from natural gas (fossil methane).

With a maximum output (currently 810 Gg p.a.) a reduction of the overall emissions of Rostock by 12.3 Gg, i.e. approx. 1.5%, can be achieved.

The dynamic climate alliance objective of Rostock intends a reduction of carbon emissions by 2% p.a..

The generated electricity is sufficient for illuminating the city of Rostock; 10 to 11 GWh of electricity are needed for city lighting per year.

According to the framework concept "climate protection", each citizen of Rostock uses 0.75 MWh of electricity at home per year. In theory, approximately 14,500 inhabitants of Rostock could cover their yearly consumption of household electricity with carbon-free power by the EVG. This for example equals the number of inhabitants of the Südstadt district.

Bibliography:

Doedens, Heiko; Gallenkemper, Bernhard; Ketelsen, Ketel; Kranert, Martin; Fricke, Klaus: **Status der MBA in Deutschland**; Müll und Abfall; ISSN: 0027-2957; y.: 39, no. 12, 2007, pages 576-579

Gesetz für den Vorrang Erneuerbarer Energien (Erneuerbare-Energien-Gesetz - EEG); Ausfertigungsdatum: 25.10.2008; BGBl. I 2074 pages [English version: http://www.erneuerbare-energien.de/inhalt/42934]

Evers, Klaus: written information; Amt für Umweltschutz der Stadt Rostock [Rostock Office for Environmental Protection]; 24 September 2008

Gülzower Fachgespräche, Volume 24: Trockenfermentation – Stand der Entwicklungen und weiterer F+E-Bedarf; 4/5 February 2006 in Gülzow; Published by Fachagentur Nachwachsende Rohstoffe e. V. (FNR), 2006; 143 pages

SRU - Sachverständigenrat für Umweltfragen: UMWELTGUTACHTEN 2008, Umweltschutz im Zeichen des Klimawandels; Juni 2008, 1077 pages;

http://www.umweltrat.de/02gutach/downlo02/umweltg/UG_2008.pdf; 2.10.2008 [English version: http://www.umweltrat.de/english/edownloa/envirrep/UG_2008_summary.pdf]

Thomé-Kozmiensky, Karl J.; Thiel, S.: Die Mechanisch(-biologisch)e Abfallbehandlung hat ihre prinzipielle Funktionsfähigkeit nachgewiesen; Müllmagazin 1/2008, pages 4 – 12

Tischer, Christoph; Gaßner, Hartmut: **EEG-konformes Biogas aus Hausmüllverwertung;** Müll und Abfall, 38, no. 5, pages 228-230, 2006

Troge, Andreas: Der Beitrag der Abfallwirtschaft zum Klimaschutz; Müll und Abfall, 39, no. 5, 2007; pages 208-213

Turk, Thomas; Tobias Bahr, Klaus Fricke, Jürgen Hake: Nachrüstung von MBA durch Vorschaltung von Vergärungsanlagen; 20. Kasseler Abfallforum; pages 606 – 616; Witzenhausen-Institut GmbH; 2008

Universität Rostock, Lehrstuhl für Verfahrenstechnik / Biotechnologie in Kooperation mit Institut für Energetik und Umwelt gGmbH und der Bundesforschungsanstalt für Landwirtschaft: **Erhebung der mit Trockenfermentationsverfahren erschließbaren energetischen Potenziale in Deutschland Vergleichende ökonomische und ökologische Analyse landwirtschaftlicher Trockenfermentationsanlagen;** Abschnitt 2 des Schlussbericht zum Forschungsvorhaben „Biogaserzeugung durch Trockenvergärung von organischen Rückständen, Nebenprodukten und Abfällen aus der Landwirtschaft"; 2007, 124 pages; http://www.fnr-server.de/ftp/pdf/literatur/TV/Abschnitt2-IE.pdf; 2 October 2008

Zeifang, Markus: KOMPOGAS: hoch effizient und bewährt; 20. Kasseler Abfallforum; pages 369 – 374; Witzenhausen-Institut GmbH; 2008

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Modernization of a Swiss MBT-plant with the SCHUBIO®-Process

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Abstract

The only operating mechanical-biological Swiss treatment plant for municipal solid waste (MSW) and biowaste (KBA Hard) will be modernized and the SCHUBIO®-Process will be implemented for the first time on industrial scale. The project and the characteristics of the innovative process are presented in this paper. It is shown, that all output fractions from MSW as well as from biowaste are completely recyclable.

Keywords

SCHUBIO®-Process, Municipal Solid Waste, Biowaste, washing process, Schaffhausen, KBA Hard

1 Introduction

The SCHUBIO®-Process has been developed with a background of long-time experience from mechanical-biological waste management. The process is based on the WABIO-Process and related wet fermentation technologies as shown in Figure 1.

For the first time fermentation of municipal solid waste has been implemented in 1989 in Vaasa, Finland on industrial scale with the WABIO-Process.

The company Deutsche Babcock Anlagen (DBA) took over the WABIO-Process and erected in Bottrop, Germany the first fermentation plant for biowaste. After DBA merged with the company Steinmüller in 1999, the DBA-WABIO-Process was abandoned.

Since then EcoEnergy has developed and brought to the market a washing process based on the concept for mechanical treatment from the DBA-WABIO-Process. The SCHUBIO®-Process, formerly called NMT-Process, has been taken over by the company SCHU AG Schaffhauser Umwelttechnik in 2008.

Startup for the first plant on industrial scale is planned for 2010 in Schaffhausen, Switzerland.

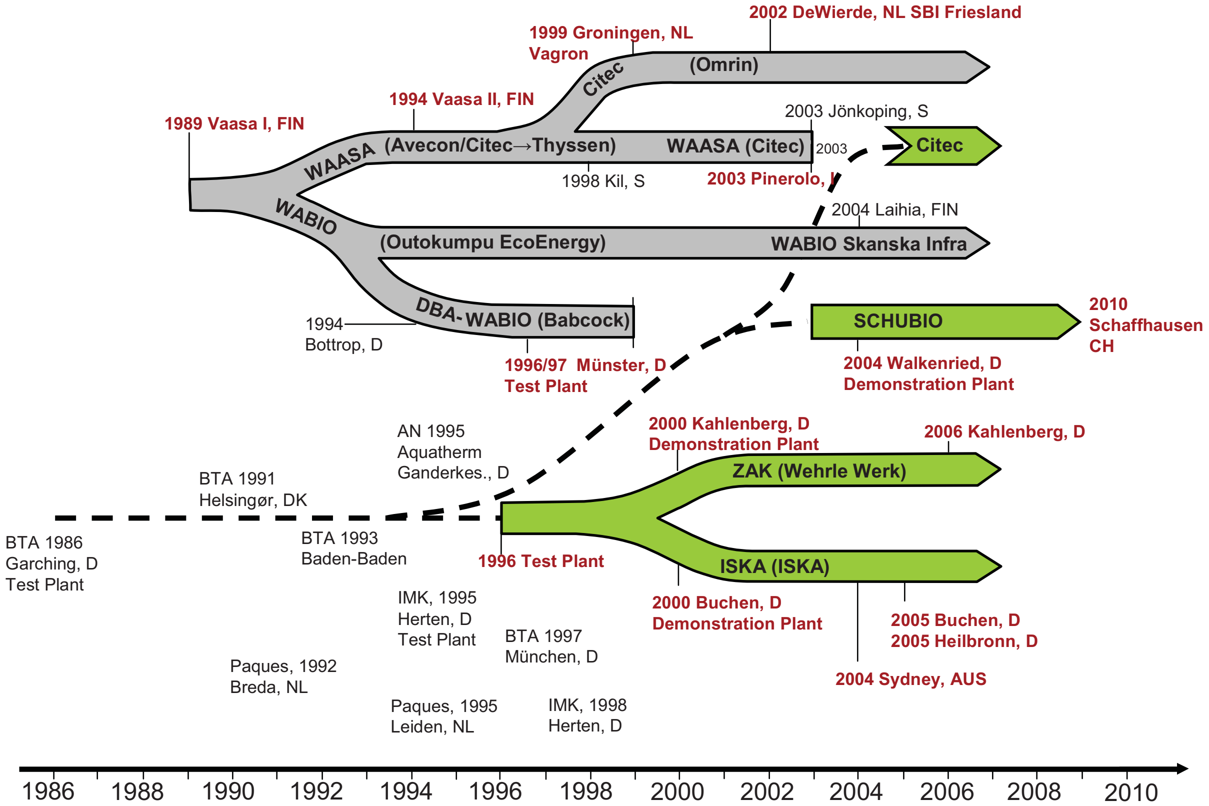

Figure 1: Development of Wash- and Percolation Technologies

The SCHUBIO®-Demonstration Plant is in operation since 2004 and has been operated with different input material. The Demonstration Plant was built with help from a grant by Deutsche Bundesstiftung Umwelt (DBU) (Table 1) and is still in operation.

Table 1: Development SCHUBIO®-Process

Year	**Development SCHUBIO-Process**
2000	Grant application to DBU
2004	Erection of Demonstration Plant and test runs in AWZ Wiefels, Germany
2005 - 2007	Pilot phase of the process at the EcoEnergy site in Walkenried, Germany
2008	Dimensioning tests, KBA Hard, Switzerland Take over of the process by SCHU AG Schaffhauser Umwelttechnik
2009	Planned start of construction Modernization KBA Hard, Switzerland

The Demonstration Plant is housed in a container and can be moved easily to different sites. Consequently, the design of the new KBA Hard could be verified by tests on site with the original input material (see Figure 2).

Figure 2: Different locations of the SCHUBIO®-Demonstration Plant

2 The SCHUBIO®-Process

The SCHUBIO®-Process can be applied for treatment of municipal solid waste as well as biowaste. First the material is pretreated by shredding and sieving at 100 mm as is common practice for MBT-technologies. The coarse fraction is baled and can be used for energy recovery. The fine fraction < 50 mm and 50 – 100 mm respectively is separated into inert fractions, organics fractions and a fluid fraction, containing dissolved matter, fine inert particles < 100 µm and organics < 1 mm. Water, heated to 40 °C, is used as separation agent and circulated in the process. Viscosity of the water is decreased by heating. Consequently the separation effect as well as efficiency of the dewatering is increasing.

The entire process yields surplus water even with municipal solid waste (MSW). The water retention potential of inert matter is minimal. Thus the inert fraction can be dewatered, down to a residual water content of < 5 %. The organic fraction can be dewatered to < 40 % water content due to several combined treatment steps. The separation of inert matter and the separation into fractions with different particle size are preconditions for the thermo-mechanical celllysis. The celllysis is causing the organic fibers to fray and separate, thus breaking down the cell walls so that cell water is released.

The inert fractions are rinsed, first with fresh water then with circulated water, and can be recycled as building material. If required further treatment in a demolition waste recycling plant yield even better quality. The following products are obtained from the waste:

- stones - gravel - sand - fine sand - silt.

The organic fractions are dewatered by screw presses after sieving. Dewatering includes also the cell water due to the thermo-mechanical celllysis as described above. Furthermore, the soluble, easily fermented biomass is transferred into the press water. Figure 3 shows the process flow diagram of the SCHUBIO®-Process for the KBA Hard with MSW and biowaste.

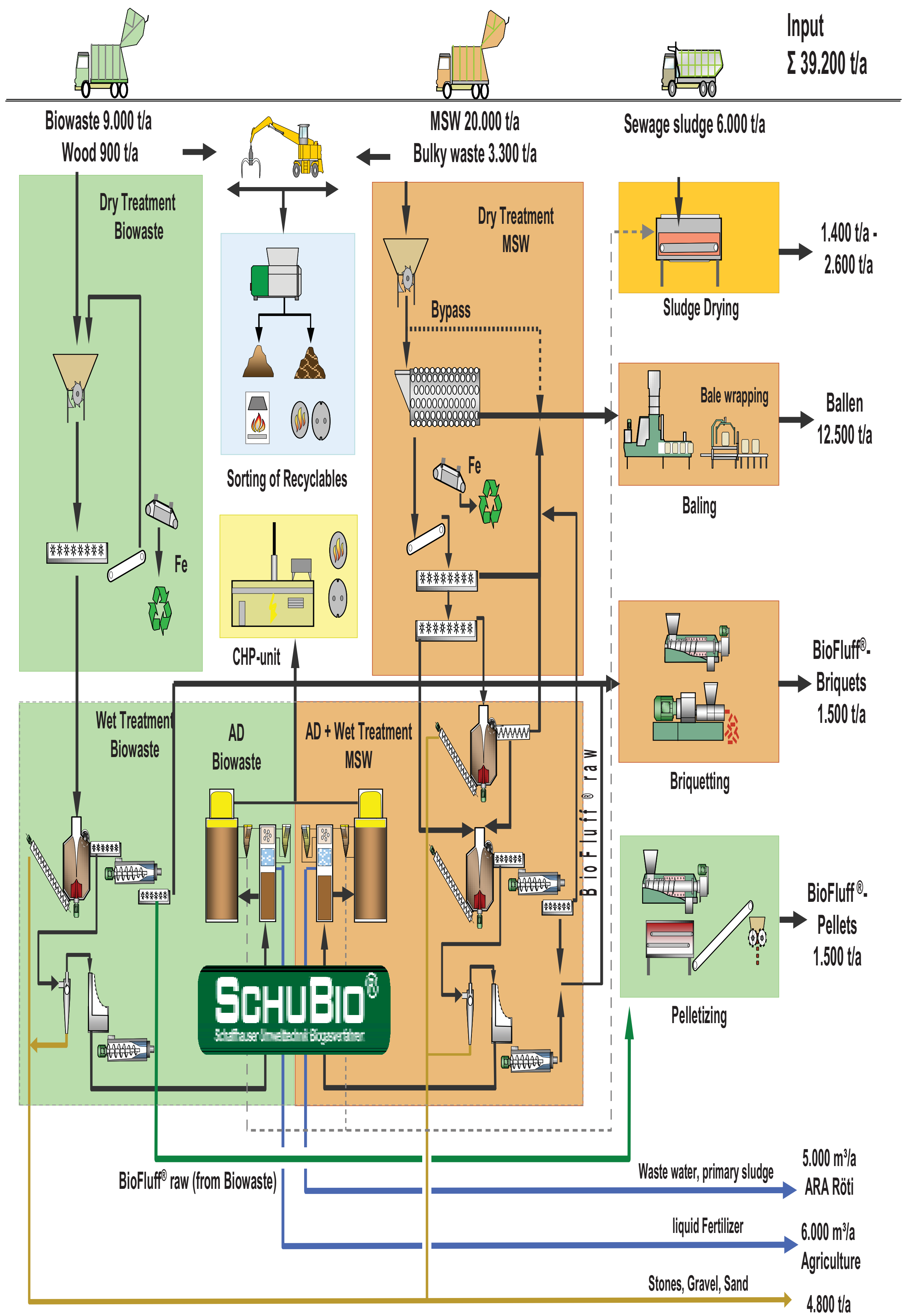

Figure 3: Process Flow Diagram KBA Hard with SCHUBIO®-Process

The pollutant content of the organic fractions (BioFluff®) is low, due to the process concept. The material contains also little chlorine because of the separation of plastics. Chlorine is present only as a soluble salt on a so called “background level”. The dewatering is achieved mechanically and not by drying so that all soluble pollutants are flushed out with the wash water and press water. Depending on the water cycle concept, 50 % to 90 % of pollutants are discharged, improving the quality of the BioFluff®.

Pressing of the organic fractions 2 and 3 is done at a temperature of > 70 °C for improving efficiency. Part of the heating energy comes from steam, produced with waste heat from the CHP- units and also from the press energy.

The Biomass has to be dried further for pelletizing. After drying the biomass is sieved at 15 mm and the still remaining plastics are discharged in the coarse fraction.

The fine fraction consists of nearly 100 % native biomass, the BioFluff®. The dried and sieved BioFluff® is conditioned according to the required recycling pathway. BioFluff® is a low polluted, dry stabilized biomass and is a versatile secondary raw material. The BioFluff® from MSW will be pressed to briquettes and used for thermal utilization.

In the SCHUBIO®-Process the easily biodegradable matter is transferred to the circulation water. The water contains organic matter up to a particle size of < 1 mm and is fed into an anaerobic digestion tank with biomass retention.

The chemical oxygen demand (COD)-degradation depends on the anaerobically degradable COD and reaches 85 % to 95 % degradation. Retention time is 5 to 10 days. Conventional biogas plants have a retention time of 18 to 21 days. The biogas is used to operate a CHP-unit. The generated power is fed onto the grid and the waste heat is used for drying sewage sludge and biomass from biowaste before pelletizing.

After digestion the waste water from the anaerobic digestion tank is treated in an aerobic reactor with biomass retention. The cleaned water is then reused as wash water for the SCHUBIO®-Process or discharged to a waste water treatment plant. The residual sludge form the anaerobic and aerobic process stage is the pollutant sink of the process.

3 Project Description

The MBT-plant KBA Hard in Beringen, Switzerland, has been built 35 years ago. The plant has been converted from a waste incineration plant and has been in operation as a MBT-plant for 20 years now. At the time the implemented composting technology was considered most innovative and has been known by the term “Schaffhauser Modell”.

Currently about 18.000 t/a MSW, 6.000 t/a Biowaste and about 6.000 t/a sewage sludge as well as 3.000 t/a bulky waste are treated in the plant.

At present, solids (MSW and industrial waste) are shreddered and sieved, yielding a dry, coarse fraction with high heating value and a wet fine fraction with lower heating value. The coarse fraction is baled and the bales are incinerated in the waste incineration plant KVA Buchs, either immediately or after intermediate storage at the KBA Hard site. The fine fraction is mixed with sewage sludge and composted in the rotting hall. After composting, the material is dried, stabilized and mass reduced and is likewise incinerated in the KVA Buchs. Biowaste is mechanically treated and composted separately.

The equipment has reached the end of its technical lifetime and must be replaced. Moreover, the new waste treatment technology should meet the requirements of better energy efficiency and preservation of resources.

The operating municipality, Kläranlageverband Schaffhausen, Neuhausen am Rheinfall, Feuerthalen und Flurlingen has therefore decided to modernize the KBA Hard by implementing the SCHUBIO®-Process. In the following figures the planned layout of the KBA Hard is shown:

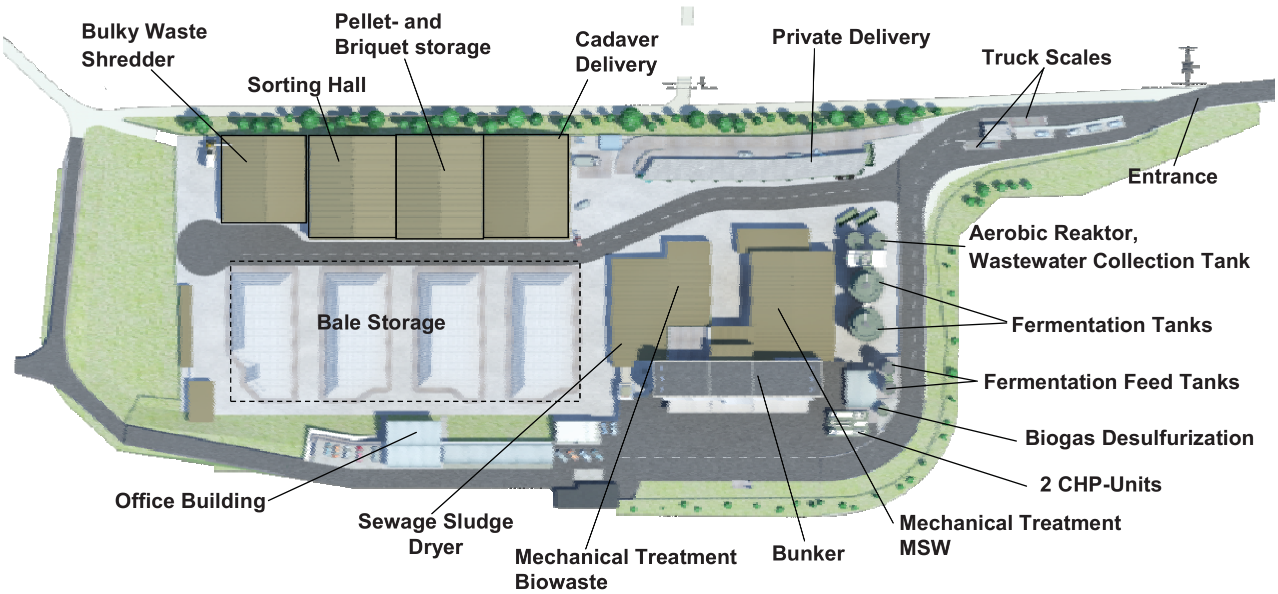

Figure 4: Modernization KBA Hard Top rview

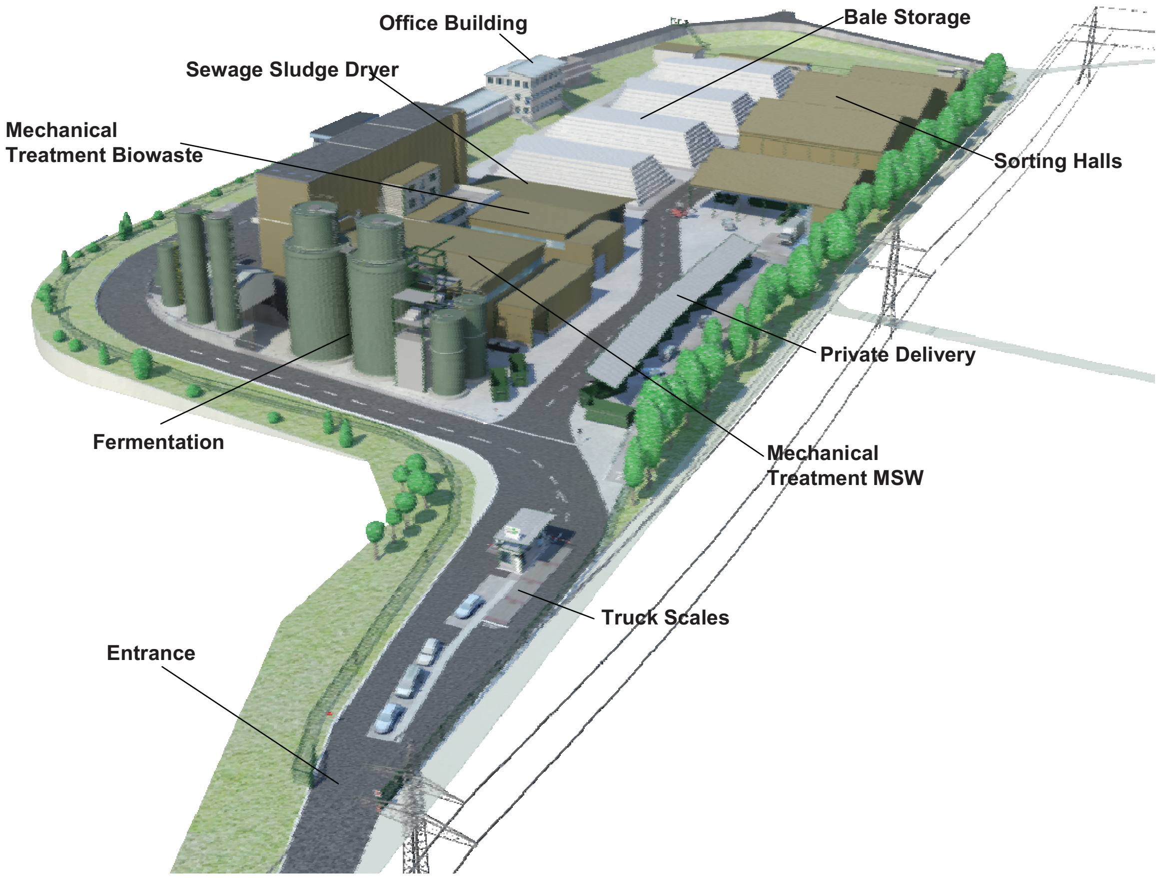

Figure 5: Modernization KBA Hard Overview

The new plant equipment will fit into the existing operation building. Only the fermentation tanks are located outside, as well as the two 450 kW CHP-units. The present rotting hall will be dismantled and the area will be used for bale storage. The logistics for private delivery will be improved and the shredder for bulky waste will be moved to an enclosed hall. The total investment is about 30 Million Swiss francs.

4 Sustainable Waste Separation

Explicit goal of the SCHUBIO®-Process is a complete recycling of the waste wherever possible. In the following we establish the recycling properties of the produced materials.

4.1 Biomass

4.1.1 Biomass from Biowaste

The organic fractions from biowaste are less polluted than most conventionally produced compost materials and meet the regulations for distribution of compost easily.

The following Table 2 shows the heavy metal content of the organic fractions (O1 ,O2, O3) compared to the input (Biowaste < 50 mm) and to the compost from the present KBA Hard as well as to the average of Swiss compost approved for horticulture. The data are also compared with the German and Swiss regulations for compost use.

A significant decrease of heavy metals is evident in the organic fractions. Exception is the chromium and nickel content of the fine fraction (O3) which is an artifact resulting from the test conditions. The phenomenon is common for demonstration plants, constructed from chromium nickel steel. Fine steel particles from abrasion and modification of the plant end up in the fine fractions.

Table 2: Heavy metals in the organic fractions from biowaste compared to biowaste-input and KBA Hard compost (average)

Parameter (mg/kg DM)	Bio-waste < 50	Bio O 1	Bio O 2	Bio O 3	Compost KBA Hard	Swiss Compost Hort.	Stoff-VO (CH)	Bio-AbfVO (D)
Lead (Pb)	21,0	16,0	11,6	15,8	47,5	69,7	120	150
Cadmium (Cd)	n.d.*	n.d.*	n.d.*	n.d.*	0,2	0,1	1	1,5
Chromium (Cr)	13,5	14,5	12,5	45,5	23,2	20,0	100	100
Copper (Cu)	30,5	18,0	9,5	17,3	56,8	58,4	100	100
Nickel (Ni)	9,5	8,5	6,3	22,8	16,3	15,8	30	50
Zinc (Zn)	94,5	57,0	95,0	94,0	215,3	155,4	400	400
Mercury (Hg)	0,1	n.d.**	n.d.**	n.d.**	0,1	n.d.	1	1

* Detection Limit 0,4 mg/kg DM ** Detection Limit 0,1 mg/kg DM

Already in 2000 the German Federal Environmental Agency (UBA) has proposed gradual limit values for fertilizers in soil with the objective to avoid long-term pollutant accumulation in the soil (UBA, 2002). Comparison shows that the organic fractions (O1, O2,-O3) meet even these soil-adapted limit values.

Table 3: Heavy metals in the organic fractions from biowaste compared to KBA Hard compost (average) and soil-adapted limit values

Parameter (mg/kg DM)	Bio-waste < 50	Bio O 1	Bio O 2	Bio O 3	Compost KBA Hard	Proposal UBA 2000		
						Clay	Loam	Sand
Lead (Pb)	21	16	11,6	15,8	47,5	71,75	50,45	29,15
Cadmium (Cd)	n.d.*	n.d.*	n.d.*	n.d.*	0,2	1,09	0,73	0,31
Chromium (Cr)	13,5	14,5	12,5	45,5	23,2	71,34	42,94	21,64
Copper (Cu)	30,5	18	9,5	17,3	56,8	46,72	32,52	18,32
Nickel (Ni)	9,5	8,5	6,3	22,8	16,3	50,62	36,42	11,57
Zinc (Zn)	94,5	57	95	94	215,3	173,71	138,21	74,31
Mercury (Hg)	0,1	n.d.**	n.d.**	n.d.**	0,1	0,72	0,37	0,08

* Detection Limit 0,4 mg/kg DM ** Detection Limit 0,1 mg/kg DM

The organics fractions (biomass) 2 and 3 are dispensed in the Schaffhausen region as peat substitute to hobby gardeners and nurseries. The organics 1 fraction will be used as biomass fuel.

4.1.2 Biomass from MSW

The biomass fractions from MSW (O 2 and O 3) show also a significant decrease of pollutants and meet the limit values for compost as well.

The following tableTable 4 shows the heavy metal content of the organic fractions compared to the input (MSW < 50 mm) and to the compost from the present KBA Hard as well as to the average of Swiss compost approved for horticulture. The data are also compared with the German and Swiss regulations.

Table 4: Heavy metals in the organic fractions from MSW compared to MSW-input and KBA Hard compost (average)

Parameter (mg/kg DM)	MSW Input < 50	MSW O 2	MSW O 3	Compost KBA Hard	Swiss Compost Hort.	Stoff-VO (CH)	Bio-AbfVO (D)
Lead (Pb)	190,0	62,8	57,0	47,5	69,7	120	150
Cadmium (Cd)	n.d.*	n.d.*	n.d.*	0,2	0,1	1	1,5
Chromium (Cr)	38,0	46,8	36,0	23,2	20,0	100	100
Copper (Cu)	111,0	75,9	45,5	56,8	58,4	100	100
Nickel (Ni)	24,5	19,0	17,5	16,3	15,8	30	50
Zinc (Zn)	400,0	227,5	130,5	215,3	155,4	400	400
Mercury (Hg)	0,4	0,1	0,2	0,1	n.d.	1	1

*Detection Limit 0,4 mg/kg DM

Nevertheless, application of the organic fractions from MSW in agriculture is still excluded because of the origin from MSW. For the current project the material will be used as low polluted fuel in cement kilns. The required fuel criteria in the cement industry are comparable with criteria for co-combustion in a coal fired power plant.

To evaluate the properties of the organic fractions from the SCHUBIO®-Process the following tableTable 5 shows the requirements for RDF (formulated by the German "Bundesgütegemeinschaft Sekundärbrennstoffe" (BGS) and the requirements of a coal fired power plant for co-combustion of RDF in comparison with the organic fractions.

Table 5: Heavy metal content of organic fraction from the SCHUBIO®-Process compared to RDF requirements from BGS and a coal fired power plant

Parameter in mg/kg DM	BGS	Coal power plant	MSW-O 1	MSW-O 2	MSW-O 3	Bio O 1	Bio O 2	Bio O 3
Arsenic (As)	5	5	n.d.*	n.d.	n.d.	n.d.	n.d.	n.d.
Lead (Pb)	190	70	84	61,3	58,8	16	13,3	16,2
Cadmium (Cd)	4	0,4	9,0	n.d.	n.d.	n.d.	n.d.	n.d.
Chromium (Cr)	125	125	94,5	39	36,3	14,5	13,2	45,3
Copper (Cu)	350	120	41,5	94,6	45,7	18	9	16,7
Nickel (Ni)	80	80	31,5	21,7	17,5	8,5	6,4	22,5
Mercury (Hg)	0,6	0,6	6,3	0,14	0,2	n.d.	n.d.	n.d.
Antimony (Sb)	25	25	-	140	n.d.	n.d.	n.d.	n.d.
Tin (Sn)	30	60	23	24	28	n.d.	n.d.	n.d.
Thallium (Tl)	1	1	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Cobalt (Co)	6	6	3	n.d.	n.d.	n.d.	n.d.	n.d.
Manganese (Mn)	250	250	108,5	90	110	185	97	155
Vanadium (V)	10	25	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

*n. d. = not detected

The plastics content in the material correlates with the heavy metal content and is increasing with particle size of the fraction. Sieving of the organics 2 fraction from MSW (MSW O2) yields a low-polluted fine fraction, while the plastics are enriched in the coarse fraction as is shown in tableTable 6 as a result from a sieving test at 20 mm. The fine fraction < 20 mm and the fine fraction O 3 meet the requirements for co-combustion in a coal fired power plant.

Reduction of heavy metal pollution is evident. Antimony is even reduced by a factor 20. Chromium, Copper and Cadmium are also reduced significantly. With less plastic, the chlorine content is also lower.

Table 6: Sieving of fraction Organics 2 from MSW at 20 mm

Parameter	MSW O 2 >20 mm	MSW O 2 <20 mm	MSW O 3
Lead (Pb) mg/kg DM	73,9	91,4	92,7
Chromium (Cr) mg/kg DM	128,4	78,2	100,4
Copper (Cu) mg/kg DM	249,9	68,8	85,5
Nickel (Ni) mg/kg DM	78	52,2	74
Tin (Sn) mg/kg DM	80,8	88,8	61,5
Manganese (Mn) mg/kg DM	205,9	189,7	259,1
Cadmium (Cd) mg/kg DM	5,3	1,4	0,1
Mercury (Hg) mg/kg DM	n.d.	n.d.	n.d.
Antimony (Sb) mg/kg DM	293	12,9	1,1
Chlorine in % DM	1,45%	1,00%	0,38%
Heating value Hu in kJ/kg	23.587	19.626	14.616

Chlorine content is another important parameter for the properties of RDF. By separating plastics, particularly the chlorine carrier PVC and by reducing the salt content through washing we can achieve low chlorine pollution. Even co-combustion in a coal fired power plant is possible. The plastics accumulate in the fraction organics 1 (O1) with corresponding higher chlorine content (see Figure 6).

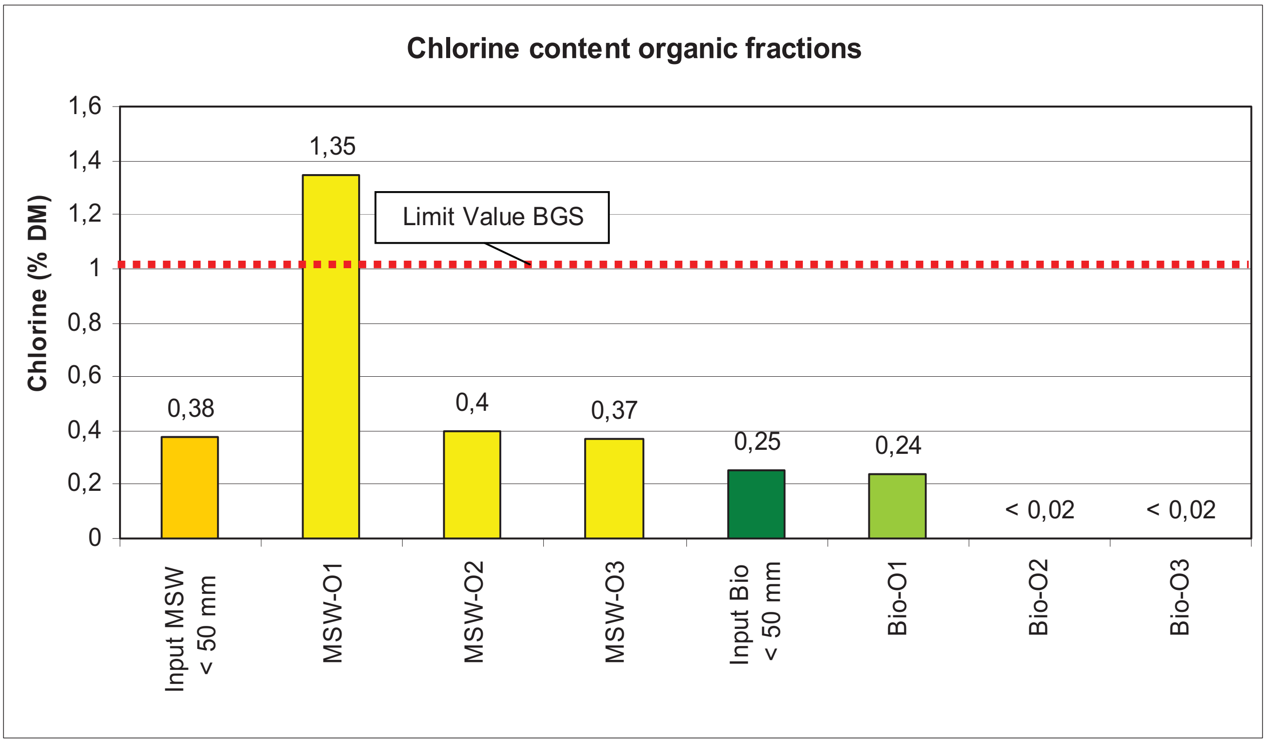

Figure 6: Chlorine content of the organic fractions from MSW and Biowaste

4.2 Biogas

The liquid phase contains the anaerobically digestible organics and is used for biogas production. Compared to anaerobic digestion processing the complete waste stream, the SCHUBIO® -Process reaches a biogas energy yield of 75 % to 85 %.

Table 7: Comparison of biogas yield of different AD processes for Biowaste and MSW

Material / Process	Nm³ Biogas / t Input	Nm³ Methane / t Input
Green waste, Biowaste		
SCHUBIO®	85 - 110	55 - 77
Kompogas - guaranteed	115	63
Kompogas – real value	125	72-80
Dranco - guaranteed	140	77
Dranco- real value	157	90
Strabag - guaranteed	115	n. s.
Strabag- real value	100 - 135	55 - 81
Bekon - real value	87	48
MSW, Household waste		
SCHUBIO®	75 - 90	49 - 63
Dry anaerobic digestion		
Valorga - real value Hannover Input < 60 mm	100	55 - 60
Dranco - real value Bassum Input < 40 mm	130	72 - 78
Wet anaerobic digestion		
Schaumburg - real value	60	39 - 45
Lübeck - design	100	n. s.
Percolation		
ISKA - real value Buchen, Heilbronn	40 - 60	26 - 45
ZAK - real value Kaiserslautern	50 - 60	33 - 45

Biogas is processed in two CHP-units with 450 kW each. The waste heat is used as process heat for the thermo-mechanical-celllysis as well as for drying the sewage sludge, sludge from the digestion tanks and the fine silt fraction from the process. The final dry matter content is 65 % to 85 %, depending on the amount of waste heat, so that the waste heat is completely used at all times.

4.3 Waste water

The waste water from AD still contains a considerable amount of nitrogen. Nitrogen from the waste water from MSW and biowaste is recovered by using a multistep chemical scrubber. The product is an ammonia-sulfate-fertilizer. The exhaust from the sludge dryer contains also nitrogen and passes the scrubber where the nitrogen is recovered.

A part of the pre-cleaned waste water is reused in the process. The excess, pre-cleaned water is treated in the municipal waste water treatment plant.

The water consumption of the SCHUBIO®-process is low, due to the high mechanical dewatering and due to the reuse of water in the process (see Figure 3).

4.4 Dried sewage sludge

The sewage sludge and the excess sludge from AD contains several important fertilizer components such as phosphorus but also Mg, K and Ca. Part of the nitrogen is driven out in the dryer, but some N is still left.

The dried sludge is incinerated in a Sewage sludge incineration plant. It is planned to recover heavy metals from the ashes, integrated into the existing fly ash washing, by reheating and evaporating the heavy metals (Schu and Seiler, 2008). The remaining ashes are then very low polluted and can be used as fertilizers. Phosphate is then recovered not only from biowaste and sewage sludge but also from MSW.

Phosphate recovery is significant because saving resources becomes increasingly important.

4.5 Inert matter

The SCHUBIO®-process produces different inert fractions, separated after grain size. These fractions are either already suitable for recycling or will be recyclable with mechanical aftertreatment. Since the market for recycling material from MSW is not established yet, the inert fractions stones, gravel and sand will be landfilled for the present. The fine silt fraction < 100 μm is more polluted because of the unfavorable weight-surface ratio. This fraction is collected separately and dried together with the sewage sludge.

5 Not recyclable fractions

All output materials described above are nearly completely recyclable. Even the polluted surplus sludge and the fine silt fraction, designed as pollutant sink of the process, can be partly recycled as material.

Only the coarse fraction from mechanical pretreatment and the fraction organics 1 are not recyclable. These fractions consist mostly of plastics. They are baled and incinerated in a waste incineration plant.

There is currently no sustainable solution for material recycling of mixed plastic in sight. Because of the high pollution level the material can only be incinerated in a waste incineration plant.

One of the main purposes of the SCHUBIO®-Process is the separation of plastics from biomass, to ensure the usability of the biomass fractions. Several process steps are important for this purpose:

1. Selective shredding and separation of a plastics-enriched coarse fraction by sieving at 100 mm.

2. The biomass from the fraction 50 – 100 mm is concentrated in the fraction < 50 mm by washing and pressing. The fraction > 50 mm contains the plastics.

3. In the fraction < 50 mm, the biomass is ground to a particle size of < 10 mm by washing and pressing at high temperature. By sieving at 10 mm, the coarse fraction with plastics is separated from the biomass fraction.

The separated biomass fractions are low polluted and can be used as substitute fuel in biomass incineration plants, coal fired power plants and cement kilns or used in agriculture as peat substitute.

The depletion of pollutants in the biomass fraction by sieving as described in chapter 4.1 causes in reverse increased pollution in the plastics enriched coarse fraction. This coarse fraction is therefore similarly difficult to recycle as the other plastics enriched fractions. The problems with the disposal of plastics with regard to their pollution level are described in a separate publication by Reinhard Schu.

6 Literature

Kupper et al.	2007	Organische Schadstoffe in Kompost und Gärgut. Hrsg.: BAFU, Schweiz
Schu, R. und Seiler, U.	2008	HOK- und reststofffreie Abgasreinigung im Jahr 2013. In „Energie aus Abfall“, Band 4, Hrsg.: K. J. Thomé-Kozmiensky, M. Beckmann, TK Verlag, Neuruppin
Umweltbundesamt (UBA)	2002	Zur einheitlichen Ableitung von Schwermetallgrenzwerten bei Düngemitteln. 31.07.2002, UBA.

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Simplified Treatment of Municipal Solid Waste

by Adjustment of Percolation

BIOLEACHATE° Process

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Abstract

Mechanical and biological treatment has become established as a concept for handling municipal solid waste. The biological process aims to degrade the organic fraction of the waste to a stabilized product through fermentation and rotting processes. The organic fraction and water are the main sources of emissions on landfills. Therefore waste treatment is especially focused on the wet organic fraction. There is a direct relationship of organic waste and water content through biological degradation and dewatering of solid waste. Most of the MBT-systems have been developed and installed in countries with a sanitary management of municipal solid waste which is financed by public fees or waste charges. When applied in developing and emerging countries these technologies initially have to be adjusted technically for a different composition of solid waste firstly. Secondly the limited budget for treatment of municipal solid waste requires to a cost-effective facility process. As a result for this application the approved system of percolation is adjusted to the simplified treatment, BIOLEACHATE° process.

Inhaltsangabe

Die mechanische und biologische Abfallbehandlung hat sich als ein Konzept zur Aufbereitung von Siedlungsabfällen aus Haushalten und Gewerbe etabliert. Dabei steht die biologische Behandlung im Zentrum der Aufbereitung. Die biologische Umsetzung zielt auf den Abbau durch Vergärung und Rotte, um den biogenen Abfallanteil zu reduzieren und ein stabilisiertes Endprodukt zu erzeugen. Durch Abbau und Entwässerung entsteht ein vergleichsweise hoch belastetes Prozess- und Abwasser, das einer Reinigung zu unterziehen ist. Die meisten MBA-Systeme sind in Ländern mit relativ geordnetem Abfallmanagement entwickelt und installiert worden. Bei Anwendung der Technologien in den Schwellenländern müssen erstens diese technisch der andersartigen Abfallzusammensetzung angepasst werden. Zweitens sind kostenreduzierte Behandlungsmethoden gefragt. Das bewährte Perkolationssystem wurde deshalb zu dem vereinfachten Verfahren *BIOLEACHATE°* modifiziert.

Keywords

anaerobic digestion, biodegradation, biogas, dewatering, leaching, mechanical-biological treatment, percolation, process water treatment, reduction of pollutants, waste water treatment

1 Mechanical and Biological Treatment of Mixed Municipal Solid Waste

1.1 Introduction

Throughout the world the treatment and utilisation of municipal solid waste based on economic and ecological aspects is gaining increasing importance. With reference to the global problem of preserving natural resources and promoting environmental protection waste management is concerned with the following central ideas:

- **Conservation and management of natural resources**
- **Waste avoidance** (quantity and toxicity)
- **Waste reuse and recovery** (materials, energy)
- **Safe disposal** (landfilling, incineration).

In most countries, industrial and household solid waste are disposed at dumpsites. Landfill disposal, in particular of waste containing organic fractions, is producing significant emissions (outgasing of odours and methane, release of leachate). For this reason, there are specific requirements concerning the location and the operational management of landfill sites. European regulations require a pre-treatment and especially the reduction of organic fraction before disposal on a dumpsite (EC Landfill Directive 1999):

- **Waste recovery of recyclable fraction**
- **Biological treatment of biodegradable solid waste**:

  recovery of organic fraction (composting)

  production of biogas (anaerobic digestion)

  reduction of the mass of biological degradable solid waste

1.2 Development of Percolation

In 1997 WEHRLE-WERK AG, Emmendingen, a medium-sized company in Germany which is working in the field of energy and environmental technologies bought the licence for percolation of municipal solid waste. At this time I was responsible for research and development of this idea to technical scale. From 1997–1999 a pilot plant (BIOPERCOLAT®) was continuously been operated at ZAK Kahlenberg dumpsite, Germany. In 1999 as a result of its successful development Kahlenberg gave the order to build a plant designed for a throughput of 18,000 t/y mixed solid waste. The technical plant operated from 2000 to 2003 during this period biological drying of residual waste and mechanical separation were added to ZAK process. This technical plant achieved proved and reliable results with respect to technology and economics. In 2004 ZAK Kahlenberg decided to build a plant designed for a throughput of 100,000 t/y. This plant was commissioned in March 2006 and the waste treatment is operating at a steady state for more than two years. The ZAK process is definitely one of the most innovative mechanical-biological waste treatment for municipal solid waste with an advantageous combination of aerobic processing and anaerobic digestion.

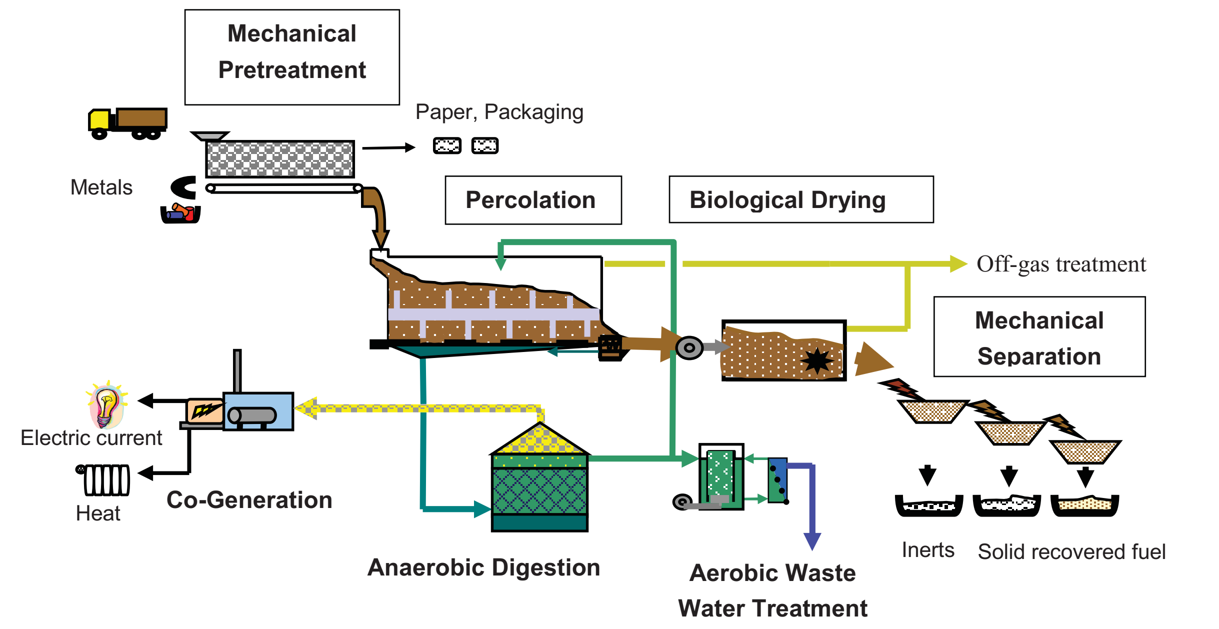

Fig. 1: MBT concept ZAK Kahlenberg

Mechanical-biological treatment is carried out with mixed municipal solid waste including the biowaste (30-50% mass). In this case the solid waste treatment is mainly focused on weight reduction and stabilisation of the municipal solid waste. The organic proportion of the waste is converted to biogas. The dewatered and dried residual waste allows material and energy utilisation (waste-for-recovery and waste-for-energy). The concept Kahlenberg has following process stages.

Mechanical and Biological Treatment

Mechanical pre-treatment (screening, separation of metals and bulky refuse)

Biological treatment (percolation, degradation, biogas production)

Biological Drying

Increasing calorific value of solid recovered fuel

Preparing for mechanical separation

Mechanical separation

Separation of inert fractions and solid recovered fuel

This process combination is one of the first of its kind to combine anaerobic digestion with subsequent production of solid recovered fuels from mixed residual waste. Contrary to the conventional mechanical-biological treatment the residual waste is not landfilled but is in fact reused as a source of energy.

1.3 Operating Results of Percolation and ZAK

The percolation process produces easily convertable organics and accelerates the anaerobic digestion. The main benefits of percolation are dewatering and mass reduction of residual waste. The biological process of the percolation supports an effective drying within 7 - 9 d of retention time. The solid recovered fuel with a residual moisture content of 15 % contains a calorific value of 11,000 to 22,000 kJ/kg. The municipal solid waste is reduced to about 35 % solid recovered fuel which is used for energy recovery as industrial combustion (Fig. 2).

Another 11% is removed by biological degradation. When converted it results in a specific biogas production of about 70 m³/t (70 % by volume CH_4) of treated solid waste. The plant operation is self-sufficient in energy and more than one third of electricity is for sale. Warming up the anaerobic digestion (mesophile) needs approx. 50 kWh/t and heat for sale is up to 200 kWh/t.

Degradation and dewatering result in excess water (30 %) which is treated by an aerobic waste water treatment (membrane bio-reactor system). About 10 % of inert substances are discharged from the original municipal solid waste.

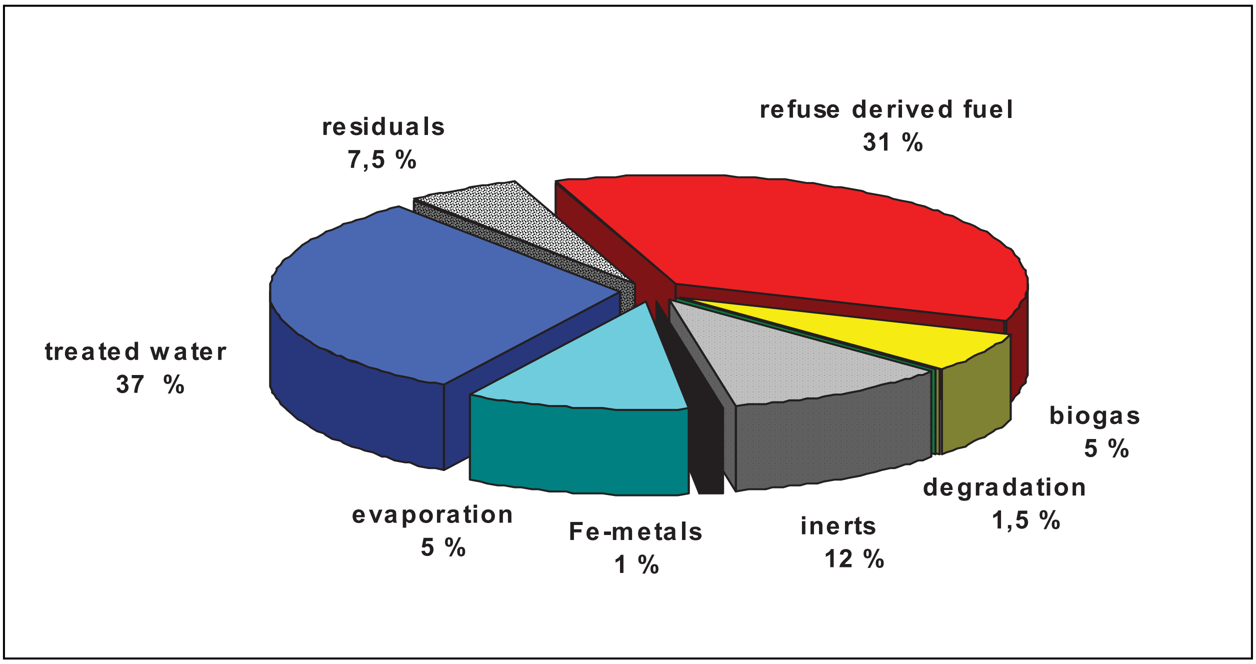

Fig. 2 Mass balance of the Kahlenberg concept (PERSON, SCHREIBER, GIBIS 2008)

2 Adjustment of Percolation to *BIOLEACHATE° Process*

2.1 Reasons for Adjustment of Percolation

The percolation process was developed for mixed municipal solid waste and has been operating reliable for more than 6 years in technical plants in Germany. When applied to developing and emerging countries percolation must initially be adjusted technically for a different composition of mixed solid waste and also for a limited budget for waste treatment. In comparison with German solid waste the organic fraction and water content are often much higher in these countries. The wet organic fraction starts biological processes even in the bins and the treatment plants receive a mixed waste with a high bioactivity. Additionally overcrowded areas are generating multiple waste exceeding the capacity of most of MBT processes that operate up to 2,000 t/d throughput. The retention time of biological treatment requires large plants and great efforts in operating management.

Secondly the limited budget for treatment of municipal solid waste requires a cost-effective processing facility. The starting point of developing and emerging countries for treatment of municipal solid waste is much lower than German waste management. Lower cost technologies are required. As a result for this application the approved system of percolation is adjusted to the simplified treatment, BIOLEACHATE° process.

2.2 Leaching and Dewatering

The wet organic fraction keeps water in the centre of the treatment of municipal solid waste. Water is the main fraction of solid waste. It has a key role in biological processes as hydrolysis and aerobic treatment (see Fig. 3).

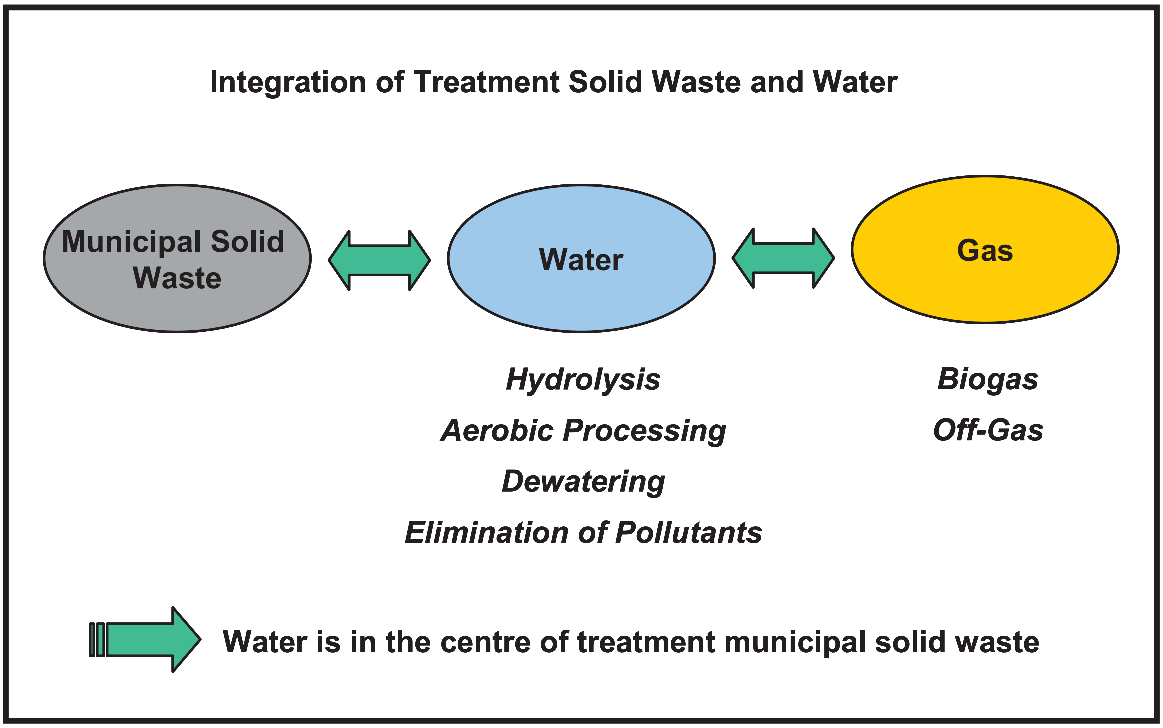

Fig. 3 Water in the centre of treatment of MSW

Technically leaching is the washing out of soluble organic fractions for anaerobic digestion. After less than 18 hours of treatment more than 80% of soluble COD is leached into process water (see Fig. 4). Shortly after beginning leaching the formation of organic acids increases (beginning of hydrolysis). Soluble pollutants (i.e. ammonia and odours) are also eliminated from residual waste.

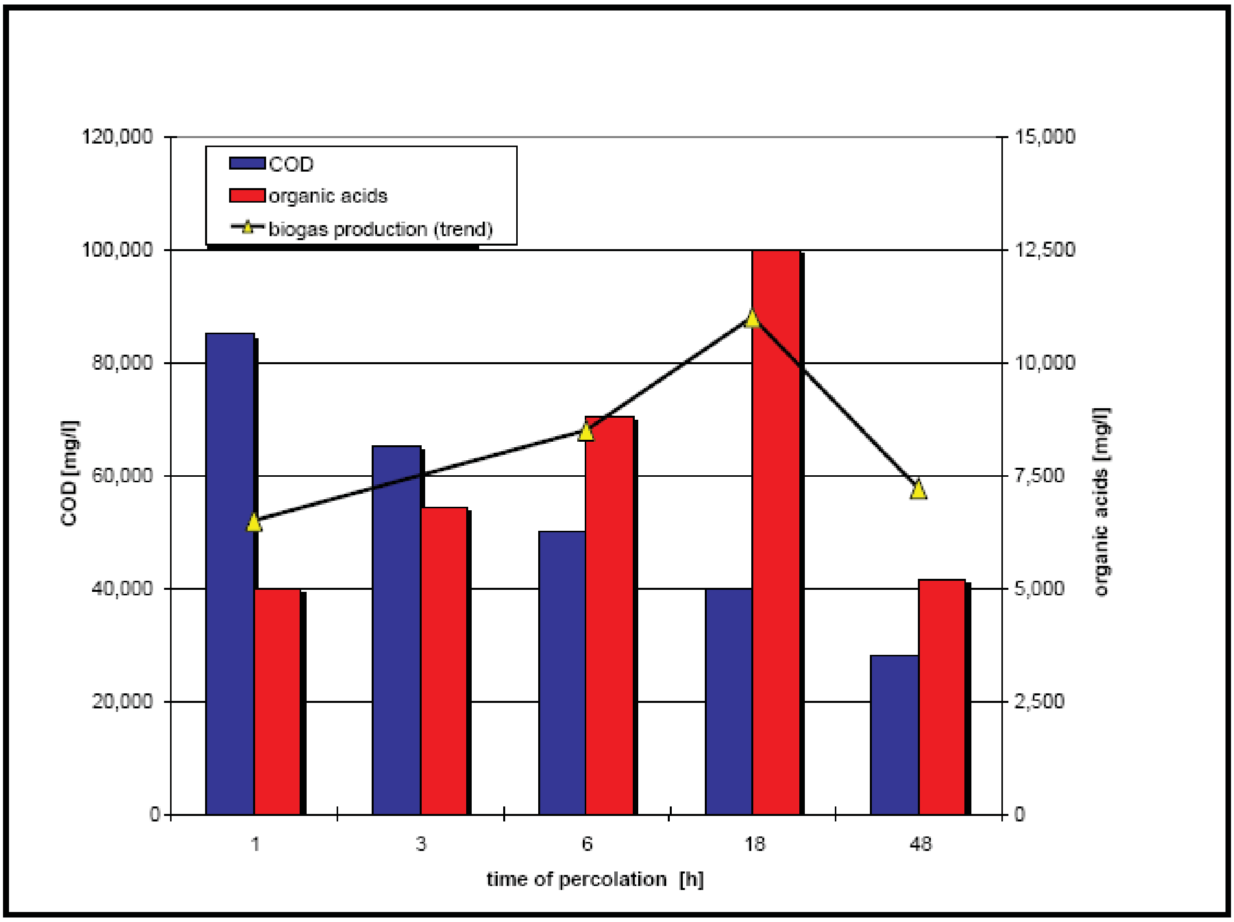

Fig. 4 COD and organic acids from leaching and biogas production

2.3 BIOLEACHATE° process

The BIOLEACHATE° process is derived from the percolation process and has its main elements in process water treatment. Mechanical pre-treatment is done by sieving and removal of metals, plastic foils and cardboard (see Fig. 5)

The screen underflow which contains the bio-organic fraction goes to the leaching process. Easily soluble and odoriferous substances are washed out or are dewatered from solid waste by the mechanical press. After separation of sand and inert fractions process water is degraded aerobically within the hydrolysis reactor. The process water is converted anaerobically into biogas. The generated biogas is used for energy production in a combined heat and power generator.

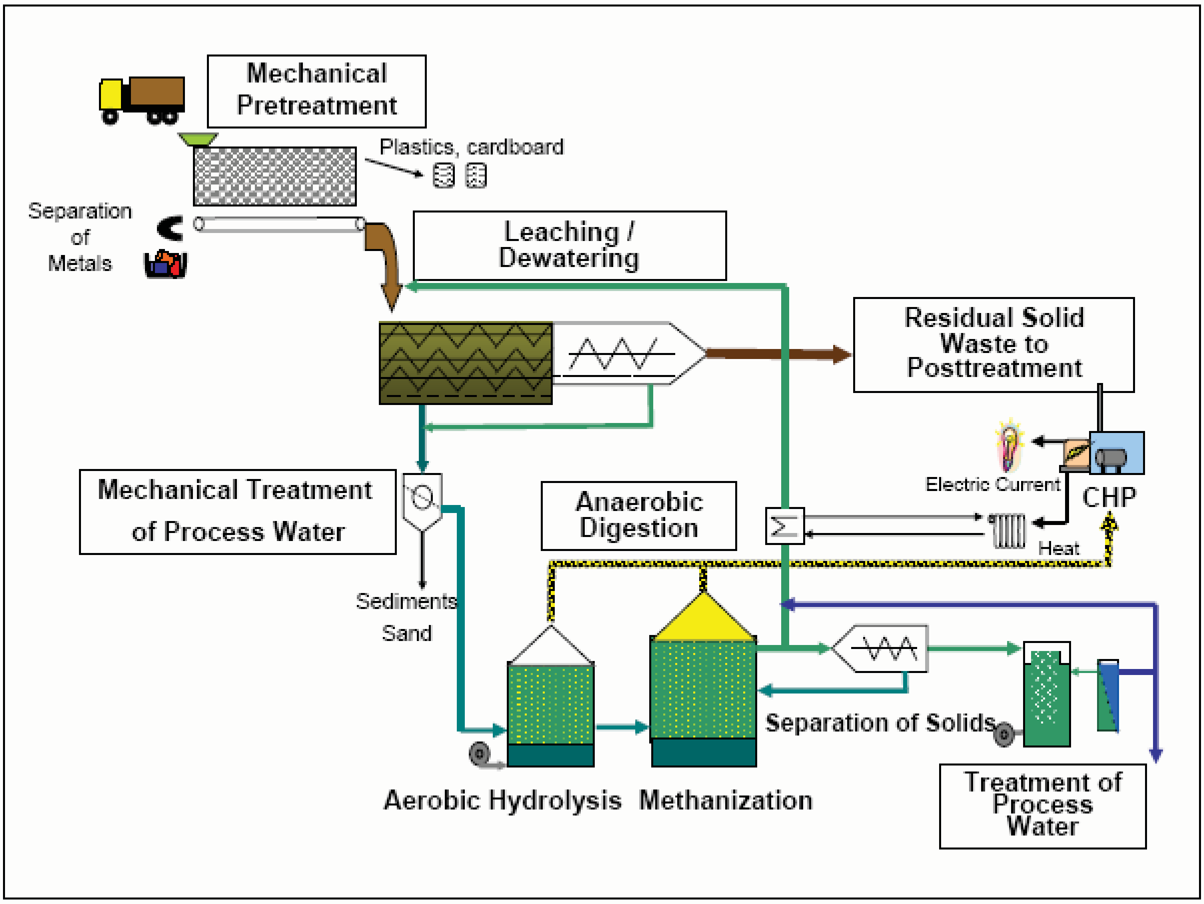

Fig. 5: BIOLEACHATE° process

The effluent of the anaerobic digester is reused as process water for leaching. Part of the circuit water and the excess waste water are treated in an aerobic process water plant. The organic fractions and nitrogen compounds are removed by denitrification and nitrification in a membrane bioreactor system.

The solid output of *BIOLEACHATE°* is treated by subsequent rotting to break down biological activity before landfilling. Another option is to reduce moisture by aerobic drying to produce solid recovered fuel (waste-to-energy). The leaching process prepares excellently residual waste for final rotting or biological drying. Soluble organics are converted to biogas and ammonia is washed out by leaching thereby supporting aerobic processes. There is also no biological break between anaerobic digestion and rotting as known in other systems. After the leaching process there are still enough organics which are easily degradable providing biological energy for aerobic processes.

3 Conclusions

The biological processing remains the centre of the mechanical-biological treatment of municipal solid waste. The biological degradation and dewatering of the *BIOLEACHATE°* process are leaching out most of pollutants into process water. InnoWaste has a broad and long experience in the percolation of municipal solid waste and the treatment of process water. The adjustment of percolation to the *BIOLEACHATE°* process is applicable to emerging countries with huge waste problems and limited budget for financing the treatment of solid waste.

4 Literature

Person, G, Schreiber, M, Gibis, G. 2008 Perkolationsverfahren MBA Kahlenberg in Bio- und Sekundärrohstoffverwertung III, Wiemer, K., Kern, K. (Hrsg.) Witzenhausen-Institut 1. A p. 617-634

RUK 2007 Layman Report from ZAK-process EU-LIFE-Project 2003 - 2006, Ingenierugruppe RUK, Stuttgart

Schalk, P. 2005 Extensive Environmental Technologies for Treatment of Municipal Solid Waste and Waste Water International Symposium MBT 2005, Cuvillier Verlag p. 352-364

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Vermicomposting of Unsorted Municipal Solid Waste

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Abstract

The Vermicomposting (aerobic composting with red earthworms) of unsorted mixed Municipal Solid Waste (MSW) being pioneered by Lavoisier, a Portuguese enterprise, with the support of the NGO Quercus, is an adaptation of an organic waste treatment technology that has been around for a long time. The innovation is the application of earthworm composting to the treatment of mixed MSW allowing immediate diversion from landfill and high levels of separation of recyclables.

The process, installed by the AMAVE - Municipal Association of River Ave Valley, includes a pre-composting phase in order to prepare the waste to feed the worms. Through pre-composting organic waste is digested by aerobic micro organisms. After this phase worms are fed with waste and digest the remaining organic matter, producing humus and cleaning plastics, glass and metals.

Keywords

Vermicomposting, Earthworms, Biowaste, MBT, Humus, Recycling, MSW, Plastic

1 Introduction

The vermicomposting (aerobic composting with red earthworms) of unsorted mixed MSW, being pioneered in Portugal by the enterprise Lavoisier with the support of the NGO Quercus, is an adaptation of an organic waste treatment technology that has been around for a long time. The innovation is the application of earthworm composting to the treatment of unsorted mixed MSW allowing immediate diversion from landfill and high levels of separation of recyclables.

The development of this technology started in 2005 with some tests in a pilot unit in Palmela, Setúbal. The results were very interesting and proved that earthworms could digest organic matter that makes up mixed MSW. Paper and cardboard disappeared, glass and metals were clean and plastics loose the odour of waste.

After those experiments, some visits to recycling facilities took place in order to check the opinion of recyclers about plastics and glass obtained through this process.

All the nine visited industrials showed saw good perspectives for the materials and so a decision was made to propose a project to the Portuguese Green Dot System (SPV – Sociedade Ponto Verde) to study the feasibility to obtain raw materials for recycling with this new technology on an industrial scale. The Green Dot System approved this project and 79 000 euros were then available to buy equipment for the Vermicomposting facility and to do the tests in the recycling units.

At the same time contacts were made with several multi municipal waste management systems to find out the possibility for construction of an industrial MSW Vermicomposting unit and finally the Municipal Association of the River Ave Valley in Guimarães (AMAVE) decided to go ahead with a project to treat 1500 tons of MSW per year, corresponding to a population of 4000 inhabitants.

The Municipal Association managed to get EU funding for this project in order to cover construction costs (137 000 euros) and so all the conditions were there to start this project: Money for construction, equipment and recycling tests and also a very complete team with an enterprise (Lavoisier), a Municipal Association (AMAVE) and an environmental NGO (Quercus).

The project was ready by April 2008, construction started in July 2008 and the unit started to receive MSW in January 2009.

2 The process in the AMAVE plant

Vermicomposting of MSW is basically the result of combining three waste management pro-cesses:

- Vermicomposting of organic waste
- Mechanical and Biological Treatment
- Plastic recycling

The unit in the AMAVE is prepared to treat 1500 tons of MSW per year in an area of 800 square meters.

The plant has a floor in concrete to prevent leachates polluting subsoil water.

It is covered by a greenhouse-like structure with 3 open walls and a closed area at one end in order to give good conditions to workers and to protect the equipment (Fig 1).

Figure 1 View of the vermicomposting unit

The process includes the following steps (Fig 2):

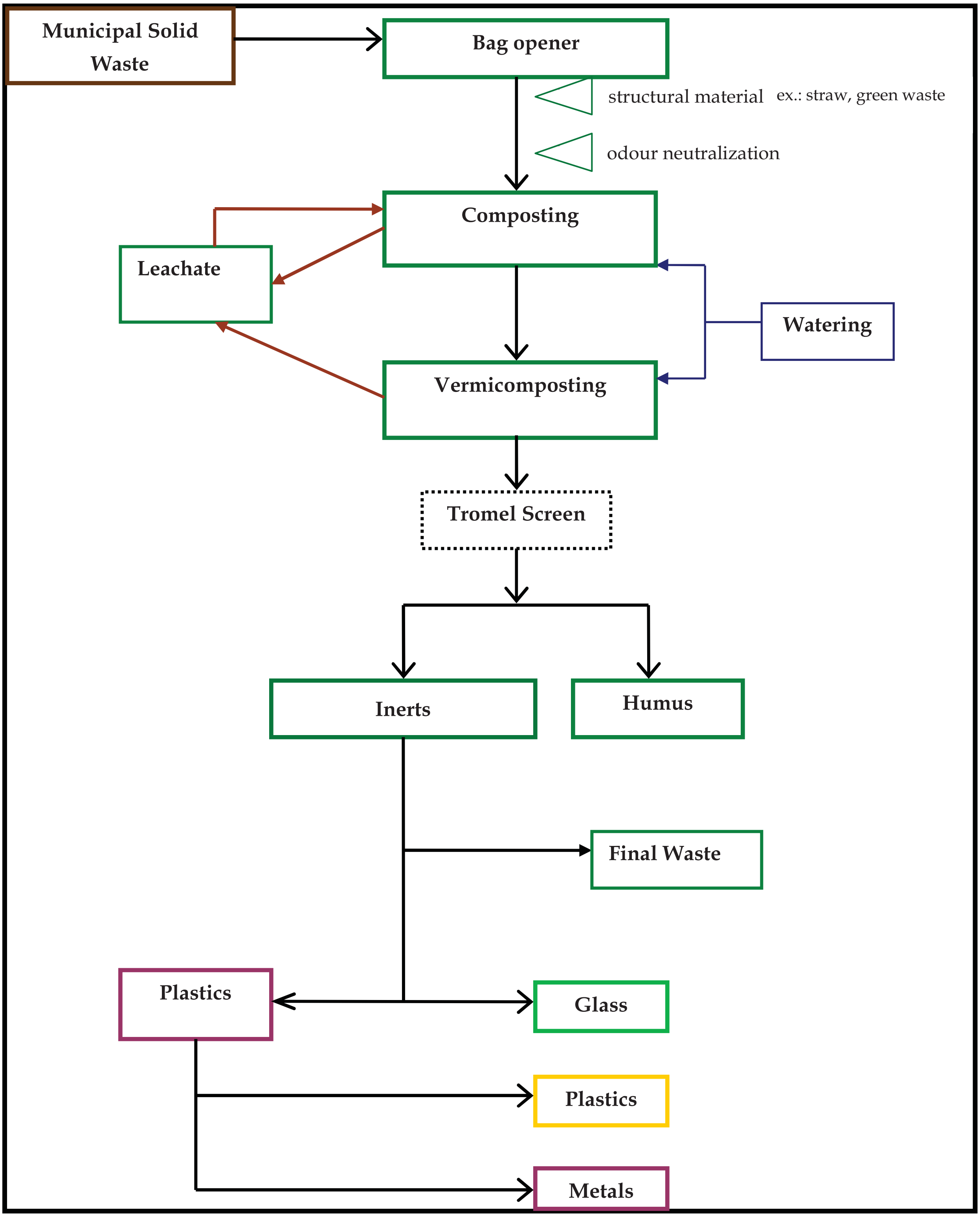

Figure 2 Schematic representation of MSW vermicomposting

a) Bag opening

Plastic bags are opened by a rotating open cylinder (Fig 3) with knifes inside to open the bags. In order to avoid breaking the glass the inner surface of the cylinder is protected with a rubber liner.

Figure 3 Bag opener

b) Pre-composting

After bag opening, waste is transferred to a windrow pre-composting system (Fig 4) where it stays during 3 to 4 weeks.

Waste is covered daily with shredded garden waste in order to prevent release of odours and other nuisances. After 3-4 days temperature rises to 60ºC or 65ºC and stays in this level during 2 weeks assuring destruction of pathogens and weeds.

Waste water is collected into a tank and lately re-injected in the windrow composting system, consequently assuring the total recovery of organic matter and avoiding the need to install a waste water treatment plant. Humidity is controlled with the daily addition of water or waste water.

The composting system is composed by 5 blocks with 24 m^2 each and built with bricks that are placed in a way that allows air circulation. Composting piles achieve 2 to 2,5 meter high. These blocks are protected from rain in order to control humidity.

Figure 4 Pre-composting pile

c) Vermicomposting

The pre-composted waste is then delivered to the vermicomposting beds (a series of modular units) (Fig 5) for another 3 to 4 weeks. As already mentioned the leachates are recirculated into the composting system avoiding the need to a waste waster treatment plant. The process is protected from direct sunlight and rain to ensure ideal conditions.

These vermicomposting beds are built the same way as the composting blocks and have the same type of irrigation system.

The process starts with a first layer of waste with 25 cm high where the worms are already in it. Then successive layers of 25 cm are applied up to a thickness of 2 metres. Worms tend to hide from light but also to move to the new added food, so after 3-4 weeks most of the worms are living in the upper layer, a few centimetres below the top of the pile.

When this happens it is time to take out the upper layer and move it to the bottom of a free bed where the process starts once again.

Through this process, earthworms digest almost all organic matter including paper that is transformed into humus or worm casts, a well known soil improver.

Figure 5 Vermicomposting bed

Before the beginning of this project there was a big question about how would worms deal with packaging like Tetrapak. The answer was quite astonishing because the worms managed to digest all the paper part of this beverage packaging, leaving only the tiny layers of plastic and aluminium.

The result of the vermicomposting is a mixed material composed of humus and inert materials like plastics, glass, metals, textiles and others that need to be separated.

d) Drying process

Humidity can not be very high during the operation of separation of humus from other materials. This means that in winter time there is the need to dry the humus with mechanical means, while in the summer it is possible to use the suns heat to achieve this goal. In the AMAVE unit there is an electric drying device, but in future biomass energy will be used to produce the heat needed to dry the waste (Fig 6).

Figure 6 Dried materials ready for sorting

e) Sorting of humus and other materials

Once humidity is low enough waste passes through a rotating grate that separates pakkaging and other materials from humus (Fig 7).

Figure 7 Rotating grate and sorting table

In the AMAVE plant humus is separated into 3 categories of granules:

- <2 mm;

- >2mm and <5mm;

- >5mm and <20 mm

Humus granules smaller than 2mm is the best product and it will be used for more noble uses depending on its chemical characteristics.

Humus of medium size will be used mainly for forest purposes and land reclamation.

The category between 5 and 20 mm is composed by humus, earthworms and inert materials (glass, ceramics and stones) and therefore must be submitted to a further treatment so that collection of the worms and separation of inert material from humus are ensured.

On the other end of the rotating grate the bulky materials are dropped in a sorting table were the following materials are separated by hand:

- Four types of plastics: Polyethylene Film, PET, Rigid Polyethylene and Mixed Plastics

- Glass

- Metals

Final waste is collected at the end of the sorting table and sent to landfill. This waste is composed mainly by textiles, shoes and other non recyclable materials and has no or negligible biodegradable fraction, so it produces no methane when placed in a landfill.

f) Plastics preparation for recycling

After being sorted the plastics still have a tiny layer of humus dust attached that must be removed in order to avoid too much work for recyclers and also to recover the humus.

With this in mind some tests have been carried at a plastic recycling plant to find the most suitable way to recover the humus dust. The result shows that two operations are required: shredding and washing of plastics.

These operations remove all humus content from the plastics and make them ready for recycling (Fig 8).

Shredding and washing machines are not installed in the AMAVE plant because the total amount of plastics that can be sorted in that unit are not enough to justify that investment, but it seems reasonable to expect that units with a capacity above 10,000 tons of MSW per year can produce enough plastics to justify the installation of plastic shredding and washing equipment.

Waste water from this process and humus sludge can be reused in order to recycle organic matter, to reduce water consumption as much as possible and to avoid the need to have a waste water treatment plant.

Figure 8 Plastics after shredding and washing (mixed plastics, polyethylene film and PET)

g) Waste water management

As said before, waste water from pre-composting and from vermicomposting is collected in two tanks and reused later in the pre-composting process. Sludge accumulated in those tanks is also pumped back into the pre-composting process.

3 Mass balance

The AMAVE unit started to receive MSW in the beginning of January at a rate of 5 tonnes per day, 5 days a week.

The first sorting operations showed the following results regarding the mass balance:

- Original waste weight loss: 35%
- Humus production: 25%
- Recyclables collected: 20%
- Final waste: 20%

This unit will start to operate under normal conditions in March 2009 and a much bigger quantity of data will be available after April 2009.

4 Humus quality

Compost resulting from MBT units is normally seen as a product that has strong limitations for soil application because of contamination with heavy metals. In the use of humus from vermicomposting of unsorted MSW precautions must also be taken in order to know exactly the characteristics of this product and to find out what would be a proper application for it.

The first set of analyses of humus produced through this process show a higher quality than compost from what is usual in MBT units (Tab 1).

Table 1 Analyses of humus and Portuguese proposed legislation for compost

Parameter	Jan 2008 (Pilot unit Palmela) (mg/kg)	Mar 2009 (AMAVE) (mg/kg)	Category I (mg/kg)	Category II (mg/kg)	Category III (mg/kg)
Cd	1,3	(*)	0,7	1,5	5,0
Pb	51	< 80	100	150	500
Cu	69	64	100	200	600
Cr	(*)	(*)	100	150	600
Hg	0,2	(*)	0,7	1,5	5,0
Ni	19	(*)	50	100	200
Zn	379	(*)	200	500	1500

Legend: (*) data not available

The humus shows very low Pb, Cu, Hg content and a medium Cd and Zn content that, according to Portuguese legislation, would classify this product as compost of category II. Data for Cr are not yet available.

Low heavy metal content in humus may be due to the following reasons:

- Bioaccumulation of heavy metals by earthworms;
- High production of humus from paper and cardboard;
- Higher proportion of humus produced per volume of waste input through vermicomposting compared to normal MBT.

5 Costs of the process

The first data concerning the investment costs of MSW vermicomposting can be obtained by the analyses of the AMAVE project (Table 2).

Table 2 AMAVE vermicomposting unit costs

Designation	**Cost (euros)**
Construction	137 000
Equipment – Bag opener, rotating grate and sorting table	50 000
Equipment – Bob Cat and shredder	100 000
Others – Construction and equipment	20 000
Technical work	10 000
Total	**317 000**

According to the available data, investment costs of this unit were 317 000 euros for a treatment capacity of 1500 tons of MSW per year, hence corresponding to an investment cost of 211 euros/ton.

This is clearly an interesting value because contrary to what was possible with this unit there are opportunities of economies of scale which can be easily be achieved in units with capacity above 10 000 tons/year.

In this units costs of plastic shredding and washing were not included, because it is not viable to include those equipments in such a small project, but for bigger units, like those above 10 000 tonnes/year, the increase of costs obtained by the inclusion of those equipments is largely surpassed by the reduction of costs achieved through the scale effect.

Costs for the operation of the AMAVE unit are still not completely clear because of the still short working time of this unit, but is has been already identified that human resources are the most relevant cost. In fact, according to the two months working experience, there is a daily need of two workers to operate the unit and another worker once a week to help in the sorting process.

This results in more or less 2, 3 workers for 1500 tonnes/year, but in bigger units, because of the use of more mechanical means this number of workers would be significantly reduced.

The high rate of plastics, metal, glass and paper (into humus) recycling brings important incomes from the Portuguese Green Dot Society and the sale of humus is also an interesting source of income to cover operation costs.

According to investment and operating costs and expected incomes, the treatment of a tonne of MSW in a unit like the AMAVE one will range between 35 to 40 euros. In bigger units it is expected to reach below 30 euros/tonne.

6 Greenhouse gases emission reductions

One tonne of mixed (residual) MSW sent to vermicomposting avoids approx 119 kg CO_2 eq./tonne. The equivalent tonne of mixed (residual) MSW sent to mass burn incineration and to landfill (using Portuguese energy mixes) produce net emissions of 247 kg CO_2 eq./tonne and 486 kg CO_2 eq./tonne respectively. (E.Value 2008)

In other words, comparing 1 tonne mixed MSW sent to vermicomposting with 1 tonne sent to mass burn incineration, the vermicomposting results in 336 kg CO_2 eq./tonne less emissions than the mass burn incineration.

7 Future projects

Vermicomposting of unsorted MSW is now seen in Portugal as an alternative to landfill for waste that is not collected at source. As a result, some municipalities have shown some interest in this technology and new projects are coming soon.

The first project in line, expected to start working in August-09, is located in Beja, a town in the southern part of the country in the region of Alentejo. This project will treat five thousand tonnes of MSW in the first phase, to be increased to fifteen thousand tonnes in a second phase.

The second project is expected to be operational by September-09 and is located on the Island of S.Miguel in the Azores in the municipality of Nordeste where it will treat 2.5 thousand tonnes of MSW.

Other projects are also in sight but their design and funding are still under discussion.

8 Vermicomposting and MSW management

Municipal Solid Waste management is a problem that still needs to be fully addressed in order to ensure environmentally, economically and socially sound solutions.

In spite of all efforts to reduce waste and to increase selective collection, in many countries there is still a high percentage of final waste that needs to be treated and for which several methods have been used like landfill, incineration and more recently MBT.

Vermicomposting of unsorted MSW can be classified in the family of MBT solutions, because it uses mechanical and biological processes to treat waste that wasn't separated at source.

This technical option appears to offer several advantages compared to more conventional treatment solutions.

First of all, it shows an interesting mass balance, with a very low final waste percentage of only 20% of the original waste, which means that it can significantly contribute to increase recycling rates, especially for plastics, and reduce the need for landfill and incineration.

Secondly, it is a low cost solution, which may be helpful in many countries where governments are now facing economical problems.

Thirdly, this solution can work in a small scale, which means that it can be installed closely to the waste source, thus reducing transport costs.

And finally, because it is a modular solution, vermicomposting of MSW can also receive and treat separately organic waste from selective collection thus increasing humus quality.

As a conclusion, this process seems to be a good opportunity to those countries that still have a low recycling rate of packaging and don't have many plants to recycle organic waste.

Climate conditions are also an important factor. Earth worms cope better with the mild climate conditions so we think that besides Portugal, this process fits particularly well in countries like Spain, France (South part), Italy, Greece and other countries in the Mediterranean Basin.

For countries with colder weather it is still possible to use this technology but it must be adapted to protect the worms during winter time.

Out of Europe, and in some cases using different species of earthworms, there are huge opportunities for this process in regions were temperatures are not very cold, like Southern USA, Central and South America, Africa, South and South West Asia, Australia and the Pacific Islands.

9 Literature

Agência Portuguesa do Ambiente	2008	Proposal for technical specifications for compost quality and use. Portuguese Environmental Agency, Lisbon
Laboratório Químico e Agrícola Rebelo da Silva	2008	Analyses of humus from vermicomposting. Analyses of sample 599-D from humus produced in vermicomposting of MSW unit of Lavoisier in Palmela. Fertilizer Analytical Laboratory, Lisbon.
Laboratório Suma Matosinhos	2009	Analyses of humus from vermicomposting. Analyses of sample 2335-09 from humus produced in vermicomposting of MSW unit of AMAVE in Riba d'Ave. Suma Laboratory, Matosinhos.
E.Value – Projectos e Estudos em Ambiente e Economia, Lda	2007	Application of MSW management CO_2eq emissions model to vermicomposting of MSW. E.Value, Lisbon.
E.Value - Projectos e Estudos em Ambiente e Economia, Lda	2006	Impact of options and waste management opportunities to mitigate green house gases emissions in Portugal. Report issued for the Portuguese Environmental Ministry. E.Value, Lisbon.
Antão da Silva P. and	2008	Aplication of vermicomposting to mechanical and

Berkemeier R.		biological treatment of municipal solid waste in order to recycle plastic, glass and metal packaging – Report number 1 issued to the Portuguese Green Dot Society. Lavoisier, Lisbon.
Antão da Silva P. and Berkemeier R.	2009	Aplication of vermicomposting to mechanical and biological treatment of municipal solid waste in order to recycle plastic, glass and metal packaging – Report number 2 issued to the Portuguese Green Dot Society. Lavoisier, Lisbon.

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Bio-stabilization of municipal solid waste prior to landfill: Environmental and economic assessment

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Abstract

A bio-stabilization was undertaken to pre-treat municipal solid waste (MSW), characterized by high moisture and organic matter, prior to landfill. The bio-stabilization included 16 days of active stage with enhanced aeration and 84 days of curing stage. The results showed that MSW weight was reduced by nearly 85% and MSW stability improved, with respiration activity (AT_4) and anaerobic gas production (GB_{21}) being reduced by 93% and 87%, respectively. The dramatic degradation of organic matter occurred in the active stage of bio-stabilization. Based on the bio-stabilization results, the economic and environmental analysis was conducted following 3 scenarios: the conventional landfill (CL), the combination of active stage of bio-stabilization and subsequent sanitary landfill (AL), and the combination of both active and curing stage of bio-stabilization and subsequent sanitary landfill (ACL). The results showed that AL could substantially save land resource and mitigate landfill pollutions, and the costs of AL would be the lowest as well.

Keywords

Municipal solid waste, Bio-stabilization, Landfill, Environmental and economic analysis

1 Introduction

Landfill is the most prevalent disposal method for municipal solid waste (MSW) management worldwide, as it is considered to be simple and low cost. Nevertheless, the amount of MSW is increasing dramatically these years. Considering the decreasing of valuable land resource, and long term environmental pollution such as leachate and landfill gas (LFG) (TCHOBANOGLOUS ET AL., 1993), raw MSW should not be landfilled directly (KOMILIS ET AL., 1999). This problem would be more critical in the developing countries, where MSW is often characterized by high moisture and organic matter content (MÜNNICH ET AL., 2006; NORBU ET AL., 2005). Bio-stabilization, an effective pretreatment prior to landfill, is regarded to be an environment friendly technology (ADANI ET AL., 2004; LORNAGE ET AL., 2007; SHAO ET AL., 2008).

Bio-stabilization involves enhanced biological degradation of organic matter, which can reduce MSW weight and volume, and decrease the environmental pollutions, such as leachate and landfill gas. On the other hand, bio-stabilization needs extra construction investment, operation and management (O&M) costs, which also have their own environmental impacts. However, the additional costs may be off-set by numerous economic advantages resulting from the combination of bio-stabilization and subsequent landfill, such as more efficient utilization of land space, leachate production and greenhouse gas emissions reduction, and post-closure costs savings.

Although the reduction of environmental impact through bio-stabilization has been reported quantitatively (MÜNNICH ET AL., 2006; NORBU ET AL., 2005; LORNAGE ET AL., 2007; ADANI ET AL., 2004; SHAO ET AL., 2008), there is still limited information about the time when shift the bio-stabilization period into subsequent landfill, oriented to minimum pollution potential and maximum benefits.

This paper presents the performance of bio-stabilization of MSW characterized by high moisture content and organic matter content, and environmental and economic analysis were conducted to optimize the combination of bio-stabilization and subsequent landfill are discussed.

2 Materials and Methods

The MSW used in this experiment was sampled from a residential area located in Shanghai, China. It comprised 60% ($w \cdot w^{-1}$, in wet weight, the same below) of kitchen waste, 23% ($w \cdot w^{-1}$) of paper, 11% ($w \cdot w^{-1}$) of plastics and 6% ($w \cdot w^{-1}$) of the others, which represents the typical MSW in developing countries. The whole bio-stabilization experiment was divided into two stages, i.e. active stage and curing stage. The active stage was carried out in the column reactor (1200 mm of height and 400 mm of internal diameter, described in detail by ZHANG ET AL. (2008)) for 16 days of enhanced aeration, with air-inflow rate fixed at 0.056 m^3 per kg wet wastes per hour, and the wastes were turned every 2 days. The following curing stage was performed in the column for 84 days and the wastes were turned every 7 days.

The moisture was determined under 70°C for 2 days. The volatile solids (VS) content, assimilated to the ignition loss at 550°C, was estimated as the total organic content of a sample. Plastic was sorted before determination of VS as it is inert material in MSW. The leaching test, which can effectively estimate the leachate from a landfill, was performed at liquid/solid (L/S, $v \cdot w^{-1}$) =10 and the suspensions were filtered through 0.45μm membrane filter after centrifuging at 10,000 rpm. The total organic carbon (TOC) was determined by a TOC-VCPH (Shimadzu Co., Japan) and NH_4-N was determined by micro-Kjeldahl distillation methods.

The respiration activity (AT_4) was measured from the consumption of O_2 per unit of dry matter during 4 days, which was developed from the method described by HE ET AL. (2006). Briefly, air tight bottles were filled with 10 g collected samples (shredded into 2–3 mm particles) without inoculum and were cultivated at 35°C for 4 days. The cumulated O_2 consumption was measured every day. The gas production potential (GB_{21}) described the gas production under the anaerobic conditions during 21 days, which can predict the gas production potential after landfilling. The collected samples to be analyzed (50 g WM, wet matter) were incubated with digested sludge and water over a period of at least 21 days at 35°C. The gas was collected by air bag and determined volumetrically by drainage.

3 Result

3.1 MSW weight

The changes of total MSW weight, moisture content and organic matter were presented in Figure 1. As the results of the bio-stabilization showed, the reduction of MSW weight could be divided into three stages: 0-16 days was the fast degradation stage, corresponding to the period of the active stage and the MSW weight sharply reduced to 36% of initial weight; 16-58 days was the slowdown stage and the MSW weight decreased continuously to 20% of initial value; 58-100 days is the slack degradation stage with the MSW weight reduced to 13% at last.

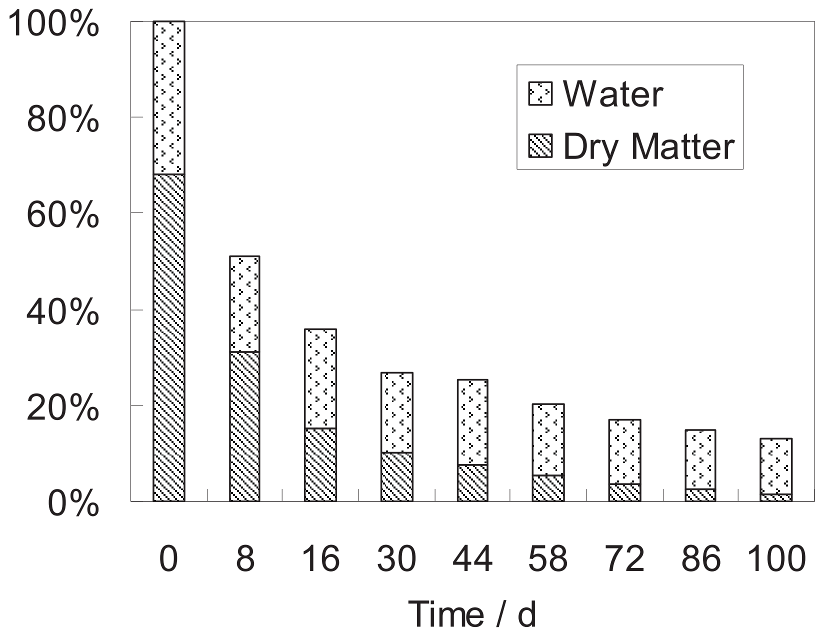

Figure 3 Evolution of MSW weight

During the bio-stabilization, the moisture reduction had the similar trend with weight reduction. During the active stage, the weight of water decreased to 23% of the original at day 16, which was a bigger ratio than the decrease of the total MSW weight. Compared with the weight loss of dry matter, the faster decrease of moisture content mainly contributed to weight reduction. Reduction in MSW weight during curing stage was relatively slow. The weight loss of water was faster than that of dry matter.

3.2 Volatile solid

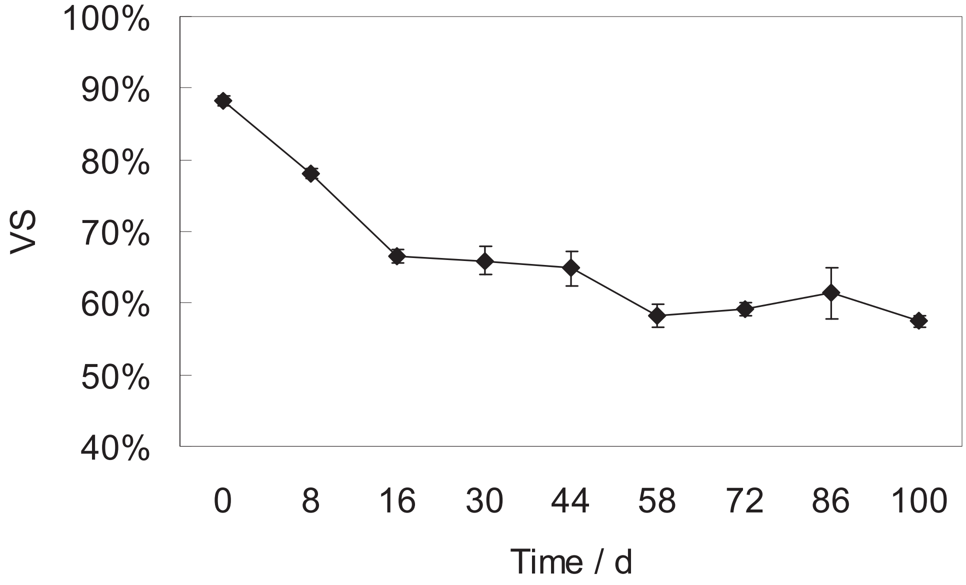

Figure 2 Evolution of VS

The evolution of VS content could reflect the reduction of biodegradable organic matter (Figure 2). The VS content decreased relatively fast, from 88.2% to 66.5%, during the active stage due to the degradation of liable organic matter. At day 100, the waste was stabilized and VS content achieved around 60%. The readily degradable organic matter was substantially reduced through aerobic degradation, which can abate the initial strong organic leachate generated during the acetogenic stage, leading to a more rapid onset of methanogenic conditions (ROBINSON ET AL., 2005).

3.3 Leachate test

The potential loading of leachate pollution could be dramatically reduced by bio-stabilization as revealed by the leaching test. According to the results of leaching test (Figure 3), it was the first 8 days that the TOC concentration monotonously decreased to 10% of the initial peak value with the degradation of dissolved organics; after that, the TOC concentration almost kept steady.

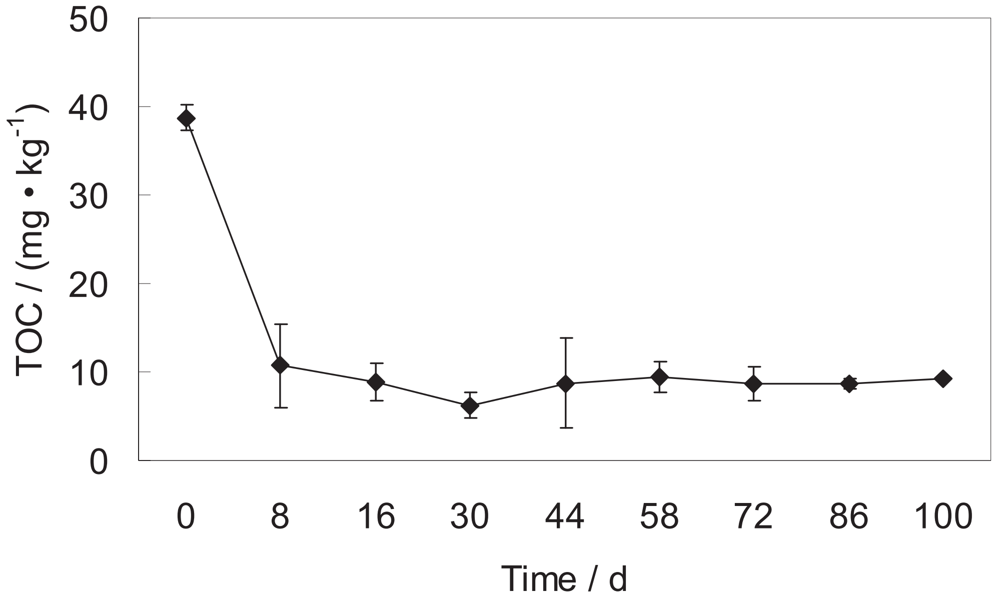

Figure 3 Evolution of TOC

3.4 Biological stability

The initial AT_4 index was 223.6 mg $O_2 \cdot g^{-1}$ DM. After 100 days treatment, the AT_4 index kept steady around 20 mg $O_2 \cdot g^{-1}$ DM, with a reduction of nearly 90%. The respirometric test had the advantage of giving both a quantitative response, related to the amount of organic matter, and qualitative information of its level of biodegradability. The dramatic decrease of AT_4 reflected the MSW's improvement in stability.

Landfill gas generation occurs mainly during the methanogenic phase of the landfill life cycle, and more than 90% of the gas is methane and carbon dioxide (ELFADEL ET AL., 1997). The associated environmental problems are odors, methane flammability, global warming. Methane also can be utilized as energy (MEHTA ET AL., 2002).

The GB_{21} test could provide information about the landfill gas production potential (Figure 4). The GB_{21} index decreased from 375.4 to 48.6 Nl/kg DM with a reduction of 87%.

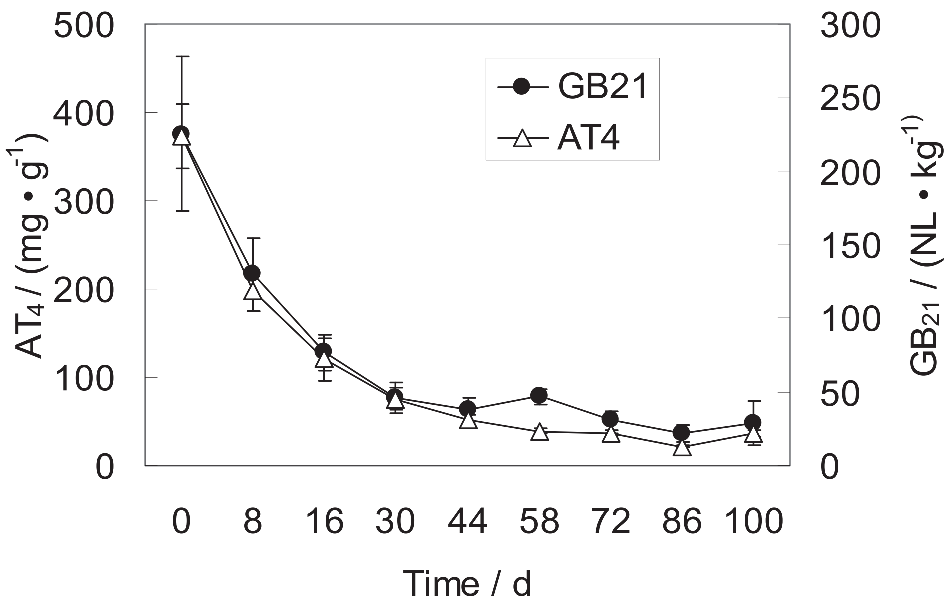

Figure 4 Evolution of biological stability indicators

4 Environmental and Economic Analysis

4.1 Scenarios

During the bio-stabilization, the marked time of the evolution of MSW, characterized by high moisture and organic matter content, was day 16, namely when the active stage ended, and day 58, which was consisted of the active stage and 42 days of curing stage.

Based on the marked time of the evolution of MSW during bio-stabilization, this study compared 2 scenarios constructed for handling MSW from conventional sanitary landfill (Table 1). The 2 scenarios for the combination of bio-stabilization and subsequent landfill are: active stage treatment prior to landfill (AL); active stage plus curing stage prior to landfill (ACL). The conventional sanitary landfill (CL) was included as the baseline as usual scenario for comparison. Considering the different characteristics of bio-stabilization products, the adopted landfill technologies were different: CL and ACL, the landfill follows the prescriptive sanitary landfill in local standard; AL, similar as CL and ACL without the construction, O&M related to landfill gas collection. In order to test the hypotheses, the MSW production scale was assumed as 500 t·d^{-1}, the active landfill time of bio-stabilization plant were both 20 years.

Table 1 The Scenarios

Scenarios	Bio-stabilization		Landfill
	Active Stage	Curing Stage	
CL	--	--	Sanitary landfill
AL	16 d	--	Sanitary landfill
ACL	16 d	42 d	Sanitary landfill (without LFG collection)

4.2 Land area saving

In all the scenarios, the unit area necessary for MSW landfill is 0.2 $m^2 \cdot t^{-1}$. The land needed for landfill of 3 scenarios is 6.9×10^5 m^2, 1.4×10^5 m^2 and 9.1×10^4 m^2. The land area for landfill was substantially saved in AL and ACL with the reduction of MSW weight, which potentially constitutes a major source of benefit. Although the bio-stabilization plant needs additional land involved construction and O&M, the land used for bio-stabilization could be off-set by the advantages of subsequent land source saving in landfill. The land area for bio-stabilization in ACL could be calculated according to the current local composting construction standard, and the AL would be assumed to take its half because of the elimination of curing stage. The actual land needed in each scenario is 6.9×10^5 m^2, 1.7×10^5 m^2 and 1.5×10^5 m^2.

4.3 Environmental pollutions estimate

The MSW in developing countries was characterized by high moisture content, which greatly affected the quantity of leachate generation. During the bio-stabilization, there was no extra leachate generated as the moisture reduced mainly via evaporation. As a result, the leachate generated only during landfilling. After MSW landfilling, water flows out as leachate when the moisture content exceeds the field capacity. At day 16, the shifting time of the active stage and the curing stage, the moisture had reduced to 43%, which is lower than the field capacity, approximately ranging from 48% to 52% (DE VELÁSQUEZ ET AL., 2003). Meantime, the organic matter content was at such a low level that it could not produce more water by its own degradation any more. As a result, the leachate from MSW itself would be 0.18 $t \cdot t^{-1}$ MSW, -0.07 $t \cdot t^{-1}$ MSW and -0.23 $t \cdot t^{-1}$ MSW ("-" means that the MSW could absorb water from other sources).

The leachate in 3 scenarios could be calculated mainly according to 2 sources, namely the infiltration of precipitation and MSW itself. Given that the leachate from CL was 100%, those of AL and ACL would decrease to 14% and 3%, respectively.

During the bio-stabilization, the MSW was stabilized and the released odors could be collected and removed. Only in CL did the landfill generated odor pollutions. Utilization of LFG, in controlled combustion for the purpose of producing energy and thereby displacing fossil fuel and abating emissions of pollutants, is an added global environmental benefit. 40% of generated methane was assumed to be collected, while 60% of methane generated was not captured. The alternative option to minimize methane emission is that of encouraging methane oxidation in the soil covering in landfill. The IPCC suggested the oxidation factor in landfill to be 0.1 in developing countries for their management. By this, the methane emissions in CL, AL and ACL are 4.9×10^7 m^3 and 1.6×10^7 m^3 and 3.6×10^6 m^3, respectively.

4.4 Economical benefit and cost

The bio-stabilization is much like composting of MSW, such as the in-vessel system method regarding to the process of forced aeration, periodic turning and so on. The cost involved in the bio-stabilization constituted of land use, equipment, construction and O&M. Since the compost should meet the certain quality demands of markets and the additional process, such as screening and bagging, also increase the costs, so the bio-stabilization would be less expensive than composting. The costs of bio-stabilization in ACL can be estimated according to the threshold of composting costs listed in local standards (Table 2). The cost of bio-stabilization in AL is 60% of that in ACL because of the absence of curing stage.

Table 2 Construction and O&M cost

	Construction		**O&M**	
	Item	**Cost** (10^4 \$ $t^{-1}\cdot d^{-1}$)	**Item**	**Cost** (10^4 \$$\cdot t^{-1}$)
Bio-stabilization	--	6 ~ 10	--	16 ~ 26
Landfill	Site Estabishment Leachate System Equipment Purchase Site Office+Compound facility Investigation, design and engineering	16 ~ 26	Gas Collection Laborer(s) Cover material Equipment Fuil/Oil Cost Road Maintenance Other Materials	20~ 45

Typical sanitary landfill costs are incurred in site construction and O&M, which cost 6.5 USD$\cdot t^{-1}$ and 6.6 USD$\cdot t^{-1}$ according to local standard (Table 2). The costs associated with landfill gas management (including piping) in ACL are saved. As to CL and ACL, utilizing captured methane to generate electricity presents potential revenue. The electricity production efficiency is assumed to be 4.86 kWh/kg CH_4 combusted. JOHANNESSEN ET AL. (1999) found that the private breakeven price of electricity for the Landfill-Gas-to-Energy projects is lower than US$0.04/kWh. In China, the price for electricity power to local power grid is US$0.062/kWh. In addition, in order to ensure the social environmental benefits from the clean energy, the current social subsidy of US$0.037/kWh would be appropriate for the LFG-to-Energy project.

Table 3 Costs and Benefits (×10^7 USD)

Scenarios	Costs		Benefits	Total
	Bio-stabilization	landfill		
CL	0.0	-4.6	1.5	-3.1
AL	-0.8	-1.6	0.5	-1.9
ACL	-1.4	-0.7	0.0	-2.1

By the environmental and economic analysis (Table 3), it was found that AL and ACL could substantially save land resource and minimize landfill pollutions regarding to leachate quality and quantity as well as methane emission, and their costs would be lower than that of conventional sanitary landfill.

5 Conclusion

1) Through bio-stabilization, the weight of MSW was reduced by nearly 85% and the VS content decreased to approximately 60%. It was observed that MSW was relatively stabilized after 58 days, with AT_4 and GB_{21} index decreased by 93% and 87%. However, the fastest degradation was occurred during active stage.

2) By the environmental and economic analysis, it was found that ACL (active stage and curing stage prior to landfill) and AL (active stage treatment prior to landfill) could substantially save the costs of conventional landfill. However, the AL was characterized by lowest cost and the ACL has lower pollution potential.

6 Literature

Adani, F.; Tambone, F.; Gotti, A.; 2004 Biostabilization of municipal solid waste. Waste Management, 2004, 24, 775-783.

de Velásquez, M.T.O.; Cruz-Rivera, R.; Rojas-Valencia, N.; Monje-Ramírez, I.; Sánche- 2003 Serial water balance method for predicting leachate generation in landfills. Waste Management and Research, 21, 127-136.

Gómez, J.;		
ElFadel, M.; Findikakis, A.N.; Leckie, J.O.;	1997	Modeling leachate generation and transport in solid waste landfills. Environmental Technology, 18, 669-686.
He, P.J.; Lü, F.; Shao, L.M.; Lee, D.J.;	2006	Oxygen limitation in static respiration activity index test. Journal of Chemical Technology and Biotechnology, 81, 1177-1184.
Johannessen, L.;	1999	Guidance note on recuperation of landfill gas from municipal solid waste landfills. The International Bank for Reconstruction and Development, The World Bank, Washington, DC.
Komilis, D.P.; Ham, R.K.; Stegmann, R.;	1999	The effect of municipal solid waste pretreatment on landfill behavior: a literature review. Waste Management and Research, 17, 10-19.
Lornage, R.; Redon, E.; Lagier, T.; Hébé, I.; Carré, J.;	2007	Performance of a low cost MBT prior to landfilling: Study of the biological treatment of size reduced MSW without mechanical sorting. Waste Management, 27, 1755-1764.
Mehta, R.; Barlaz, M.A.; Yazdani, R.; Augenstein, D.; Bryars, M.; Sinderson, L.;	2002	Refuse decomposition in the presence and absence of leachate recirculation. Journal of Environmental Engineering ASCE, 128, 228-236.
Münnich, K.; Mahler, C.F.; Fricke, K.;	2006	Pilot project of mechanical-biological treatment of waste in Brazil. Waste Management, 26, 150-157.
Norbu, T.; Visvanathan, C.; Basnayake, B.;	2005	Pretreatment of municipal solid waste prior to landfilling. Waste Management, 25, 997-1003.
Robinson, H.D.; Knox, K.; Bone, B.D.; Picken, A.;	2005	Leachate quality from landfilled MBT waste. Waste Management, 25, 383-391.
Shao, Z.H.; He, P.J.; Zhang, D.Q.; Shao, L.M.;	2008	Characterization of water-extractable organic matter during the biostabilization of municipal solid waste. Journal of Hazardous Materials, doi:10.1016/j.jhazmat.2008.09.035.
Tchobanoglous, G.; Theisen, H.; Vigil, S.;	1993	In Integrated solid waste management Engineering Principle and management issues. McGraw-Hill: New York.
Zhang, D.Q.; He, P.J.; Jin, T.F.; Shao, L.M.;	2008	Bio-drying of municipal solid waste with high water content by aeration procedures regulation and inoculation. Bioresource Technology, 99, 8796-8802.

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Defining the best process for a Mechanical-Biological Treatment Plant

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Abstract

Before outlining a Mechanical-Biological Treatment (MBT) or Mechanical-Biological Pre-treatment (MBP) process, we should take a look at 3 points that are essential to the success of a plant project.

- Firstly, we will see why we need to have good knowledge of the composition of the source Household Waste (HW).
- Then, we will mention the new trend of favouring recovery of recyclables.
- Finally, we will show the advantages of sorting prior to pre-fermentation.

After looking at these 3 points, we will see, in simple terms, which objectives are decisive when choosing the treatment method.

Finally, we propose an MBT process enabling you to achieve the set objectives, and the possible adaptations for changing or upgrading it.

1 The essential points

1.1 Composition of the collected refuse

The quality of a finished product depends on the choice and quality of the materials that are used in the process of manufacturing it. Although this observation might seem self-evident, it is often neglected when sorting and treating household waste.

We sometimes tend to think that, merely because a particular household waste treatment method has proved its worth on certain sources, it is applicable everywhere.

Whereas actually, depending on the country, the composition of sources of household waste can differ widely. HW composition depends on lifestyle, on consumer habits, and on the waste recovery means implemented.

In certain countries, different selective collection systems are in place. In France, and here in Germany, for example, door-to-door selective collection is in place for packaging and for household refuse separately, and sometimes even for biowaste, and tips or recycling centres are available to which people can voluntarily take their sorted waste, such as garden waste, bulky items, pollutants, etc. Whereas, in some countries, the collection system is less complex, or indeed a single one.

Clearly therefore, in order to define a sorting and treatment process, it is essential to determine the various substances that make up the source waste in question, to determine their percentages, and their particle-sizes, and to identify organic matter, so as to work out the fraction that it is advantageous to recover.

By way of a small practical example, in Poland, where coal is the fuel used to heat the majority of homes, and where coal ash is to be found in household waste bins, it will be preferred to filter out the 0-25 mm fraction, so as to remove that pollutant.

1.2 Favouring recovery of recyclables

This new idea is born out of the observation that, even in countries where collection means are very complex, a large proportion of recyclables, as high as 25% sometimes, is still to be found in household waste. Naturally, in countries in which collection is not very diversified, such recyclables sometimes represent a majority fraction of the inflow of the source HW.

Regardless of the objectives to be achieved by an MBT plant, the prime purpose nevertheless remains to reduce the proportion or the weight of waste going to landfill.

Also, it would seem rather absurd to feed certain substances into the process when they constitute a pollutant for the finished product, or indeed to reject them as non-recyclable when they are recyclable or transformable in some other manner.

This applies, for example, to plastic bottles and containers, steel, etc. that constitute well-identified recyclables that are easily recoverable prior to crushing and pre-fermentation, by means of simple mechanical pre-treatment sorting.

It is also very advantageous and quite possible to recover plastic films and plastic sheeting. Those substances offer high Lower Heating Values (LHVs), and can thus be transformed into energy.

To sum up, recovery of such recyclables:

- makes it possible to reduce the reject percentage and thus to reduce the landfill percentage;
- improves the quality of the finished product (the compost), because the pollutant presence of such recyclables is reduced; and
- increases the overall percentage of recycling and transformation of the waste.

1.3 Advantage of sorting prior to pre-fermentation

Conventional MBT processes generally include 60 mm to 100 mm primary screening and in-tube accelerated pre-fermentation, or indeed direct forced pre-fermentation of all of the source HW, followed by mechanical sorting operations prior to or after fermentation, and by specific treatments depending on whether it is desired to produce ordinary compost or transformation through biomethanisation.

Although pre-fermentation tubes have proved themselves to be genuinely effective in degrading organic matter, provided that they are given sufficient time, use of them at the start of the process suffers from two major drawbacks:

- the pollution caused by mixing up all of the source HW; and
- the over-dimensioning of the pre-fermentation equipment.

1.3.1 Limiting the pollution of the source HW

We have already mentioned the advantage of recovering certain recyclables such as plastics, steels, and plastics films. It is much easier technically and more sensible to remove them before the initial fermentation.

The various types of matter are then less mixed, less sticky, and also less wet. It is thus easier to separate them by mechanical sorting (such as magnetic separation, optical sorting, air separation, etc.).

Furthermore, the recyclables to be recovered are much less soiled than if they had been left for 3 or 4 days in decomposing organic matter.

In addition, after fermentation, not only are such recyclables more difficult to recover, their soiled state sometimes make them impossible to recycle or transform. They are then often rejected to landfill.

In the same way, it is more sensible to remove the pollutants from the stream of organic matter as early as possible. As we have already said, the quality of the finished product depends on the quality of the matter fed into the process.

1.3.2 Optimising the size of the plant

In most existing household-waste treatment plants, the pre-fermentation tubes are placed at the process head. They thus sometimes receive all of the incoming source household waste.

Yet the percentage of fermentable matter, and in particular of organic matter, is falling constantly. In France, for example, it accounts for only 30% of the source household waste.

Pre-fermentation is thus often dimensioned to accept all of the incoming waste even though only 30% of the matter is genuinely degradable, resulting in a very costly investment that, in addition, requires a large area.

To sum up, sorting recyclables and transformables and preparing the fermentable fraction, so as only to send the organic portion of the household waste to fermentation, makes it possible to:

- reduce the investment and energy consumption related to accelerated pre-fermentation;
- considerably reduce the overall space required for the process;
- genuinely adapt the MBT process to match the source HW;
- increase the recovery of the non-soiled recyclable or transformable matter (plastic containers, plastic bottles, steels, and the like);
- limit the risks of polluting the fermentable fraction and improve the quality of the finished product; and
- reduce the pre-fermentation time and optimise degrading.

2 Objectives of the MBT plant

Mechanical Biological Treatment or Pre-treatment of household waste can have various objectives that are simple but that should be clearly defined.

Naturally, ideally the treatment process is also changeable or upgradeable.

These objectives, which are not mutually exclusive, are as follows:

- To produce compost.
- To stabilise the organic matter by composting.
- To produce energy.
- To recover the recyclable materials.

2.1 Producing compost

Here, the objective is to produce a quality compost that complies with the relevant standard, where there is one, or at least that can be used by local consumers such as farmers, horticulturalists, private individuals, etc.), with two sub-objectives:

- to extract to compost most of the fermentable fraction of the waste; and thus
- to limit the production of rejects sent to landfill.

2.2 Stabilisation by composting

For this objective, it suffices merely to stabilise the fermentable organic matter by composting or methanisation before it is sent permanently to landfill or dumped temporarily pending transformation into energy.

2.3 Producing energy

This takes place as follows:

- either by methanising the fermentable fraction of the household waste;
- or by transforming the high-LHV fraction into energy: through direct incineration or through deferred incineration by manufacturing recycled solid fuels…

2.4 Recovering recyclable materials

As we have already said, the idea is to use magnetic, manual, optical, or other sorting to recover recyclable materials such as ferrous metals, non-ferrous metals, cardboard, and plastics materials. This objective, which is generally merely a secondary aim of the mechanical-biological treatment, should become an essential point.

In the light of what we have said previously, it is clear that the sorting and treatment processes satisfying any of these objectives can be very open-ended and must, above all, be suitable for being changed or upgraded.

However, clearly, setting aside the social acceptability of the project, the choice also depends on the local opportunities for outlets for the recycled or transformed products and for disposing of the rejects from the treatment, and in particular on the available incineration or landfill capacities:

- Methanisation will be considered only once the biogas users have been identified.

- Similarly, the compost should be produced to meet demand that is specified by a market survey: volume, type of compost, periods of use, etc.
- Stabilisation of the waste merely reduces the quantity of waste to be stored in landfill sites: it is therefore necessary to ensure that the available landfill resources remain sufficient.

Once the objectives have been specified, the prior survey can address the economics of the project, its environmental impacts, etc., and determine which techniques to implement.

3 Standard process proposal

The standard or typical processes that we are proposing to you address several objectives. They are the result of analysis of experience and feedback, and they do not constitute genuine models. They are merely open-ended and changeable compromises.

However, we have chosen to present to you a modular sorting and treatment process, based on the objectives set, and suitable for changing depending on opportunities.

3.1 1st Process: 2 modules

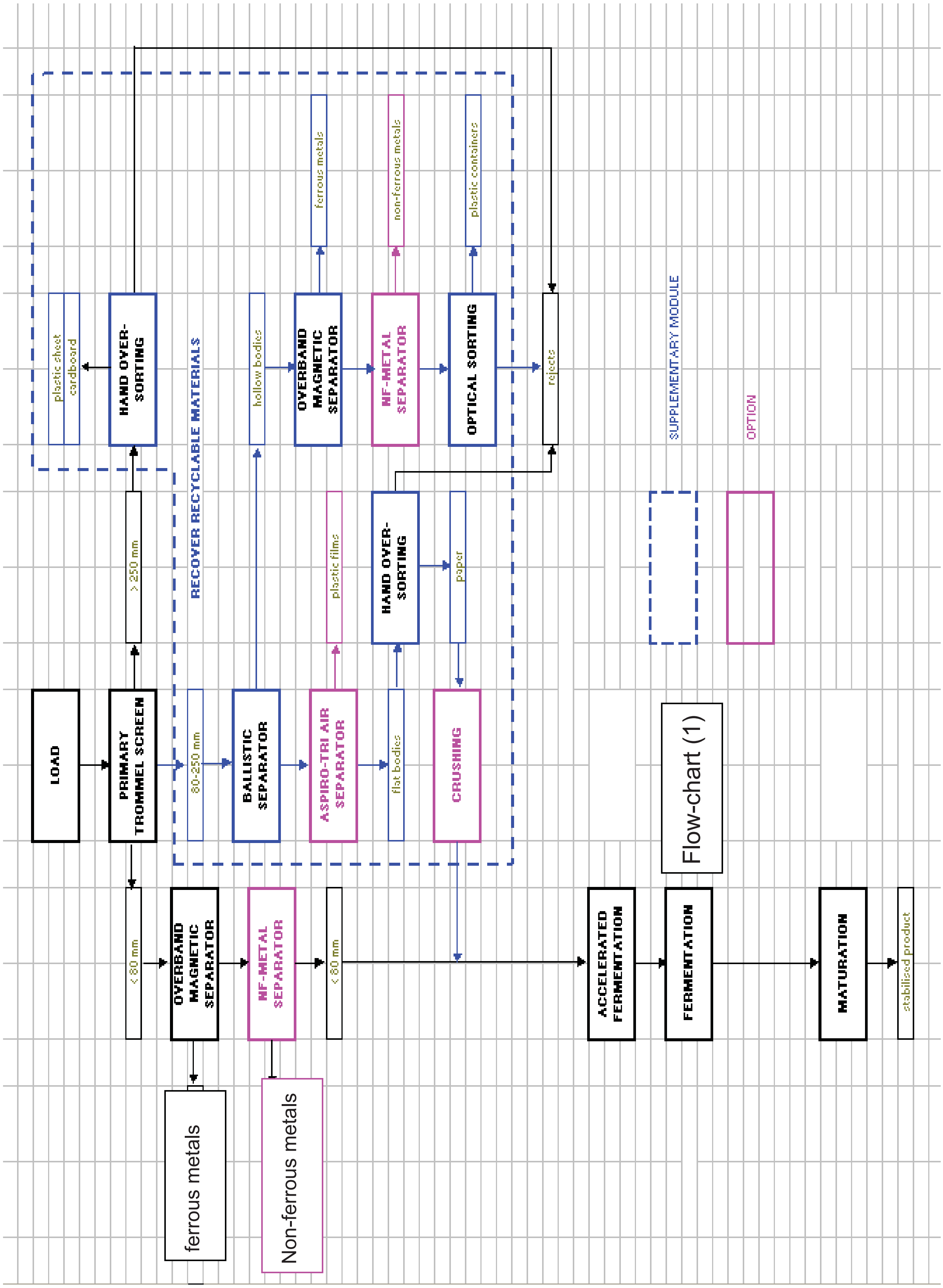
This first process, already developed, meets the following objectives:

- Stabilisation, for landfill/dumping.
- Recovery of recyclables.

As you can see in the first flow-chart (1), the basic module represented by the black boxes makes stabilisation possible. It is supplemented by a module represented by blue boxes for recovering recyclables.

Naturally, the investment and the equipment selected depend on the overall tonnage to be treated, and, as we have seen earlier, on the composition of the source waste. The same applies for the separation particle sizes proposed for the trommel screen.

In addition, during the primary separation, it is also possible to consider a cut-off at 250-400 mm. The more we reduce the extent of the particle-size fraction, the easier it is to dimension the recovery equipment that follows. Indeed that equipment is then more effective.



The pink boxes are optional. Naturally, equipment is not installed if the investment for it is not justified by a sufficient tonnage of products to be recovered.

3.2 2nd process: 3 modules

This second flow-chart (2) makes it possible to meet the following objectives:

- Recovery of recyclables.
- Production of compost.

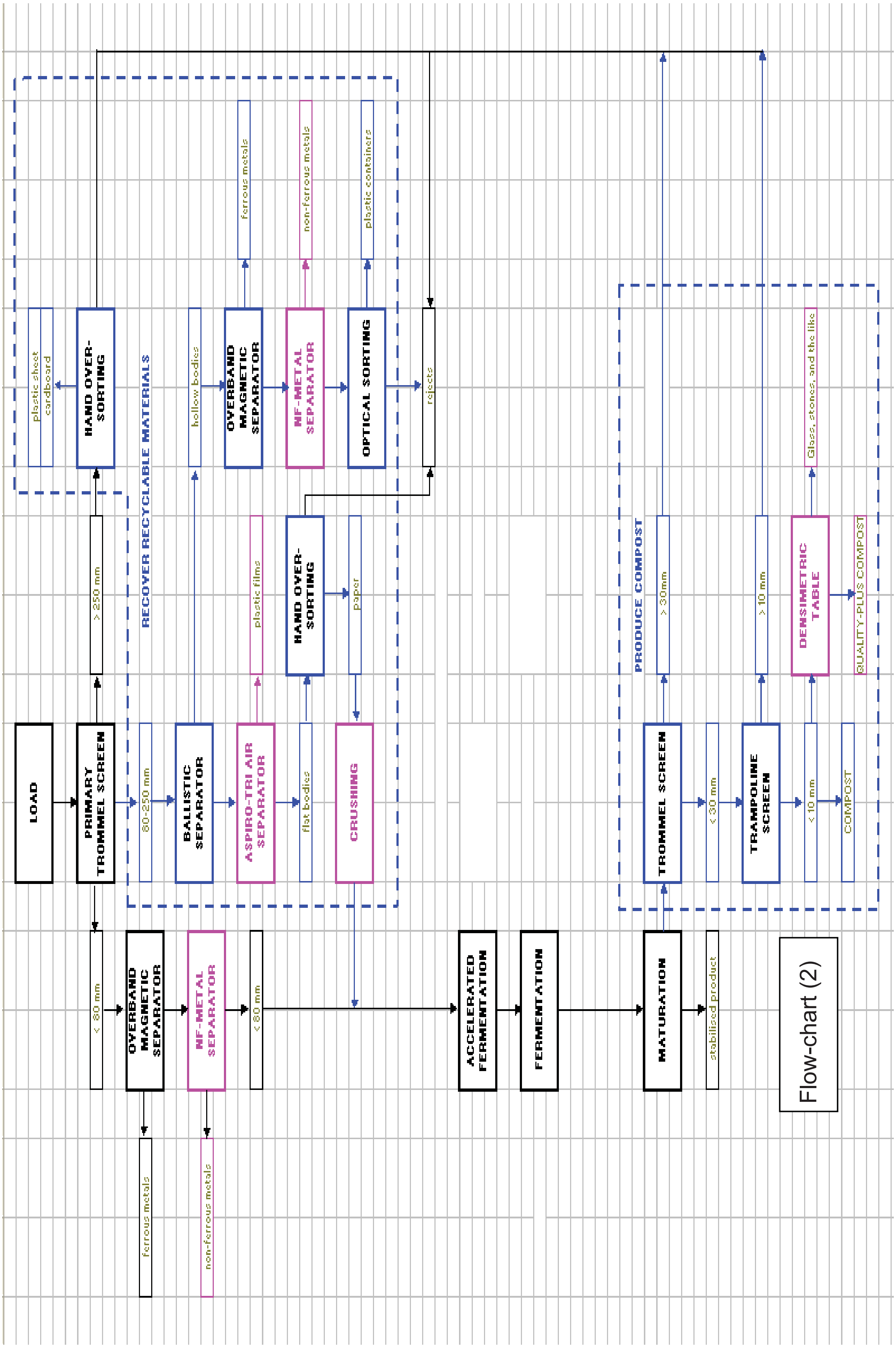
Here too, the particle sizes for the trommel screen and for the trampoline screen of the compost production module (i.e. for the ripening) will depend on the requirements concerning the compost (e.g. when a standard is to be complied with).

3.3 3rd process: 4 modules

This final flow-chart (3) makes it possible to meet the following 3 objectives:

- Recovery of recyclables.
- Production of compost.
- Transformation into energy.

It is the most comprehensive because it makes it possible to optimise the added value procured from recycling and transforming household waste.


LOAD
PRIMARY TROMMEL SCREEN
> 250 mm
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plastic sheet
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RECOVER RECYCLABLE MATERIALS
80-250 mm
BALLISTIC SEPARATOR
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OVERBAND MAGNETIC SEPARATOR
ferrous metals
ASPIRO-TRI AIR SEPARATOR
plastic films
NF-METAL SEPARATOR
non-ferrous metals
flat bodies
HAND OVER-SORTING
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OPTICAL SORTING
plastic containers
rejects
CRUSHING
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ferrous metals
NF-METAL SEPARATOR
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ACCELERATED FERMENTATION
FERMENTATION
MATURATION
stabilised product
PRODUCE COMPOST
TROMMEL SCREEN
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TRAMPOLINE SCREEN
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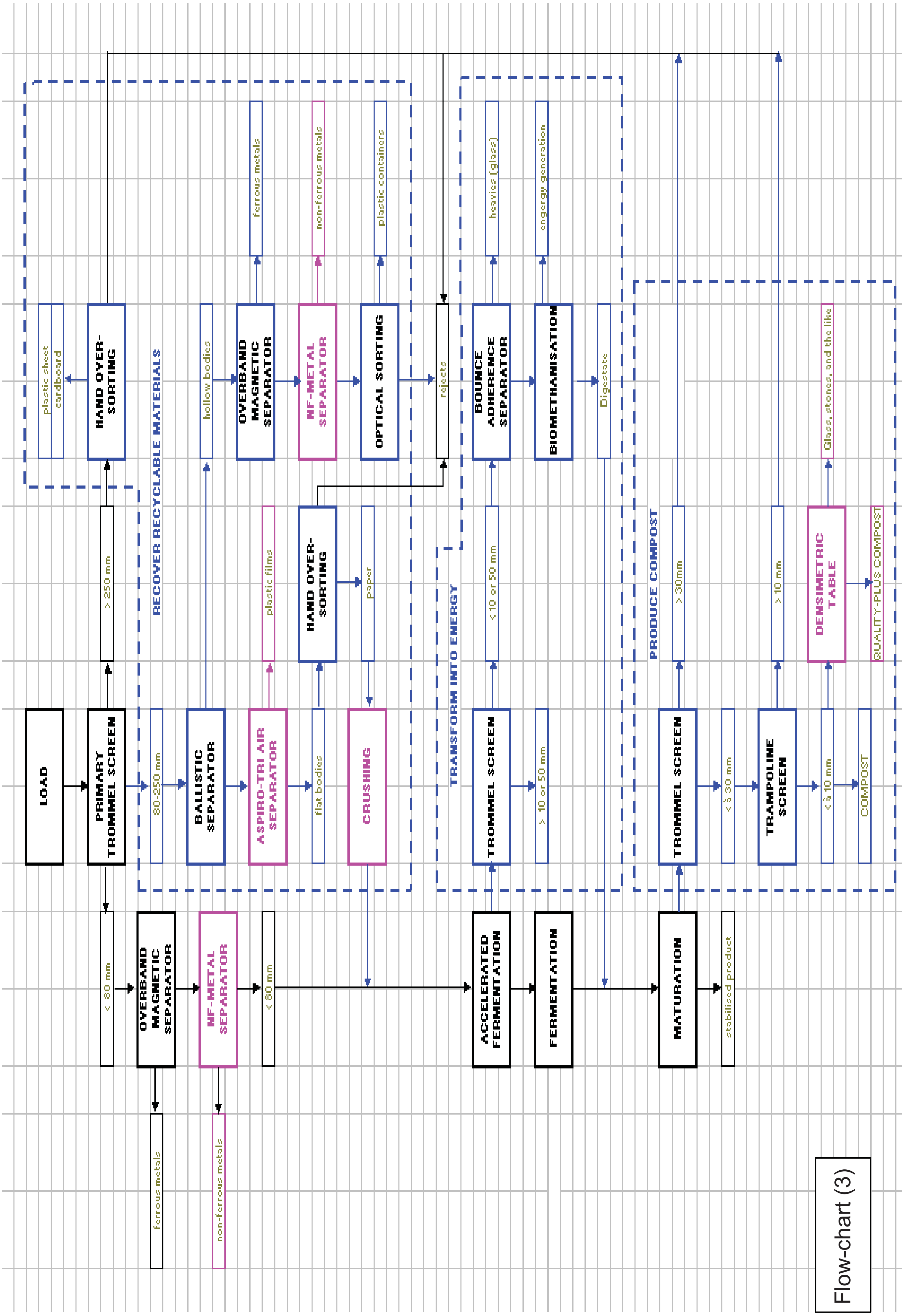
DENSIMETRIC TABLE
Glass, stones, and the like
QUALITY-PLUS COMPOST
COMPOST
Flow-chart (2)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plastic sheet
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RECOVER RECYCLABLE MATERIALS
80-250 mm
BALLISTIC SEPARATOR
hollow bodies
OVERBAND MAGNETIC SEPARATOR
ferrous metals
ASPIRO-TRI AIR SEPARATOR
plastic films
flat bodies
HAND OVER-SORTING
NF-METAL SEPARATOR
non-ferrous metals
CRUSHING
paper
OPTICAL SORTING
plastic containers
rejects
TRANSFORM INTO ENERGY
TROMMEL SCREEN
< 10 or 50 mm
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BOUNCE ADHERENCE SEPARATOR
heavies (glass)
BIOMETHANISATION
engergy generation
Digestate
ACCELERATED FERMENTATION
FERMENTATION
MATURATION
stabilised product
PRODUCE COMPOST
TROMMEL SCREEN
> 30mm
30 mm
TRAMPOLINE SCREEN
> 10 mm
10 mm
DENSIMETRIC TABLE
Glass, stones, and the like
QUALITY-PLUS COMPOST
COMPOST

Flow-chart (3)

Renewable energy production from organic fraction of municipal solid waste through two-phase anaerobic digestion

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Abstract

The organic fraction of municipal solid waste (OFMSW) can be a significant energy source for renewable energy generation. The total production of municipal solid waste (MSW) in Turkey was 25 million tones per year. Anaerobic digestion (AD) process may be a solution to the problems of energy demand and waste management since it provides biomethanation along with waste stabilization. AD can be operated in single or two phase configurations. Two-phase processes have some advantages over one phase systems in terms of selection of microorganisms, process efficiency, and reactor size. In this study, biochemical methane production (BMP) experiments were performed in order to investigate whether phase separation enhanced the efficiency of methanogenic activity or not. The performances were compared in terms of tCOD and VS reductions, and cumulative gas production. The experimental results indicated that 10% and 23% increases in tCOD and VS removals were achieved, respectively, by phase separation. The acetic and propionic acids were not detected in the reactors which was an indication of successful methanization.

Keywords

Anaerobic, biogas, organic fraction of municipal solid waste, phase separation

1 Introduction

The demand for energy and industrial materials are on a significant rise parallel to the rapid industrialization and population growth in many developing countries. Therefore, alternative energy sources need to be investigated, since the conventional energy sources are being exhausted rapidly (Bhattacharyya et al., 2008). Municipal solid waste (MSW), with its significant organic fraction (30-50%), can be an alternative energy source for power generation by biomethanation process. The total production of MSW was 25 million tones per year for 2004 in Turkey which created a significant energy content and in this context; it must be used for the energy generation (TURKSTAT 2007; Dogan et al., 2008). Therefore, anaerobic digestion (AD) process may be a solution to the problems of energy demand and waste management because it provides biomethanation along with waste stabilization. Through AD, organics are decomposed by specialized bacteria in an oxygen-depleted environment to produce biogas and stable solid. Each of these products can be used for beneficial purposes; the biogas, which consists of up to 65% methane, can be combusted in a cogeneration unit and produce green energy. The solid digestate can be used as an organic soil amendment.

AD can be operated in single or two phase configurations. Single phase incorporates both acid formation and methane production in the same reactor, while two phase operation attempts to separate acid formation from methane production, usually by providing two reactors (Speece, 1996). Two-phase processes have some advantages over one phase systems. First of all, the selection and enrichment of different bacteria are achieved and the control of acidification phase enhances the stability of the system by preventing overloads that may affect methanogens. Another advantage is that the tank volumes are smaller due to the applicability of short hydraulic retention times and therefore, the system is more cost effective. Last advantage of the separation is that high solid containing wastes, which may be problematic, are liquefied through the acidification step and the application of this step increases the efficiency of the system. On the other hand, conventional one-phase digestion is not effective for wastes with high solid content since significant increase in fluid and digester volume is observed during one-phase operation systems (Demirer and Chen, 2005). In addition, the conventional systems applied to produce methane from organic waste are often inefficient, time-consuming and costly. The production of volatile fatty acids (VFA) proceeds at a much higher rate when concentrated soluble or high solid feeds are used in these systems. Therefore, the conversion of VFAs to methane does not take place due to acid accumulation, pH drop and consequent inhibition of methanogenesis in the one phase systems (Ghosh et al., 1975; Ghosh, 1987). This is why the application was shifted from single phase to two phase configurations in time.

In this study, biochemical methane production (BMP) experiments were performed in order to show the applicability of the phase separation for the enhancement of the gas production from OFMSW. For this purpose, one acidifying reactor was operated for 30 days under optimum conditions (with organic loading rate of 15 g VS/L.day, hydraulic retention time of 2 days and pH value of 5.5). These conditions were determined beforehand by operating five acidifying reactors with three different organic loads and pH values. The effluents of the acidifying reactor and raw solid waste were used separately as feed for the operation of the BMP reactors and the results were compared. Therefore, the objective of this study was to investigate the effectiveness of two-phase system in the enhancement of biogas production during the treatment of OFMWS.

2 Materials and Methods

2.1 Organic Fraction of Municipal Solid Waste and Anaerobic Seed Culture

The organic fraction of municipal waste (OFMSW) used in this study was composed of food and kitchen wastes collected from houses and, vegetable and fruit wastes collected from markets. All these wastes were separated from glasses, plastic materials and were coarsely shredded in a grinder having an average size of about 4 mm. Required amount of paper, which was kept in water for a week, was added to this mixture in order to simulate the municipal solid waste composition in Turkey, and thus to have a paper content of %6.47 (Table 1) (TURKSTAT, 2007). As a final step, all the waste was well mixed manually for homogenization. The waste was stored in deep-freeze at -20 ^{0}C prior to use for the prevention bacteriological activity and the characteristics of it are presented in Table 2.

Table 1 Typical solid waste composition in Turkey

PARAMETER	**VALUE** (%)
Textile	0.56
Metal	1.13
Glass	2.12
Plastic	2.55
Paper	6.47
Organic	64.15
Others (ash, slag, inert materials)	23.02

The mixed anaerobic sludge culture from the anaerobic digesters of Ankara Central Wastewater Treatment Plant was used as inoculum. The volatile suspended solid (VSS) concentration of the sludge was 8017 ± 1438 mg VSS/L. The seed sludge was screened through a 1 mm size sieve before used in order to remove debris, fibers.

Table 2 Characterization of the OFMSW used.

PARAMETER	VALUE [a]
Density (kg/m^3)	1022.0±8.5
Bulk density (kg/m^3)	963.0±9.2
Total solids (g/kg)	299.0±6.4
Volatile solids (g/kg)	262.0±3.7
Total COD (g/kg)	241.0±2.5
TKN (g/kg)	4.00±0.50
Total P (g/kg)	2.00±0.10
pH	5.18±0.20

[a] Data are expressed as mean ± SD of the three replicates.

2.2 Experimental Set-up

At the beginning of this study, one acidifying fed-batch type continuous stirred tank reactor (CSTR) was operated under the determined optimum acidification conditions. After this reactor reached to the steady state, its acidified effluents were used as substrate for the half of the reactors in the BMP experiment. On the other hand, the remaining half of the BMP reactors was directly fed by the raw solid waste. The BMP reactors containing acidified solid waste served as the methane reactor of a two-phase system, whereas the ones fed by the raw solid waste were used as one- phase reactors (Figure 1).

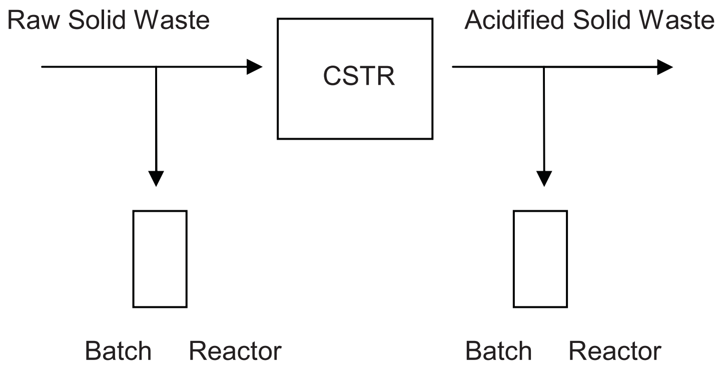

Figure 1 Schematic presentation of the experimental set up

In the BMP experiment, 250 ml serum bottles with effective volume of 150 mL were used as batch reactors. The reactors which contained basal medium (BM) were flushed with N_2 gas for 5 min to maintain anaerobic conditions after seeding. All the reactors were sealed with rubber stoppers and plastic screw-caps, and continuous mixing was applied at 200 rpm. The reactors were operated for 40 days at 35 ± 1 ^{0}C and the gas production was measured with water replacement device. The reactors had controls and blanks; and were operated in duplicates. Two total COD (tCOD) concentrations (5000 mg/L and 4000 mg/L) were applied for different reactors simply to achieve food to microorganism (F/M) ratios ranged between 0.2-1.35; suitable for the BMP tests as stated in the literature (Prashanth et al, 2006). Higher tCOD concentrations were not applied since any ratio over the range might have an inhibitory effect on the reactors due to overloading. Hence, the reactors having tCOD value of 5000 mg/L and 4000 mg/L were coded as 1 and 2, respectively (Table 3).

Table 3 Experimental set-up information of the BMP reactors

Reactor	**Substrate**	**COD (mg/L)**
A1	Acidified solid waste	5000
A2	Acidified solid waste	4000
N1	Raw solid waste	5000
N2	Raw solid waste	4000
Control	-	-

2.3 Analytical Methods

Volatile fatty acid (VFA) measurements were conducted by using a Trace Gas Chromatograph (GC) Ultra (Thermo Co.) with a flame ionization detector (FID) fitted with a Zebron ZB-FFAP column, having length of 30 m, internal diameter of 0.25 mm and film thickness of 0.25 µm, injector temperature of 250 ^{0}C. Operating conditions were: injector temperature, 250 °C; FID temperature, 350 °C; oven temperature program: 100–250 °C (8°C /min); duration, 2 min. Helium was the carrier gas in the system. Formic acid (%98, Riedel-de Haen, Germany) was added to the filtered samples in order to decrease the pH below 3 for the conversion of volatile fatty acids to their undissociated form.

The pH values were measured by pH-meter and pH probe (Hanna Instruments HI 8314 Membrane). The TS, VS, VSS, TP and TKN measurements were performed according to the Standard Methods 2540B, 2540E, 2540D, 4500-P B-E and 4500-N_{org} B, respectively (APHA, 2005).

3 Results and Discussions

Biogas production is one of the significant indicators used in the evaluation of the reactor performance. Figure 2. depicts the cumulative biogas productions measured during the course of operation. The results indicated that acidification step enhanced the biogas productions and the production values reached to 265 mL and 160 mL in A1 and N1, whereas the values measured as 212 mL and 110 mL for A2 and N2, respectively. Moreover, higher productions were observed in A1 and N1 clearly; that is, the reactors with higher influent tCOD loads ended up higher biogas productions in the final as stated in the literature (. Demirer et al. 2000; Uzal et al., 2003).

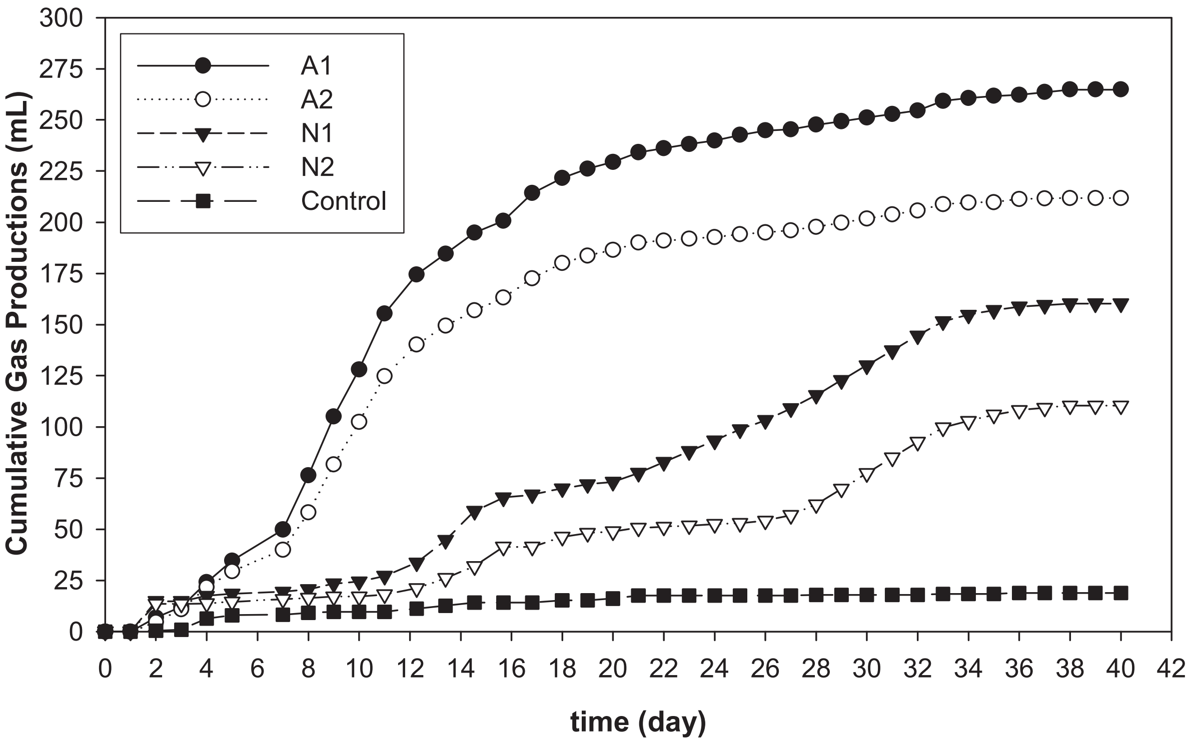

Figure 2 Cumulative gas productions measured throughout the experiments

On the other hand, the tCOD and VS reductions were presented in Figure 3. The removals in tCOD were calculated as 39% and 29% for the reactors A1 and N1, and the percentages were 36 % and 27% for A2 and N2, respectively. The reductions were higher in A1 and A2 since the waste used to feed these reactors was converted to the organic acids in the acidification process applied prior to BMP experiment and these readily biodegradable acids were directly utilized by the methanogenic microorganisms in the batch reactors. Therefore, the removal was more likely to be achieved due to the direct utilization of the acids. Clearly, the conversion of raw solid waste into the organic acids was achieved in the reactors N1 and N2 first, and then conversion to the biogas took place. Moreover, the activity of the acidogenic bacteria might have affected the methanogens adversely which resulted in lower process efficiencies than A1 and A2.

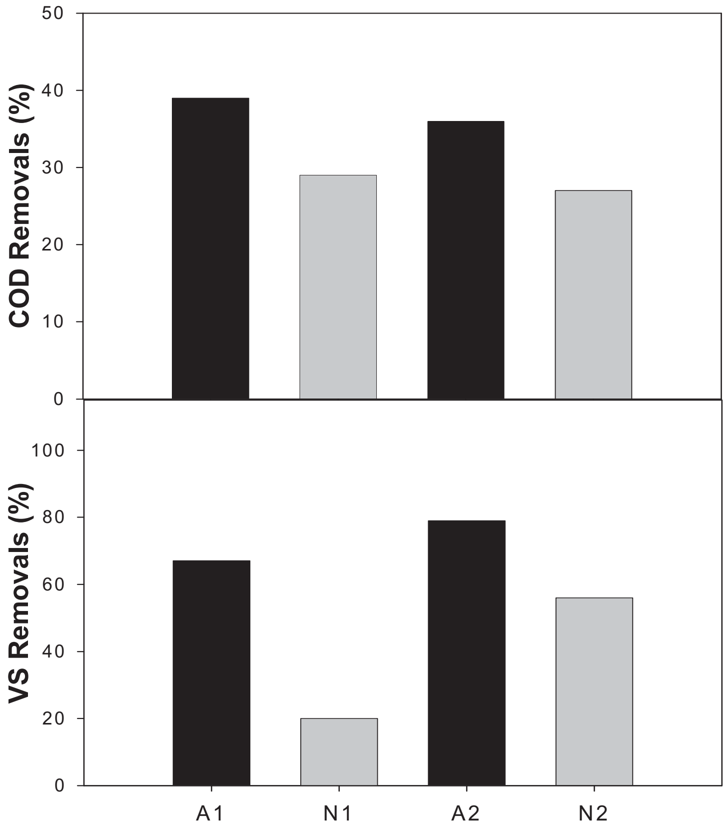

Figure 3 tCOD and VS reductions observed in the reactors

VS removal efficiencies estimated as 67% and 21% for the reactors A1 and N1, respectively in the study; yet the percentages were 79% and 56% for A2 and N2, respectively. Higher removals were achieved again in the reactors A1 and A2 due to the reasons stated above. The results also supported by the biogas production profiles observed between the reactors. The phase separation enhanced the removal of volatile organics in the reactors and in turn the biogas production. At the end, the results revealed that phase separation improved the performance of the methane reactor in terms of tCOD, VS removals and biogas productions as stated in the literature studies (Demirer and Chen, 2004; 2005)

Total VFA (tVFA) concentrations were also analyzed at the end of the operational period and the values were determined as 30, 146, 99, and 197 mg (as Hac)/L for reactors

A1, N1, A2 and N2, respectively (Figure 4). It has to be underlined that lower acid concentrations were measured in the reactors A1 and A2 than N1 and N2, and the reason might have probably been the utilization of them by microorganisms. The tCOD removals in the reactors were also consistent with the tVFA concentrations. The reactors having higher tCOD reductions had lower acid concentrations which meant that the utilization of organic acids brought about the reduction in the tCOD values.

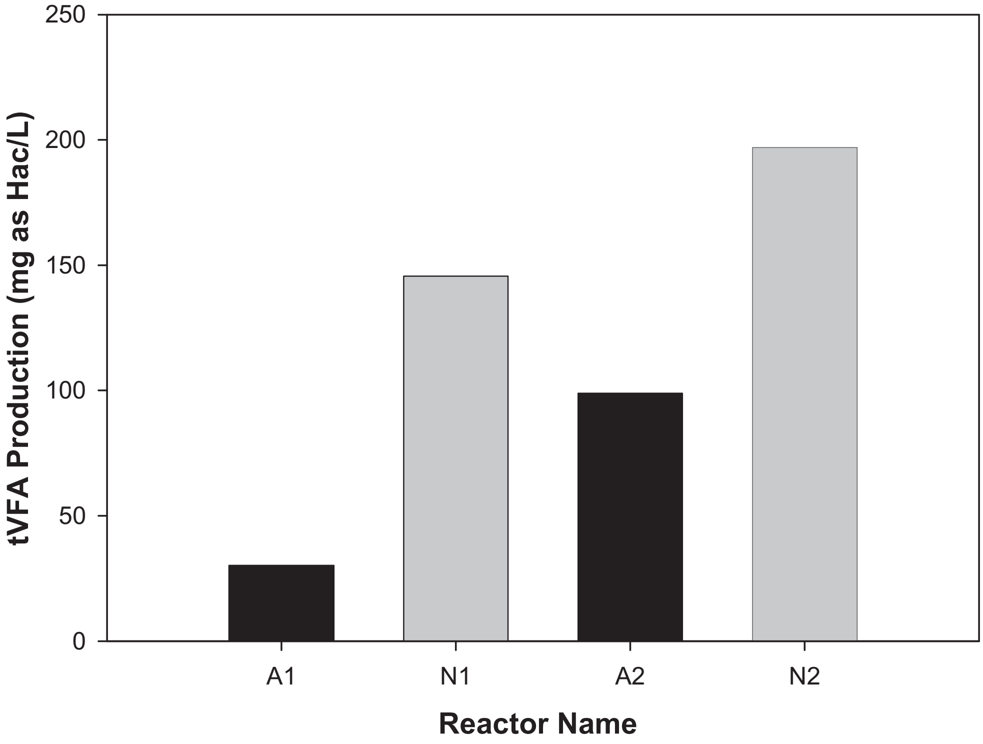

Figure 4 tVFA production of the reactors

When the VFA compositions were analyzed, the main organic acids appeared to be butyric and isobutyric for all the reactors; and isovaleric for the reactors N1 and N2 (Figure 5). There was no acetic acid content in the reactors and the reason was probably the utilization in methanogenesis step. In addition, Viturtia et al. (1995) stated that lower acetic acid concentrations, compared with other acids, were the indication of methanogenic activity; hence, methanogenic activity, which resulted in biogas production, took place in this study.

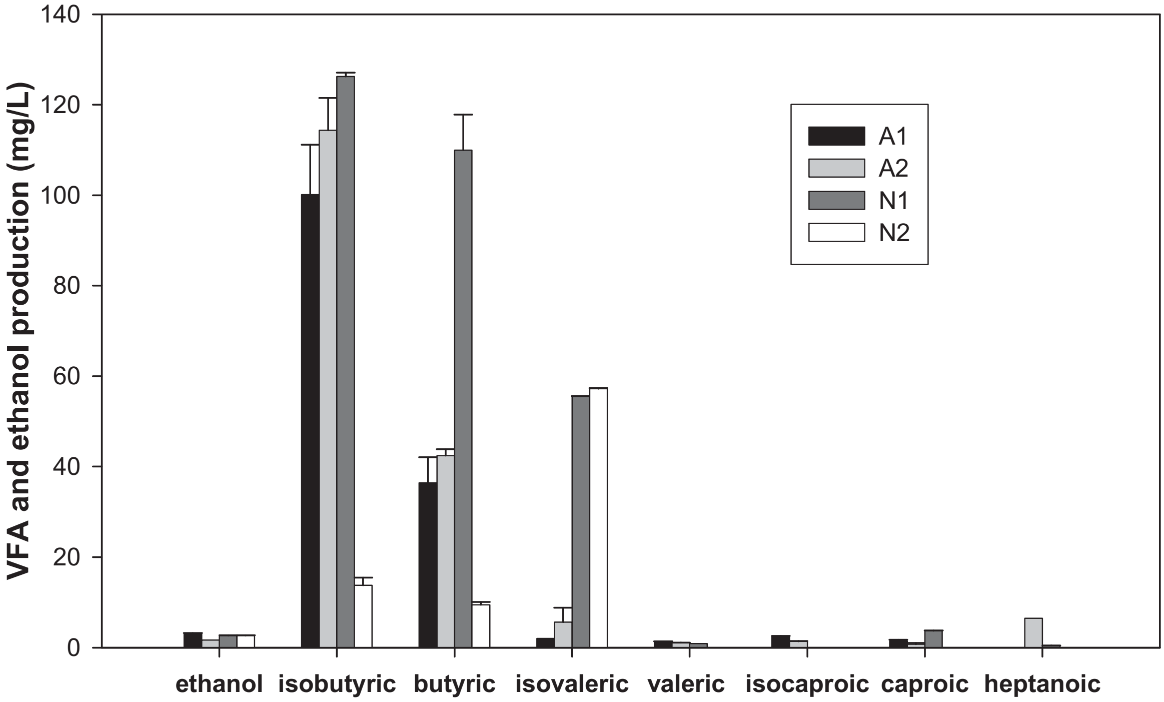

Figure 5 Different VFA productions in the reactors

Besides, propionic acid was not detected in the reactors since it was again utilized immediately by microorganisms due to its simple structure (Speece, 1996). In the study, the concentrations of two organic acids, namely butyric and iso-butyric, were higher than other acids. This was an indication of incomplete degradation of those acids in the reactors. The reason might have been the conversion pathway of these acids as explained in the literature (Han et al., 2005). In other words, the degradation of organic substrate to butyric and iso-butyric acids was achieved first in the reactors; and then a complete conversion of those acids to acetic acid took place. The final step was the production of biogas. However, most probably the conversion of all the butyric and iso-butyric to acetic acid, and then to biogas did not take place in the reactors which led to the existence of those acids at end of the operation period.

4 Conclusions

The results of the BMP experiments revealed that the separation of the anaerobic reactor into two-phase and the application of optimum acidification conditions enhanced the performance of the methane producing reactor in terms of tCOD and VS reductions, and cumulative gas productions for the treatment of organic fraction of municipal solid waste. 10% and 23% increases in tCOD and VS removals were achieved, respectively, by phase separation. The detection of lower tVFA concentrations in the reactors A1 and

A2 was the indication of successful utilization of more acids and in turn more biogas productions. In addition, the lack of acetic and propionic acids was another key indicator for the occurrence of successful methanogenic process in the reactors. As a result, it can be concluded that the phase separation was applicable to improve the performance of the anaerobic systems operated for the treatment of the organic fraction of municipal solid waste.

5 Acknowledgments

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6 References

Kühle-Weidemeier, M. (Hrsg.);	2004	Abfallforschungstage 2004. Auf dem Weg in eine nachhaltige Abfallwirtschaft. Cuvillier Verlag, Göttingen, ISBN 3-86537-121-3.
American Public Health Association (APHA);	2005	Standard Methods for the Examination of Water and Wastewater, 21st Edition., Washington D.C
Bhattacharyya, J.K., Kumar S., Devotta S.	2008	Waste Management 2008. Studies on acidification in two-phase biomethanation process of municipal solid waste. 164-169
Demirer G. N. and Chen S.	2005	Process Biochemistry 2005. Two-phase anaerobic digestion of unscreened dairy manure. 40. 3542-549.
Demirer G. N. and Chen S.	2004	Journal of Chemical Technology and. Biotechnolog 2004. Effect of retention time and organic loading rate on anaerobic acidification and biogasification of dairy manure, 79(12) 1381–1387.
Demirer G. N., Duran M., Ergüder T. H., Güven E., Ugurlu Ö.and Tezel U.,	2000	Biodegradation 2000. Anaerobic treatability and biogas production potential studies of different agro-industrial wastewaters in Turkey.11. 401–405.
Dogan E., Dunaev T., Erguder T.H., Demirer G.N.,	2008	Chemosphere 2008. Performance of leaching bed reactor converting the organic fraction of municipal solid waste to organic acids and alcohols. 74. 797-803.

Ghosh, S.	1987	Journal of Environmental Engineering 1987. Improved sludge gasification by two-phase digestion. 113(6). 1265-1284.
S. Ghosh, J. R. Conrad, D.L. Klass	1975	Journal of Water Pollutution and Contol Federation 1975. Anaerobic acidogenesis of sewage sludge. 47(1). 30-45.
Han S., Kim S., Shin H.	2005	Process Biochemistry 2005. UASB treatment of wastewater with VFA and alcohol generated during hydrogen fermentation of food waste. 40.2897–2905.
Viturtia A. Mtz., Mata-Alvarez J., Cecchi F.	1995	Resources Conversion and Recycling 1995. Two-phase anaerobic digestion of fruit and vegetable wastes. 13. 257-267.
Speece R. E.	1996	Anaerobic Biotechnology for Industrial Wastewaters. Archae Press, Nashville, TN.
Prashanth S., Kumar P., Mehrotra I.	2006	Journal of Environmental Engineering 2006Anaerobic Degradability: Effect of Particulate COD. 132 (4). 488-496.
TURKSTAT	2007	TURKSTAT, Turkish Statistical Institute; [cited October 2007] Available from: http://tuik.gov.tr/VeriBilgi.do
Uzal N., Gökçay C. F., Demirer G.N.	2003	Process Biochemistry 2003. Sequential (anaerobic/aerobic) biological treatment of malt whisky wastewater. 279-286.

Mechanical-biological treatment as a strategically project for the social and environmental development

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Abstract

Through the experiences of different countries, notably Chile, Haiti and Brazil, the using of the Mechanical Biological Treatment of residues was projected involving a series of components directed to the development and improvement of the life quality for the populations. The application of the MBT, as a solution for a parcel of the urban residues, is carried through by technical and holistic elements, where the economic, social and environmental aspects are equated in an integrated proposal of handling and treatment. The concept of valuation of residues is extended to beyond the productive activities, including pedagogical activities, territorial organization, environmental protection and social inclusion.

Keywords

Waste treatment, social and environmental development, emissions reduction, environmental education

1 Summary

The MBT combined with the recycling improvement was developed from the concept of the valuation of the residues, which results in the improvement of the garbage transforming it into a raw substance for the recyclable market. Thus, after the application of treatment technologies such as the mechanical and biological treatment there is a reduction of the environment risks due to the controlled degradation of the organic masses.

Through experiences in different countries, especially in focus Chile and Haiti, the implementation of the mechanical-biological waste treatment was projected combining some factors seeking to provide development and a better way of life to the surrounding community.

The application of the MBT as a solution for the household waste is executed based on technical and integrated elements, so that the economic, social and environmental aspects are solved as a proposal for integrated handling and treatment.

2 Technical introduction of MBT

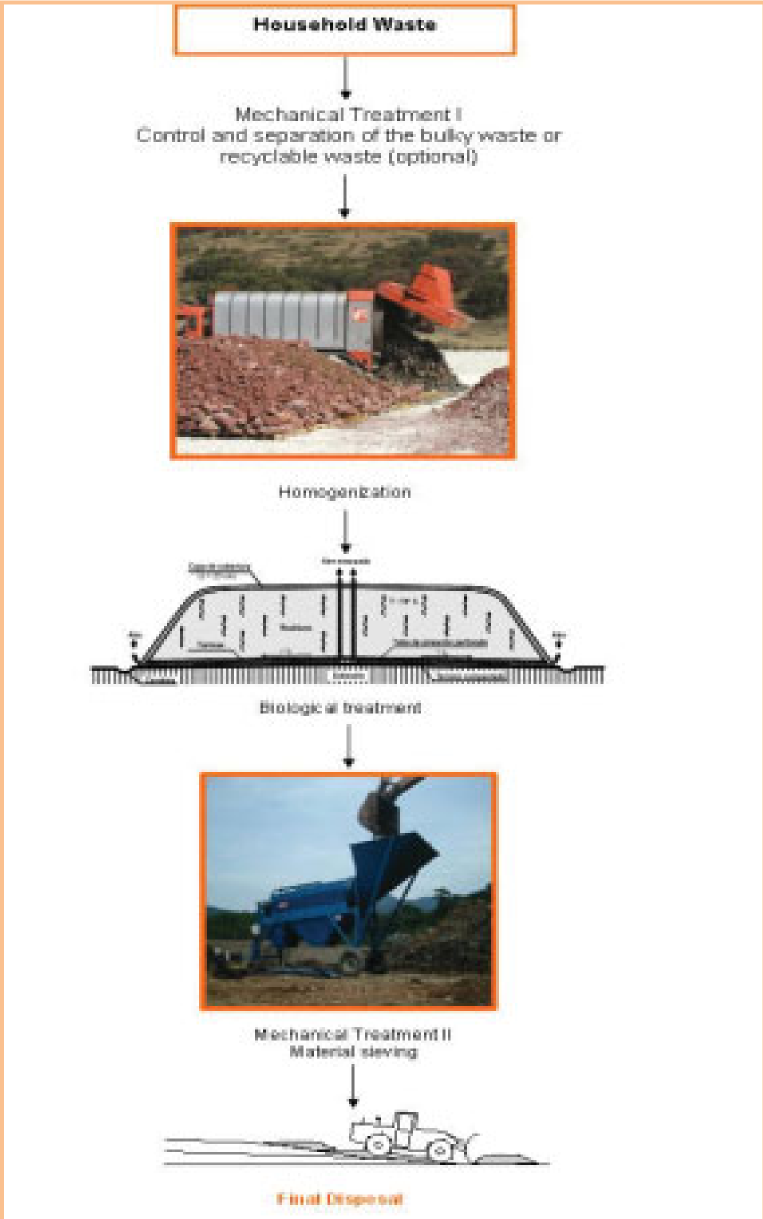
The MBT aim is the biological stabilization of organic fractions found in household waste up to reaching the characterization as an inert mass. It means that after the MBT the organic fractions will be microbiological inactive having as consequence gas emissions reduction and also reduction of the organic load at the leachate.

<u>Waste treatment advantages</u>

- Possibility of parallel compost production.
- Duplication of landfills duration – the area for traditional landfills is much larger and consequently the investment for its acquisition will also be so. However the area with application of MBT, besides being smaller (smaller investments), will suffer less impact and will not affect the neighboring owners. Also the utilized area may have multiple uses in the management of waste. Example: Centre of selection and preparation of raw material for recycling, without any contamination risks to workers.
- Reduction in emission potential - 90% reduction of methane production and of organic load present in leachate.
- Improvement of landfill operation by reducing dust emissions, paper flow and odor emission.
- Minor settlings (favorable for the early installation of a surface cap)

Valuable or hazardous materials are separated from the delivered waste before the mechanical treatment is initiated. During this mechanical treatment the waste is crushed and homogenized in a closed drum, with the addition of leachate from any dump (for instance from old waste dumps) without incurring in further treatment costs and maintaining an environmentally friendly disposal of the leachate. The next step is the biological treatment of the waste. During this stage the biologically decomposing organic waste mass is treated as an aerobic-cell (with oxygen) and as a microbiological process to achieve almost entire waste decomposition.

This stage can be reached by a rotting duration of approx. 4-9 months. Complete decomposition of the biological organic mass is the prior aim. (Any remaining biological decomposing organic mass in the waste causes an uncontrollable anaerobic-cell (without oxygen) and microbiological decomposing process as found in traditional waste dumps). The optional stage is the mechanical treatment II and consists of sieving the material prior to final disposal. After the biological stage the treated material will be land-filled with special equipment focusing to increase the emplacement density from 0,8 to 1, 4 t/m³.



3 Mechanical and biological treatment products

The products obtained from the application of the mechanical-biological treatment have great potential to re-enter the production chain due to application of the concept of waste valorization during the MBT operation. The waste valorization (or waste recovery) saves resources, reduces pollution, creates jobs and contributes to the sustainable development and to a better environment.

The treated residues have changed their characteristics so that their reuse is possible while safeguarding human health and creating potential for development of communities. So you can get as a product of MBT: high-quality organic compost, reuse of recyclable waste from household collection, cover material (bio-filter) and energetic material (biomass or plastics).

4 MBT: social development and environmental protection

The planned politic and operation implementation of the MBT committed itself to a sort of balanced and healthy environment, coordinating all the transformations of the built environment, aiming the welfare of the community and promoting the full development of the social functions of the city.

The social development is the evolution of the components of the society (human capital), and how they are related (social capital). The MBT projects, "Every and all Development is a Social Development," because we believe that there is no development without changing both social and human capital.

With this in focus and attached to the technical capabilities of the Mechanical Biological Treatment we are trying to establish ties with the community through the provision of "green jobs". These jobs are going to be trained and employed by a marginalized population at the economic productive system which now is going to exercise a fundamental role in the development of technologies for treatment and reuse of waste.

5 Individual Projects Overview

5.1 Chile

The project for „The Support of the Administration of Solid Waste for the Community of Vila Alemana“ considered the elaboration of an urban plan for the integrated management of solid waste (PAGRU) and the introduction, monitoring and qualification of a pilot module for the mechanical-biological treatment of waste for the community of Vila Alemana.

During the period in which the project PPP was drawn and developed, different activities were implemented, which have as a goal the introduction of an integrated system and mechanically biological treatment of the urban waste as the first step on the part of the city administration to make possible/reach a lasting development and converge its own interests with the prevention of the environmental pollution and the reduction of the significative impact by the unsuitable handling of the urban solid waste.

The goal was to produce concrete information about the course and the characteristics of the methodology of the mechanical-biological treatment, which on the one hand supplied with concrete technical and economic arguments so that the city of Villa Alemana can opt for a total introduction of the system for its community and thus also on the other hand the country can evaluate better the best form for the introduction of this technological type in its communities.

Starting in a far spectrum from the expected results and from the execution of this PPP project ,it is expected in a general form to contribute to the public knowledge in connection with the substantial improvements (social, environmental, operational, economically) which an integrated management plan for solid waste can produce.

The introduced environmental operation to solve the daily urban problems as well as the handling of solid waste form the starting point for the local development and growth under the perspective of the self-preservation.

In particular, this project has gotten straight that the traditional techniques for dump aren´t an efficient possibility to solve the environmental problems attached to the operation of the waste. These dumping grounds will be transformed into a world and social passive which is transferred to the future generations and offends the self-preservation development.

In this same logic, the PPP project has made possible to spread and communicate publicly in the national level the technical, social and environmental conditions of a MBA before the landfilling as well as to justify the position that each operational activity must be planned in an integral context for an economy plan and not as an isolated measure with less self-preservation projection.

In order to introduce the knowledge of the MBA and the concept of „only deposit such solid waste that has exhausted its possibility of reusing, recycling or being used in any other form, for example energetically. Under this perspective it is successful to save means, to diminish the pollution and decrease the necessary space requirement for the final deposition of solid waste, to create new jobs around the new technology and to educate the population so that it finally can contribute to the self-preserving development and improvement of the quality of life.

As a conclusion the PPP project has shown that the mechanically biological treatment (MBA) of a management plan accompanies an effective solution (with operational, environmental and economic positive results) and has been tried out in the Chilean context and therefore are applicable to other municipalities with similar characteristics in Chile and Latin America.

The implementing of the project will be a concrete alternative solution to be introduced in the municipality of Villa Alemana and Marga Marga community, V region-Valparaiso-Chile and will transform into a reference project for the country.

Source: Faber Recycling GmbH – October 2008

5.2 Haiti

An economical activity that doesn't depend on draining resources, doesn't pollute the environment and uses as the basic input the creation, the innovation and the garbage. An economical activity that develops products with high value, highly labor concentration, generating occupation in all of the professional levels, with wages above the average of the country. An activity that links the economical to the social development, being it for the inclusive potential that it embraces, as well as for the human performing inherent to the production and the educational guides. These are the ECOPARC'S projects main characteristics.

The Project ECOPARC, whose purpose is the application of technologies for treatment and final disposition of residues, involves in its presuppositions a differentiated range of performance. This time the intention is to cross the border of the technical actions involving the society and the public power in a process of operational and normative adaptation concerning the management of residues.

The Project ECOPARC appears founded on the pillars of a new time, ruled from now on no more in the exhaustion of the nature nor in the exacerbated conservation movement, but we mention here a sustainable alternative that involves technology, economy, environment and social improvements.

We intended to build a calendar of development for the environmental economy, with the establishment of indicators and statistics, diagnoses, training and promotion of businesses. The "waste economy" has potential to be a vector of development for the Country and it should be understood as a strategic sector.

Truitier landfill – October 2008

Source: MBS Consulting

ECOPARC Plan

Source: MBS Consulting

The ECOPARC is so called sustainable applied, materializing itself in the creation of the infrastructure adjusted to the involvement of the society in an enterprise whose intention is the environment preservation and to improve the dynamics of the local economy.

6 Conclusion

The enormous volume of waste generated daily in the urban centers has brought a series of environment, social, economic and administrative problems, all of them linked to the increasing difficulty in implementing and maintaining adequate waste disposal areas.

Therefore it is necessary to contain the generation and to give and adequate treatment to the waste. For this, it´s necessary to invest in technologies that allow to reuse and to recycle the materials in disuse. We can´t face the waste as an “useless remaining portion” anymore, but as something to be transformed into a new substance to return to the productive cycle in a healthy way.

The differentiated impacts generated by the solid urban waste justify the necessity of concrete interventions, possible by the planning of adequate management programs. The use of management tools in the solution of the problem comes from the ample variety of waste generated daily in the cities, demanding different technical actions as a solution. The treatment of waste materials that can be inserted in the economic activity again becomes then necessary, maximizing the consequent environment profit of minimizing and reusing the “waste” through its valuation.

Proposals of integrated management centers are ruled not only in the capacity of accomplishment of productive activities, but in the bond of these activities with the program of environment education objectifying permanent and accessible actions to the sensitization of the whole population for the responsible consumption and desirable practices for the participation in the collection program.

The Project impersonates a conjugation of strategies put in movement, which have as unfolding the leverage of the process of accumulation of capitals and consolidation in the domestic and external market of the raw material commerce coming from processes that value materials. Therefore, it handles about an intrinsic relation between strategies and enterprise dynamic in set with a genesis based in the socio-environmental formation.

Low-Cost-Techniques of Intensive Biodegradation and Maturation

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Low – Cost - Techniques for aerobic treatment

Abstract

Techniques for mechanical-biological treatment of solid fraction of household waste taking their seats in the waste management business of many countries. MBT facilities working as a complement or as a low cost option for incineration facilities. Further on there is still a large demand for many MBT facilities to improve the aerobic biological treatment process, to reduce operation costs and to increase reliability. With the help of some examples the possibilities to improve existing facilities will be shown and technical solutions for planning and construction of new facilities will be discussed.

Inhaltsangabe

Technologien zur mechanisch-biologischen Behandlung von festen Siedlungsabfällen haben ihren Platz in der Abfallwirtschaft vieler Länder gefunden. MBA-Anlagen fungieren als Ergänzungsbaustein oder kostengünstige Alternative zur Verbrennung. Im Bereich der aeroben biologischen Behandlung besteht weiterhin in vielen MBA-Anlagen Bedarf an einer Optimierung des Prozessablaufes, der Senkung der Betriebskosten und der Erhöhung der Betriebssicherheit. Anhand von Beispielen werden Möglichkeiten aufgezeigt, wie in bestehenden Anlagen Verbesserungen erreicht werden können und welche technischen Lösungen für Planung und Bau neuer Anlagen berücksichtigt werden sollten.

Keywords

MBA, aerobe Behandlung, Vorrotte, Nachrotte, Optimierung, Betriebskosten

MBT, aerobic treatment, composting, maturation, optimization, operating cost

1 Introduction

1.1 MBT – Current status and perspectives

Despite all difficulties techniques for mechanical-biological treatment of the solid fraction of household waste (MBT) took their seats in the European market. Exemplary for this development are the 48 plants operating in Germany which have a processing capacity of 6 million t/a and thus treat about 25% of Germany's solid fraction of household waste [1].

But the potential of MBT techniques is far from being fully exploited in Europe. While some countries like Denmark and Sweden focus on burning their household waste, there is still a great demand in France, Italy, Spain and Great Britain [2].

Even though MBT techniques in Europe still remain behind their possibilities and even though some MBT plants serve only for pre-treatment before final incineration, the MBT technique has still more advantages compared to direct dumping as it is done in many newly industrialising and developing countries. Due to the missing waste separation and since household waste normally has a high content of organic substances the mechanical-biological pre-treatment could save some valuable landfill capacities and the emission of landfill gases and leachates could be reduced by more than 90%. Simple MBT concepts are in demand [3].

1.2 Optimising potential

The start-up of new plants in 2005 and the subsequent operating experiences made the optimising potential of MBT plants subject to discussions and expert articles.

The main task of MBT plant operators during the aerobic treatment is to create ideal conditions for micro-organisms to maximise the degredation of organics. This is only possible if there is enough water and oxygen available and optimum temperatures are achieved. A continuous ideal three phase ratio (air – water – input material) is considered indispensable [4].

In practise modifications apply to intensive biodegradation and maturation in MBT plants to optimise the treatment progress and reach a higher operational safety and, above all, lower operational costs.

2 Optimising potential in aerobic treatment

2.1 The biodegradation process – Everything under control

The main goal of biological treatment is to reduce and stabilise the waste amounts to ensure a secured dumping on the landfill. The treatment is continued until reaching a set value. An optimised biodegradation process enables to reach this value as quickly as possible.

Usually, an aerobic biodegradation process is realised in two steps: an intensive biodegradation for the first two to three weeks followed by maturation for four to eight weeks.

Intensive biodegradation is marked by intensive aeration of the input material. Dynamic rotting systems (dynamic windrow, line) are completed by regular turning and irrigation whereas a flexible adjustment of turning intervals is usually not possible in this system. Static rotting systems are not intended to be turned. Some plants, however, realise a one time turning with irrigation at a high expenditure (conveying technology, wheeled loader). If this cannot be done, the static rotting material is being irrigated constantly. The result of the technological requirements of the intensive biodegradation is an unsatisfactory rotting process due to poor rotting conditions. The problem is thus postponed to the maturation.

The maturation of most MBT plants is realised in material heaps that are processed by turning. Some plants optimise the maturing process with an underfloor aeration system. The desired degree of stabilisation of the material is obtained after a couple of weeks depending on treating intensity.

The rotting process can be optimised through intensive treatment of the material. Regular turning can notably reduce the maturation period. Systematic irrigation is essential as well since a great amount of humidity evaporates due to high temperatures inside the heaps. Special turning systems including a device for direct irrigation during the turning process will furnish special benefit. Thus, simultaneous turning and homogeneous irrigation can take place in one working step. The turning technology has to be powerful enough to enable the turning of all maturing heaps in one day if necessary.

2.2 The input material – flexibility counts

The organic content of the input material which goes through the biological process is decisive for the necessary duration of the process. It is determined mainly by the delivered household waste, but also by the quality of previous pretreatment through the mechanic separation.

When planning MBT plants the duration of the biological process is normally estimated according to empirical values of the past. The capacities and areas for intensive biodegradation and maturation are construed accordingly. A more or less continuous quality is assumed and, therefore, a relatively constant duration of process.

In practise this assumption was proven wrong. Plant operators report very unstable contents of organic substances in input material. Deviations of more than 200% from the average have been registered. The contents even vary within a couple of days. This requires flexibility concerning duration and intensity of the biological treatment.

Since intensive biodegradation often enables a batchwise treatment (composting tunnels or boxes), it is possible to treat single batches specifically at a time. The maturation in most plants does not enable such treatment because they are often treated in trapezoidal heaps where a separate storage and treatment of the charges is impossible. This requires optimisation.

Changing the maturation treatment from trapezoidal heaps to windrows allows the separate storage of single charges and to treat them individually by higher turning frequencies or better irrigation if necessary. The disadvantage of windrow composting concerning area utilisation is easily compensated through shorter maturation periods.

2.3 The financials – Efficient application of technology

A duly treatment of the input material through turning and irrigating causes expenses which are not to disregard when operating a plant. Therefore, the application of suitable turning technology should be thoroughly planned. Again, the change from trapezoidal heaps to windrow composting will provide financial benefits as the below exemplary calculation shall express:

Exemplary calculation operational costs MBT maturation:

Input in maturation:	40.000 t/a	
Specific weight:	0,55 t/m³	
Maturation period:	6 weeks	
material in maturation area:	approx. 8.400 m³ material/maturation period	
Tuning capacity:	1.000 m³/h with trapezoidal heap turner	
	2.000 m³/h with windrow turner	
Turning expenses:	100,- €/h with trapezoidal heap turner	
	85,- €/h with windrow turner	
Turning frequency:	2 times per week	
Machine hours:	875 h/a with trapezoidal heap turner	
	437 h/a with windrow turner	
Total costs:	trapezoidal heap:	87.500,- €/a
	windrow:	37.145,- €/a

2.4 Practical experience - Examples

2.4.1 MBT Cröbern

The MBT Cröbern south of Leipzig has licence for 300.000 t/a and is thus the biggest MBT in Germany. The biological treatment consists of a two stage process with an intensive aerobic biodegradation in static composting tunnels followed by a roofed maturation of several weeks.

The original design of the maturation was based on five composting areas with one trapezoidal heap each. Those should be turned one to two times per week. Due to operational liability, two self-propelled trapezoidal heap turners were in plan for this. In the second half of 2005 there occurred more and more difficulties in maintaining the required stabilisation rates of the maturation output material. This was caused by some heap areas that had been either too wet or too dry or characterised by some other maturation processing due to their composition. When there was an unsatisfactory maturation processing in one part of the trapezoidal heap, consequently the whole trapezoidal heap had to be turned even if some areas would not have to be turned. This resulted in a great utilisation of the turning technology and thus to a lot of down time due to repair works.

Figure 1: Maturation MBT Cröbern after changing to windrows

To find a solution for this problem, the reorganisation of the maturation area into smaller heaps was discussed in order to treat the individual batches independently. The operating company *WEV* tested the possibility to optimise the stabilisation rates with a separate treatment of the single windrows instead of one heap. After a couple of months testing the maturation was reorganised into windrows.

2.4.2 MBT Rosenow

The MBT Rosenow is located in the North East of Germany. This plant approved for 125.000 t/a has also a two phase aerobic process. The intensive biodegradation lasts two weeks in static tunnels with one time turning while unloading and re-loading the tunnels. The maturation takes place under roof.

From the beginning in 2005 until 2008 the maturation was carried out in six dynamic trapezoidal heaps which were turned two times per week with mobile technology and irrigated upon necessity.

At the beginning of 2008 the redesign towards windrows was started. Figure 2 shows the maturation area. The area of now seven windrows was originally used for two trapezoidal heaps.

Figure 2: Maturation MBT Rosenow after reorganisation towards windrows

According to the plant's operator *ABG* the new composting technique generates better results in the rotting process enabling the company to achieve the stipulated stabilisation level of the output material. Discrepancies to the ideal maturing process can be easily addressed with higher turning frequencies or adjusted irrigation. Because of replacing the turning technology the operational costs could be reduced significantly and operational liability increased at the same time.

2.4.3 MBT Schwanebeck

West of Berlin the MBT Schwanebeck is located. This plant was approved back in 1997 and after two extensions it has a total capacity of 88.500 t/a. The MBT processes not only the organic fraction separated by its own mechanical preparation but also the organic fractions of other municipal waste treatment plants.

The biological treatment includes intensive biodegradation in composting tunnels followed by maturation in windrows on roofed ground. Initially planned as trapezoidal heap system the maturation was in the end changed to windrow composting turned by front loaders in 2006. To reduce the maturation time it was decided to purchase a special turning machine with corresponding irrigation unit in the middle of 2008.

Figure 3: Maturation MBT Schwanebeck, irrigation unit

The goal was to be able to treat the windrows more intensively and at the same time reduce the volume of the stored material to create better maturation conditions. After half a year of operation with the new system the facility owner *ABG* is very satisfied with the results and even records decreasing operational costs for the maturation scope of the plant.

2.4.4 Dynamic tunnel composting – a pilot scheme

In Great Britain the demand for MBT techniques is increasing, too. Due to legal instructions and increasing fees for waste dumping the reduction of such waste amounts is in everybody's interest. Cities and communities as well as private disposal companies are interested in the possibilities of MBT techniques. In the course of this cutting-edge approaches are being taken.

In the scope of a pilot scheme in the South East of Great Britain the combination of known technologies for agitated lane composting and contained static tunnel composting is being tested. The new process can be described as dynamic tunnel composting. The material in the contained aerated tunnel is being turned additionally to optimise the maturing process.

Figure 4: Dynamic Tunnel Composting – view of the pilot site

The compact design of the tunnel allows a great reduction of exhaust air meaning a significant decrease of operational costs. Emissions are limited to a definite contained space. The turning machine agitates from outside the aggressive environment. This prolongs the operational safety and the lifespan of the technology. Beneficial results of this pilot scheme are expected in July 2009.

3 Summary

There are possibilities for optimising the maturation of MBT material in many already existing plants. A successful way is to reorganise from trapezoidal heaps to windrow composting. The operational costs can be lowered and there are positive effects for the maturation process that should be taken into consideration when planning future treatment plants.

Combining proven turning technology with a new tunnel design improves the maturation process control of MBT material and cuts operational costs due to smaller emission amounts. Relocating the turning technology to the outside of the aggressive composting environment results in higher operational liability and longer equipment's life.

Literature

Grundmann, Thomas	2007	Vorwort zu den MBA-Steckbriefen 2007/2008. Arbeitsgemeinschaft Stoffspezifische Abfallbehandlung (ASA) e.V.
Turk, Thomas; Müller, Wolfgang; Hake, Jürgen; Dorstewitz, Helge	2007	Deutsche MBA Technologie als Exportgut für Europa? Bio- und Sekundärrohstoffverwertung II. Witzenhausen Institut für Abfall, Umwelt und Energie GmbH, ISBN 3-928673-50-5
Bilitewski, Bernd; Wagner, Jörg	2007	Sind MBA-Anlagen zukunftsfähige Entsorgungsanlagen? Bio- und Sekundärrohstoffverwertung II. Witzenhausen Institut für Abfall, Umwelt und Energie GmbH, ISBN 3-928673-50-5
Rohring, Daniel	2008	Technisch-Wirtschaftliche Optimierungspotentiale der mechanisch-biologischen Abfallbehandlung in Deutschland. Bio- und Sekundärrohstoffverwertung III. Witzenhausen Institut für Abfall, Umwelt und Energie GmbH, ISBN 3-928673-52-1

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Simulation of biological plants

working with municipal solid waste

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Abstract

To build mechanical biological plants, municipalities and engineer departments need tools to compare different proposals.

The methodology to test a plant aims knowing the flow sheet of each stream in the composting or anaerobic digestion plant, quantifying the weight of refuses, gas losses, stabilised waste and compost. With a universal model of matter we can establish the material balance for dry matter, organic matter, and various categories of MSW.

With a library of equipment tools and various kinds of waste, many simulations become possible in fictive plants. The validation of the simulation software has been successfully tested after the plant building. The first software was developed under excel but today, it has been improved through a special application of Ecoval, named Compowaste.

Keywords

MBT, MSW, Municipal Solid Waste, Simulation, Compost, Composting, Impurities.

1 Introduction

In France more than a hundred MBT plants were working twenty years ago. Most of them stopped because without maturation there was little difference with direct land spreading. Before 1998 all composts made with MSW had high levels of heavy metals and impurities.

French standards appear in 2006 for compost agriculture uses, to oblige composting plants to produce good composts, otherwise they had to close in February of 2009. If the quality of compost obtained from MSW and from biowaste is the same, a composting plant of MSW will be economically very interesting, considering the costs of landfilling or incineration.

Nowadays composting and anaerobic digestion plants are quickly growing in Europe. About eighty projects to treat two million tons of municipal solid waste are starting in France.

To compare different proposals the analyses must be made in the same way for each flow, for the inputs and the outputs and for every machine. In consequence the comparison is easier.

2 Methodology

The simulation is based on models. Some rules are used for sampling, analyses, material balance of tools.

2.1 Sampling

Sampling is based on European standard EN 14899 about Characterisation of waste, sampling of waste materials. For each flow in a plant, a sampling plan is prepared, depending on the type of analysis. Generally a probabilistic sampling is made, so each element has an equal chance to be selected.

2.2 The model of matter

The model of matter is standardised in France with dry matter sorting AFNOR XP X30 466 for MSW or Biowaste in March 2006. This model replaces the characterisation MODECOM on wet matter, which is not usable for outputs or intermediate flows in composting plants, because the wet matter of each category various for different flows (papers for example).

It is possible for MSW and Biowaste to estimate a dry matter composition with a wet matter composition, the opposite also but the result is biased.

2.2.1 Drying

Samples are dried at 70°C because at 100°C some plastics are destroyed or clogged. The wet matter contents are only biased about 0.5%. The water content is globally known for each flow.

2.2.2 Sieving

The sieving is done with a trommel. Round holes of 100, 20 and 8 mm are used on the dry matter for each flow.

2.2.3 Sorting

Fractions upper than 8 mm are sorted in 14 categories: putrescibles, papers, cardboards, complexes, textiles, sanitary textiles, plastics films, other plastics, miscellaneous combustibles, glasses, ferrous metals, other metals, miscellaneous incombustibles, special waste. All the fraction upper than 100 mm, 5 kg of 20 to 100 mm, 500 g of 8 to 20 mm are analysed. The fraction below than 8 mm can be analysed by ignition loss or impurities measurements.

2.3 Precision

Before doing the material balance, we must calculate or estimate the standard deviation of each result.

The calculation can be done with many measurements or by the Gy formulas used for sampling particulate matter. For compost made of a given composition, the fundamental variance (linked to the sampling) of mistake of the measure of a given parameter is the following one:

$$\mathrm{VAR(FE)} = \frac{Z}{Ms} \quad Z = \sum_i Z_i \text{ And } Z_i = (A_i - A_{moy})^2 T_i Mf_i$$

Formula in which:

- Ms is the mass of compost dried at 70 °C,
- A_i is the content of the parameter in a fragment of clue i,
- A_{moy} is the average content of the parameter in the compost,
- T_i is the weight content of fragments of clue i in the compost,
- Mf_i is the mass of a fragment of clue i.

2.4 Material balance

The Bilco software of the French firm Brgm is used to build a material balance. Due to errors, the measurements are inconsistent. The measurements are redundant and incoherent. The objective of the data reconciliation is to find a set of estimates of the measured values which are closed as possible to the measurements. It is possible also to calculate the estimate errors from the measurements errors. Due to the redundancies, the estimates are always more or as accurate as the measurements.

3 Simulation

3.1 The library of tools

The main tools used in plants are sieves, rotating drums, selective conveyors, densitometric tables, overbands, composting parks with some parameters as aeration and turnings, drying, watering, etc.

For each tool, the input and the outputs are measured in existing plants. In the end statistics are done to obtain a model.

3.2 The input

The MSW matter is described by dry matter and by the water content, in an excel file. This file has to be closed and placed in the same path of the project management.

Table 1 Example of MSW input in % DM

Categories	> 100 mm	20 to 100 mm	8 to 20 mm	Total
Food and garden waste	0.3	11.82	12.66	24.78
Papers	3.28	1.67	0.03	4.98
Cardboards	1.12	1.23	0.08	2.43
Complexes	0.23	1.18	0.07	1.48
Textiles	2.06	0.97	0.03	3.06
Sanitary textiles	8.79	11.76	0.07	20.62
Plastics films	3.81	1.2	0	5.01
Other plastics	1.04	1.31	0.27	2.62
Miscellaneous combustibles	0	1.96	1.45	3.41
Glasses	0	0.08	0.13	0.21
Iron metals	0	1.04	0	1.04
Other metals	0.42	0.3	0.01	0.73
Miscellaneous non combustibles	0.24	0	0.58	0.82
Special waste	0	0	0	0
< 8 mm				28.82

The total is equal to 100 and the wet matter about 42.5% DM.

Biowaste can be also used. It is interesting to measure the fraction below than 8 mm because these elements increase in a composting plant to make compost.

3.3 The graph drawing

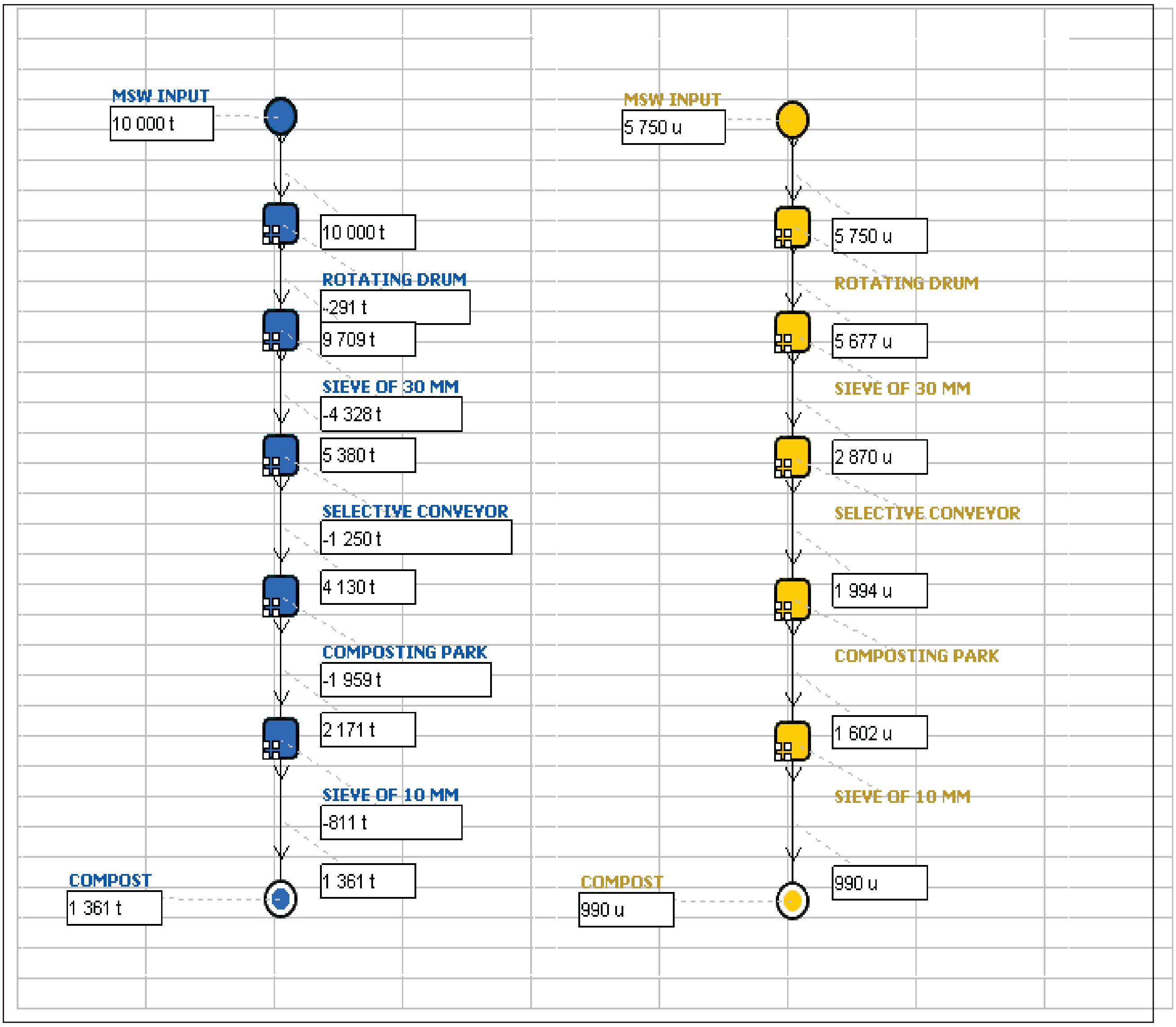

Figure 1 The graph drawing in wet and dry matter

Some parameters are defined for each equipment or tool. In a special window of Compowaste we can follow the state of the process and modify it.

3.4 Modifications

It is possible to modify the input composition, the parameters of each tool, the graph or the scheme plant. The result is immediately calculated and shown in a special window.

A new tool or model is created by changing the outputs compositions. Then, in a new project, you use one of these outputs as input to simulate as you want but always in the same basis of matter description. Anaerobic digestion, shredders and new sieves are tested but the simulator only uses performed models.

3.5 Calculations

Compowaste works with Ecoval, software developed by Diadème Ingénièrie since 2005. The simulator calculates the composition of each flow in mass or in percentage.

Table 2 Example of reject upper than 30 mm in % DM

Categories	> 100 mm	20 to 100 mm	8 to 20 mm	Total
Food and garden waste	0	2.95	0.96	3.91
Papers	13.37	10.06	0.63	24.06
Cardboard	0	0	0	0
Complexes	0.39	2.01	0	2.4
Textiles	7.41	1.67	0	9.08
Sanitary textiles	0.3	0.77	0.05	1.12
Plastics films	8.07	3.7	0	11.77
Other plastics	8.81	9.01	0.11	17.93
Miscellaneous combustibles	0.99	2.86	0.05	3.9
Glass	0	5.74	0.22	5.96
Iron metals	2	3.21	0.03	5.24
Other metals	1.43	0.76	0	2.19
Miscellaneous non combustibles	0	4.56	0.17	4.73
Special waste	0	1.17	0	1.17
< 8 mm				6.54

These results, for each flow, can be exported in another excel file.

4 Uses

4.1 Material balance in composting plants

All Mechanical Biological Treatments plants can be tested by simulation:

- MBT with composting and landfilling,
- MBT with composting, anaerobic digestion and landfilling,
- MBT with composting, compost uses, anaerobic digestion, RDF and landfilling.

The knowledge of outputs is important, but almost them the production of RDF with a high calorific value becomes a good way taking into account the price of energy. The table 2 shows RDF will be easily produced by taking off glass, iron and stones.

4.2 The economic point of view

The simulation will be done according to the prices of:

- Investment,
- Landfilling,
- Energy: biogas and electricity,
- Operating cost.

The equipment costs only represent 25% of the investment. An economy of 5% on the equipment is quickly lost by the operating cost because per example a trommel length of 8 meters instead of 10 meters, an input flow of 12 tons per hour instead of 10 tons per hour, small wide of conveyors. An economy on a rotating drum will immediately increase papers in landfills.

What is the most important now? Producing energy from biogas and put composts in landfills with taxes or producing composts without landfilling?

MBT with composts agriculture uses or landscape uses is cheaper but creates problems to publish the European Directive on biowaste.

4.3 The waste management

The main public aim is to improve the recovery rate and to decrease the rejects for land spreading or incineration.

It is clear that the quality of composts made from MSW can be the same as the quality of those made from biowaste, if the best available technology is used.

The best technology used for MSW composting consists on the following sequence: separate disposal of special waste, mainly batteries and WEEE (waste electrical and electronic equipment); rotary drum during four days; sieving at 30 mm; double selective conveyor; second sieving at 10 mm; maturation. It is possible to do better, but already the compost of Lantic in France is not far from the Ecolabel standard! Better composts should be made after sieving at smaller holes than 10 mm.

Instead of landfilling 200 kg per inhabitant with selective treatment of biowaste and MBT process, it is possible to landfill only 125 kg without selective collection of biowaste, MSW composting and MBT for all rejects.

4.4 Users

The engineer must use a simulator to know, with the best accuracy, the material balance of his project or of many projects. Now we find in composting or anaerobic plants precisions on flows about 10 to 20%, more in some cases! Nowadays that is unacceptable.

Researchers are interested in the simulation, to improve plants by new models, by new tools. The composting plant of Lantic working with MSW since 2004 was simulated in 2002. First we analysed the MSW according to dry matter method, then we chose a rotating drum for 4 days of stay duration seen in Canada and in the South of France, a sieve with holes of 30 mm at Paris, a double selective conveyor at Mont de Marsan and at least a flip flow sieve found in a quarry. Each tool was tested and analysed according to the dry method, not standardised in 2002.

Managers need simulations. A simulator like Compowaste for technical problems associated with an economic point of view should improve the waste management. Many ideas can be tested. Obviously the problems are not similar in European countries, but why is it forbidden to make agriculture compost with MSW in some countries?

5 Conclusion

What is new? The matter description is made on dry matter and the water content is globally known. Trommel are used to sieve at 100, 20, 8 and soon 5 and 2 mm. Composting MSW or biowaste is based on the characterisation of organic matter by chemical fractioning and estimation of its biological stability.

Compowaste is based on Cemagref models obtained since thirty years in composting plants.

In France we have now eighty projects, forty MBT with agriculture uses, thirty MBT with anaerobic digestion, ten MBT with stabilisation and landfilling. Soon France will treat 3 million tons of MSW by MBT.

6 Literature

1 Brussels DG ENV.A.2/LM	2004	Draft discussion document for the ad hoc meeting on biowaste and sludges
2 Brussels DG ENV.A.2/LM	2001	Biological Treatment of Biowaste – Working Document (2nd draft)
3 JOCE 2001/688//CE	2001	Eco label
4 Baptista. M. Morvan. B.	2004	Methodology for evaluating the overall efficiency of biological plants. AWAST Deliverable 15
5 Briand. M.	2004	Analysis of heavy metals. composting plant of Lantic
6 Morvan. B. Blanquart. JP. Le Saos. E.	2004	Composting plant test of Lantic
7 AFNOR standard XP X30 466	2005	Household and related refuse – Characterisation method – Dry product analysis
8 Morvan. B.	2005	Producing an agriculturally usable fine fraction by MBT of MSW. MBT 2005

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The Latest Generation of RTO Plants

Andreas Breeger

Abstract

The deadline for implementing the 30th BImSchV (German Federal Immission Control Ordinance) for mechanical biological waste treatment has expired. In the meantime, the exhaust air cleaning plants (thermal post-combustion and biological systems) have been in operation for up to four years. Operating experience regarding compliance with the limit values, corrosion issues and difficulties due to siloxanes exists and will be presented in this essay. In particular, practical examples of operational RTO systems optimized for applications in the MBT field will be introduced.

Keywords

Regenerative thermal oxidation plants, 30th BImSchV, German Federal Immission Control Ordinance, siloxanes, corrosion, mechanical-biological waste treatment

1 Reduction of Emissions for MBT Plants

The deadline for implementing the 30th BImSchV (German Federal Immission Control Ordinance) for mechanical biological waste treatment expired on 1 June 2005. In order to comply with the demanding limit values and values allowed for total organic carbon loads, RTO plants (Regenerative Thermal Oxidation plants) came into operation, either individually or in combination with biofilters. In some cases, exhaust air cleaning plants have been in operation longer than four years. Hence, it is now possible to draw conclusions on the operating experience collected.

Figure 1: RTO plant with scrubber

2 Compliance with Limit Values

Among RTO plants, there is general compliance with the threshold values set forth by the 30th BImSchV. However, a prerequisite is the normal operation of both MBT plants (Mechanical Biological Treatment) and the exhaust air cleaning plants. The demanded availability, a standstill of eight consecutive hours or 96 hours per annum, is partially difficult to achieve due to prevailing exhaust air conditions or other general conditions (biogas qualities) and current exhaust air concepts.

Odour: The limit value of 500 OU/m³ is generally complied with. To achieve this, sufficiently large and suitably designed biofilters have to be used in combination plants and effective separation of ammonia through preceding scrubbing has to be carried out at RTO plants.

Dust: The limit value of 10 mg/m³ DAV (Daily Average Value) is complied with.

Dioxins/Furans: The limit value of 0.1 ng/m³ is undercut in some instances by a factor of 10 and more.

Nitrous oxide (N_2O): The allowed laughing gas loads of 100 g/Mg are complied with. In order to prevent the formation of laughing gas, ammonia has to be separated from the exhaust air using scrubbers that are operated in acidic environments. However, it has to be mentioned that laughing gas, which can be produced in the preceding biological rotting processes, is not separated by the installed exhaust air cleaning technologies.

Total organic carbon (TOC): It is the load limitation of 55 gC/Mg of waste input that is the leading value for the design of exhaust air cleaning plants and not the allowed emission concentration of 20 mg/m³ (DAV). This partially results in concentration values of 5 mg/m³. These highly demanding limit values can generally be complied with at normal operation of the exhaust air cleaning plants. However, previous operating experience indicates that the normal operation is massively limited by basic conditions of the exhaust air. This issue is dealt with in the following sections.

3 Deposits in RTO Plants

Organic silicon compounds may be released during rotting processes. The concentrations usually range between 0.1 and 10 mg/m³. Possible causes may be among other things (Carlowitz, 0. et al., 2005 / Otterpohl, R. et al., 2005):

- Anaerobic conditions in the rot
- Moisture content in the rot
- Temperatures in the rot
- Composition of the waste

The silicon oxidizes in the RTO and clogs the heat exchanger with layers so that absorbing the exhaust air is hindered or no longer possible. As a result, the built-in components have to be cleaned of these deposits at certain intervals. Depending on the preceding process, the built-in components may even require cleaning every 20 days. The cleaning effort is generally very time consuming, as shutting down and restarting the RTO may take up to 24 hours. Such frequent cleaning intervals wear out the heat exchangers, thus necessitating their complete replacement approximately every two years. The time required for replacing the heat exchangers is up to seven days for each RTO line depending on the size of the facility.

Figure 2: Siloxane problems in RTO plants, destroyed heat exchangers

The RTO plants in use generally have multiple lines to comply with the availabilities demanded. Compliance with TOC loads at single line operation has partially proved to be difficult.

The approach taken by Wessel Environmental Technologies to solve this issue is to reduce the entrainment of organic silicon compounds in the RTO. Traditional procedures for the separation of silicon such as adsorbing units cannot be used due to the qualities of the exhaust air (damp and dust-laden). The formation of organic silicon compounds can usually be limited to specific phases of the rotting process (e.g. aerobisation during the first 24 to 36 hours of the intensive decomposition). To reduce the entrainment of siloxanes in the RTO plants, these exhaust air flows should be unloaded. About 10% of the total exhaust air flows have to be treated. Analyses have shown that approximately 90% of the formed siloxanes belong to the so-called D_5 compound. During a diploma thesis in 2007, research was conducted with specific absorbents in scrubbers at a half-technical scale. One reason for the choice of the absorbents is that they may be recycled. During the research, separation degrees of up to 80% for the D_5 compound were achieved.

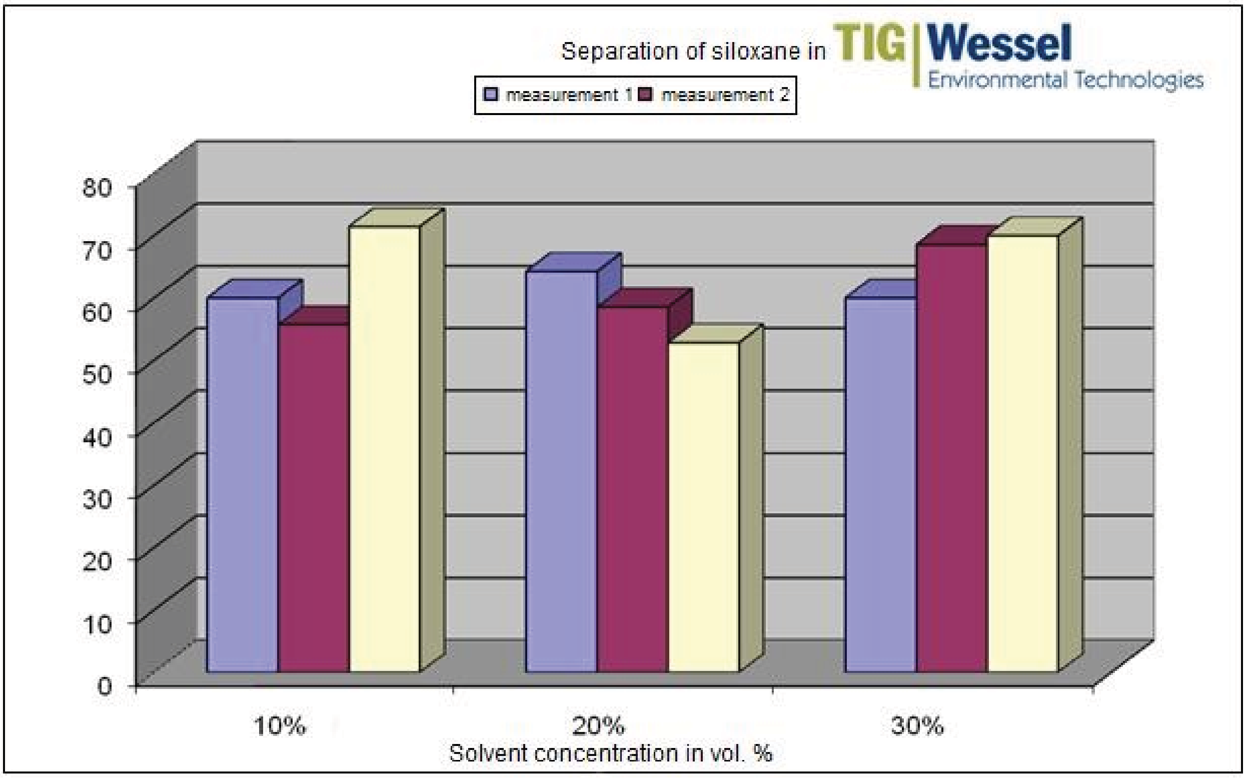

Figure 3: Separation chart for D5 compounds

In the next step, on-site field tests at MBT plants are to be carried out. This might lead to a significant prolongation of the cleaning cycles of RTO plants and to sustainable mitigation of the issue of complying with TOC loads and plant availabilities.

4 Corrosion Issues

Biological waste treatment facilities generally run the risk of being affected by corrosion. Buildings such as rotting halls are especially at risk (Fricke, K. et al.). This is caused by the damp and aggressive atmosphere. The following corrosive active components can be found among others in the process air: halogens (chlorine, fluorine), ammonia, and acids. The installed RTO plants have not been exempt from corrosion. In some cases, massive damage has occurred after only three months. The dirty gas canals are particularly affected; the clean gas canals and the combustion chamber are affected to a lesser extent. Pitting is a frequently encountered damage caused by halogen corrosion. Another cause is salt deposits of ammonium sulphate which is produced in the preceding scrubbers.

Figure 4: Corrosion in the dirty gas canal

Since the effort of avoiding corrosive substances in the exhaust air is not economically feasible, the RTO plants have to receive the best possible protection against corrosive attacks. According to what we know today (it has to be emphasized that there is not yet a “state of the art” to talk about due to the relatively short operating time of the plants) the following measures will help to avoid corrosion:

Moisture entrainment: Reduction of moisture entrainment in RTO plants by using high performance drop separators in the scrubbers. Pre-heating of exhaust air prior to the RTO and after the scrubbers to reduce relative moisture and suppress condensation effects during RTO.

Combustion chamber: With regard to high exhaust air temperatures (> 50°C / 122°F are possible) and an accordingly high moisture entrainment in the RTO facilities, external wall insulation should be added to the required internal wall insulation. This increases the temperature level of the steel wall to such an extent that condensation is impossible to occur and consequently, corrosion is avoided. Another protective measure is the use of diffusion-tight insulating material.

Dirty gas canal: Special steels such as Alloy 59 should be used in order to prevent corrosion in the dirty gas area; conventional stainless steels such as 1.4571 or 1.4539 are not permanently resistant to halogen compounds. However, the use of alloy materials is not financially possible. This is the reason why high-quality coatings such as those in the chemical industry are frequently used. When selecting the coatings, particular attention has not only to be paid to chemical resistance but also to maximum operating temperatures. In the dirty gas area of an RTO facility, temperatures of up to 200°C (392°F) may occur under certain operating conditions. Multi component polymer coatings have proven to be effective.

Figure 5: Re-engineered dirty gas canal

The RTO plants for more recent MBT plants are generally designed to permit easy dismantling and exchange of worn areas.

5 Prospective Outlook

The problems in the operation of exhaust air cleaning plants addressed by the 30th BImSchV (German Federal Immission Control Ordinance) have been recognized. The first approaches to solve the encountered issues in the field of corrosion have been found and are soon to be implemented. Meanwhile, after six months of permanent usage, the state-of-the-art RTO plants have proven their value. The previously encountered corrosion issues have not been detected so far.

Figure 6: The latest generation of RTO plants

More intensive work will be required to find solutions for the siloxane problems in RTO plants. It is up to the operators of MBT plants, designers, research institutes and plant engineers to work together on this issue.

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Gaseous emissions reduction from aerobic MBT of municipal solid waste

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Abstract

Surface gaseous emissions, composition of soil gas and VOC concentration were determined on a French MBT plant, where the biodegradation process is aerobic. Measurements were performed on both the composting windrows and on the landfill cell which receives the sorting rejects. This allowed the comparison of the global methane and CO2 gases, as well as the characterization of the degradation process on the different parts of the site. The performance of the sorting chain allow to obtain a high-grade compost, which can be valorised on agricultural fields, and leads to deposit much smaller quantities of degradable waste than in a classical landfill site, and to lowering seriously the generation of methane. Therefore, landfill gas (LFG) does not need to be recovered and treated by classical means, e.g. flares.

Keywords:

aerobic MBT, gaseous emissions, landfill cell, surface flux, VOC

1 Introduction

Mechanical biological (MBT) treatment of municipal solid waste (MSW) is mainly used to stabilize the organic matter prior to landfilling. Other processes allow energy recovery (by collecting biogas generated during anaerobic digestion) and/or return of organic matter to the soil. Different processes exist. We have evaluated the gaseous emissions of one of the French MBT aerobic plants within two different studies. The first study aimed to measure the gaseous emissions during the composting process, and the second one focused on the biogas generation from the associated landfill. In order to characterize the gaseous emissions, several direct and indirect measurement methods were used during two campaigns, respectively on the composting plant, then on the two first cells of the landfill. Some methods were used on both the composting plant and the landfill, allowing the comparison between surface fluxes and biogas composition.

2 Composting process

Municipal solid waste is received in bags from door-to-door collection. The first step is an aerobic biological pretreatment in two composting drums, where bags are opened and waste is physically and biologically pre-degraded. The duration of this step is 3 to 4 days, in order to initiate the degradation of paper and cardboard. Then, a high grade sorting process is undertaken, the final separation being done at a 10 mm mesh. Thus, the fine and biodegradable fraction of the waste is well separated and goes to the composting hall, where it is mixed with screened green waste compost at a 2:1 ratio. Composting of the biodegradable fraction is done in turned windrows, passively aerated. The rejected coarse fraction is landfilled close to the plant.

3 Material and methods

The investigation covered three composting windrows of different ages and two cells of the in-site landfill:

– windrow A, situated in an open shelter, was constituted between one and two weeks prior to the first measuring day, and was turned by an automatic machine twice a week,

– windrow B, also under the shelter , was constituted between 15 days and one month before the first measurement, and was also turned twice a week,

– windrow C, outside the shelter, was at least 2 months old when the measurements started and was not turned,

– cell 1 of the landfill was rehabilitated. It has a 1 m clay cover plus planted soil;

– cell 2 was full of the composting rejects, but uncovered yet at the time of measurements. Therefore we expected the maximum surface emissions from this cell.

Gaseous emissions were characterized by different techniques:

- Three different devices were used for surface emission measurements on the composting windrows: two flux chambers (one static, one dynamic) and one tunnel; low concentrations of methane (CH_4), carbon dioxide (CO_2), ammonia (NH_3) and nitrous oxide (N_2O) were monitored by an FID (Autofim II) specifically for methane and a photo acoustic analyzer (Innova) for all these gases; higher concentrations of CH_4 and CO_2 were measured with an infrared portable apparatus (Ecoprobe 5). The static chamber was also used for surface flux measurements on the cell n° 2 of the landfill,

- Composition of the soil gas (CH_4, CO_2) was assessed by the use of a probe and the portable analyzer Ecoprobe 5; these measurements were performed on both the windrows (where “soil” means compost) and the landfill cell,
- Concentrations of trace gases (VOC) were established on some samples taken on the static chamber, also on the windrows and the landfill cell surface.

Due to the relatively high porosity of the material compared to the soil which are usually scanned with the static chamber, there were some differences between the fluxes determined with the static chamber and the dynamic one on the compost windrows (fluxes measured with the static chamber being the lowest). Results of the comparison of the techniques will be published elsewhere (report: MALLARD *ET AL*, 2008). The flux measured with the static chamber represents more or less the gaseous flux emitted by the surface of the windrows in a total absence of convective gas flows. Nevertheless, due to the short measurement time, a large number of local fluxes can be determined with this method, allowing the interpolation and cartography of the surface emissions.

3.1 Surface fluxes measurements

Measurements of methane and carbon dioxide surface fluxes were performed with a patented static chamber (see Figure 1). Monitoring of the gas concentration increases in the chamber was done in parallel with a flame ionization detector (FID) for low concentrations of methane (down to 1-2 ppmv), and a CH_4/CO_2 infra-red analyzer (Ecoprobe 5) for larger concentrations (up to 100 % v/v). Interpolation of these points gives access to the cartography of global emissions and to the mean surface fluxes. Methane and CO_2 fluxes were calculated for windrows of different ages, and for the landfill cell, allowing the comparison of emissions between the composting process and the landfill.

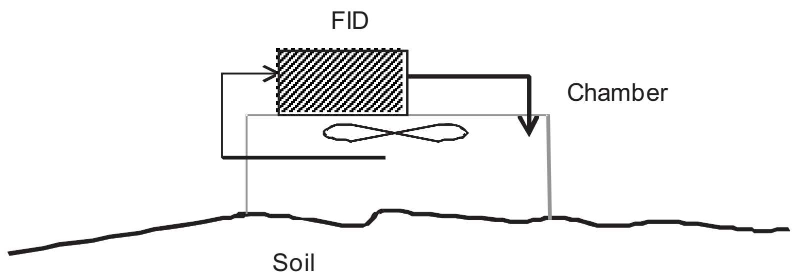

Figure 1 : apparatus for gaseous surface emissions (static chamber)

3.2 Composition of biogas

Composition of the biogas was determined at 1 meter depth with a soil gas probe and the Ecoprobe 5 analyzer. The analyzer also comprises an electrochemical cell to measure oxygen concentrations in the soil gas.

Photo 1 : CH_4 and CO_2 measurements on soil gas (Ecoprobe 5)

3.3 Trace VOC emission

Some VOC samples were taken on the flux chamber for identification and quantification, following US-EPA TO15 and TO17 air toxic methods. Sampling was done using the following methods:

- on the windrows, sampling was performed by pumping 1 liter of chamber air on 3-zones adsorbent tubes (“Air Toxics” type) at 100ml/min, thus the sampling time is 10 minutes. On some points, during the time period of air sampling, the combustible gases (methane + trace VOC) concentration increase was monitored by the FID, which allowed an estimation of the VOC fluxes, using the hypothesis that VOC concentrations follow the global combustible gas monitored by the FID,

- on the landfill cell, air from the chamber was sampled by diffusion in an emptied steel canister. This method theoretically gives access do compounds of low molecular weight which are not stable on solid adsorbents, such as vinyl chloride.

Analysis was done by preconcentration on Perkin Elmer ATD400 or Turbomatrix (with the thermodesorption of the adsorbent tubes), gas chromatography and mass spectrometry. This method allows the identification of VOC, and the quantification down to 1 $\mu g/m^3$ for the most usual compounds, by using standard gas mixtures of aromatic and chlorinated compounds. On the landfill cell 2, toxic compounds: BTEX and chlorinated solvents, were specifically searched. On the windrows, the analysis purpose was different: identification of the major VOC by the mass detector, and quantification of the most abundant ones.

4 Results

4.1 Surface emissions of CH_4 and CO_2: comparison between the windrows and the landfill cell

The first finding is that methane emissions from the open cell of the landfill are very low: see Figure 2. It comes from the fact that a large part of the organic matter is diverted from the waste to the composting process. Waste which is landfilled contains mostly materials such as plastics, foams… which are not easily biodegraded.

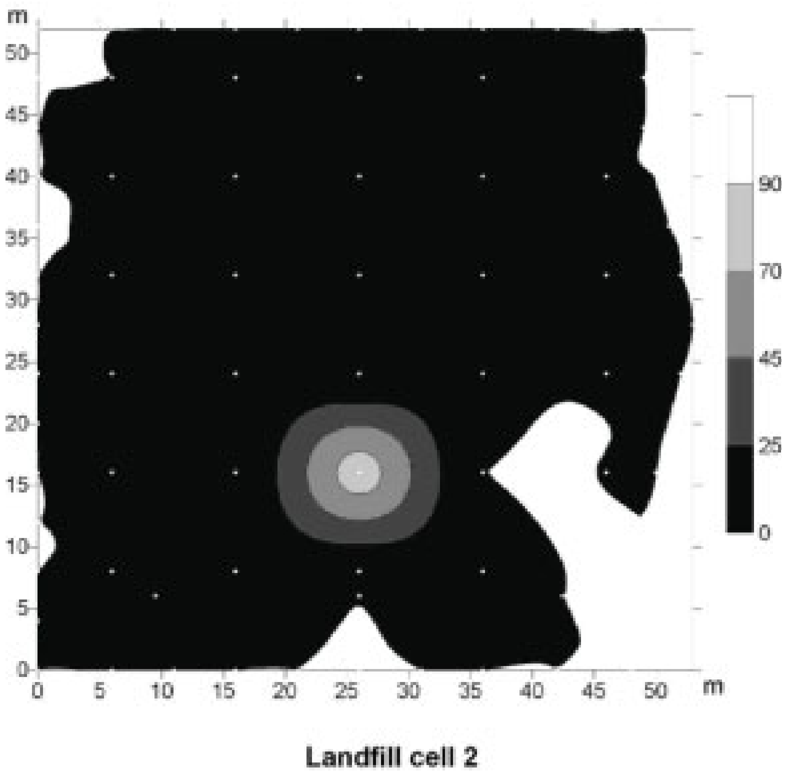

Figure 2 : Interpolated methane emissions on landfill cell 2, ml/m²/min

Methane emissions from the three composting windrows are very different, as shown on Figure 3, due to the “age” of the material - e.g. the stabilization of the organic matter. Methane emission increases with the age of the windrow, but also when the windrow is not turned (windrow C). Furthermore, methane emissions are higher at the top of the windrow, which is natural, as temperature – measured in the same time with an infrared camera – and gas fluxes are known to be higher at tops.

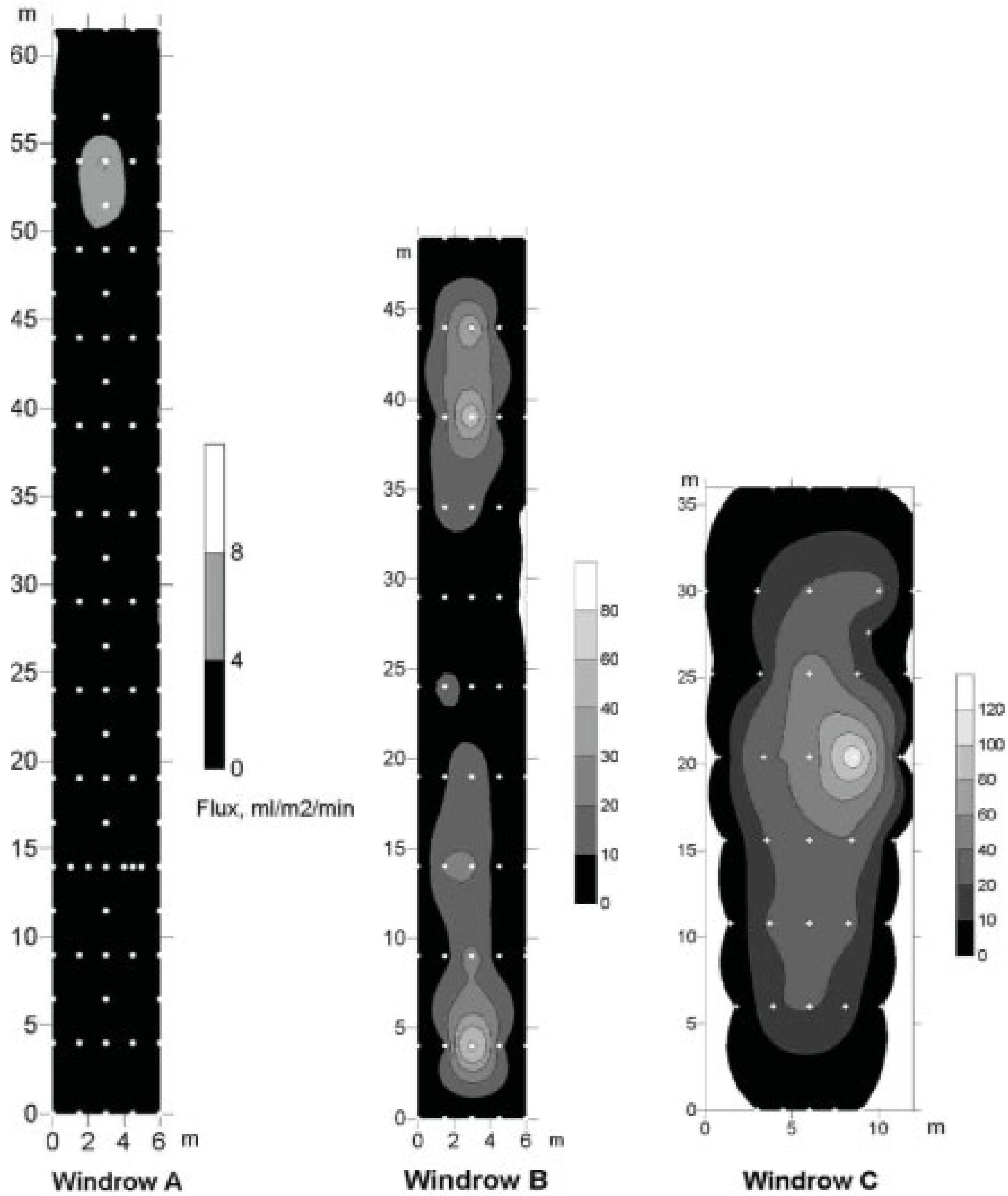

Figure 3 : Interpolated methane emissions on windrows, mL/m²/min

Meanwhile, CO_2 emissions are more stable, indicating the constancy of the aerobic degradation. Therefore, the interpolations of CO_2 fluxes on the different parts of the site are not detailed here.

The major finding is the comparison of the surface emissions between the composting plant and the landfill cell measured with the static chamber. Results are given in the Table 1.

Table 1 : CH4 and CO2 fluxes on composting windrows and the landfill cell

	Composting plant : windrows			Landfill, cell 2 : waste refuse
	A	**B**	**C ***	
Age of the windrow/storage	2 weeks	1 month	2-3 months	< 2 years
Interpolated surface area, m^2	368	293	382	2760
Mean CH_4 flux, $L \cdot h^{-1} \cdot m^{-2}$	0,08	0,60	1,1	0,25**
Mean CO_2 flux, $L \cdot h^{-1} \cdot m^{-2}$	6,4	8,3	6,0	2,3
Total CH_4 flux on each part, m^3/h	0.029	0.176	0.42	0.69
Total CO_2 flux on each part, m^3/h	2.36	2.43	2.29	8.65

** maturation step, not turned; ** methane is partially oxidized through the surface layer*

Mean carbon dioxide fluxes are quite similar on each windrow, whatever their age. Mean emissions from the landfill are a little smaller, indicating that aerobic degradation process is less important in the landfill cell.

Methane emissions vary more, from a small value on the younger windrow (2 weeks) to a higher one on the older windrow. This latter value is mainly due to a singular point which shows a high methane flux on this windrow (7.3 $L \cdot h^{-1} \cdot m^{-2}$). In comparison, mean methane emission is smaller on the landfill, than on two of the 3 windrows, due to low organic content of waste and partial oxidation in the cell cover (results will be published elsewhere : BOUR *ET AL*, 2009). Landfilling of the rejected fraction from composting, which contains a small proportion of organic matter and is partially stabilized, leads to small methane emissions, which do not need to be recovered. A simple oxidizing cover could be sufficient to manage this residual emission, with special care on rainwater management.

Because of the surface area involved, both methane and CO_2 emissions are comparable with the sum of the emissions of the windrows. This shows that in the case of MBT prior to landfilling of municipal waste, it is important to take into account both the emissions of the landfill site and of the MBT plant, particularly in this case where the composting material is rather fine and thus poorly aerated, leading to significant emission rates of methane.

4.2 Gas composition in the compost

As for the surface fluxes, windrows of different ages and the landfill cell n° 2 were studied. Methane and CO2 concentrations at 1 m depth are given by the Ecoprobe 5. The repartition in composition for both the windrows and the landfill cell are given in figures 4 and 5 under box-plot graphs.

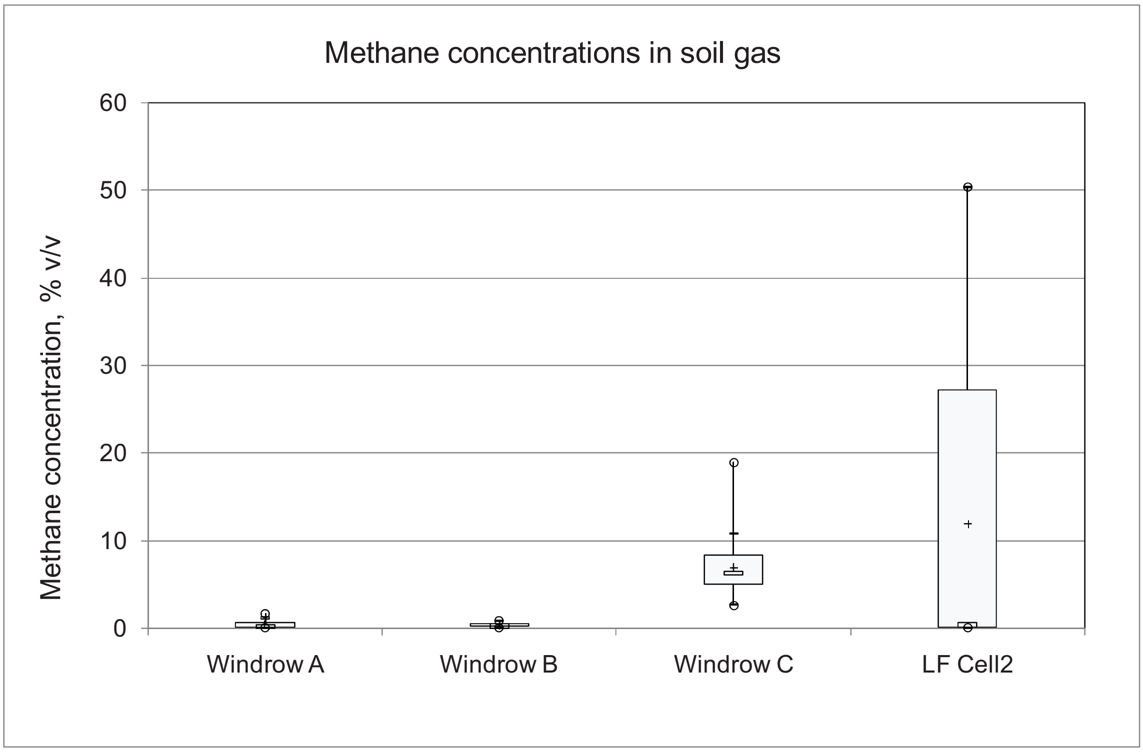

Figure 4 : repartition of methane values in soil gas, windrows and landfill cell

Methane concentrations are very low (mostly null) in the younger windrows, A and B. Windrow C, which is older and not turned (thus having less oxygen available for biodegratation processes) contains more methane: mean concentration is 6.9 % v/v, median value is 6.2. The higher concentration measured at 1 m depth on windrow C corresponds to the higher methane surface flux. The landfill cell has a very different behavior: methane concentrations are very dispersed, from 0 to 50 % v/v, the mean and median values are different.

CO_2 concentrations show a different behavior: most values are very similar for the three different windrows, and close to 17 % v/v, which correspond to the consumption of the atmospheric oxygen in aerobic degradation. Mean and median values are also very close, which confirms that the degradation processes are the same within the three windrows. On the contrary, CO_2 concentrations at 1 m depth in the landfill cell are very similar to the methane concentrations at the same location, indicating that the soil gas is a mixture of methane and CO_2 in similar proportions. This is the signature of a typical biogas emitted by the anaerobic degradation of municipal waste.

Both methane and CO_2 concentration values inside the landfill cell are much dispersed: one can imagine that the landfilled waste, which is very heterogeneous, has a variable amount of residual organic matter.

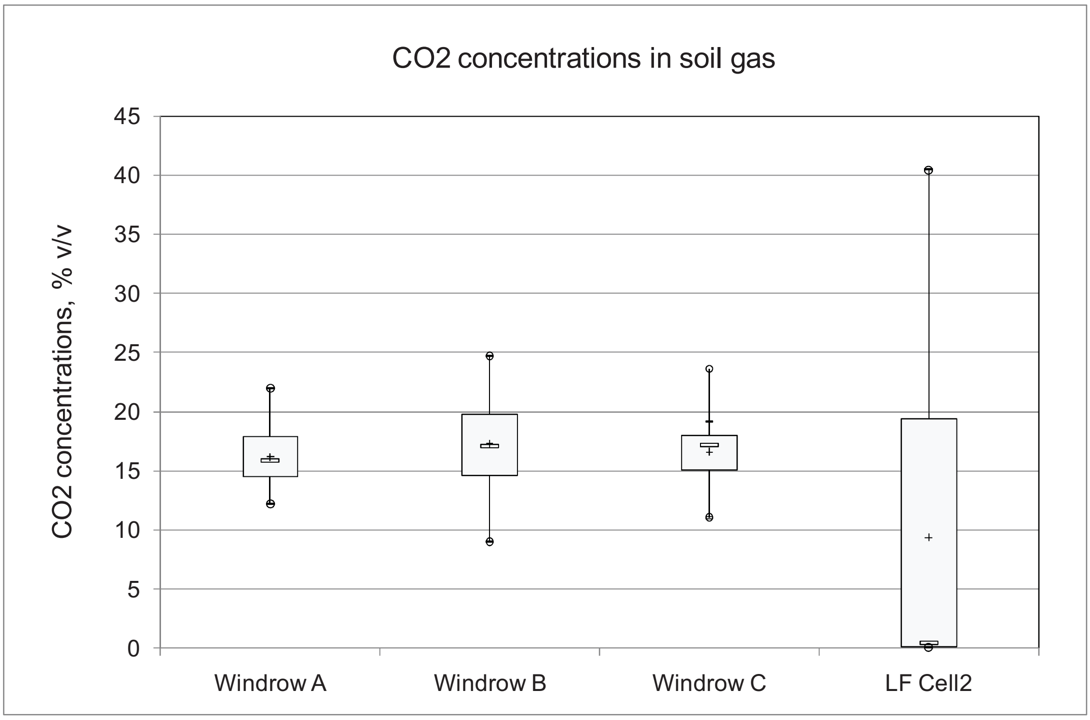

Figure 5 : repartition of CO2 values in soil gas, windrows and landfill cell

4.3 Effect of windrow turning on the gas concentrations

The effect of windrow turning has been assessed by CH_4 and CO_2 in 1-meter depth measurements repeated within 24 hours after the turn.

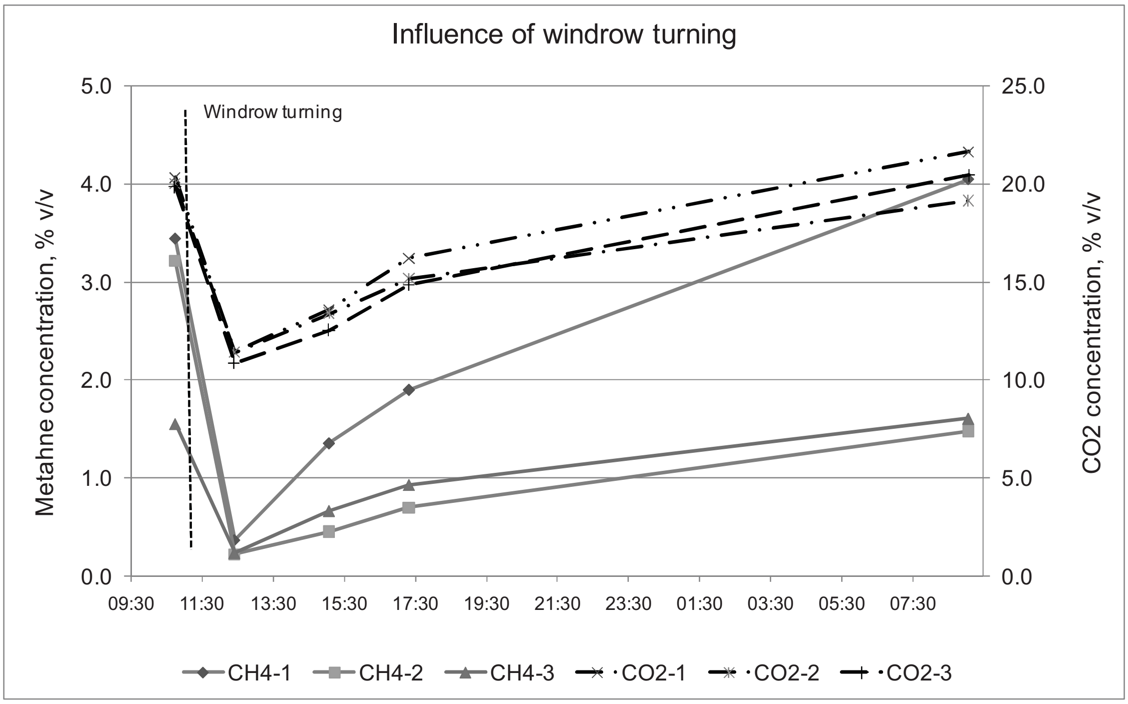

Figure 6 : effect of windrow turning on CH4 and CO2 concentrations in the compost

CO_2 and CH_4 concentrations are considerably lowered just after turning of the windrow. However, after 24 hours, these concentrations are quite the same as before the turning. This shows that the available oxygen does not last long inside the windrow. The substrate is relatively fine and homogeneous, it is therefore important to turn regularly the windrows, which is done at least twice a week on this plant.

Since these measurements, improvements have been brought to the process. The following changes will be made in the composting process itself. In order to obtain an optimum biodegradation, organic matter extracted from the municipal waste will be mixed with crushed vegetal residues, and the process will be operated in closed boxes with forced aeration, in order to keep a higher amount of oxygen within the material, helping the aerobic biodegradation.

4.4 Surface VOC emissions

4.4.1 Composition

As the analytical procedures for identification were different between the samples from the windrows and the landfill cell, it is not possible to compare exactly all the VOC present in all the samples. But tendencies can be established. Major results are given in Table 2.

Concerning the presence of toxic compounds, the major finding is that trichloroethylene and tetrachloroethylene were never detected on any of the samples. Benzene and toluene are, except in one case, never detected on the samples taken on the windrows. Meanwhile, they are present on the two samples taken on the landfill cell 2, but at rather low concentrations. This is always the case for MSW landfills Their presence in the landfill gas shows that, or the stored waste probably contains some industrial waste, or they come from the degradation of higher molecular weight compounds. More work would be needed to clear this point. Nevertheless, the low concentration level indicates that these compounds will not be responsible for a health risk.

There are more VOC, and at larger concentrations, in the gas samples taken on the windrows that on the landfill cell. Several compounds such as the terpenes (a-pinene, limonene) come from the green waste which is crushed and mixed to the organic matter of the municipal waste. The other compounds probably come from the municipal waste, and are combined with the organic matter which undergoes composting. A-pinene and limonene on the landfill cell probably come from the crushed bark used as a temporary cover.

Table 2 : VOC composition of air samples taken on the static flux chamber

Compounds	Wind. A, 2	Wind. A, 21	Wind. B', 82	Wind. C, top	Wind. B, C8	Cell 2 Can 4	Cell 2 Can I
Ethanol	2354	1496			70		
Pent-1-ene			356	1058			
Pentane		969	846	569			
Acetone	1989	481			1693		
Dimethylsulfide			1350	383			
Methyl vinyl cetone	1302				1287		
Butan-2-one (MEK)	4503	1158			6481		
Butan-2-ol	2774	1000			5628		
Benzene			147			32	5
Pentan-2-one					283		
Methyl-3 butanol	505				416		
n-Heptane						66	15
Toluene						203	20
Octane			124	127		33	8
m+p Xylenes			53		77	299	14
o-Xylene + Styrene			90	30	51	214	10
a-Pinene			289	50	313	1506	57
Decane					128	50	46
Limonene	1961	3	12266	862	2341	540	341
Undecane			264				

Concentrations are given in $\mu g/m^3$

4.4.2 Estimation of VOC surface fluxes

While the air was sampled on adsorbent tubes, the flammable gas concentration was monitored by the FID on some sampling points. We used the hypothesis that VOC concentrations follow the global flammable gas concentration in order to evaluate the VOC fluxes. Partial results, calculated on one point, are given in Table 3.

As the measured concentration of VOC in the static air chamber are low (in the $\mu g/m^3$ range), the corresponding fluxes are naturally very low. Though these fluxes were not measured directly, this calculation helps to evaluate local VOC emissions from the composting windrows. This work needs to be continued to get better precision.

Table 3 : approximate VOC fluxes, point n° 2 on the windrow A

Compound	Flux, µl/m²/min
Ethanol	29.4
Acetone	19.7
Acetate de methyle	5.8
Methyl vinyl cetone	10.7
Butan-2-one (MEK)	36.0
Butan-2-ol	21.8
Acetate d'ethyle	8.4
Methyl-3 butanol	3.3
Limonene	8.3

5 Conclusions

The two different studies on the gaseous emissions of a French MBT plant and the associated landfill gave the opportunity to compare the relative impacts of the plant and of the landfill. Due to the fact that a large part of the organic matter is sorted out from the MSW to undergo composting, the gaseous emissions of the landfill cell are really lowered compared to a classical landfill without MBT. In addition, the sorting of the waste is sufficiently efficient to obtain a high grade compost, which allows its use in amending agricultural soils.

6 References

Bour, Zdanevitch, Briand, Llinas	2009	“Estimating methane emission and oxidation from two temporary covers on landfilling of MBT treated waste”. Submitted for presentation to the Sardinia 2009 symposium
Mallard, Zdanevitch, Pradelle, Frejafon	2008	« Projet EMISITE: évaluation sur site de différentes méthodes de mesure des émissions gazeuses d’une installation de compostage » Final report, ADEME n° 0675c0081, August 2008

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Fire Extinguishing Concepts for Recycling Plants

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This fire extinguishing concept analyses problems that may occur with fires in recycling plants and shows improved procedures for safe and economical automatic fire fighting.

1 Fire Extinguishing Concepts for Recycling Plants

1.1 Problem Outline

In view of growing piles of waste and the related problems of disposal, the importance of recycling companies in the economy is increasing. Objective-oriented waste treatment and recycling of raw materials make an important contribution to the protection of earth's resources. Solid fractions used for interim storage, e.g. paper, cardboard, or plastics, may have calorific values of over 14 MJ/Kg with corresponding fire load and thus bear a major risk potential for human beings as well as for buildings. After evaluating the type, amount and configuration of combustibles, those agents and methods should be chosen that have the most effect on the scope of the specific fire potential. We know from a study by the Düsseldorf Institut für Abfallwirtschaft [Institute for Waste Management] that even spontaneous ignition of recycling products is possible under certain storage circumstances.

1.2 Fire Risk

Fires may spread at a high speed and are thus a major risk for staff working nearby and for material assets. Firefighters often do not have much time to bring a spreading fire under control. As we find in the media, fires in recycling plants often result in a total loss. In a number of cases, people have been injured or lives lost. On top of that, combustion products (dioxines, furans) pose an extreme threat to the environment. In order to use storage facilities and sorting equipment for a longer period of time, improved fire detecting and extinguishing systems for key areas are needed. In extreme cases, firefighters either cannot, or can hardly reach the source of fire. The fire detecting and extinguishing system must be able to determine the fire early, extinguish it in the respective dump, bunker, container or shredder and stop it from spreading. The required method hence must both insulate and cool the building, equipment or stored material on fire, and extinguish the fire.

2 Choice of Extinction Method

2.1 Possible Extinction Methods

For the extinction of fires in recycling plants, conventional methods like low expansion foam or deluge systems with a 1% foaming agent have been used so far. Medium expansion foam is another means that has been used for combating fires in recycling or incineration plants – sometimes with more success, sometimes with less success.

2.2 Assessment of Fire Extinction Methods

Choosing a fire extinction system based on safety, economics, and loss prevention (secondary damage) requires an evaluation of all possible automatic fire extinction methods. Regulations and guidelines as well as experiments and insights were used for this evaluation.

Characteristics/type	Low expansion foam	Deluge System 1%	Medium expansion foam	ONE-SEVEN
Fire classification	A-B	A-B	A-B	A-B-C
Water demand	60%	100%	30%	15%
Cooling effect	40%	80%	10%	100%
Suppression effect	80%	10% (steam)	60%	100%
Wetting ability	good	good	low	very good
Floor load	very high	very high	very high	low
Foaming agent	5%	1%	3%	0.5%

2.3 Choice of Method

Since the fire extinction methods described above are either not efficient or too costly, we would like to introduce a system that masters fire risk and is economically sensible. This system is the ONE-SEVEN Compressed Air Foam System.

It can be described as follows:

3. ONE-SEVEN Compressed Air Foam Extinction System

This compressed air foam extinction system has been used in fire fighting for decades. Now it is a state-of-the-art procedure which is regulated by German standard DIN 14430. For insurance reasons the system is currently being checked at the testing and certification institution VdS in Cologne. A timely authorisation is likely, as the procedure is in the last stage at FM Global (potential authorisation by the first quarter of 2009). With the help of this system, the foam produced (with a consistent bubble diameter of 0.5 mm) can be transported over long pipe distances (1,000 m length, 400 m height) and dispersed through the applicable nozzles (throwing range up to 30 meters). Because of its quenching effect, which is many times higher than conventional water-based fire extinction methods, its extremely moderate water consumption and minimum secondary damage, this method is a convenient solution for high fire loads. A comparison of extinction by water and the ONE-SEVEN system at the research centre in Karlsruhe resulted in the following data for the same fire situation:

ONE SEVEN® test at Forschungsstelle für Brandschutztechnik in Karlsruhe
Test with DIN-C pipe at 100 l/min

	Water	Compressed air foam
Cooling capacity	0.83°/sec	10.3°/sec
Water consumption for extinction	800 litres	175 litres
Water consumption for ultimate extinction	600 litres	235 litres
Foaming agent consumption	0	1.24 litres
Water residue	Large amounts of residue	no non-vaporized water 200 litres vaporized 200 litres in burnt materials

Fire extinction with ONE SEVEN enabled a cooling capacity 12 times higher than extinction by water alone. The compact foam mainly stays on the fire source and can be removed with a wet vacuum cleaner. At the fire source, about 50% of the water used is vaporized and 50% remains in the burnt materials, reducing water damage to a minimum. Extinction is achieved by a foam layer that suppresses the fire and strongly cools its source. In this respect, the high cooling capacity of compressed air foam is crucial. Another advantage is fast suppression or insulation of toxic gases and smoke particles. The alcohol resistant foaming agent ONE-SEVEN Class B-AR is classified as water danger class 1.

Stationary ONE-SEVEN compressed air foam extinction units offer a number of important and in some cases decisive advantages for the use and application of this system for automatic and semi-automatic fire fighting:

- By using a special “class B” foaming agent that requires only a 0.6% additive to the water, it is possible to produce a compressed air foam that effectively combats fires of plastics and other recycling materials.

- The consistency of this compressed air foam can be varied from wet and fluid to dry and sticky by using different pressures of compressed air for the water/foaming agent mixture. Because of fire extinction, side effects (cooling, separating, suppressing and wetting effect) and flow properties of the compressed air foam, up to 80% of the extinguishing agent come into effect (compared to 25-30% for sprinkler/water spray systems).

- In this way, fires can be extinguished a lot quicker and with less extinguishing agent compared to other extinguishing methods or agents – some of which might not even be suitable for automatic fire fighting of recycling materials at all. Because of its penetrating and strong cooling capacity, the vast majority of hot spots can be reached and extinguished.

- In contrast to conventional foam extinguishing methods, the foam created by the ONE SEVEN compressed air foam system is produced by a central foaming unit (foam generator or foaming module) which is located outside the danger area and thus is independent of ambient air. This is an advantage for plastics on fire since flue and conflagration gas that develop in large amounts and spread quickly in this type of fire cannot influence or damage foam production.

- Further spreading of the fire is prevented through early detection and very fast fire suppression and extinction.

- The foam can be transported via pipes to special rotors which sufficiently impinge on the burnt material. With one unit and special rotors, areas of 100 to 200 square meters can easily be impinged with foam. This drastically reduces necessary pipe installations compared to water extinction systems with full coverage.

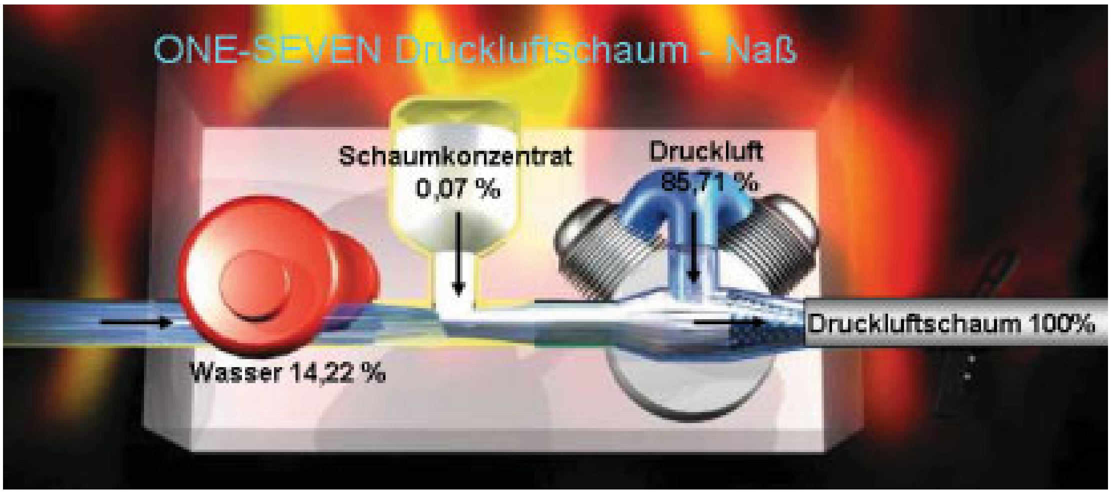

Figure 4: Compressed air foam ONE SEVEN (wet):
Water 14.22%; Foam concentrate 0.07%; Compressed air 85.71%; Compressed air foam 100%

3.1 Extinguishing Capacity

In 2005, the producer of this system in cooperation with Esting and Research Institute carried out comprehensive tests on major fires in the Runehamar tunnel of Norway. These tests were monitored and documented by three internationally reputable test institutes:

1. TNO from the Netherlands
2. NBL Sintef from Norway
3. NRC from Canada

The goal of these tests was to prove the performance of ONE SEVEN fire extinguishing systems for the extinction of different kinds of blazing fires.

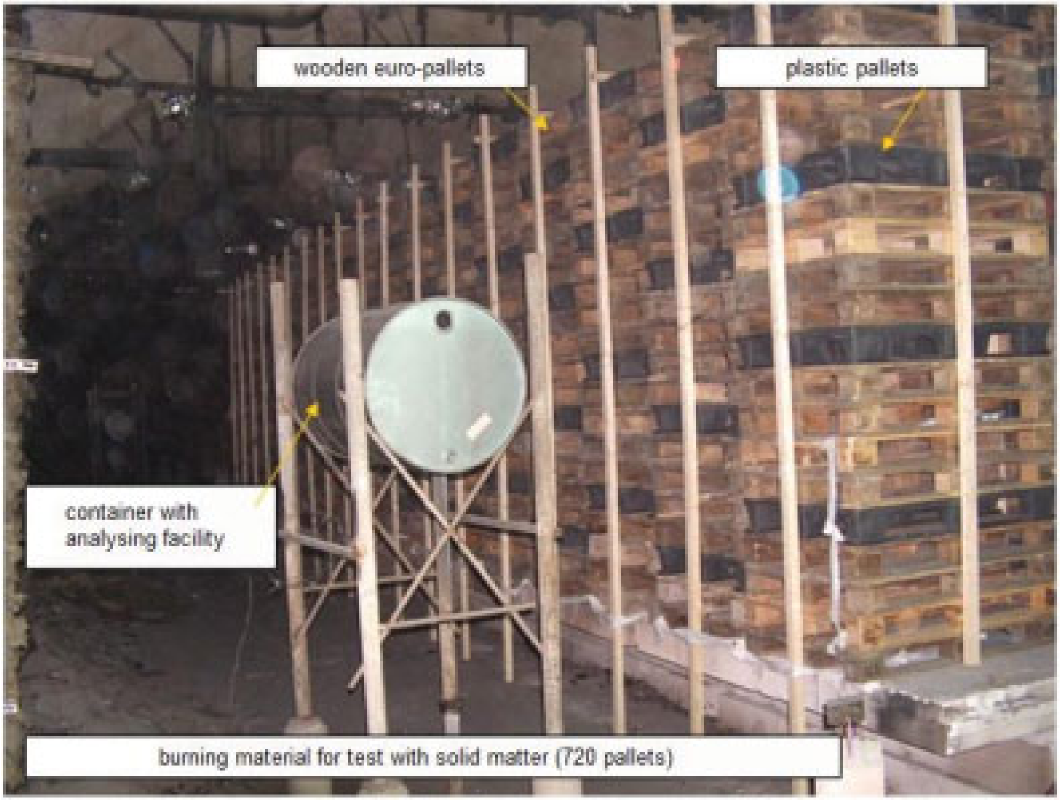

Figure 6: Test 1 (solid matter)

A fire on a fully loaded truck was simulated. For this test, 720 euro-pallets (80% wood, 20% polypropylene) were piled up to 14.4 m length, 3 m height and 2.4 m width.

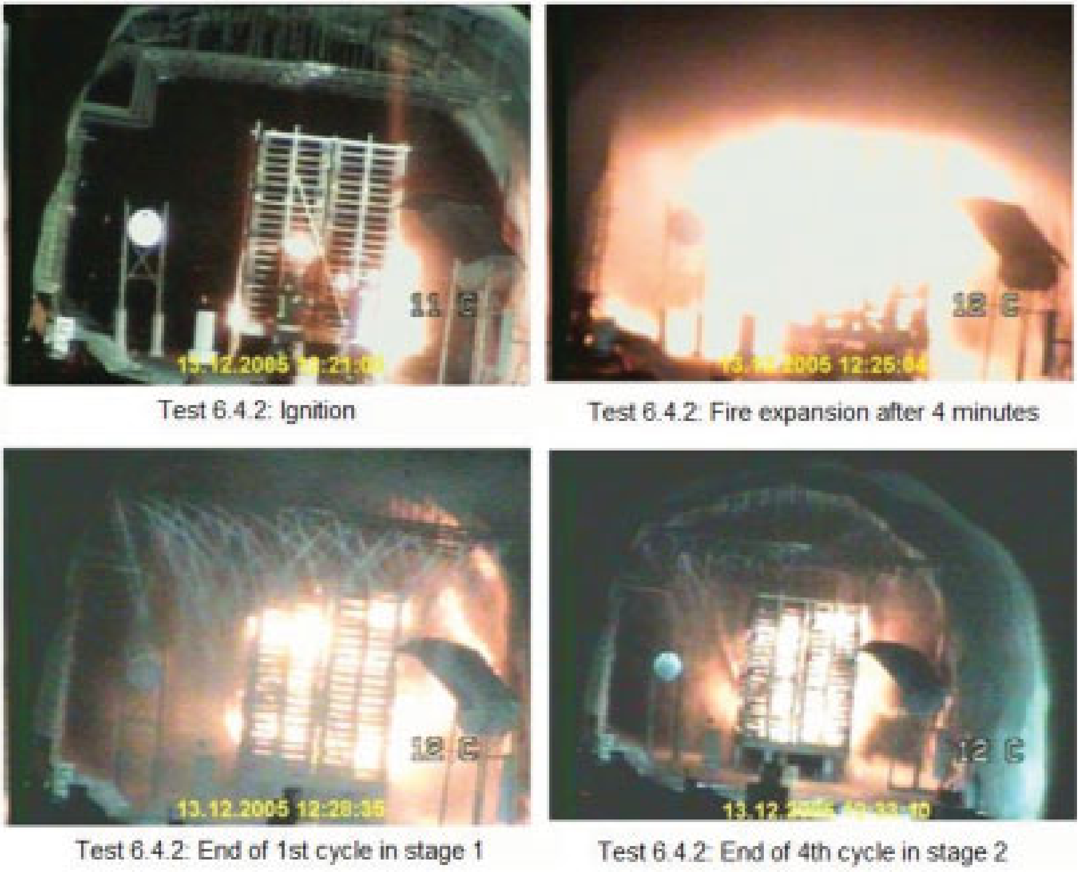

Figure 7: Test series – solid matter

The One Seven system was able to control this extreme scenario. Despite heat production above 160 MW and temperatures over 1,000°C (1,832°F) the fire was brought under control within less than 7 minutes. It was fully extinguished after less than 22 minutes.

Figure 8: Test 2 (liquids)

For the second test, a 25 m x 4 m tank was filled with 5,000 litres of diesel fuel. Immediately after ignition, temperatures rose dramatically and smoke emission was extreme. Test results show that this blazing fire, with a heat production of 140 MW and temperatures of up to 1,200°C (2,192°F), was extinguished within 2 minutes.

3.2 System Suitability and Use

Because of its extraordinary extinguishing properties for recycling facilities, recycling company Lober in Bavaria has equipped each of their halls and storage areas with ONE SEVEN compressed air foam system.

ONE SEVEN Extinction system for automatic fire fighting in a storage hall for recycling products

Additional real-world results can be found in Oranienburg, where 13 tyre yards which were set on fire by arson were extinguished by a One-Seven unit within 6 hours after burning for one and a half days. One-Seven units have since been installed in secondary material storage areas in the Bremen and Bitterfeld power plants.

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Experience of MBT-Landfills and Stability Investigations

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Stability and Operation of the MBT-Landfill Hillern

Abstract

The technical requirements for landfilling of MBT-residues on landfills in Lower Saxony are described and the realisation of the requirements on the MBT-landfill Hillern is explained. In terms of a certain compliance with the geomechanical stability of the MBT-landfill body, recommendations for the landfill operation are developed based on extensive site-specific investigations and stability calculations.

Keywords

MBT-landfill, landfill operation, stability calculation, stability proof

1 Introduction

Since mid 2005, only pretreated domestic and municipal waste may be landfilled. Due to this pretreatment, the waste material and treatment residues to be landfilled differ significantly from the waste usually landfilled with respect to physicochemical and biological as well as mechanical properties. At the time of the changeover there was still little experience regarding properties in landfill behaviour of mechanical-biologically pretreated material (MBP / MBT) on an industrial scale. Detailed guidelines had yet to be developed regarding landfilling practice and constructing corresponding landfill bodies considering site-specific boundary conditions, composition of the waste and physical as well as mechanical properties.

The present paper outlines the requirements for landfilling of MBT-residues on landfills in Lower Saxony and the realisation of the requirements on the MBT-landfill Hillern in the district of Soltau-Fallingbostel. In this context, the results of the geotechnical investigation for constructing MBT-landfills and the resulting requirements for the landfilling practice are presented.

The *Ingenieurbüro für Abfallwirtschaft* Prof. R. Stegmann und Partner (IFAS - Consultants for Waste Management) co-ordinated the attempts of landfilling MBT-residues on the MBT-landfill Hillern in mid 2005 and has been giving advice on the landfill practice since then (Hupe et al., 2006; Hupe et al., 2008). The geotechnical investigation and the geotechnical tests for landfilling MBT-residues have been carried out in collaboration with the engineering office Prof. Dr.-Ing. Walter Rodatz und Partner, Consulting Engineers for Geotechnical Enginieering (RuP) and the Institute for Soil Engineering and Soil Mechanics of the Braunschweig University of Technology (IGB·TUBS).

2 Boundary Conditions

2.1 General Provisions for MBT-Landfill Stability

Hardly any stability problems like slope failures used to arise on landfills for municipal waste, where, up to mid 2005, only untreated waste was deposited. This was mainly due to the relatively high tensile strength of fresh domestic refuse, particularly as a result of strengthening fibres, fibre cohesion (Kölsch, 1995) and some coarse components as well as the relatively high permeability owing to the heterogenous structure.

MBT-residues, on the other hand, have a fundamentally different structure and different geotechnical properties: Tensile strength, for instance, is reduced because of the elimination of reinforcing fibres; and pre-treatment makes the material much finer, more homogenous and also less permeable. The mechanical and hydraulic properties of MBT-residues vary from conventional domestic refuse in coarse fractions to fine textured sewage sludge.

Stability issues in landfills are often closely connected to the water balance and the drainage properties of the deposited waste. Rodatz and Oltmanns (1993) for instance point out the slip of 80,000 m^3 of conditioned sewage sludge (strength $\varphi' = 34°$, permeability $k_f = 1 \times 10^{-9}$ m/s) of a 19 m high slope as a result of excessive pore water pressure during disposal works.

Pore water pressure $u = \gamma_w \times h_w$ occurs in water-saturated components, especially with a high placement water content or because of water-logging and unfavourable drainage. This has to be taken into account with stability proofs (see also NMU, 2007/8). Excessive pore water pressure Δu occurs with stress increments $\Delta\sigma$ e.g. as a result of further filling steps or because of deformation of the landfill body. Undrained strength and excessive pore water pressure, inter alia, have to to be known and considered in total stress analyses.

It is customary in practice to determine the drained strength parameters angle of repose φ' and cohesion c' as well as stiffness E_S of MBT-residues in the laboratory and then deduct the characteristic stability proof and usability test values from this, using appropriate geotechnical methods. The characteristic strength values, bulk density values and water levels, if applicable, then help to determine the

- stability (here: slope failure stability) for the global safety (until 2007) or with partial safeties (from 2008 at the latest) required as well as the
- usuabilty (here: system-compatible deformation)

of the planned landfill construction.

The necessary safety values are basically in line with geotechnical situations resp. loading case.

2.2 MBT-Section of the Hillern landfill

The mechanical-biological waste treatment of the waste deposited in the Hillern landfill is carried out in the residual waste disposal plant Bassum (RABA, *Restabfallbeseitungsanlage*). The landfill area of the MBT-landfill is 5,000 m^2 at the basis. The annual increase of landfill thickness is at around 4-5 m with a disposal of 26,000-30,000 Mg/a. The MBT-landfull body will overlie the adjacent landfill segment, which, up until mid 2005, had been filled with untreated municipal waste, with two slope segments.

On the basis of the investigation conducted by IFAS in the summer of 2005 on the disposal of MBT-residues on the MBT test site subject to regulations, the regular disposal is carried out by a caterpillar and a 30 Mg compactor, which has been used before in landfill practice. The landfill density that can be attained during regular operation is at 0.65 kg_{TM}/l (or 95 % of that value in accordance with Annex 3 of the Waste Storage Ordinance, AbfAblV) at a desirable water content of 25-30 % in relation to wet mass (Hupe et al., 2006). From 2005-2008 an average landfill density of 0.66-0.90 kg_{TM}/ at a water of 17-32 % in relation to wet mass was reached in landfilling practice. With this, the established landfill density values are within the range of densities that were determined on other sites:

- Landfill densities for a MBT waste fraction < 60 mm of 0.6-0.9 kg_{TM}/l (Kühle-Weidemeier, 2004)
- Dry densities in function of dry bulk density of the material and the chosen landfill technique: 0.75-0.88 kg_{TM}/l (Entenmann, 2007)

- Results in determining the dry density of 7 landfills 0.75-1.12 kg_{TM}/l (Entenmann, 2008)

2.3 Mechanical and Hydraulic Properties

The examination of the mechanical and hydraulic properties of waste to be landfilled is necessary for the calculation of the landfill outer slope stability and the load-time settlement behaviour. As these parameters for the MBT-residues cannot be directly deduced from the usual (geotechnically) classified parameters, project-specific laboratory tests had to be carried out. What is also important to consider is that MBT-residues are not soil-like waste material, meaning that the usual reinforcing components that take up traction present in conventional, untreated municipal waste are missing. For the stability proof and usability tests the following parameters were determined on-site by analogy with geotechnical methods (see section 4):

- Water content in accordance with DIN 18 121
- Proctor density and optimal water content in accordance with DIN 18 127
- Particle size distribution after wet sieving in accordance with DIN 18 123
- Shear parameters in shear testing with a large shear test jig in accordance with DIN 18 137
- Permeability in accordance with DIN 18 130 (k-value determination)

3 Requirements for Landfilling MBT-Residues

3.1 Requirements in Lower Saxony

In April 2007, the Ministry for the Enviroment of Lower Saxony decided on provisions regarding landfills with MBT waste material. In January 2008, the Ministry added guidelines on how to determine mechanical properties, how to monitor excessive pore water pressure and minimise lecheate formation. The following section deals with requirements for geotechnical stability and explains measure for minimising rainwater infiltration and lecheate in MBP-landfills. There are requirements that have to be met with respect to geotechnical stability for the following parameters:

- Stability
- Testing and using appropriate construction methods
- Landfilling
- Monitoring (in conjunction with backfitting during service operation)
- Documentation and evaluation of operation and monitoring

3.2 Stability and Landfilling

These are the basic requirements concerning landfilling of MBT-residues in Lower Saxony:

Stability: "Stability has to be ensured through friction within the landfill body or through supporting banks. Excessive pore water pressure can significantly result in reducing friction and consequently pose a threat to stability. Provided that there is not enough support, excessive pore water pressure is only admissible if stability is demonstrably not threatened. Otherwise measures have to be taken to prevent the creation of excessive pore water pressure in principle."

Drainage elements within the landfill body: "The threat of excessive pore water pressure in landfills with little permeability can also be averted by shortening the flow path of the lecheate. For this both horizontal and vertical linear flat drainage elements can be installed within the landfill body. These drainage elements can also be made out of suitable waste if these comply with the provisions of the Waste Storage Ordinance (AbfAblV) or the Waste Disposal Ordinance (DepVerwV). The drainage elements are to be directly connected to the lecheate collection system of the landfill."

Site-related laboratory test to determine shear strength, water permeability and compressibility have to be carried out to prove the stability. Alternatively, data of corresponding parameters of a joint project can be taken as a basis, if an expert confirms the transmissibility of the data to the respective individual landfill. On this basis and with reference to the landfill boundary conditions, it is then established which prerequisites have to be met to prevent excessive pore water pressure and stability threats.

When taking the tests, the construction speed of the MBT-landfill body as well as possible consequences for pore water pressure have to be considered. In this context it has to be attested that the landfill body still has a sufficient water permeability or swift consolidation, i.e. a swift reduction of excessive pore water pressure, even in compact storage, to prevent pore water pressure that can be a potential threat to stability.

As a precaution with a view to critical pore water pressure and excessive pore water pressure, intermediate drainage layers were developed for the MBT-landfill Hillern and included in the verification calculation (see section 5). Due to this constructive method for minimising potential pore water pressure, no further pore water pressure measurements have to be taken during landfill operation.

3.3 Measures to Minimise Rainwater Infiltration and Lecheate Formation

In accordance with the amendment of the Waste Storage Ordinance (AvfAblV), it is no longer obligatory to cover the surface of the landfill area for MBT-residues with materials impermeable to water. Only “where required suitable construction methods should be taken to minimise rainwater infiltration.”

In the MBT-landfilling practice of the the MBT-landfill Hillern it has proven favourable to forego a temporal cover of the current landfill area for technical as well as operational reasons. Instead of this, additional monitoring measures, inter alia, have been introduced to monitor the water balance.

Pursuant to the provisions regarding landfills with MBT waste material of Lower Saxony, lecheate formation in a MBT-landfill has to be kept to an absolute minimum in accordance with the state-of-the-art. It must not exceed 7 % of annual precipitation.

Landfiling operation at the MBT-landfill Hillern fulfils these requirements by taking the following measures:

- The open landfill area is limited to the minimum necessary for the landfilling operation to run smoothly and flawlessly.
- Areas that are not charged over longer periods of time are temporarily covered during the winter months as necessary to drain off the rainwater.
- MBT wastes are stored in relatively dry conditions and have an important field capacity, so that, even through the evaporation of the open landfill area, little rainwater infiltrates the deeper layers of the MBT-landfill body and leads to lecheate reformation.

The previsous observations concerning lecheate drainage confirm these facts. In the summers of 2006 and 2007, no lecheate drainage in the base drainage was recorded during longer periods of time. Only very little lecheate is recorded in winter. Even after rainfall, there is no significantly higher lecheate drainage, meaning that all requirements to minimise lecheate formation have been met.

4 Laboratory Examinations for the Determination of Geotechnical Parameters

4.1 Overview

Results of project-specific laboratory examinations of representative MBT solid waste (here: fresh MBT waste and three months old MBT waste from the landfill body) can be seen in table 4.1.

Fig. 4.1: Geotechnical parameters of fresh and settled MBT solid waste samples of landfill Hillern

MBT Solid Waste Sample	Water Content DIN 18121		Permeability k_{10}	Oedometroc Modulus E_S	Proctor Density ρ_{pr}	
	Mean Value [% DM]	Mean Value [% WM]	[m/s]	[MN/m^2]	Reference DM [g/cm^3]	ReferenceWM [g/cm^3]
3 months settled MBT material (MBT-A with three samples each)						
MBT-A1	58	37	n.a.	n.a.	n.a.	n.a.
MBT-A2	64	39	3 x 10^{-10}	1.1 – 2.5	0.862	1.411
Fresh MBT material (MBT-N with three samples each)						
MBT-N1	47	32	n.a.	n.a.	n.a.	n.a.
MBT-N2	47	32	2 x 10^{-6}	1.4 – 2.1	0.856	1.260

DM: dry matter; WM: wet matter; n.a.: not analyzed

4.2 Water Content

Three samples were taken from each of the four test batches and analysed with regard to water content. Both fresh samples show very homogenous water contents of approximately 47% DM or 32% WM. In contrast, samples taken after three months of settling show heterogeneous water contents that mirror the differing water contents even in small parts of the MBT-landfill body. Average values are 58-64% DM and 37-39% WM.

4.3 Compressibility (Proctor Density)

Compressibility of MBT-material was determined by carrying out a Proctor test according to standard DIN 18127 (Proctor work W ≈ 0.6 MNm/m³, test cylinder D = 20.4 cm).

Fig. 4.2: Results from laboratory examination of proctor density of MBT material from landfill Hillern (Institute for Soil Engineering and Mechanics, Technical University of Brunswick - IGB TUBS)

Parameter	Fresh Material MBT-N2	Settled Material MBT-A2
Water Content [%-WM]	32.1	38.9
Water Content [%-DM]	47.2	63.8
Proctor Density ρ_{pr} [g/cm^3]	0.856	0.862
Density of Wet Sample [g/cm^3]	1.260	1.411

WM: wet matter, DM: dry matter

Results belong to the higher range of proctor density values which were already measured at former examinations in the range of 0.77 – 0.84 g/cm³ with w_{Pr} of 47-52% for fresh MBT-material. Results are within the standard MBT range.

4.4 Permeability

Analysis of water permeability was conducted according to standard DIN 18130-1 with two solid waste samples over a period of five weeks. Permeability values k_{10} (elementary test) were:

- Fresh material MBT-N2 $k_{10} = 2 \cdot 10^{-6}$ m/s
- Settled material MBT-A2 $k_{10} = 3 \cdot 10^{-10}$ m/s

Because of the material composition with comparatively little fine material, a permeability value of $k_f = 1 \cdot 10^{-9}$ m/s (medium system permeability) was used, taking into account bibliographical reference on stability and deformation proofs for MBT-material of Hillern landfill. In addition, stability for a local permeability of $k_f = 1 \cdot 10^{-10}$ m/s was analysed as a limit case in the framework of a sensitivity study.

4.5 Stiffness

Oedometric modulus E_S was calculated according to standard DIN 18135 and under conditions specified in table 4.3. Compression tests were carried out in eight load steps σ_V = 0.02-0.25 MN/m^2 with loading and unloading cycles for simulation of in situ pressures (compression and overlay pressure) with stress increments as a result of surcharge and three time settling recordings on two MBT samples.

Fig. 4.3: Results of laboratory examinations of oedometric modulus ES on MBT material from the Hillern landfill (IGB TUBS)

Parameter	**Fresh Material MBT-N2**	**Settled Material MBT-A2**
Water content at emplacement [%-DM]	47	64
Water content at removal [%-DM]	41	48
Emplacement density $\rho_{d,E}$ [g/cm^3]	0.85	0.86
E_S [MN/m^2] for σ = 0.02 – 0.06 MN/m^2	1	1
E_S [MN/m^2] for σ = 0.06 – 0.12 MN/m^2	2	2
E_S [MN/m^2] for σ = 0.12 – 0.25 MN/m^2	7	7

DM: dry matter

At equal load steps, both fresh and settled MBT-material produced the same oedometric moduli. Both solid samples showed distinctive time settling behaviour. The (geotechnical) transition from consolidation settling (finite primary settling) to long term settling (infinite secondary settling) was not clear. For settled material primary settling stopped after about three weeks; for fresh material settling speeds after 4-5 weeks were still the same if not higher. The reason can probably be found in the more active biological chemical decomposition processes of fresh material.

For test proofs, stiffness of MBT-materials was indicated with $E_{S,k}$ = 1 MN/m^2 for $\Delta\sigma$ = 0.02-0.25 MN/m^2 to be on the safe side with regard to time settling behaviour and potential long-term settling.

4 Geotechnical Verifications

4.1 Assumptions and Boundary Conditions

Following an engineering assessment, the verifications or respectively calculations of the stability and deformation of the MBT-landfill body were carried out including proven geotechnical methods, paying special attention to

- the site-related boundary conditions,
- the results of laboratory tests,
- the provisions, standards and recommendations related to landfills and geotechnical aspects,
- a traffic load from landfilling operations on the site,
- intermediate layers as systematic surface drainages and
- the failure of intermediate drainage layers – also for the assessment of stability without intermediate drainage layers.

On the basis of tests in the context of literature research, the following values were chosen for the geotechnical verifications:

- mean moisture density γ_k = 12 – 15 kN/m^3
- saturation degree S_R at a mean particle density of ρ_s = 2.0 – 2.5 g/cm^3 for
  - fresh MBT-material S_R = 65 – 75 % at w = 47 %
  - settled MBT-material S_R = 85 – 95 % at w = 64 %
    with regard to the max. pore water pressure on the safe side
  - MBT-material Hillern S_R = 100 %

Further boundary conditions of MBT-tipping on the Hillern landfill:

- emplacement area at base: approx. 5,000 m^2
- emplacement volume per year: 26,000 – 30,000 Mg/a
- raise of emplacement height per year: approx. 4 – 5 m/a
- fluctuation of emplacement volumes or respectively discontinued emplacement due to seasonal or weather-induced fluctuations or respectively varying emplacement velocity

Horizontal intermediate drainage layers with 5 m vertical spacing, 30 cm thickness and a min. outward slope of 1.5% are planned for the MBT-landfill body. In conjunction with a saturation of the MBT-material of up to S_R = 100% and at normal traffic loads with a successive built-up of the landfill body, this, inter alia, results in a load-induced excessive pore water pressure due to the 1 m thick emplacement layer with consolidation of 5 m thick layers with unpressurised draining into the surface drainage.

4.2 Slope Stability

The stability of the slope at N = 1 : 3 was calculated pursuant to standard DIN 4084 with varying possible circular and polygonal slip planes under special consideration of the built-up by layers with overlapping consolidation of the layers. The (in 2007: global) stability to be proven was $\eta \geq 1.3$ for the operating state (LF 2: construction state) and $\eta \geq 1.4$ (LF 1) for the final state. For the case of a "failure of the intermediate drainage layers", a safety factor of $\eta \geq 1.2$ (LF 3) was considered tolerable.

According to the partial safety concept pursuant to DIN 1054-2005, which has been applicable since 2008, effects E are multiplied with partial securities γ and resistances R are divided by partial securities γ. It has to be verified that E ≤ R, inter alia, for the serviceability limit state (GZ 1C) or respectively an efficiency factor of

$$\mu = E/R \leq 1.0$$

At first, due to a lack of more detailed tests, partial security values γ following the values given in DIN 1054-2005 were assumed for the MBT-material and examined for the load case combinations LF 1, LF 2 and LF 3.

		LF 1	**LF 2**	**LF 3**
Permanent effects	γ_G	1.00	1.00	1.00
Harmful variable effects	γ_Q	1.30	1.20	1.00
Coefficient of friction tan φ'	γ_φ	1.25	1.15	1.10

Based on the tests, the following values were assumed:

Mean permeability of the MBT-material	$k_f = 1 \cdot 10^{-9}$ m/s
Density	$\rho_k = 1.2$ t/m^3
Stiffness	$E_{S,k} = 1$ MN/m^2
	with $\Delta\sigma = 0.02 – 0.25$ MN/m^2
Angle of friction	$\varphi'_k = 35.0°$

Since the documents evaluated so far did not provide sufficient evidence for a potential cohesion c' of the MBT-material, it was assumed that $c'_k = 0$.

The simulated emplacement velocities (development of the landfill height over time) are shown in figure 5.1. The maximum emplacement velocity proven to be safe starts at max. v ≈ 8 m/a and then decreases to max. v = 6 m/a when reaching the final height, or respectively

H_{MBT} = 0 – 3 m v_{MBT} = 0.7 m/month
H_{MBT} = 3 – 13 m v_{MBT} = 0.6 m/month
H_{MBT} = 13 – 18 m v_{MBT} = 0.5 m/month

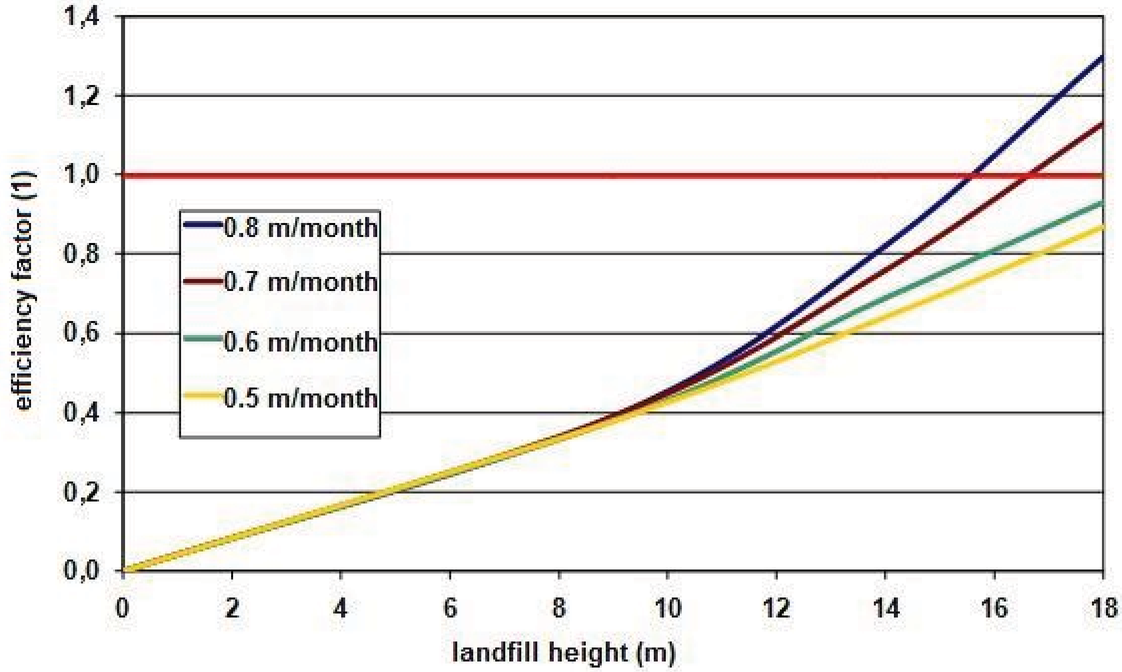

Figure 5.1: Efficiency factor (emplacement velocity) vs. emplacement height

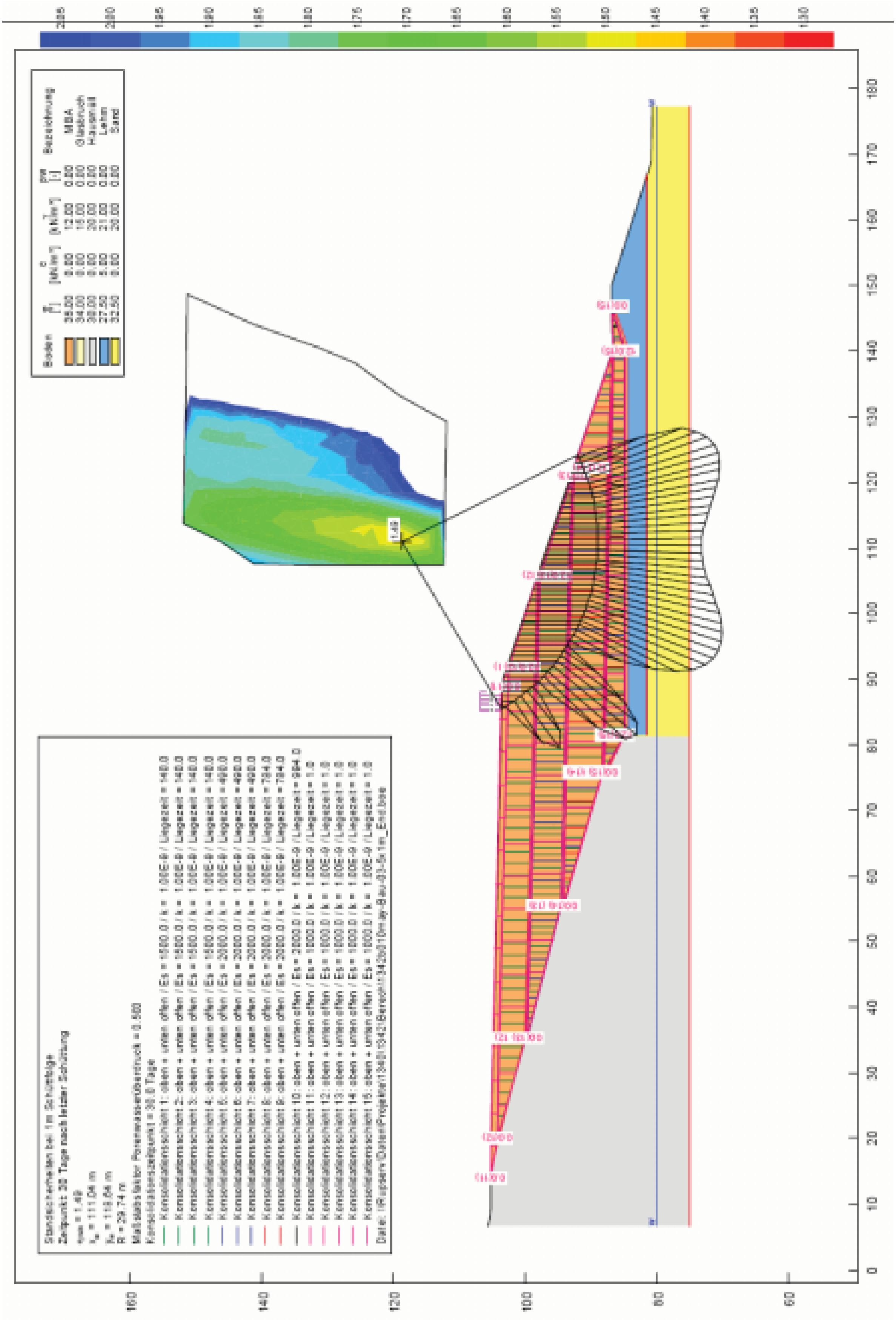

Fig. 5.2: Slope stability verification for the MBT-landfill body in its final state

Legend to fig. 5.2:

Slope stabilities at 1m emplacement layer
Time: 30 days after last filling
η_{mn} = 1.49
x_m = 111.04 m
y_m = 118.64 m
R = 29.74 m
Scale factor excessive pore water pressure = 0.500
Consolidation period = 30.0 days

Consolidation layer 1: top + bottom open / Es = 1500.0 / k =1.00E-9 / settlement period = 140.0
Consolidation layer 2: top + bottom open / Es = Es = 1500.0 / k =1.00E-9 / settlement period = 140.0
Consolidation layer 3: top + bottom open / Es = Es = 1500.0 / k =1.00E-9 / settlement period = 140.0
Consolidation layer 4: top + bottom open / Es = Es = 1500.0 / k =1.00E-9 / settlement period = 140.0
Consolidation layer 5: top + bottom open / Es = 2000.0 / k =1.00E-9 / settlement period = 490.0
Consolidation layer 6: top + bottom open / Es = 2000.0 / k =1.00E-9 / settlement period = 490.0
Consolidation layer 7: top + bottom open / Es = 2000.0 / k =1.00E-9 / settlement period = 490.0
Consolidation layer 8: top + bottom open / Es = 2000.0 / k =1.00E-9 / settlement period = 784.0
Consolidation layer 9: top + bottom open / Es = 2000.0 / k =1.00E-9 / settlement period = 784.0
Consolidation layer 10: top + bottom open / Es = 2000.0 / k =1.00E-9 / settlement period = 994.0
Consolidation layer 11: top + bottom open / Es = 1000.0 / k =1.00E-9 / settlement period = 1.0
Consolidation layer 12: top + bottom open / Es = 1000.0 / k =1.00E-9 / settlement period = 1.0
Consolidation layer 13: top + bottom open / Es = 1000.0 / k =1.00E-9 / settlement period = 1.0
Consolidation layer 14: top + bottom open / Es = 1000.0 / k =1.00E-9 / settlement period = 1.0
Consolidation layer 15: top + bottom open / Es = 1000.0 / k =1.00E-9 / settlement period = 1.0

soil	φ [ ]	c [kN/m²]	γ [kN/m³]	pw [-]	type
	35.00	0.00	12.00	0.00	MBT-material
	34.00	0.00	15.00	0.00	cullet
	30.00	0.00	20.00	0.00	domestic waste
	27.50	5.00	21.00	0.00	loam
	32.50	0.00	20.00	0.00	sand

For example, for the operating states H_{10} = 10 m + 1 m (emplacement height) = 11 m total height, H_{15} = 16 m and max. H_{18} = 19 m total height with $k_f = 1 \cdot 10^{-9}$ m/s and a reduced permeability $k_f = 1 \cdot 10^{-10}$ m/s, the efficiency factor μ immediately after emplacement is:

H_{10} = 11 m total height	$k_f = 1 \cdot 10^{-9}$ m/s	μ = 0.37	
H_{15} = 16 m total height	$k_f = 1 \cdot 10^{-9}$ m/s	μ = 0.59	
H_{18} = 19 m total height	$k_f = 1 \cdot 10^{-9}$ m/s	μ = 0.84	(LF 2)
H_{18} = 19 m total height	$k_f = 1 \cdot 10^{-10}$ m/s	μ > 1.0	(LF 2)

With increasing landfill height, the efficiency factor increases successively or respectively the stability decreases; however, stability is still verified in the final state. By way of calculation, with a reduced permeability $k_f \approx 1 \cdot 10^{-10}$ m/s, slope stability could no longer be verified in a layer of only 5 m immediately after reaching the final height and with fully saturated MBT-material. According to plan and without further verifications, e.g. for a – in terms of stability: positive – slower emplacement or partially saturated landfill material, the permeability of the material must be $k_f \geq 1 \cdot 10^{-9}$ m/s.

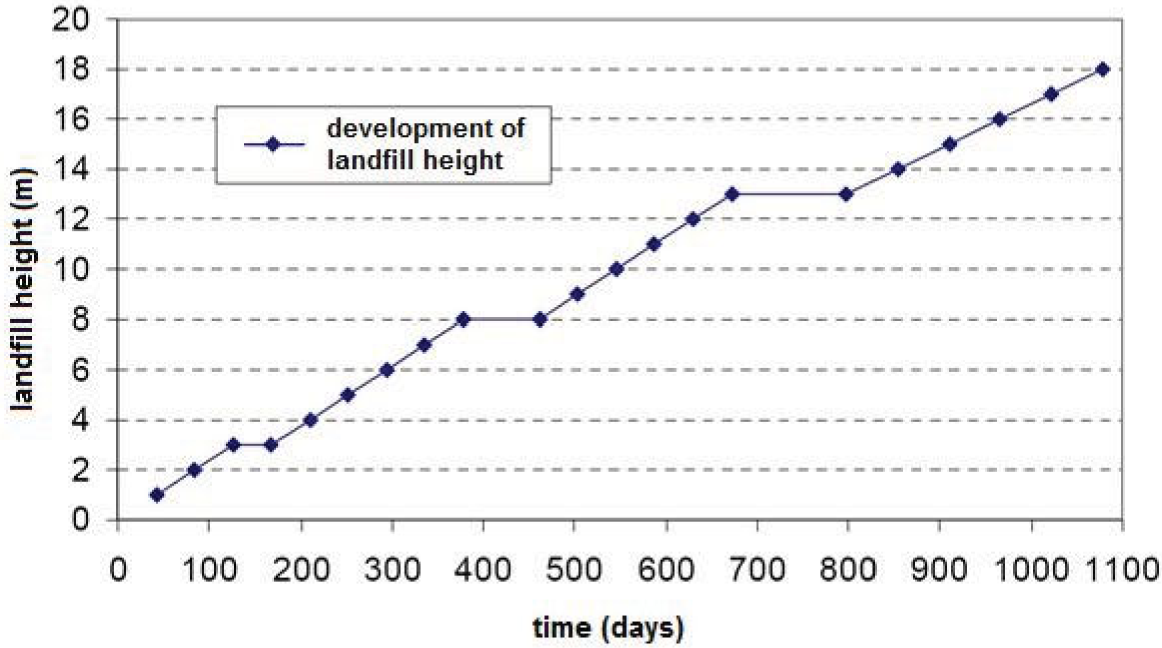

Fig. 5.3: Landfill height vs. time

A conservative estimate for the stability verifications assumed a high emplacement velocity of v_{MBT} = 0.7 – 0.5 m/month. Only <u>one month after completion of the filling process</u> on the final level, the slope stability already increases or respectively the efficiency factor decreases from μ = 0.84 to μ = 0.75.

H_{18} = 19 m final height (1 month) $k_f \approx 1 \cdot 10^{-9}$ m/s μ = 0.75 (LF 1)

In case of failure of one of the intermediate drainage layers, the stability or respectively the efficiency factor would be μ = 0.97 instead of μ = 0.75.

The calculations demonstrate the positive effects or respectively the need for intermediate drainage layers in MBT-landfill construction with relatively shear-resistant, but compressible MBT-material with a very low permeability.

A strength parameter of φ'_k = 35.0° was used for the calculations. Under otherwise unchanged conditions (permeability $k_f \approx 1 \cdot 10^{-9}$ m/s, density ρ_k = 1.2 t/m^3, saturation S_R = 100 %, max. emplacement velocity v_{MBA} = 0.8 m/month up to 19 m landfill height at a slope angle of 1 : 3), and with the material of the MBT Hillern at μ ≤ 1.0, the minimum shear strength for the required slope stability is $\varphi'_k \geq 30°$. This strength – and the permeability – should be validated.

Further comparative calculations with higher emplacement velocities demonstrated e.g. that filling velocities significantly above 1 m/month and, at the same time, unfavourable water balance as well as a low water permeability of the refuse (by way of calculation) would cause an extensive slope rupture shortly after emplacement. At the MBT-landfill Hillern, this scenario is prevented by operational and constructive measures.

4.3 Prediction of Deformation

For the intermediate drainage layers (layer thickness 0.3 m, one layer per maximum MBT filling height of 5 m, outward slope N ≈ 1.5%) and under consideration of the landfilling process and overlapping consolidation of the horizontal layers, the settlements S were determined. For the aforementioned emplacement velocities, consolidation ratio of U = 50% (= 50 % remaining subsidence) of the lower MBT-layers for the laying of the surface drainage or respectively the upper MBT-layers were taken into account. Furthermore and as a point of reference, the settlements for the respective consolidation ratio U = 100%, solely resulting from the compressibility of the MBT-material due to further built-up, were determined as the settlement to be expected.

For the MBT-material, permeability was assumed to be $k_f \approx 1 \cdot 10^{-9}$ m/s, stiffness $E_{S,k}$ = 1 MN/m^2 and mean moisture density ρ_k = 1.2 t/m^3. Pursuant to DIN 1054-2005, for the verification of the serviceability limit state (GZ 2) – in this case: verification of the settlements of the surface drainages – the partial securities for permanent and varying effects were set at $\gamma_G = \gamma_Q$= 1.00.

The result of the subsidence calculation is shown as a cross-sectional outline in figure 5.4. Accordingly, the maximum settlements above the slope bottom of the existing landfill or respectively at maximum filling height are:

$H_{Drain} \approx$ 3 m	max. $S_{Drain} \approx$ 0.64 m	min. $S_{Drain} \approx$ 0.60 m
$H_{Drain} \approx$ 10 m	max. $S_{Drain} \approx$ 1.27 m	min. $S_{Drain} \approx$ 1.06 m
$H_{Drain} \approx$ 15 m	max. $S_{Drain} \approx$ 1.42 m	min. $S_{Drain} \approx$ 0.86 m
$H_{LFS} \approx$ 19 m	max. $S_{LFS} \approx$ 1.07 m	

H_{Drain} Height level of the intermediate drainage layer
H_{LFS} Height level of the landfill surface (final level MBT-landfill body)
S_{Drain} Subsidence of the intermediate drainage layer

In view of the target slope of N ≥ 1.5 % in the final state, the calculated settlements of the drainages must be compensated with surcharges during emplacement. The calculated settlements of the landfill surface, which is sloped for the (partial) run-off of precipitations, can be compensated with surcharges during emplacement or with post-shaping measures.

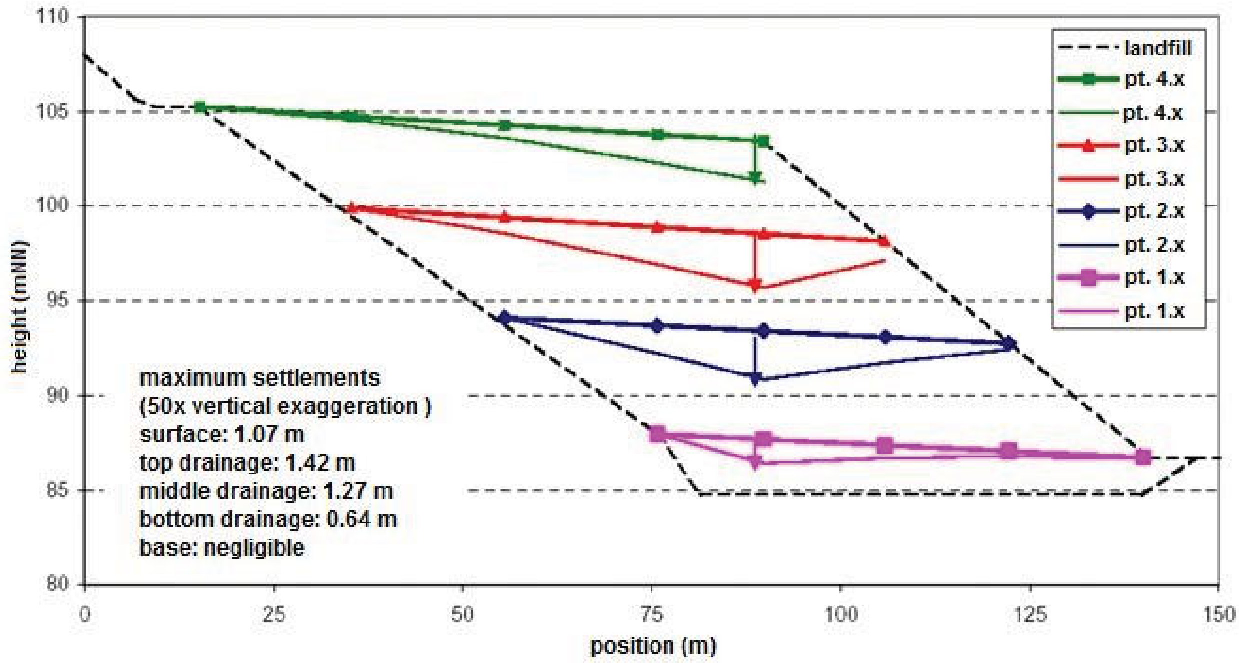

Fig. 5.4: Prediction of Settlement for MBT-landfill

Consolidation ratio: 50% (inherent and currently induced settlements)

Settlement calculation for the MBT-landfill body Hillern, based on the intermediate drainage layers, settlements are shown in vertical exaggeration

5 Recommendations

The mechanical-biological treatment of municipal solid waste changes the composition of the landfilling material as well as its chemical-physical, biological and waste-mechanical properties. Hence geotechnical verifications must be given for new MBT-landfills and new requirements for the emplacement of MBT-material must be taken into consideration.

This report discusses the provisions of Lower Saxony for the landfilling of MBT-material and illustrates their realisation on the example of the MBT-section of the Hillern landfill which is run by Heidekreis Waste Management in the Soltau-Fallingbostel district.

With a view to safeguarding the geomechanical stability of the MBT-landfill body Hillern and similar MBT-landfills, the following recommendations can be made:

- The permeability of the MBT-material shall be checked, especially in the event of changes in the delivered MBT-output.
- The shear strength of the MBT-material shall be checked, especially in the event of changes in the delivered MBT-output.
- Geotechnical methods (particle distribution, water content, compactibility) act as a reference in the classification of MBT-material and should not be over-interpreted, especially with regard to strength, stiffness and permeability.

- In order to lessen potential excessive pore water pressure through settlement compensation, intermediate drainage layers with surcharge shall be installed in relation to the dimensioning; at the Hillern landfill, drainage layers are located as follows:
    - in the slope between the MBT-landfill body and the adjacent domestic waste (existing landfill body) and
    - in the MBT-landfill body with a vertical distance of $\Delta H \approx 5$ m with a maximum MBT-layer thickness of $D \approx 5$ m
    - with a drainage layer thickness of at least 30 cm and
    - with an inclination of the drainage subsequent to final settlements of at least 1.5%.
- The maximum emplacement velocity shall not exceed 5m/year at normal operation.
- The landfilling shall be documented in a space-time waste register.
- The geotechnical verifications shall be checked and updated if necessary, especially in the event of changes in the technical boundary conditions at the landfill or the quality of the delivered MBT-output.
- For landfilling operations, further fundamental aspects must be considered:
    - Low emplacement water contents and functioning drainages as well as a low built-up velocity can minimise the occurrence of excessive pore water pressure. This increases the stability and reduces deformation.
    - Sloped, smooth MBT-surfaces in the construction state minimise water-logging through precipitations and therefore unfavourable saturation.
    - Landfill areas that are not charged over a longer period shall be temporarily covered in order to drain surface water.
    - In the operating state, slopes shall have a maximum inclination of 1:3.

In view of the operation of the MBT-section of the Hillern landfill, it can be stated that the provisions of the Ministry for the Environment of Lower Saxony and the ZUS AWG are met with in terms of

- Stability,
- Testing and using appropriate construction methods,
- Landfilling,
- Monitoring (in conjunction with backfitting during service operation),
- Expected limitation of leachate and
- Documentation and evaluation of operation and monitoring.

6 Bibliography

Hupe, K., Heyer, K.-U., Stegmann, R.	2006	Einbauversuche mit MBA-Reststoffen – Erfahrungen von der Deponie Hillern. In: Deponietechnik 2006 (Hrsg.: Stegmann, Rettenberger, Bidlingmaier, Bilitewski, Fricke), Hamburger Berichte 29, Verlag Abfall aktuell, Stuttgart, 111-130.
Hupe, K., Oltmanns, W., Heyer, K.-U., Jäger, R., Stegmann, R.	2008	Standsicherheit und Ablagerungsbetrieb der MBA-Deponie Hillern. In: 3. Praxistagung Deponie 2008 „Zwischenlager, Deponien, Nachsorge". (Hrsg.: Wasteconsult international), Cuvillier Verlag, Göttingen, 57-72.
Kölsch, F.	1996	Der Einfluss der Faserbestandteile auf die Scherfestigkeit von Siedlungsabfall. Mitteilungen Heft 133/1996, Leichtweiss-Institut für Wasserbau der Technischen Universität Braunschweig
Rodatz, W., Oltmanns, W.	1993	Rutschung einer Klärschlammdeponie bei Sanierungsmaßnahmen. 8. Christian Veder Kolloquium, Institut für Bodenmechanik und Grundbau, TU Graz
Kühle-Weidemeier, M.	2004	Konstruktion und Betrieb einer MBA-Deponie unter Berücksichtigung der rechtlichen Vorgaben und aktueller Erkenntnisse. In: AVL-Workshop „2005" – Deponien stilllegen – Deponien weiterbetreiben – am 05.05.04 in Ludwigsburg
Entenmann, W.	2007	Einbau von MBA-Material und anderen Reststoffen auf Deponien. In: Müll-Handbuch (Hrsg.: Bilitewski, Schnurer, Zeschmar-Lahl), Erich Schmidt Verlag, Berlin, 4350
Entenmann, W.	2008	Einbau von MBA-Material – Anforderungen, Monitoringmaßnahmen, Emissionen, Erfahrungen. In: Deponietechnik 2008 (Hrsg.: Stegmann, Rettenberger, Bidlingmaier, Bilitewski, Fricke, Heyer), Hamburger Berichte 31, Verlag Abfall aktuell, Stuttgart, 249-263.
Niedersächsisches Umweltministerium	2007	Ablagerung von mechanisch-biologisch behandelten Abfällen: Umsetzung AbfAblV Anhang 3 Nr.2 Satz 3"; ZUS AWG, Dezernat 32 – Abfallwirtschaftliche Beratung, 10.04.2007
Niedersächsisches Umweltministerium	2008	Annahme und Einbau mechanisch-biologisch behandelter Abfälle: Ergänzende Hinweise vom 16.01.2008 zum Erlass vom 10.04.2007

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Contracting Solution for Energy-Supply of a Food-Production Site

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RDF-CHP Plant Stavenhagen, Contracting Solution for Energy-Supply of a Food-Production Site

Abstract

Putting the RDF CHP-plant Stavenhagen (Refused Derived Fuels Combined Heat and Power Plant) in operation by the contractor Nehlsen AG, enabled supplying the company Pfanni, potatoes based food products, with process vapor and electricity, not from a primary fossil fuel but from a secondary solid fuel, generated from a MBT Mechanical-Biological-Waste-Treatment plant. The advantages of this innovative energy supply process are saving of fossil energy resources and thermal remediation of waste, which is a consequent completion with the principles of waste recycling economy. The remains quality of this process complies perfectly with the preconditions of waste for landfill discharge. In addition this plant secures current jobs of the food and food-supporting industry, including creation of new jobs within the RDF CHP-plant. Last but not least the MBT plant represent a real investment alternative for energy supply at the company Pfanni.

Keywords

RDF CHP Plant, MBT Plant, Company Pfanni, Process steam and electricity

1 General Description of the CHP Stavenhagen

The operator of the RDF CHP-plant Stavenhagen (Refused Derived Fuels combined heat and power plant) is the company Nehlsen Heizkraftwerke GmbH & Co. KG. Since summer 2007, the RDF CHP-plant has been supplying the company Pfanni, manufacturer of potato and potato-based instant products, with process steam and electrical power by means of a cogeneration system. Energy supplier and client are situated close-by. The surplus electric power, that would not be used neither by Pfanni nor by the RDF CHP-plant in Stavenhagen, would be fed into the local electrical grid.

The first project for the energy contracting at Nehlsen was based on considerations of the Pfanni company in Stavenhagen to realise a restructuring of their power supply.

Due to rising prices for natural gas and electricity as well, as the possibility to produce steam and electricity locally by means of a power cogeneration system, the idea came up for replacing the existing natural gas-fired heat supply station by RDF-fired heat and power station.

The first calculation showed that 95.000,00 t/a of RDF are needed. This amount could be generated from two regional MBT-plants. This idea comply strategically with both, material recycling and thermal utilisation of waste (Energy from Waste). The decision for building this power plant was felt in May 2005 under the pre-condition that in August 2007 the new power plant would cover the energy demand, steam and electricity, of the company Pfanni.

The higher estimated labour demand of the new power plant compared with a gas power plant was evaluated positively, because the desire of improving the social structure in Mecklenburg-Vorpommern.

With the new energy concept the company Pfanni is able either to extend its existing production or to develop new production lines with a high demand of steam or electricity.

The primary generated steam 400 ^{o}C / 42 Bar is mainly directed to the turbine for power production. One part of the generated steam is used at 16 Bar for food production and the other at 11 bar for cooking purposes.

The project Heizkraftwerk Stavenhagen to supply Pfanni with process steam and electricity was a major impact in the Unilever Group, because with the new type of energy supply the costs for steam and electricity could be substantially reduced. This showed itself especially in the light of the steadily rising price of natural gas, the Pfanni in an amount of 14 million m^3 / a for the processing of 160,000 t / a of potatoes had to relate.

The reform of the energy was accompanied by an expansion of the Pfanni production at the site Stavenhagen, both with regard to a location for Pfanni as well as a reassessment of the flow volume of fuel meant. At this point in the planning for the fuel needs 95,000 tonnes a year at a standard calorific value Hu of 14 MJ / kg.

2 Incineration Unit and Boiler

The incineration unit is designed for reception, storage and fuel feeding device using a crane. The storage capacity is around 2.000 t, which is sufficient for 4 days full operation. The produced solid fuel via MBT is combusted in the furnace of a moving grate incinerator. The holes in the grate elements supply the primary combustion air.

The incineration heat input is around 45 MW. Resulting fly ash and flu gases would be separated within the applied semi-wet absorption process and filter unit. The annual amount of filter residue is about 5.600 t. The amount of resulting slag at the bottom of incinerators is around 20.000 t/a.

3 Turbo Generator Kit and Air Capacitor

The produced high pressure steam boiler is used a condensing-extraction turbine The turbine has a sampling nozzle (16 bar (g)) for the provision of production steam for the factory.

The steam of low pressure level is cooled down in the air capacitor. Depending on the need of production steam the power generation varies. At the maximum need, approximately 4.8 MW elt are generated, if there is no need 9.6 MW elt are generated.

4 Flue Gas Purification

A highly efficient, two-stage gas cleaning unit is built downstream of the boiler. The purpose of this part of the overall system is to purify the flue gas according to the German flue gas emission regulations “17 BImSchV.

In the first purification stage the flue gas is treated in a spry dryer using lime as adsorbent. In the second treatment stage activated carbon and lime are used to polish the already treated flue gas stream. In addition a sludge recycling loop is arranged to ensure efficiency. Finally a dust separation filter is used before the cleaned flue gas released to the atmosphere. It is a six-chamber filter designed with vertically placed flat tubes.

The injection of lime, activated carbon recycling rate are optimised by controlling the temperature, pressure and humidity. The cleaning of the filter tubes is done on line in the pulse-jet process. As a filter material a 100% PTFE is used.

5 Some interesting Remarks

- The full load operation hours in 2008 as first operation year were in a range of 8200 hours
- The boiler efficiency according to the incineration efficiency diagram was always achievable also for solid fuel with lower heat value
- The temperature in the filter was controlled between 140-150 ^{o}C to avoid condensation and corrosion.
- Via the co-generation process 10.000.t/a reduction of CO2 were achieved.
- The expectation regarding SO2 and HCl concentration are indeed surpassed
- Removal of Dioxin was achieved using activated carbon as additive with lime in the second injection area
- The concentration of Hg in the cleaned gas are well below 10 µg/m³
- A 200 m³ silo for Ca(OH)2 provide much better flexibility than 100 m³ silo

Municipal Solid Waste bio-drying eco-balance and Kyoto protocol

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Abstract

Bio-drying is a process aimed to Refuse Derived Fuel generation through water evaporation and post-treatment of selection. This option allows avoiding direct combustion of waste and opens to alternative strategies as co-combustion in thermal power plants where the efficiency of electricity generation could be higher than the one of conventional incinerators. The present paper analyses in details a few aspects related to CO_2 balances for bio-drying in order to give a contribution to a correct understanding of the process.

Keywords

Bio-drying, CO2, emissions, Kyoto Protocol, MSW, RDF

1 Introduction

The European Union (EU) policy recommends to reduce the contribution of municipal solid waste (MSW) management to the environmental impacts and to improve the material recycling and the energy recovery. One of the topic on the carpet today regards the green house emissions from the waste treatment and disposal plants and the Kyoto protocol targets.

One of the waste treatment options that takes into account the aspects requested from the EU policy is the bio-drying process. Bio-drying is an aerobic process that makes part of the Mechanical Biological Treatments (MBT).

For the management of this process an aeration into the waste is adopted. The aim of this process is to exploit the exothermic reactions for evaporating the highest part of the wetness of the waste with the lowest conversion of organic Carbon. This approach is adopted for obtaining a bio-dried material that can be transformed into Refuse Derived Fuel (RDF) after some post-treatments: a post separation of metals, glass and inert allows generating an amount of recyclable materials. Additional post treatments could be adopted in order to obtain a lower amount of RDF with a higher Lower Heating Value (LHV), but this strategy would cause a generation of residues to be landfilled. The impact of landfilling those residues is not zero as fine materials with a residual biological activity could support an uncontrolled anaerobic digestion process in the landfill. The consequent biogas generation, that could not be totally collected, should be responsible for a greenhouse gas impact depending of the amount of methane in the fugitive emissions.

The scheme of this strategy is shown in Figure 1, where an alternative BMT option is also reported: bio-drying is related to the concept of one-stream treatment, as no initial screening is adopted; in the BMT sector the two-stream option is widely adopted but has the disadvantage of generating a stabilized organic fraction that showed big troubles in being used on land alternatively to being landfilled. For this reason the present paper analyses only the one-stream strategy.

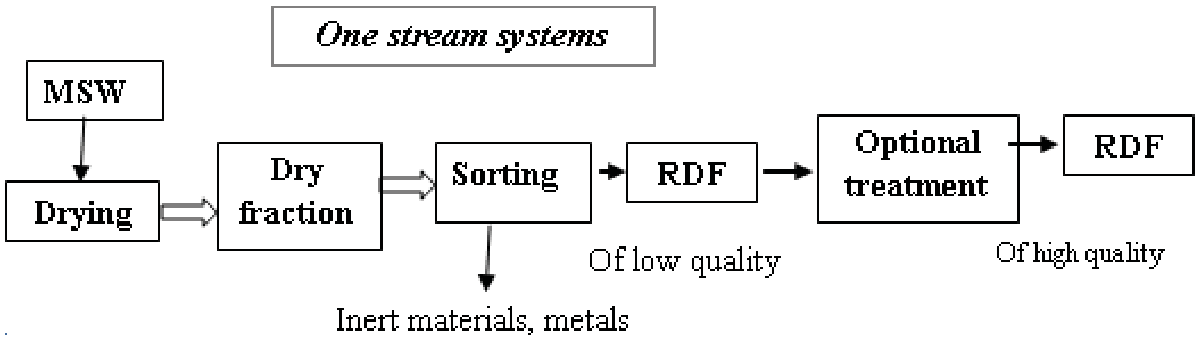

Figure 1 One-stream option based to MSW bio-drying

When bio-drying is proposed, it must be taken into account the organic percentage in the MSW to be processed. That depends on the waste management politics (selective collection efficiency) and economic situation of each country.

The main contents of this paper concern the MSW bio-drying strategy eco-balance and its link to the Kyoto Protocol. The generation of carbon dioxide is related to the biological step where the organic fraction is bio-chemically oxidated. Thus this CO_2 has not to be taken into account referring to the Kyoto Protocol. Anyway the BMT option plays a role in the greenhouse gas balances by the need of electricity (with indirect CO_2 emissions for its generation), by the emission of N_2O and by the CO_2 balance related to the exploitation of RDF through combustion. Concerning the emissions to air, the presence of N_2O gives a contribution that could be not negligible, taking into account that the organic Nitrogen during the bio-drying process is converted into NH_3 and N_2O. The landfilling of the residues generated from the RDF production are not considered in this paper as its generation is taken into account only referring to post-treatment of separation of recyclable materials. To this concern it must be pointed out that the LHV obtainable for RDF without residues generation to be landfilled strongly depends on the LHV of the initial MSW, on its organic fraction content and on its content of glass, metals and inert.

2 Methods

In order to have adequate information on the greenhouse gas emissions from the bio-drying process, a bio-chemical model was used [Rada et al., 2007]. Starting from the ultimate analysis of MSW and using the mass, air flow and temperature dynamics of pilot experimental runs, the model gives as one of the results the dynamics of NH_3 during the bio-drying process. The adoption of an experimental factor in order to assess the N_2O emissions starting from the NH_3 concentrations allows having data useful for a CO_2 balance (N_2O is 310 times more impacting than CO_2). Thanks to this model and assessing the RDF composition from the separation of glass, inert and metals from the bio-dried waste, some scenarios related to the RDF can be created.

From the process point of view, the model gives the parameters reported in Table 1, to be used for overall balances, integrated with real scale data [Rada et al., 2005a and 2006a].

Table 1 Bio-drying parameters

Parameter	Units	Value	Notes
Lasting	D	7-14	Depending on the presence of a recirculation system of process air
Air flow-rate	m^3/kg_{MSW}	3-10	Depending on the presence of a recirculation system of process air and on the amount of organic fraction in the MSW
Mass loss	%	OF%*0.65	OF% = percentage of organic fraction in MSW
Energy loss	%	2%	Referred to the initial LHV of MSW
Volatile solid loss	%	12%	Referred to the overall mass loss
C/VS_{OF}	%	55.7%	Carbon in OF

An important aspect to be taken into account concerns the electrical consumption of the one-stream strategy. In Table 2 some data related to electricity needs are reported. The efficiency of post-separation can be assumed as 100% as a first approximation (high values depends on the fact that the separation process is applied to dried materials) [Rada et al., 2006b].

Table 2 Electrical consumptions

Stage	Units	Value	Notes
Shredding	kWh/kg_{MSW}	0.011	Adopted to open bags
Aeration	kWh/kg_{MSW}	0.035	Without air recirculation
Moving	kWh/kg_{MSW}	0.015	Before and after bio-drying
Post-separation	kWh/kg_{MSW}	0.008	Inert, metals and glass separation

At the base of the calculations it is important to state the emission factors related to bio-drying and process air treatment. In Table 3 some data are reported. Two scenarios are taken into account: a simple bio-filter or a bio-filter with a regenerative thermal oxidation system (RTO). In the second case a consumption of natural gas characterises the approach with a consequent generation of CO_2. Data refers to real scale plants [Rada et al., 2005b and 2006c]. An intermediate case could be set with process air treatment based only on RTO. The limit of this intermediate approach is related to the emissions of NH_3, as the efficiency of bio-filter should be missed. As NH_3 plays an important role in the generation of secondary particulate (reacting with NO_x [Rada et al., 2006d]) in the present paper it has been chosen to study the effect of coupling bio-filter and RTO. Additionally the absence of a bio-filter could worsen the emission factor of N_2O.

Table 3 Emission factors related to CO_2

Pollutants	Units	Emission factors for the case with bio-filter	Emission factors for the case with bio-filter+RTO
CO_2 (fossil)	kg/t	0	19.6
N_2O-N	g/t	5.5	5.5
CH_4	g/t	0	0
CO_2 (non fossil)	kg/t	47.6	47.6

The calculations refer to the MSW characterized in Table 4. In particular, apart from the general data on MSW, it was important to assess some details on organic fraction content, on Carbon presence in and out of biodegradable fractions, on Nitrogen presence in the volatile solids.

Table 4 MSW characterisation for the case-study

Parameter	Units	Value	Notes
Wetness	%	33.57	-
VS/TS	%	72.87	TS = total solids
C_{MSW}	%	29.18	Overall MSW
H_{MSW}	%	4.02	Overall MSW
O_{MSW}	%	14.91	Overall MSW
N_{MSW}	%	0.30	Overall MSW
OF%	%	30	Organic fraction %
C_{fossil}	%	12.13	Referred to MSW
$C_{non.fossil}$	%	17.05	Referred to MSW

Concerning the use of RDF many options are potentially available: co-combustion in cement works, co-combustion in thermal power plants (both as partial substitute of conventional fuels as coal), combustion in dedicated plants. In the present paper the selected case-study concerns the use in existing thermal power plants as the aim is the comparison between a conventional option (direct combustion) and an alternative option with the maximisation of electricity generation by RDF exploitation (high capacity thermal power plants show high efficiency to this concern).

Concerning direct combustion, data from Table 4 allow the assessment of a greenhouse gas balance apart from three aspects. The first one is related to the CO_2 emissions from plant construction. This aspect will not be taken into account for all the considerations (thus also for the construction of a bio-drier). The second one concerns the emission factor of N_2O. In this case, the literature gives data in the case of direct combustion: a value of 6 g N_2O /t_{MSW} will be assumed [Rada et al., 2006c] supposing the adoption of a catalytic treatment of the off gas. In the case of a thermal power plant the emission factor of direct combustion without a catalytic stage [Rada et al., 2006c] has been adopted as the process is anyway a combustion: 30 g N_2O /t_{MSW}. The third one concerns the efficiency of electricity generation through direct combustion of MSW. In this case, supposing the construction of a large MSW incinerator, the net efficiency of electricity conversion can be assumed as 28%.

Co-combustion as substitution of coal means partial substitution of fossil CO_2. For making this calculation the emission factor from coal is necessary. In the case study data for the thermal power plant that receive the RDF for co-combustion are reported in Table 5.

Table 5 Thermal power plant data

Parameter	Units	Value	Notes
LHV	MJ/kg_{coal}	30	Coke
C	%	90	-
Electrical efficiency	%	40	Referred to a large scale

3 Results and discussion

In Table 6 some results related to the presented case-study (bio-drying of MSW with 30% organic fraction content) are reported. In particular, data refer to the characterisation of the RDF that can be generated. Additional data refer to the substitution of coal through RDF. From Table 6 it is clear that the effect of bio-drying and post-treatment is a concentration of energy in a lower mass. The resulting LHV of RDF can be considered good as higher than 15 MJ/kg value considered a target for RDF generation.

Table 6 RDF characterisation and balances for the case-study

Parameter	Units	Value	Notes
Initial LHV	kJ/kg_{MSW}	11818	-
Initial mass loss	%	19.5	Only by bio-drying
$LHV_{biodried\ mat.}$	$kJ/kg_{biod.mat.}$	14387	-
Post-selection loss	$kg_{reciclable}/kg_{MSW}$	0.108	Glass, metals, inert
Net RDF mass	Kg_{RDF}/kg_{MSW}	0.697	-
$C_{fossil.RDF}$	kgC_{fossil}/kg_{RDF}	0.174	Useful for CO_2 assessment
LHV_{RDF}	kJ/kg_{RDF}	16129	-

In Tables 7 and 8 the balances of CO_2 are reported. The calculations take into account direct and indirect CO_2 emissions. N_2O has been converted into equivalent CO_2 through an equivalent factor. In this case the bio-filter option has been considered.

Table 7 CO2 balances for direct combustion

Parameters	Units	Direct combustion	Notes
Fossil C	kg_{CO2}/kg_{MSW}	0.444	-
N_2O role	kg_{CO2}/kg_{MSW}	0.002	-
Electricity generation	kg_{CO2}/kg_{MSW}	-0.900	Saving coal
Overall balance	kg_{CO2}/kg_{MSW}	-0.454	-

Table 8 CO_2 balances for indirect combustion (co-combustion)

Parameters	Units	Indirect combustion	Notes
RDF generation	kg_{CO2}/kg_{MSW}	0.068	Electricity from coal
Biological N_2O role	kg_{CO2}/kg_{MSW}	0.002	-
C_{RDF} combustion	kg_{CO2}/kg_{MSW}	0.444	Fossil C in RDF
Thermal N_2O role	kg_{CO2}/kg_{MSW}	0.010	-
Electricity generation	kg_{CO2}/kg_{MSW}	-1.135	Saving coal by RDF
Overall balance	kg_{CO2}/kg_{MSW}	-0.611	-

It must be pointed out that according to the hypotheses, no difference between options is taken into account as depending on transportation emissions. That means the plants are assumed to be all close one to the other.

Data in Tables 7 and 8 demonstrate that in spite pre-treatment of MSW for RDF generation costs energy (electricity and a minor amount of the initial LHV), the availability of a large scale thermal power plant where RDF could substitute coal could be an interesting opportunity. Even if we consider an RTO the advantages of RDF in a large thermal power plant are confirmed.

This advantage would be more clear if the conventional strategy of direct combustion were based on a small area of MSW generation. In this case a low capacity incinerator would be associated to a low electrical generation efficiency: the scale effect is one of the problems of MSW combustion.

4 Conclusions

In this paper a strategy based on MSW bio-drying for RDF generation has been analysed. By this option direct combustion is avoided. Among the alternative strategies based on RDF, co-combustion in thermal power plants has been selected as a case study as the efficiency of electricity generation can be higher than the one of conventional incinerators. The present paper has analysed in details a few aspects related to CO_2 balances for bio-drying in order to give a contribution to a correct understanding of the process. Results show that the role of N_2O is not dominant in the case of the bio-drying option. Also in direct combustion this pollutant plays a secondary role. RTO has some disadvantages related to the use of natural gas but in terms of CO_2 the results are acceptable.

5 Literature

Rada E.C., Franzinelli A., Taiss M., Ragazzi M., Panaitescu V., Apostol T.	2007	Lower Heating Value dynamics during municipal solid waste bio-drying, Environmental Technology, vol. 28, pp.463-469.
Rada E. C., Taiss M., Ragazzi M., Panaitescu V., Apostol T	2005.a	Un metodo sperimentale per il dimensionamento della bioessiccazione dei rifiuti urbani, Rifiuti Solidi, Anno XIX, N.6, pp. 346-353, ISSN: 0394-5391.
Rada E. C., Ragazzi M., Panaitescu V., Apostol T	2006.a	Experimental characterization of Municipal Solid waste bio-drying, Waste Management and Environment III, Vol. 92, pp. 295 – 302, ISBN I-84564-173-6.
Rada E. C., Ragazzi M., Fabbri L., Panaitescu V., Apostol T	2006b	Life Cycle Analisis applicata alla bioessiccazione: aspetti energetici, Rifiuti Solidi, Vol. XX, N.2, pp. 89-97, ISSN: 0394-5391.
Rada E. C., Ragazzi M., Panaitescu V., Apostol T	2005b	Energy from waste: the role of bio-drying, Stintific Buletin (Ro), seria C: Electrical Engineering, vol 67, nr. 2, pp. 69-76, ISSN 1454-234x.
Rada E. C., Fabbri L., Ragazzi M., Panaitescu V., Apostol T	2006c	Life Cycle Analisis applicata alla bioessiccazione: aspetti ambientali, Rifiuti Solidi, Vol. XX, N.3, pp. 183-190, ISSN: 0394-5391
Rada E. C., Cocarta D., Ragazzi M., Panaitescu V., Badea A.	2006d	Trattamenti meccanico-biologici di RU e particolato secondario, XII Convegno di Igiene Industriale – Corvara (BZ), versione CD, Italy.

Recyclable materials recovery after biological treatment of the residual fraction: quality improvement and contribution to landfill diversion targets

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Abstract

Even in districts where source separated collections are implemented, a Residual Fraction remains. This fraction can be treated in MBT (Mechanical Biological Treatment) Plants that, other than stabilising biologically the waste, can produce a fuel and other recyclable fractions. Further materials recovery for recycling purpose is possible: the critical point is the quality of the materials that should be recycled.

Results of experimental and industrial experiences of simple materials recovery techniques applied to residual waste in different plants where the residual fraction has been submitted to aerobic biodrying process are presented.

Keywords

MBT, Biodrying, recycling, residual fraction

1 Introduction

A simplified schema of Municipal Solid Waste Management shows that the usual disposal systems for the Residual Fraction, the waste that remains after the source separated collection, are: landfill; Waste to Energy (WTE) plant; co-combustion in cement factory or electrical power plant.

For each solution a pre treatment in Mechanical Biological (MBT) Plants could be useful in order to further decrease the residual biological activity, to produce a combustible of constant characteristics and to allow a better selection of recyclable fractions. The landfill disposal modalities must comply with 1999/31/CE directive (landfill directive) requiring a progressive reduction of the biodegradable waste to be disposed. At the same time it is important to avoid that potentially recyclable fractions will be conveyed in landfill. Deep evaluation of each recycling process is need to be sure to get real benefits (first of all for the environment). The critical point is the quality of the extracted fraction to be recycled: the quality requirements for a good acceptability are, in many cases, difficult to fulfil or fulfilling with complicated processes making the project unfruitful.

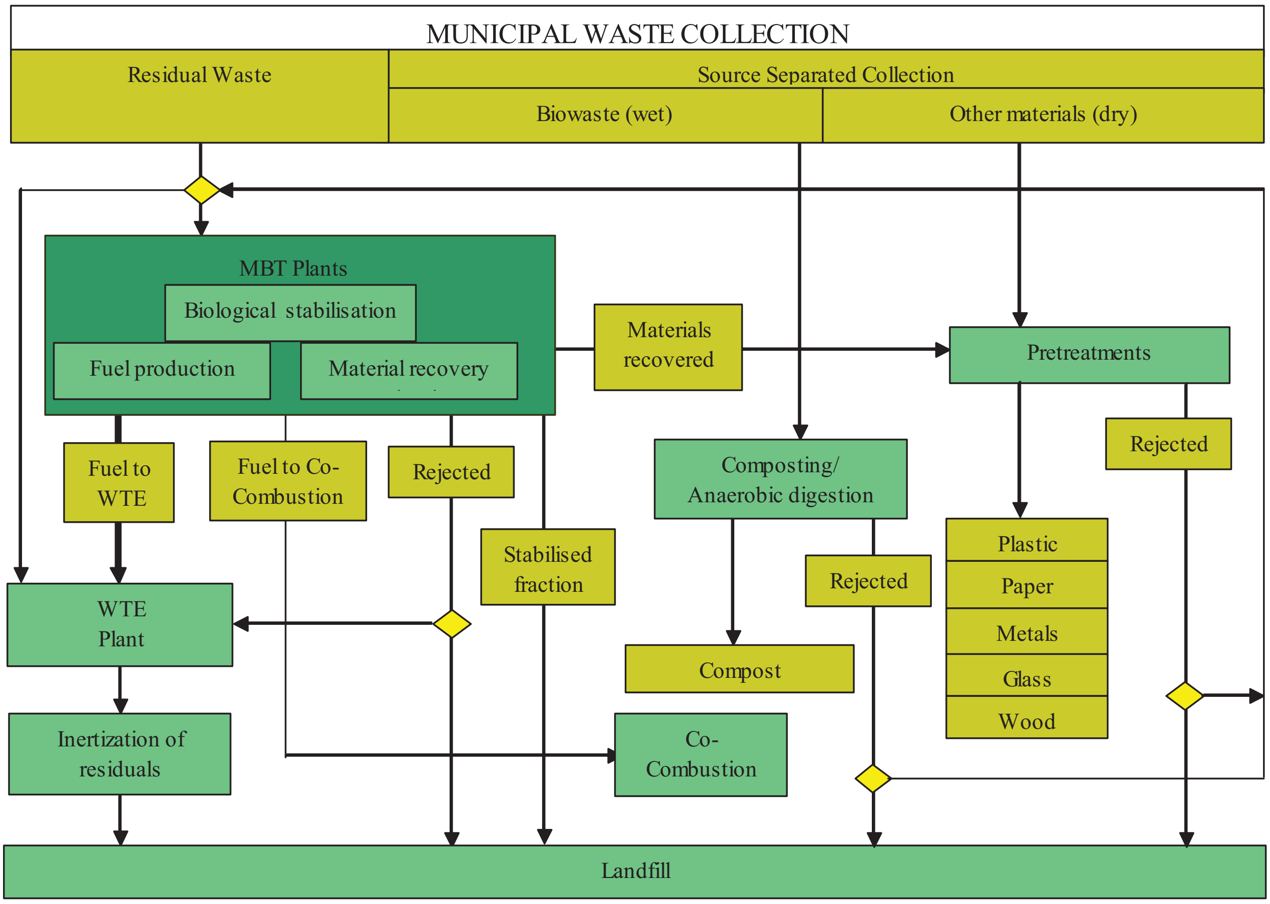

Figure 1 Simplified schema of Municipal Solid Waste management system

Results of experimental and industrial experiences of simple materials recovery techniques applied to residual waste in different plants where the residual fraction has been submitted to aerobic biodrying process are presented.

2 Trials and Data Collection

Ecodeco Group built in Europe 10 MBT biodrying-based plant (year 2008) treating more than 1.000.000 t/y of Municipal Solid Waste (MSW) and producing more than 250.000 t/y of Refuse Derived Fuel (RDF). In this kind of plant the waste is dried by forced ventilation that increases bacterial activity, i.e. the temperature, producing an evaporation of water. The process stops when low moisture content does not allow the sustainability of bacterial activity.

Data for this study were collected in two different ways.

In the first, historical data from “in operations plants” producing RDF, Ferrous material, Non Ferrous Material and Grits (Namely U.K. plants of London and Dumfries in Scotland, where grits are collected) are retrieved (Ecodeco 2008).

In the second, because no plants are equipped with devices able to separate plastics and paper, a pilot plant where simple mechanical selections (screening, air separations) connected with optical scanner separation (NIR IR OPTICAL Scanner) was prepared.

This machine was placed in the plant of Cavaglià (Biella district, Piemonte Region) and the biodried material has been tested in it. The experimental trials were performed in 2008.

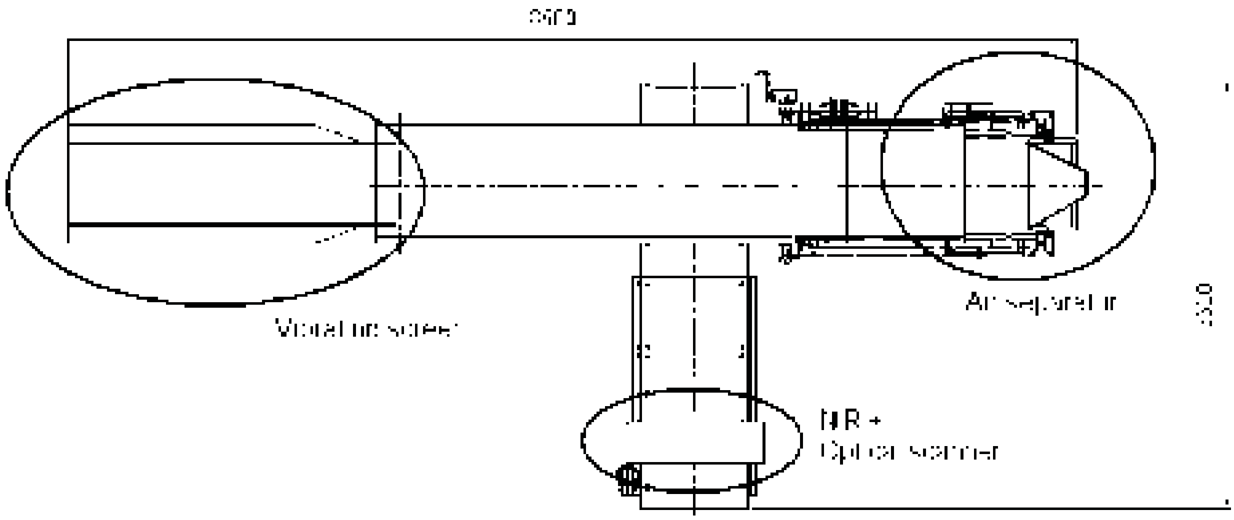

Figure 2 Layout of the Pilot Plant

The input data of Cavaglià plant were analysed on the basis of the official Piemonte source separated collection data (REGIONE PIEMONTE 2008) and local evaluation of MSW composition.

Table 1 Composition and source sep. collection data

Source Separated Collection Rate		45,3 %
Residual Fraction Composition		**Fraction Interception****
organic	25,9 %	33,4 %
green	3,0 %	73,2 %
plastic	17,9 %	22,3 %
paper	26,4 %	46,9 %
wood	1,5 %	81,8 %
textiles	4,4 %	9,4 %
glass	5,5 %	63,9 %
metals	3,4 %	37,8 %
other*	12,0 %	7,0 %
TOTAL	100,0 %	
Residual Fraction characteristics		
Moisture		33,0 %
BMW ***		65,0 %
NCV****		11.726 kJ/kg
* inerts, leather, battery, sanitary towels ** referred to the sum of Residual Waste and source separated waste *** Biodegradable Municipal Waste ****Net Calorific Value		

The biodried material that represents the input to the above described pilot plant is the biodried material where plastic and paper content aren't changed because only organic content and moisture are decreased. The averaged weight loss (due to water evaporated and organic material converted in CO_2) was 28% of the input weight.

Comparative results of input-output data coming from these trials are presented in the following. All data are referred to the content in input MSW to MTB plant (before the biodrying process). Three types of plastics (pet=polyethylene terephthalate, pe=polyethylene, pp=polypropylene) were selected in output.

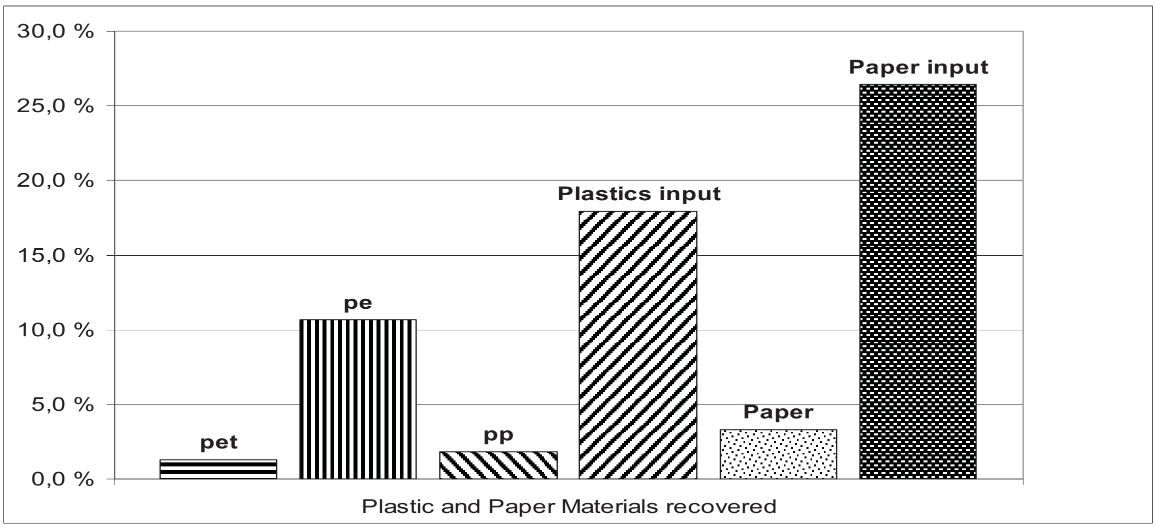

Figure 3 Recovery of Plastics and Paper compared with the input content

The historical data based upon 2008 average input/output materials coming from U.K. plants are shown in the following.

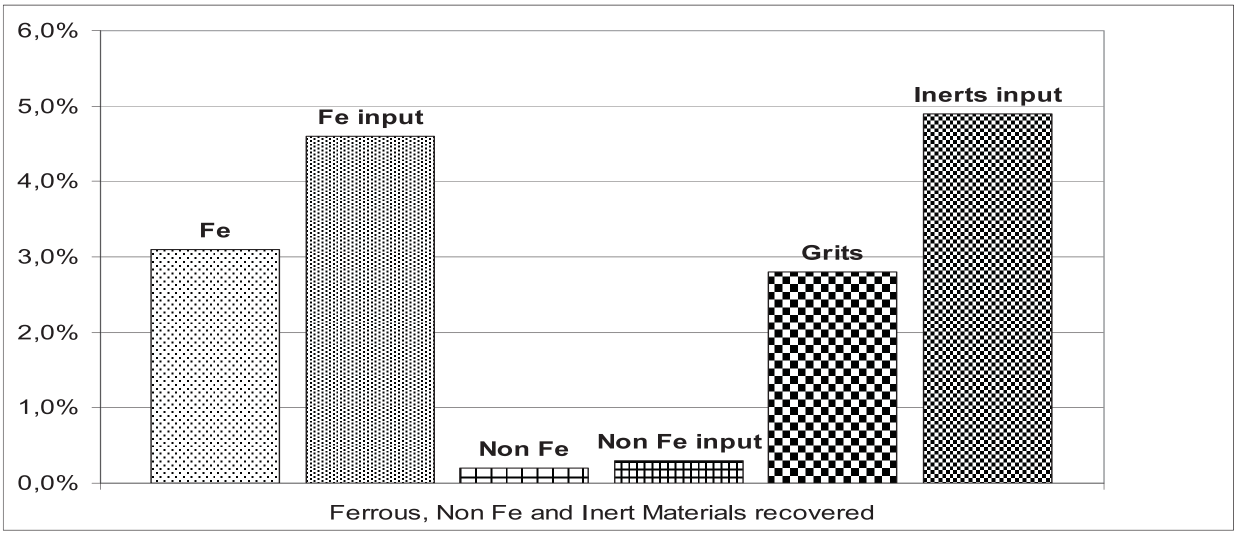

Figure 4 Recovery of Fe, non Fe, Grits compared with the input content

3 Discussion

It has to be outlined that the pilot plant was set in order to maintain purity standards for the materials recovered that allow them to be accepted by the recycling industries.

The same quality for recycling was reached in U.K. plants.

Based upon the above presented data, some scenarios can be analyzed.

In the following table a comparison between a plant oriented only to produce RDF for Cement industry and one modified in a way that recyclable materials are diverted is presented.

Table 2 Comparison between only RDF production and RDF plus Recycling scenarios

Input data		**Scenarios**			
Recovery Rate		**Only RDF production**		**RDF and material recovery**	
Paper	12,5%	**Output Fraction**		**Output Fraction**	
Plastics	76,5%			Plastics recovered	13,7 %
Fe	67,4%			Paper recovered	3,3 %
Non Fe	66,7%			Metals recovered	2,3 %
Inerts	57,1%			Inert recovered	3,1 %
Aer. Treat.Weight Loss**	28%	<20 mm rejected	12,0%	<20 mm rejected	12,0%
		>20 mm rejected	21,3%	>20 mm rejected	15,4%
		RDF High Quality	38,7 %	RDF Low Quality	22,1 %
		Characteristics of RDF		**Characteristics of RDF**	
		RDF NCV	17372 kJ/kg	RDF NCV	12732 kJ/kg
		RDF Ash	15%	RDF Ash	17,0 %
** Weight difference between input and oputput waste to/from aerobic treatment due to water evaporation and organic fraction degradation					

The composition for the input waste are those of Cavaglià plant and the recovery rates are the same as found with the pilot plant and recorded data from U.K. plants.

A more detailed analysis using well know tools (like LCA methods) have to be made on specific cases. From a general point of view, the literature is in agreement in considering favourable the recycling option (WRAP 2006); LCA study on RDF production and utilisation in cement plants showed positive results too (SCOTTI ET AL, 2008).

A simulation of process from residual fraction with high rate of source separated collection (Treviso district, Veneto Region), is shown in the following (CONSORZIO PRIULA 2008)

Table 3 Expected output in a district with high rate of source separated collection.

Source Separated Collection Rate	70,0 %	Weight Loss	17,6 %
Residual Fraction Composition		**Expected output***	
Glass	1,6 %	RDF	11,4 %
Plastics	58,0 %	<20 mm Rejected	9,3 %
Metals	1,6 %	>20 mm Rejected	16,6 %
Non Combustibles	0,7 %	Fe	0,7 %
Paper	29,9 %	Paper	3,7 %
BMW**	8,2 %	Non Fe	0,1 %
TOTAL	100,0 %	Plastics	40,6 %
Moisture	24,8 %		
*set up for paper and plastics recovery enhanced **BMW=Biodegradable Municipal Waste			

The simulation has been done using a trivial mathematical model derived from trials above described and completed with weight loss trials on samples of this kind of waste. The difference between this simulation and the above data in table 2 is that here the inert recycling fraction has not been considered.

A more detailed economical analysis is not easy without focusing on a specific case due to the large spread of the recycling materials value and rejected disposal cost.

An important feature of this kind of process must be the flexibility allowing the plant to modify the quantities between RDF and Recycling fractions depending on markets requests; and this is possible because the plastic-paper recycled fractions are mixed in RDF stream before the optical scanners separation.

At the end, attention has to be paid at the chlorine content of RDF due to the PVC fraction. As usual PVC materials can be selected by NIR IR scanners devices.

4 Conclusion

Data show that the residual fraction contains materials that can be recycled.

The combined utilisation of biological treatment, recycling techniques and RDF production is a useful option to fulfil landfill directive and recycling targets.

Flexibility is an essential feature to ensure the real disposal of all the end products coming from MBT plants.

Further development of this research is the modification of an "in operation" industrial plant to make it able to collect recycling fractions and analyze data over one year period. This further step will give basic data to evaluate in detail operational costs and I/O parameters for LCA study.

5 Literature

Ecodeco.	2008	Internal Data Report See http://ecodeco.it
Regione Piemonte	2008	Indagine sui Rifiuti Urbani. See: http://extranet.regione.piemonte.it/ambiente/rifiuti/urbani.htm
WRAP	2006	Environmental benefit of re cycling-full report-WRAP 2006 see: http://wrap.co.uk/applications/pubblications.htm
Scotti S., Barone F., Minetti C.	2008	Integrated system of RDF production and cement factory utilisation: environmental analysis of an industrial example. Second International Symposium on Energy from Biomass and Waste- Venice 17-20 November 2008
Consorzio Priula	2008	Preliminary report on Waste Composition and Source Separated Collection Rate. See http://consorziopriula.it

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Effect of bio-drying on sorting and combustion performances of municipal solid waste

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Abstract

The aerobic and combined hydrolytic–aerobic bio-drying processes were separately set up to investigate sorting and combustion performances of MSW by bio-drying. Results showed that the sorting efficiency was found to be correlated with water content negatively (correlation coefficient, R=–0.89) and organics degradation positively (R=0.92). The high heating values were correlated with organics degradation positively (R=0.90), whereas the low heating values were negatively correlated with water content (R=–0.96). The potential emissions of combustion gases were correlated with organics degradation (correlation coefficient, R=0.67 for HCl, R=0.96 for SO_2, R=0.91 for PCDD/Fs and R=–0.60 for NO_x). Interestingly, the bio-drying could significantly improve the ratio of gas emissions to low heating values, although it resulted in the increase of the emissions per kg of combustion wastes.

Keywords

Municipal solid waste; bio-drying; sorting efficiency; combustion; HCl; SO_2; NO_x; PCDD/Fs

1 Introduction

The municipal solid waste (MSW) is comprised of food waste and recyclable materials, such as wasted plastics, paper, glasses and metals, etc. The latter can be utilized as resources after mechanical or manual sorting. On the other hand, combustion is one of the most effective options for disposing MSW due to minimizing the amounts of wastes and recovering energy (LIU AND LIU, 2005; ZHANG ET AL., 2008). Nevertheless, the MSW in China is typically characterized by high water content (HE ET AL., 2005), which may reduce the feasibility of sorting for beneficial utilization and the efficiency of energy recovery. The bio-drying can remove water in MSW and favor both resources recovery and combustion (ADANI ET AL., 2002; CHOI ET AL., 2001; RADA ET AL., 2005). The bio-drying could be performed by both aerobic and combined hydrolytic–aerobic processes (SUGNI ET AL., 2005; ZHANG ET AL., 2008a). The later was characterized by supplementing a hydrolytic stage prior to the aerobic degradation.

The bio-drying has showed an improvement both in sorting efficiency and in heating values for MSW (ADANI ET AL., 2002; NORBU ET AL., 2005; RADA ET AL., 2007). Nevertheless, it is still unclear the quantitative correlations of the sorting efficiency and heating values with organics degradation and water removal during bio-drying. The combustion of MSW will release the harmful emissions of acidic gases (HCl, SO_2 and NO_x, etc.) and polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs). These emissions originate from the combustion of the compounds containing chlorines, sulfurs and nitrogen which will be transformed, transferred or degradation during bio-drying. Until now, the influence of bio-drying on the gas emissions in the combustion of MSW is still unknown.

2 Materials and methods

2.1 Characteristics of the MSW feedstock

The MSW was sampled from a residential area in Shanghai, China. The sampled wastes used in this study comprised of 64% (w w^{-1}, in wet weight, the same below) kitchen waste, 20% (w w^{-1}) paper, 7.5% (w w^{-1}) plastics and 8.5% (w w^{-1}) others. The initial water content was 68% (w w^{-1}).

2.2 Experimental equipment

The trials were performed in the column reactors, as previously reported by ZHANG ET AL. (2008b). Briefly, each column (400 mm i.d. and 1200 mm height) was wrapped by 100-mm-thick hollow cotton for thermal insulation. At the bottom, a 100-mm-high layer filled with crockery balls (diameter about 5 mm) was placed for leachate drainage. Above the balls, there was a perforated baffle (2-mm mesh) to support the waste and to facilitate aeration. In order to avoid heat loss and vapor condensation, two layers of straw and cotton were placed above the waste. For aeration, a whirlpool pump (XGB-8, Penghu Co, Shanghai, China) and a gas-flow meter (LZB-10, Shanghai Instrument Co, Shanghai, China) were used.

2.3 Experimental setup and operation

Three batches, i.e. one aerobic and two combined processes, were performed for bio-drying. The aerobic process (marked as “Aerobic”) was operated with a ventilation interval of 7 min run / 23 min stop and the fed wastes were manually turned every 2 days. The combined hydrolytic–aerobic processes contained both hydrolytic and aerobic stages. During the hydrolytic stage (0–4 days), the combined processes were separately operated by natural aeration (marked as “Combined 1”) and by insufficient aeration of a ventilation interval of 10 min run / 230 min stop (marked as “Combined 2”). During the aerobic stage (5–16 days), the operation was the same as that for the Aerobic. As described previously (ZHANG ET AL., 2008a), the air-inflow rate was fixed at 0.056 m^3 per kg wet wastes per hour during the whole experiment. After mixing adequately, 28 kg of the above-mentioned raw MSW was loaded into each column and each experiment was conducted for 16 days.

2.4 Sampling and analytical methods

To assess the sorting efficiency, approximately 4 kg of MSW was sampled every 4 days when the fed materials were turned and the detailed operation for sorting was described as NORBU ET AL. (2005). After sorting, these samples were re-mixed with wastes and loaded into the column. At the same time, each sample of about 200 g was collected from the top, middle and bottom of the column and then mixed for analysis. After determining water contents, these drying samples were reduced into size $\Phi < 0.5$ mm for further analysis. Carbon, hydrogen, nitrogen and sulfur contents were measured by an elemental analyzer (Vario EL *III*, Elementar, Germany). The heating values were calculated according to ultimate analysis as suggested by HE ET AL. (2004), MARZI ET AL. (2007) and RADA ET AL. (2007). The above indices were analyzed in triplicate for all samples with standard deviations less than 10%.

2.5 Combustion experiment

The combustion experiment was performed in a combustion reactor tube (40 mm i.d. and 710 mm length). Before combustion, the reactor tube was preheated to 850^{o}C and then the drying material was put into by a ceramic boat. During the combustion, the flue gas was sampled by the sampling train and the impingers were submerged in ice bathes. The aqueous solutions of Na_2CO_3/$NaHCO_3$, ammonium sulfamate and dilute sulfuric acid/peroxide were respectively used to absorb HCl, SO_2 and NOx in combustion gases. The sampled HCl and SO_2 were then analyzed by an Ion Chromatography (ICS-1500, Dionex, USA), and NO_x was determined using ultraviolet spectrophotometric method (EPA OF CHINA, 2001).

2.6 Statistical analysis

All statistical analysis was performed using SPSS 16.0 (SPSS, Inc., Chicago, USA). Pearson's correlation coefficient was used to evaluate the linear correlation between two parameters. The correlations presented were confirmed at a 95% confidence level.

3 Results and discussions

3.1 Organics degradation and water content during bio-drying

Figure 1 presents organics degradation rate and water content during bio-drying. The calculation equations are listed in the appendix. In the first 4 days, the Aerobic had a higher organics degradation rate than the Combined 1 and Combined 2, due to more oxygen supplied. Also, from day 5 to day 8, more organics were degraded for the Aerobic. From day 9 on, both Combined 1 and Combined 2 had higher organics degradation rates than the Aerobic, due to more organics available for the combined processes. As for the total rates of organics degradation, the Aerobic had the highest rate, followed by the Combined 2 and Combined 1. The water contents for Combined 1, Combined 2 and Aerobic were mitigated during bio-drying. After bio-drying, the Combined 2 had the lowest final water content, followed by the Aerobic and Combined 1 (**Figure 1b**).

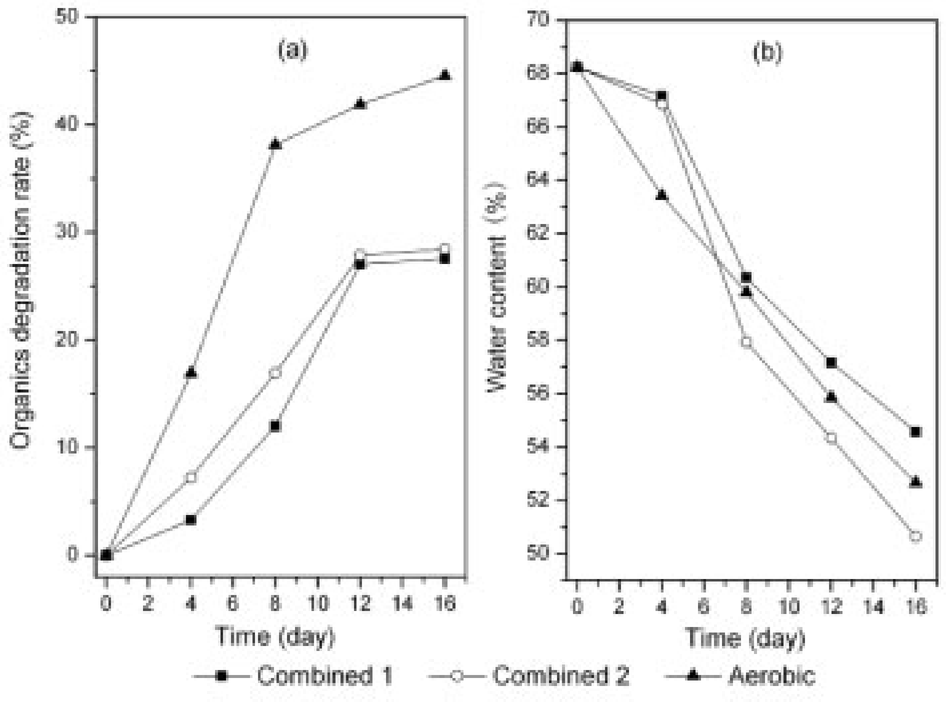

Figure 1 Organics degradation rate and water content during bio-drying

(a) Organics degradation rate; (b) Water content

3.2 Sorting efficiency during bio-drying

The sorting efficiency could be evaluated by the criterion as ***eq.(1)*** (NORBU ET AL., 2005).

$$SE = \frac{P_{<60}}{W} \times 100\% \quad (1)$$

where, *SE* (%) was the sorting efficiency, $P_{<60}$ (kg) was the amount of underflow fractions (under 60-mm screens) and *W* (kg) was the total waste.

Figure 2 indicates the evolution of the sorting efficiency of MSW during bio-drying. Obviously, the bio-drying could effectively improve the sorting efficiency for all of the three batches. After bio-drying, the sorting efficiencies for the Combined 1, Combined 2 and Aerobic were 62%, 71% and 68%, significantly enhanced from the initial of 34%. In the first 12 days, the sorting efficiency followed a decreasing order of the Aerobic > Combined 2 > Combined 1, resulting from different granule sizes reduced by organics degradation. At the last period of bio-drying, however, the Combined 2 had the highest sorting efficiency, attributed to the lowest final water content of MSW. As a whole, the sorting efficiency was correlated with the water content of MSW negatively (correlation coefficient, *R*=–0.89) and the organics degradation rates positively (correlation coefficient, *R*=0.92).

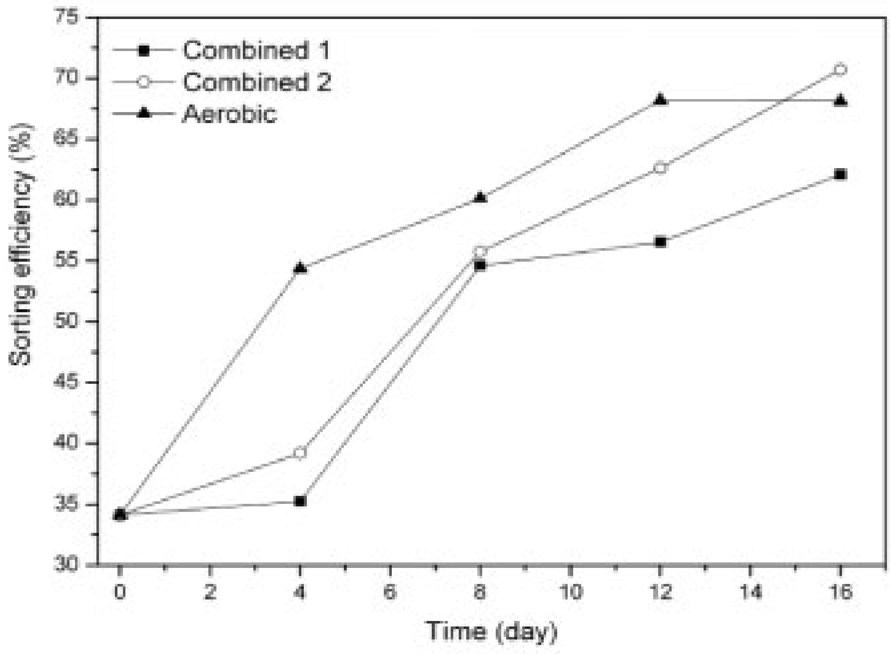

Figure 2 Evolution of the sorting efficiency of MSW during bio-drying

3.3 Heating values during bio-drying

The high heating value (HHV) indicated the quantity of heat generated from the complete combustion of the dry material, while the low heating value (LHV) reflected the heating value of wet material. The bio-drying played an important role in the improvement of both HHVs and LHVs of MSW. After bio-drying, the HHVs were enhanced from 15400 kJ/kg to 19600 (Combined 1), 20100 (Combined 2) and 19900 kJ/kg (Aerobic). Furthermore, for Combined 1, Combined 2 and Aerobic, the LHVs were respectively improved to 7540, 8590 and 8260 kJ/kg from the initial of 3557.9 kJ/kg. **Figure 3** indicates the correlation between the heating values with organics degradation rates and water contents during bio-drying. The HHVs were positively correlated with organics degradation rates (correlation coefficient, R=0.90). This could be explained that the ratio of plastics fraction was enhanced as a result of organics degradation while the plastics had a high HHV. The LHVs were negatively correlated with water content (R=–0.96).

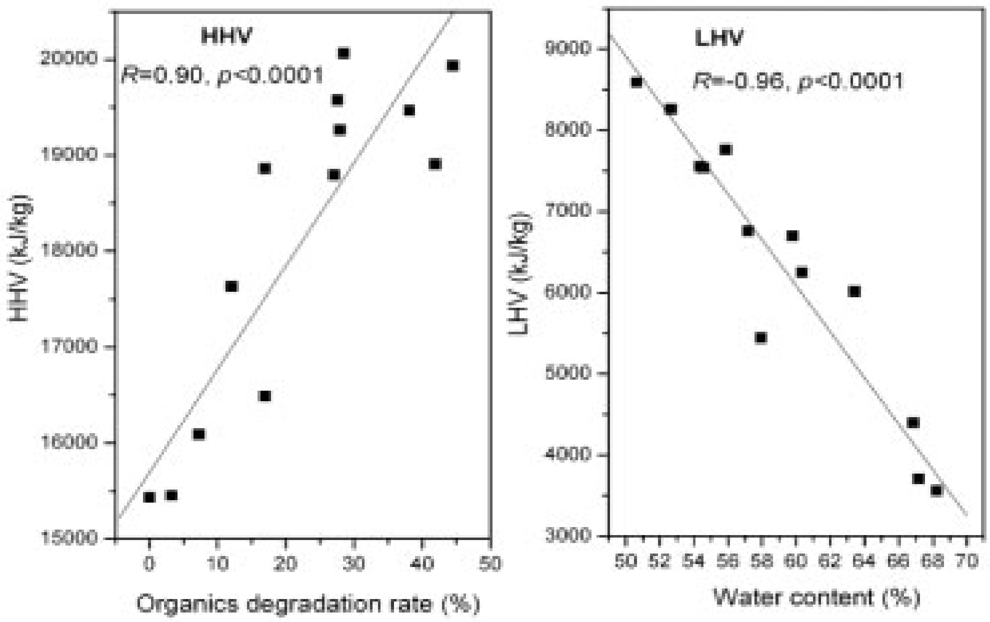

Figure 3 Correlation between the heating values with organics degradation rates and water contents during bio-drying

3.4 Emissions of HCl, SO_2 and NO_x and Potential for PCDD/Fs formation in the combustion during bio-drying

The emissions of HCl, SO_2 and NO_x in MSW combustion during bio-drying are shown in **Figure 4**. The HCl emissions of combustion increased during bio-drying with a decreasing order of the Aerobic > Combined 2 > Combined 1. After bio-drying, the HCl emissions in the combustion of MSW increased by 74.8%, 35.2% and 38.1% for the Aerobic, Combined 1 and Combined 2, respectively. Moreover, there was a positive correlation between the HCl emissions and organics degradation during bio-drying, with a correlation coefficient of 0.67.

There was a peak for SO_2 emissions in the combustion on day 4 or 8. This was a result of the increase of sulfurs concentration in organics fraction of MSW and the increase of plastics fraction containing much less sulfurs during bio-drying. Nevertheless, the bio-drying would still result in the increase of SO_2 emissions. On day 16, the SO_2 emissions for the Aerobic, Combined 1 and Combined 2 increased by 29.3%, 7.6% and 10.2% respectively, when compared with the initial.

Interestingly, the NO_x emissions could be mitigated by bio-drying especially. In the first 8 days, the combined processes released more NO_x than the Aerobic, attributed to the lower organics degradation rates (**Figure 1**). From then on, similar emissions of NO_x were observed for the Aerobic, Combined 1 and Combined 2. At the end of bio-drying, the NO_x emissions in the combustion of MSW were minimized by approximately 25%. The NO_x emissions were negatively correlated with organics degradation, with a correlation coefficient of -0.60.

The formation of dioxins during combustion could be attributed to either inorganic chlorides or organic chlorines with insignificant differences (HATANAKA ET AL., 2000; HATANAKA ET AL., 2005; YASUHARA ET AL., 2001; WIKSTRÖM ET AL., 1999; WIKSTRÖM AND MARKLUND, 2001). The PCDD/Fs formation was mainly influenced by the combustion conditions (WIKSTRÖM AND MARKLUND, 2001). Under a certain combustion condition, for the samples consist of the same ingredients, the dioxin formation or toxic equivalent (TEQ) was quantitatively correlated with chlorine contents (WIKSTRÖM AND MARKLUND, 2001; YASUHARA ET AL., 2001; YASUHARA ET AL., 2002). Therefore, under the same combustion conditions described by YASUHARA ET AL. (2002), a regression equation for TEQ (Y) and chlorines content (X) of "$Y = 0.738X + 0.115$" could be used to predict the potential for PCDD/Fs formation. The TEQ in the combustion during bio-drying is presented in **Table 1**. The bio-drying could cause the increase of TEQ and the Aerobic had the highest values, followed by Combined 2 and combined 1. Compared with the initial, the potential for PCDD/Fs formation after bio-drying increased by 58.2%, 30.4% and 30.3% for the Aerobic, Combined 1 and combined 2, respectively. There was a positive correlation between the potential for PCDD/Fs formation and organics degradation with a correlation coefficient of 0.91.

Assumed that 1 kg of raw MSW and bio-drying products was combusted, the combustion emissions were showed in **Table 2**. Unfortunately, the bio-drying caused the increase of the emissions of combustion gases. However, besides the combustion emissions, the heating value was also considered for a better combustion performance. Thereby, the index (*I*), defined as the ratio of gas emissions to LHV, was introduced to evaluate the combustion performance. *I* values for HCl, SO_2, NO_x and PCDD/Fs before and after bio-drying are also listed in **Table 2**. Interestingly, the potential emissions of combustion gases per LHV were significantly mitigated after bio-drying, as indicated by *I* values. Furthermore, the Combined 2 was proposed for bio-drying due to the lowest *I* value. Therefore, the bio-drying was favorable for the improvement of combustion performances when considering LHVs.

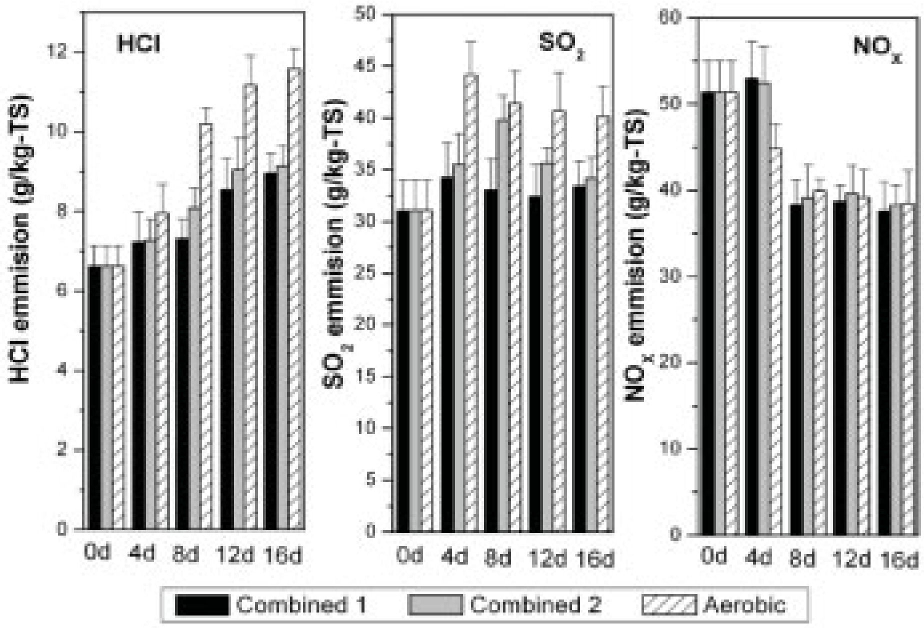

Figure 4 Combustion emissions of HCl, SO2 and NOx during bio-drying

Table 1 Potential of TEQ formation in the combustion of MSW during bio-drying

Time	Inorganic chlorine (g/kg-TS)			Organic chlorine (g/kg-TS)			Potential of TEQ[a] formation (mg/kg-TS[b])		
	A	B	C	A	B	C	A	B	C
Day 0	9.793	9.793	9.793	2.182	2.182	2.182	0.999	0.999	0.999
Day 4	10.652	10.681	11.659	2.424	2.473	2.595	1.080	1.086	1.167
Day 8	11.421	11.539	15.032	2.617	2.680	3.387	1.151	1.164	1.474
Day 12	12.395	12.934	16.045	2.809	3.013	3.630	1.237	1.292	1.567
Day 16	13.106	13.026	16.178	2.990	3.048	3.680	1.303	1.301	1.581

[a] TEQ: toxic equivalent; [b] TS: total solid; A: Combined 1; B: Combined 2; C: Aerobic.

Table 2 Combustion emissions a and I b for HCl, SO_2, NO_x and PCDD/Fs before and after bio-drying

Samples		HCl (g)	I_{HCl} (mg/kJ)	SO_2 (g)	I_{SO2} (mg/kJ)	NO_x (g)	I_{NOx} (mg/kJ)	PCDD/Fs (mg TEQ)	$I_{PCDD/Fs}$ (ng TEQ/kJ)
Raw MSW		2.1	5.9	9.9	27.5	16.3	45.5	0.32	0.9
Bio-drying products	**A**	4.1	2.6	15.2	9.8	17.1	11.0	0.59	0.4
	B	4.5	2.1	16.9	8.1	18.9	9.0	0.64	0.3
	C	5.5	3.0	19.0	10.3	18.2	9.8	0.75	0.4

[a] Combustion emissions were calculated based on 1 kg materials; [b] *I:* ratio of gas emissions to LHV; A: Combined 1; B: Combined 2; C: Aerobic.

4 Conclusions

During bio-drying, the sorting efficiency was found to be correlated with water content negatively and organics degradation positively. The high heating values and low heating values were negatively correlated with organics degradation and water content, respectively.

The bio-drying would result in the increase of HCl and SO_2 emissions and the potential for PCDD/Fs formation in the combustion of MSW. Nevertheless, the NO_x emissions could be reduced by bio-drying. Interestingly, the bio-drying could improve the ratio of gas emissions to LHV significantly, although it resulted in the increase of the emissions per kg of combustion wastes.

As a whole, the bio-drying was not only favorable for the sorting and energy recovery, but also could improve the ratio of gas emissions to low heating values. Therefore, the bio-drying could be proposed as an effective strategy before resource recovery or combustion of municipal solid wastes with high water content.

5 Literature

Adani, F.; Baido, D.; Calcaterra, E.; Genevini, P.L.;	2002	The influence of biomass temperature on biostabilization–biodrying of municipal solid waste. Bioresource Technology 83, 173–179.
Choi, H.L.; Richard, T.L.; Ahn, H.K.;	2001	Composting High Moisture Materials: Biodrying Poultry Manure in a Sequentially Fed Reactor. Compost Science & Utilization 9, 303–311.
EPA of China;	2001	Pollution control standard for MSW incineration. China Environmental Science Press, Beijing, GB 18485-2001.
Hatanaka, T.; Imagawa, T.; Takeuchi, M.;	2000	Formation of PCDD Fs in Artificial solid waste incineration in a laboratory-scale fluidized-bed reactor influence of contents and forms of chlorine sources in high-temperature combustion. Environmental Science & Technology 34, 3920–3924.
Hatanaka, T.; Kitajima, A.; Takeuchi, M.;	2005	Role of chlorine in combustion field in formation of poly chlorinated dibenzo-dioxins and dibenzofurans during waste incineration. Environmental Science & Technology 39, 9452–9456.
He, P.J.; Shao, L.M.;	2004	Waste Management. China Higher Education Press, Beijing, ISBN 704015593.
He, P.J.; Shao, L.M.; Qu, X.; Li, G.J.; Lee, D.J.;	2005	Effects of feed solutions on refuse hydrolysis and landfill leachate characteristics. Chemosphere 59, 837–844.
Liu, Y.; Liu, Y.;	2005	Novel incineration technology integrated with drying, pyrolysis, gasification, and combustion of MSW and ashes vitrification. Environmental Science & Technology 39, 3855–3863.
Marzi, T.; Mrotzek, A.; Goerner, K.;	2007	Combustion behaviour of refuse derived fuels–development of a characterization. Proceeding Sardinia 2007, Eleventh International Waste Management and Landfill Symposium, CD only.
Norbu, T.; Visanathan, C.; Basnayake, B.;	2005	Pretreatment of municipal solid waste prior to landfilling. Waste Management 25, 997–1003.
Rada, E.C.; Ragazzi, M.; Panaitescu, V.; Apostol, T.;	2005	An example of collaboration for a technology transfer: municipal solid waste bio-drying. Proceeding Sardinia 2005, Tenth International Waste Management and Landfill Symposium, CD only.
Rada, E.C.; Franzinelli, A.; Taiss, M.; Ragazzi, M.; Panaitescu, V.; Apostol, T.;	2007	Lower heating value dynamics during municipal solid waste bio-drying. Environmental Technology 28, 463–469.
Sugni, M.; Calcaterra, E.; Adani, F.;	2005	Biostabilization–biodrying of municipal solid waste by inverting air-flow. Bioresource Technology 96, 1331–1337.
WikstrÖm, E.; LÖfvenius,	1996	Influence of level and form of chlorine on the forma-

G.; Rappe, C.; Marklund, S.;		tion of chlorinated dioxins, dibenzofurans, and benzenes during combustion of an artificial fuel in a laboratory reactor. Environmental Science & Technology 30, 1637–1644.
WikstrÖm, E.; Marklund, S.;	2001	The influence of level and chlorine source on the formation of mono- to octa-chlorinated dibenzo-*p*-dioxins, dibenzofurans and coplanar polychlorinated biphenyls during combustion of an artificial municipal waste. Chemosphere 43, 227–234.
Yasuhara, A.; Katami, T.; Okuda, T.; Ohno, T.; Shibamoto, T.;	2001	Formation of dioxins during the combustion of newspapers in the presence of sodium chloride and poly (vinyl chloride). Environmental Science & Technology 35, 1373–1378.
Yasuhara, A.; Katami, T.; Okuda, T.;	2002	Role of inorganic chlorides in formation of PCDDs, PCDFs, and coplanar PCBs from combustion of plastics, newspaper, and pulp in an Incinerator. Environmental Science & Technology 36, 3924–3927.
Zhang, D.Q.; He, P.J.; Jin, T.F.; Shao, L.M.;	2008a	Bio-drying of municipal solid waste with high water content by aeration procedures regulation and inoculation. Bioresource Technology 99, 8796–8802.
Zhang, D.Q.; He, P.J.; Shao, L.M.; Jin, T.F.; Han, J.Y.;	2008b	Biodrying of municipal solid waste with high water content by combined hydrolytic–aerobic technology. Journal of Environmental Sciences 20, 1534–1540.
Zhang, H.; He, P.J.; Shao, L.M.; Lee, D.J.;	2008	Source analysis of heavy metals and arsenic in organic fractions of municipal solid waste in a megacity (Shanghai). Environmental Science & Technology 42, 1586–1593.

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Einsatz der Sensorgestützten Sortiertechnik zur Senkung des Brennwertes der Deponiefraktion in MBA-Anlagen

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Sensorbased Sorting for the Reduction of the Upper Caloric Value in Mechanical-Biological Treatment Plants

Abstract

Due to an increasing importance of climate protection and a stricter legal framework concerning disposal of waste, pre-treatment of wastes which are landfilled is necessary. In this context the landfill ordinance stipulating threshold criteria for dumpable wastes is the key legal document in Austria. Generally dumping of wastes with a TOC > 5 m.-% is prohibited. An exception is made for waste, which is mechanically-biologically treated such that an upper caloric value of less than 6,600 kJ/kg DM is achieved.

Complying with the threshold for the upper caloric value is a tough challenge in many cases due to the high energy content of plastic and wood components in the output fraction of the mechanical-biological treatment (MBT). Those materials have a much higher upper caloric value than the stipulated 6,600 kJ/kg DM and cannot be degraded in the biological stage of the MBT within the time frame of the treatment. Additionally, from the resource conservation point of view it is sensible to make those components with a high caloric value available for energetic utilization.

Non-compliance with the upper caloric value threshold implies the necessity of thermal treatment of the output stream of the MBT. As thermal treatment in a Municipal Solid Waste Incinerator (MSWI) compared to landfilling is more expensive, innovative technologies like sensorbased sorting may be considered as an economic alternative for securing compliance with the upper caloric value threshold. In that case the focus of the sorting process is not the production of a recyclable fraction in a high quality (positive sorting), it is the reduction of the upper caloric value with the result that the waste can be dumped in compliance with the legal threshold. This can be achieved by ejecting high caloric fractions like wood and plastics (negative sorting).

In cooperation with the Umweltdienst Burgenland GmbH and the AWV Liezen, both waste management actors, responsible for the management of household waste and household-like commercial waste in a specific region and operators of a MBT plant as well as a landfill, sensorbased sorting test runs with specific waste-fractions from the mechanical-biological treatment were executed. The objective of the investigations was to find out, whether sensorbased sorting is an alternative for reducing the upper caloric value.

The following paper presents results of test runs and shows opportunities and limitations of the sensorbased sorting technology for lowering the upper caloric value of MBT output waste streams.

Inhaltsangabe

Aufgrund der zunehmenden Bedeutung des Klimaschutzes kommt es infolge strikter rechtlicher Vorgaben in Bezug auf die Ablagerung von Abfällen zur Notwendigkeit der Voraufbereitung der zu deponierenden Restfraktion. Von zentraler Bedeutung in diesem Zusammenhang in Österreich ist die Deponieverordnung, welche Grenzwertkriterien für abzulagernde Abfälle festlegt, die im Fall des Restabfalls die Notwendigkeit einer thermischen Behandlung bedingen (Deponierungsverbot für Abfälle mit einem TOC-Gehalt > 5 m.-%). Eine Ausnahme stellen Abfälle aus der mechanisch - biologischen Abfallbehandlung dar, die einen Brennwert (H_o) von 6.600 kJ/kg TS unterschreiten.

Die Einhaltung des Brennwertkriteriums stellt die Betreiber von mechanisch-biologischen Abfallbehandlungsanlagen (MBA`s) insofern vor große Herausforderungen, da der Outputstrom der MBA auch hochkalorische Abfallbestandteile wie Kunststoff und Holz beinhaltet. Diese Abfallbestandteile können innerhalb der Behandlungszeit im Rahmen der biologischen Behandlung nicht abgebaut werden. Zusätzlich ist es auch in Anbetracht der Ressourcenschonung ökologisch sinnvoll diese hochkalorischen Abfallbestandteile einer energetischen Nutzung zuzuführen.

Die Nichteinhaltung des Brennwertkriteriums bedingt die Notwendigkeit der thermischen Behandlung des Outputstroms der MBA. Da eine thermische Behandlung der Restfraktion im Vergleich zur Deponierung mit hohen Kosten verbunden ist, stellt die sensorgestützte Sortierung eine mögliche wirtschaftliche Alternative zur Sicherstellung der Einhaltung des Brennwertkriteriums dar. Dabei liegt der Fokus nicht auf der Wertstoffausschleusung, sondern in der Schaffung einer deponierungsfähigen niederkalorischen Fraktion durch gezieltes Ausschleusen hochkalorischer Abfallbestandteile und führt damit zur Vermeidung der kostenintensiven thermischen Behandlung infolge des Nichteinhaltens des Brennwertkriteriums lt. Deponieverordnung.

In diesem Zusammenhang wurden in Zusammenarbeit mit der Umweltdienst Burgenland GmbH und dem Abfallwirtschaftsverband Liezen, jeweils verantwortlich für die Abfallsammlung und -behandlung von Hausmüll und hausmüllähnlichen Gewerbeabfällen in einer Region und Betreiber einer MBA und eigener Deponien, Versuche des Einsatzes der sensorgestützten Sortiertechnik für diese Fragestellung durchgeführt.

Der vorliegende Beitrag soll die Ergebnisse von orientierenden Versuchen präsentieren und damit die Möglichkeiten und Grenzen der Integration sensorgestützter Sortiertechnik zur Senkung des Brennwertes in bestehenden MBA`s darstellen.

Keywords

mechanisch-biologische Abfallbehandlung (MBA), Brennwertkriterium, sensorgestützte Sortierung, NIR

mechanical-biological treatment (MBT), upper caloric value, sensorbased sorting, NIR

1 Introduction

1.1 Present Status and Motivation

The Austrian Landfill Ordinance prohibits landfilling of wastes, which do not meet the threshold of an organic carbon content (TOC) less than 5 m.-%. An exception is made for wastes, which have undergone mechanical-biological treatment (MBT) and meet the threshold for the upper caloric value (< 6,600 kJ/kg DM) and the biological stability parameters O_2-uptake after 4 days (< 7 mg O_2/g DM) and the gas formation potential within 21 days (< 20 Nm³/kg DM) (DEVO 2008). Besides the degradation of biodegradable waste the removal of high caloric waste components is the main purpose of MBT plants in order to enable the disposal of the residual output stream by landfilling in compliance with the threshold criteria of the landfill ordinance. Non-compliance with the threshold criteria of the Austrian Landfill Ordinance results in the necessity of thermal treatment of the residual waste stream from MBT. As thermal treatment of residual waste fractions is more expensive compared to landfilling, sensorbased sorting might be an economic alternative to ensure the compliance with the required upper caloric value threshold. In that context the focus of the additional treatment step is not to create a high caloric product, it is the creation of a dumpable low caloric residual waste fraction to avoid cost-intensive thermal treatment.

1.2 Legal Framework

Waste Management Act

According to the principle of sustainability the Austrian Waste Management Act 2002 (AWG 2008) is designed to protect man and environment; the aims to reduce emissions of climate-relevant gases and to conserve resources are specifically stated. With the implementation of the Austrian Landfill Ordinance 1996 and the respective amendments (DEVO 2008) respectively with the prohibition of landfilling of wastes with a high organic content combined with the levy imposed by the Law for the Clean-up of Contaminated Sites (ALSAG 2008) a milestone in achieving the objectives of the Austrian Waste Management Act was set. The implementation of these pieces of legislature led to a massive change in the Austrian Waste Management due to the treatments plants that have been installed.

Landfill Ordinance

The Austrian Landfill Ordinance is the key legal document for disposal of wastes in Austria. The main purpose of this ordinance is to reduce and avoid negative environmental impacts due to the dumping of wastes. In this context the prohibition of landfilling of waste with a TOC > 5 m.-% is an essential element of the Landfill Ordinance. An exception is made for mechanically-biologically treated wastes and residual fractions of the mechanical treatment, if they comply with the threshold values shown in Table 1 (DEVO 2008).

Table 1 Threshold values for landfilling of waste with a TOC > 5 m.-%

Threshold	Mechanical-biological treated waste	Residuals of the mechanical treatment
TOC	-	< 8 m.-%
Upper caloric value	6,600 kJ/kg DM	6,600 kJ/kg DM
O_2-uptake after 4 days	7 mg/g DM O_2	-
gas formation potential within 21 days	0.020 Nm³/kg DM	-

Compliance with the upper caloric value criteria is a challenge for operators of waste treatment plants as the output of the mechanical-biological treatment plant, respectively of the splitting facility contains high caloric fractions like polymers and wood, which are not degraded or removed within the treatment process. From a resource conservation point of view it is sensible to make those high caloric fractions accessible to energetic utilization.

Law for the Clean-up of Contaminated Sites

Of further relevance for the handling of waste is the Austrian Law for the Clean-up of Contaminated Sites, which introduced a levy for various waste management related activities as shown in Table 2 (ALSAG 2008).

Table 2 Overview of the ALSAG levy (ALSAG 2008)

Activity	ALSAG
Landfilling on excavation waste, inert waste and demolition waste landfills	8 €/t
Landfilling on a residual waste landfill	18 €/t
Landfilling on a mass-waste landfill and landfilling of hazardous wastes	26 €/t
Thermal treatment, production of substitute fuels and transport outside Austria	7 €/t
Other activities for excavation, demolition and mineral wastes	8 €/t
Other activities for all other wastes	87 €/t

1.3 Economic Considerations

Depending on the specific destination process of the residual waste output of the mechanical and mechanical-biological treatment plant different recycling and treatment costs occur. The realisable procedural effort in economic terms is defined by the difference of the recycling or treatment costs of the achieved output qualities with or without the additional treatment step. Table 3 shows revenues and costs for different output fractions respectively destination processes. Based on Table 3 it can be seen that the quality of the processed output fraction influences the revenues respectively the costs for the output waste stream.

Table 3 Revenues/Costs for output fractions (WALTER ET AL. 2007, IKB 2009, MOD.)

Output fraction	payment	[€/t]
Mono-fraction polymers for material recycling	revenues	30 – 180
PPC (Paper-Paperboard-Carton) for material recycling	revenues	20 – 60
Wood for thermal utilization	revenues	10 – 20
Secondary fuels for thermal utilization	costs	15 – 35
High caloric fraction for thermal utilization	costs	70 – 90
MBT-residual fraction for thermal treatment in a MSWI	costs	110 – 170
MBT-residual fraction for landfilling on a mass waste landfill	costs	75 – 100

If the costs for thermal treatment of the residual fraction of the mechanical-biological treatment in a MSWI are compared to the costs for landfilling the preference for landfilling from the business management perspective becomes obvious. In cases where the MBT-operator is also operating a landfill, this effect is amplified, as the net costs for landfilling can be assumend to be much lower than 75 – 100 €/t (as mentioned in Table 3). Even summed up with the ALSAG-levy of 26 €/t the total costs still are lower than the costs for thermal treatment in a MSWI. The cost-difference between these treatment alternatives – thermal treatment of the residual fraction in a MSWI and landfilling in compliance with the upper caloric value criteria – is available for the integration of additional treatment steps, which ensure the compliance with the threshold for the upper caloric value.

2 Sensorbased Sorting – State of the Art

In cullet recycling sensorbased sorting was able to detach manual sorting for the very first time, as better qualities with higher throughput rates and recovery rates were achieved. Nowadays sensor based sorting for material recovery is state-of-the-art and can also be used for different more complex recycling tasks. The application fields of this technology are wide and sensorbased sorting is used for different waste streams, especially cullet, waste paper and polymers, additionally this technology starts to be applied for the treatment of heterogeneous waste streams (*FAIST* & *RAGOSSNIG 2008*).

Sensorbased sorting for heterogeneous wastes is mainly realised using the NIR (Near Infrared) spectrum. Due to the heterogeneity of the wastes and the varying waste composition, the whole treatment process is more challenging and a more complex task has to be managed with the same technology as it is known from the treatment of homogeneous waste streams.

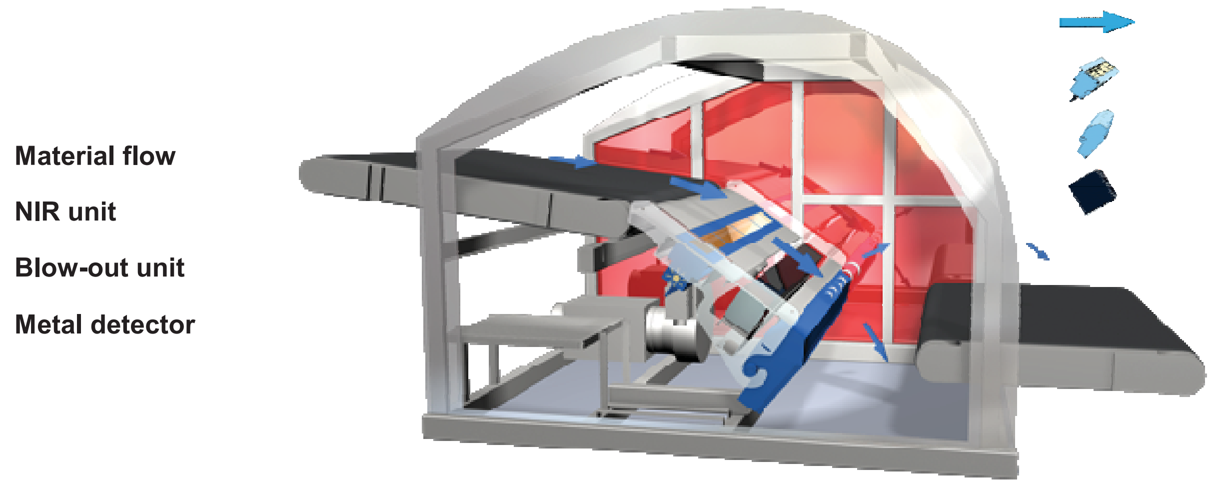

Figure 1 Sensorbased sorting machine

Sensorbased sorting of wastes can be used for the removal of pollutants (negative sorting) as well as for the enrichment of a more qualitative product (positive sorting). Figure 1 shows a scheme of a sensorbased sorting machine.

The biggest challenges of sensorbased sorting, both of homogeneous and heterogeneous waste streams, are small grain sizes (< 5 mm) as well as the identification of dark polymers. If the sensorbased sorting machine is using the NIR spectrum, which includes a spectral range from 700 – 1,000 [nm], the high absorption rate of dark objects does not allow to detect any usable spectrum. Up to now no solution for this problem has been found for the application in practice.

In case of sorting heterogeneous waste streams the consideration of the whole treatment concept respectively the where and how of the integration of a sensorbased sorting steps in the treatment concept is very important.

3 Sensorbased Sorting for the Reduction of the Upper Caloric Value

3.1 Research Design

Test runs for the investigation whether it is possible to sort out high caloric components from MBT waste streams through sensor based sorting have been conducted. The aim was to meet the threshold for the upper caloric value of 6,600 kJ/kg DM at the end of the treatment process. Hereby the focus is placed on the production of a dumpable fraction (mass should be maximized) by separation of high caloric waste components which could be energetically utilized and which would lead to non-compliance with the upper caloric value threshold.

First practical tests shall allow an evaluation, whether sensor based sorting technology can be a technically feasible alternative for securing the compliance with the upper caloric value threshold. In this context sensor based sorting test runs with specific waste fractions were executed in cooperation with the Umweltdienst Burgenland GmbH and the AWV Liezen, both Austrian waste management actors, responsible for the management of household waste (MSW) and household-like commercial waste in a specific region and operators of a MBT plant as well as a landfill.

Waste fractions from different positions within the mechanical-biological treatment process were the input for the sensor based sorting machine REDWAVE, which is using the NIR-spectrum. By means of negative sorting the high caloric components, like wood and polymers were removed in order to create a low caloric fraction meeting the upper caloric value threshold for landfilling. Subsequently the two fractions sorted apart (pass, throw-off) were manually separated in the fractions polymers, dark polymers, inert materials like bones and ceramic, stones, porcelain (CSP), metals and wood in order to evaluate the quality of the sorting process. All test runs were carried out in the testing site of the Austrian equipment supplier BT-Wolfgang Binder GmbH on the sensorbased sorting machine REDWAVE, as it is shown in Figure 1.

3.2 Waste Characterisation

Umweltdienst Burgenland GmbH

The test material of the Umweltdienst Burgenland GmbH is a waste stream with a grain size of 25 – 80 mm and an upper caloric value of 14,500 kJ/kg DM, which has passed through a dynamic biological treatment step in a degradation drum after humidifying with sewage sludge. Figure 2 shows the average composition of the waste. It can be seen that this fraction includes 51 % inert materials including metals. The rest is characterised by 30 % polymers and 19 % wood.

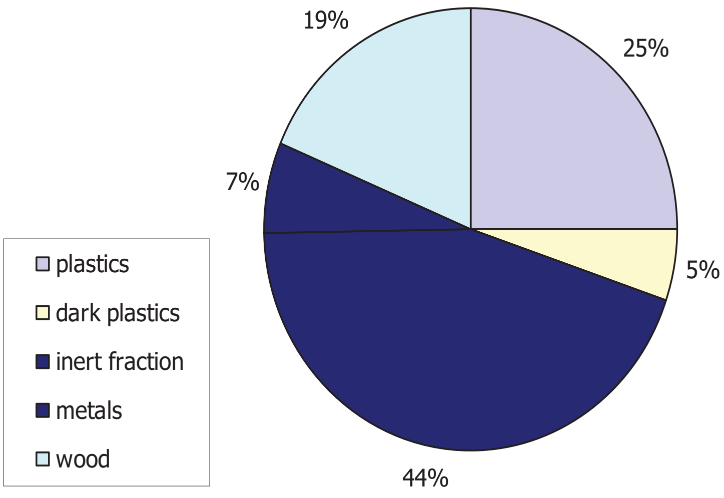

Figure 2 Waste composition input Umweltdienst Burgenland GmbH

AWV Liezen

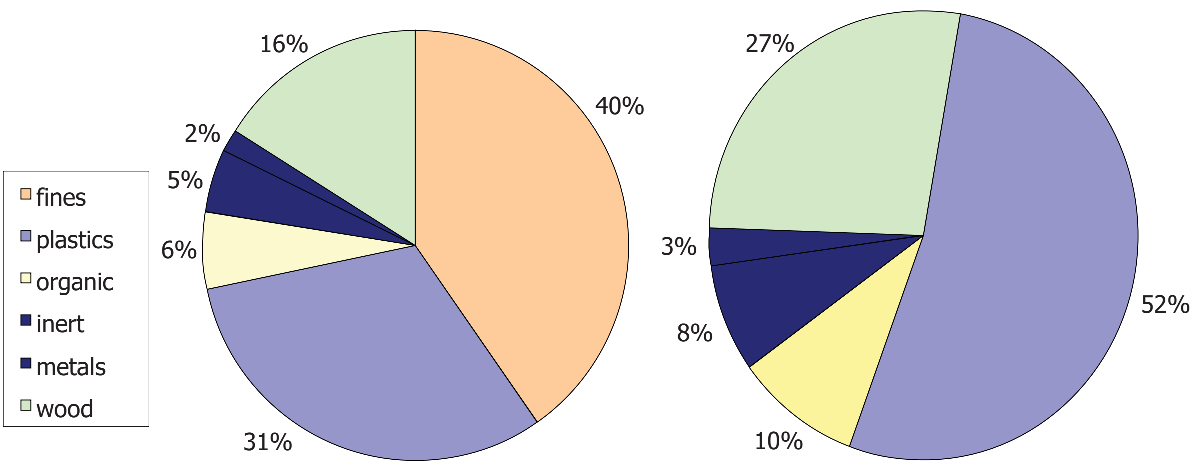

Figure 3 Waste composition after mechanical treatment incl. fine materials (left side) excl. fine materials (right side) AWV Liezen

The test runs in cooperation with the AWV Liezen were addressing two different waste streams. On one hand a waste stream with a grain size < 50 mm and an upper caloric value of 13,500 kJ/kg DM, which underwent prior mechanical treatment by shredding and screening was taken as input for the sensor based sorting machine. The average composition of the waste stream of the mechanical treatment process is shown in Figure 3. This fraction is characterised by a very high amount of fine materials (40 %) and a high moisture content of 47.3 % on the basis of moist mass. Due to this the material was screened using a mesh size of 10 mm before the test runs. The portion of the high caloric fraction was about 80 m.-%.

On the other hand a waste stream with a grain size < 50 mm and an upper caloric value of 11,500 kJ/kg DM was the input for the sensor based sorting process. Again, this fraction was screened at 10 mm due to the high amount of fine materials to allow sensor based sorting. The waste composition shown in Figure 4 (right side) displays that the waste stream is characterised by 73 m.-% high caloric components (plastic, wood, paper). The moisture content is 16.6 % on the basis of moist mass.

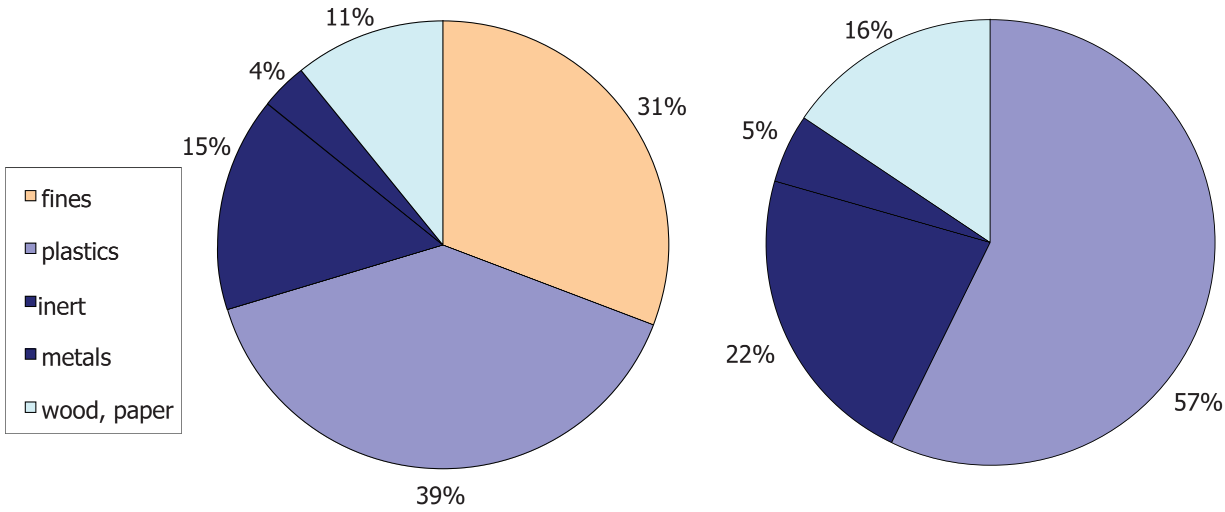

Figure 4 Waste composition (after mechanical-biological treatment) incl. fine materials (left side) excl. fine materials (right side) AWV Liezen

3.3 Test Results / Experiences

Umweltdienst Burgenland GmbH

The above described waste streams were the input for the sensor based sorting machine REDWAVE. The throughput rate was set at 1.5 t/h. Applying the NIR-based sorting technology the high caloric components were removed by negative sorting. After the automatic sorting process, the output streams (pass and throw-off) were sorted manually in order to assess the quality of the automated sorting process. The result is shown on the left side of Figure 5. The inert fraction (51 m.-% of the input) was increased to 74 m.-% in the pass stream by the means of sensor based sorting. 60 m.-% of plastic-components were ejected (without consideration of dark plastics this number amounts to 70 m.-%). 75 m.-% of the wood components were ejected. With this sorting step the amount of the fraction for thermal treatment (throw-off stream) fell to 35 m.-%. In the waste input the amount of dark polymers was 5 m.-%. As an identification and ejection of dark polymers has not been practically realisable until today, the portion of that fraction was increased to 8 m.-% in the pass stream. Enhancements concerning the identification of dark polymers have to be seen as the main focus for further developments of sensor based sorting technology, which will lead to significant improvements of the sorting results at the same time.

In a further test run the same material was sorted by the REDWAVE machine with a multistage sorting process in order to better separate high-caloric fractions from the pass stream. Here the pass stream of the first run was the input for a second sorting step, this was realized by circuitry. With multistage sorting the inert fraction in the output was increased up to 78 m.-%. Here a mass reduction of 50 m.-% of the output-fraction to be thermally treated (throw-off stream) was achieved. The results of this run are shown on the right side of Figure 5 in more detail.

More detailed information gave the analysis of the upper caloric value. The result of the analysis showed an average upper caloric value of 6,300 kJ/kg DM in the pass stream, which signifies the compliance with the upper caloric value threshold of 6,600 kJ/kg DM according to the Landfill Ordinance. These trial runs showed that the integration of a sensor based sorting machine based on NIR technology in a MBT plant can be an option to produce a higher quantity of waste to be landfilled by reducing the upper caloric value of the output stream by that additional treatment step. As up to 65 m.-% respectively 50 m.-% of the waste fraction, which is incinerated at the moment, can be dumped on landfills by the use of a single stage respectively multistage sorting step, an implementation of a sensor based sorting unit can therefore be a profitable investment. Multistage sorting allows a better removal of high-caloric components; on one hand the fraction of waste to be thermally treated is increased, but on the other hand it is easier to comply with the upper caloric value threshold for the landfilling of the pass fraction.

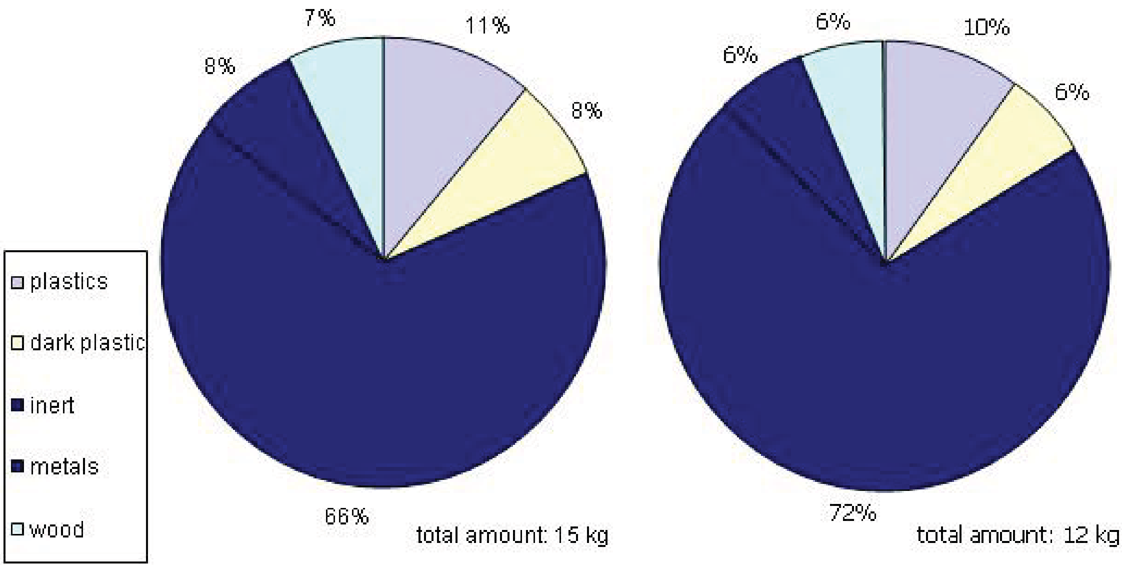

Figure 5 Waste composition pass stream single stage (left side) multistage (right side)

AWV Liezen

As the waste streams of the AWV Liezen included a high amount of fine components, the material was screened before the sensor based sorting step. Nevertheless the test runs pinpointed the current limits of the technical feasibility of sensor based sorting for heterogeneous waste streams. The small grain sizes and the material composition of the input material (many small high caloric components, difficulty of isolation of single objects) for both materials tested lead to the consequence that the separation of a high caloric throw-off and a low caloric pass fraction was not realizable with the current selectivity of the sensor based sorting step. Additionally by reasons of the arrangement of the air nozzles for ejection (spacing) as well as the fuzziness of the air blast itself in combination with the high number of components that have been identified for ejection almost all material has been thrown off.

4 Conclusion

In Austria compliance with the upper caloric value threshold according to the Landfill Ordinance 2008 is a major concern for the operators of mechanical-biological treatment (MBT) plants. According to the Austrian Landfill Ordinance the residual fraction of the MBT has to fall below the required upper caloric value threshold of 6,600 kJ/kg DM, to be dumped on a mass-waste landfill. Waste streams not meeting this strict quality requirement have to be incinerated. As thermal treatment of the residual fraction is more expensive than dumping on landfills, test runs have been executed to evaluate the possibility of integrating sensor based sorting machines in MBT plants to ensure compliance with the required threshold by removing high caloric fractions while maximizing the portion of waste that may be landfilled.

The results of the test runs in cooperation with the Umweltdienst Burgenland GmbH showed that it is technically feasible to integrate a sensor based sorting step yielding a dumpable waste fraction (65 m.-% of the input stream to the sorting step, upper caloric value: 6,300 kJ/kg DM). Other than that the test runs in cooperation with the AWV Liezen showed the limitations of the sensor based sorting technology. In this context the main problem was the small grain size of the particles (high portion of fines). Additionally, the high portion of high caloric components recognized by the sensor for ejection lead to the consequence that almost all material was ejected due to the current selectivity of the sensor based sorting process.

The test runs with different waste fractions resulting from mechanical and mechanical-biological treatment steps showed, that sensor based sorting may be used to reduce the upper caloric value in order to fall below the threshold of 6,600 kJ/kg DM. However, the real implementation of this type of sorting step must be accompanied by a thorough analysis of the physical characteristics (grain size, moisture content) of the waste stream to be treated. Too much fines – especially fine components recognized by the sensor as parts to be ejected - proofed to be detrimental to the application of sensor based sorting in that context.

The results presented may serve for a basic orientation. However, definite results require further trial runs for verification.

5 References

AlSAG	2008	Law for the Clean-up of Conaminated Sites, Altlastensanierungsgesetz, BGBl. Nr. 299/1989 idF BGBl. I Nr. 40/2008, Vienna, Austria
AWG	2008	Waste Management Act, Bundesgesetz über eine nachhaltige Abfallwirtschaft (Abfallwirtschaftsgesetz 2002 – AWG 2002), BGBl. I Nr. 102 zuletzt geändert durch BGBl. I Nr. 54/2008, Vienna, Austria
DeVO	2008	Landfilling Ordinance, Verordnung über die Ablagerung von Abfällen (Deponieverordnung), BGBl. II Nr. 39/2008, Vienna, Austria
Faist, *V. & Ragossnig, A.M.*	2008	Optical Sorting Technology – Innovative Application Fields in Waste Management, Limits and Research Demand, Optische Sortiertechnik – Innovative Einsatzfelder in der Abfallwirtschaft, Grenzen und Forschungsbedarf, Abfallforschungstage 2008, Hannover, Deutschland
IKB Abfall (Hrsg.)	2009	Costs for Landfill Ahrental 2009, Preise Deponie Ahrental 2009 der Innsbrucker Kommunalbetriebe AG, Innsbruck, Austria
Walter, G.; Becker, G. & Buermann, H.	2007	Treatment of MSW – a Profitable Business?, Gewerbeabfallaufbereitung – ein lohnendes Geschäft?, Müll und Abfall 11/07, 542 ff

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Machinery for preparing different qualities of RDF

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Abstract

The present situation in waste management in the European Union shows dynamic development of waste treatment technology. To accomplish the European Waste Directive waste treatment is essential for enhancing recycling and recovery and reducing disposal. The work was performed by means of visits to RDF plants, interviews of operating personal followed by calculations of mass balances and economical indices. Three types of RDF were defined according their qualities, “RDF light”, “RDF classic” and “RDF premium”. Each type was defined by summarizing three applications. A design recommendation for a ballistic-separator dominated RDF plant is given. Due to the reduced and different machinery this plant shows advantages related to a wind-sifter dominated plant. The differences in energy demand run up to -27%, in investment -23% and in operating costs -22%. Meanwhile two new RDF plants are built in Hagenbrunn, Lower Austria, A, and in Bernburg, Saxony, D, according the proposed technology.

Keywords

Waste, treatment, refuse derived fuel, shredder, ballistic separation, wind-sifting

1 Introduction

The present situation in waste management in the European Union shows dynamic development of waste treatment technology. To accomplish the European Waste Directive (ANONYMUS 2008) waste treatment is essential for enhancing recycling and recovery and reducing disposal. Reliable machine technology was developed in recent years (WELLACHER & PRETZLER 2007) in order to treat mixed waste materials like municipal solid waste (MSW) or commercial waste materials and to gain useful by-products. Refuse derived fuel (RDF) as one of the main by-products of these waste materials is widely used for replacing conventional fossil fuels for heat and electricity production for public and industrial needs.

RDF is offered in different qualities with a net calorific value >10 MJ/kg coming mainly from the components plastics, paper, wood and textiles. The quality is determined by the proper combination and exclusion of input waste materials and the proper machinery used for the treatment. Low quality RDF is incinerated in grid incinerators, medium quality RDF in industrial heat supply incinerators and high quality RDF in cement plants, power plants and lately also in steal mills (BÜRGLER 2008).

However recent years development shows considerable changes of quality demands. Whereas in 2001 high quality RDF was pelletized with a particle size <10 mm, in 2004 most of the produced RDF was non-pelletized with particle sizes <30 mm or <80 mm. Today a dynamic market with declining prices demands permanent flexibility of treatment plants for their incineration-business partner.

The European Union produced 26,2 million tons (Tg) plastic waste in 2004 (BÜRGLER, 2008). The disposal rate of it was 65% in 2004, so the potential for recycling and recovery runs up to 17 Tg. The other 35% are mainly prepared to RDF, 3,5 Tg of it in Germany (ZAHLTEN 2008). The preparation technology consists primarily of mechanically working machinery to ensure low treatment costs. By these means RDF is gained through separation of contaminants and other by-products.

2 Methods

The work was performed by means of visits to RDF plants, interviews of operating personal followed by calculations of mass balances and economical indices.

RDF plants treat a wide range of waste materials, like

- MSW and its by-products, e.g. oversize material
- Mixed commercial wastes with calorific values >10 MJ/kg and its by-products, e.g. light material from wind-sifters
- Mono-fraction commercial wastes, e.g. carpets, plastic films; these fractions are often used to pre-design certain parameters of a certain RDF quality
- Separate collected packaging waste and its by-products, e.g. sorting residues

State of the art RDF plants often use wind-sifters to separate contaminants and other by-products from RDF. In Figure 1 a schematic drawing of such an example RDF plant is shown. Figure 2 shows the output material ratios of such a plant using MSW and commercial waste materials as input materials.

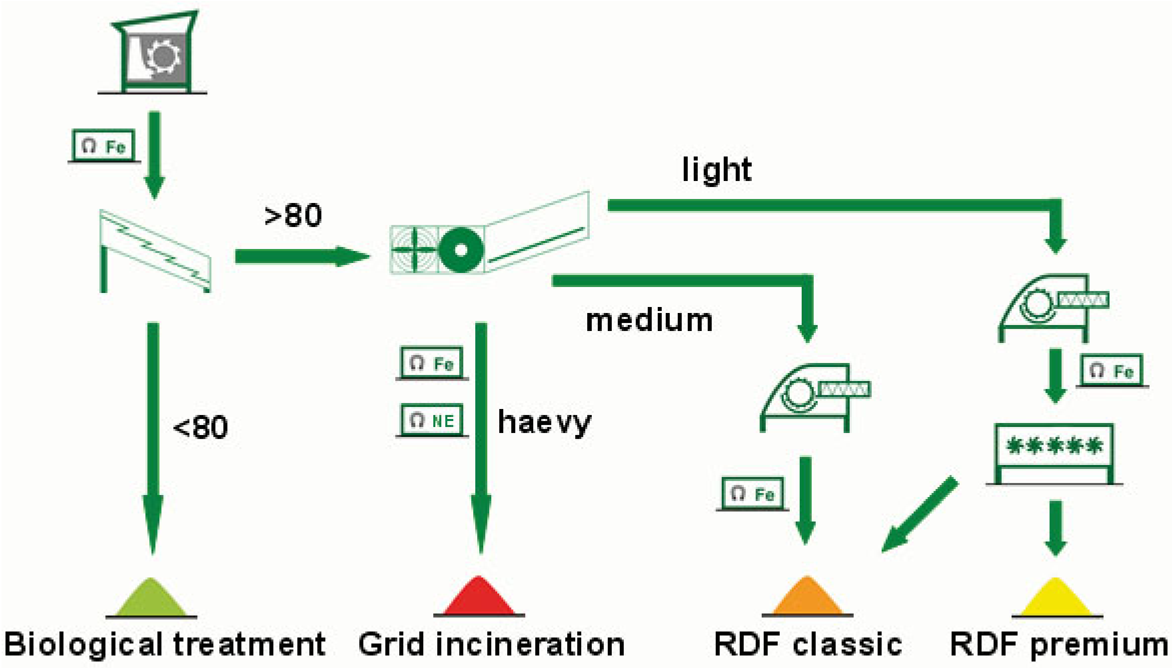

Figure 1 Example state of the art RDF plant, wind-sifter dominated

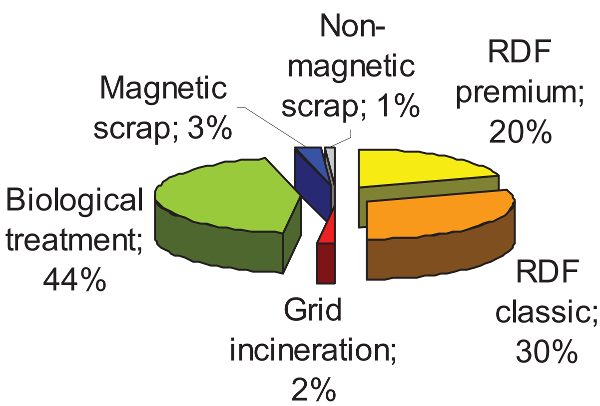

Figure 2 Output materials ration of wind-sifter dominated RDF plant

A comparison was made between a wind-sifter dominated technology versus a ballistic separator dominated technology in terms of energy demand, investment and operating costs. Profits and fees for the input and output materials are not included in the operation cost calculation. The input parameters of this comparison are shown in Table 1.

Table 1 Input parameters for the energy demand, investment and operating cost calculations

Input material	Calorific commercial waste	130.000 Mg/a
		20 Mg/h
Manipulation means	2 Loaders	8.750 h/a (in all)
Plant operation hours		7.200 h/a
Personal	Foremen	3
	Workers	12
Energy costs	Diesel	1 €/l
	Electricity	0,23 €/kWh
Wear & service	Construction	1% p.a. of investment
	Machinery	5% p.a. of investment
Interest		5% p.a.
Amortisation	Construction	20 a
	Machinery	10 a
	Loaders	15.000 h

3 Results

Three types of RDF were defined according their qualities, “RDF light”, “RDF classic” and “RDF premium”. Each type was defined by summarizing three applications, which are shown in Table 2 to Table 4.

Table 2 “RDF light” qualities, examples and summary

	Niklasdorf, A (RESCH 2007)	**WSO4, Vienna, A** (PROCHASKA 2004)	**Vattenfall, Rüdersdorf, D** (BANDILLA 2008)	**Summary** “RDF light”
Lower calorific value [MJ/kg]	12,5	13,5-14,5	12-16	**12-16**
Particle size [mm]	<120	50-250	<300	**<300**
Oversize ratio [%]	-	-	-	**<3**
Contamination ratio with inert materials [%]	-	4	<3	**<3**
Chlorine content [%]	<1	1	<1	**<1**
Ash content [%]	-	22	-	**-**

Table 3 "RDF classic" qualities, examples and summary

	Lenzing, A (Böhmer et al. 2007)	**Cement kiln, D** (Anonymus 2009)	**Cemex Calcinator, Rüdersdorf, D** (Wirthwein 2008)	**Summary** "RDF classic"
Lower calorific value [MJ/kg]	11,4	18	12-16	**12-18**
Particle size [mm]	<80	<40	20-25	**20-100**
Oversize ratio [%]	-	-	-	**<2**
Contamination ratio with inert materials [%]	<1	-	-	**<1**
Chlorine content [%]	-	<1	<0,8	**<0,8**
Ash content [%]	-	-	-	**<20**

Table 4 "RDF premium" qualities, examples and summary

	Stadtwerke Flensburg, D (Oetjen-Dehne & Kalvelage 2007)	**Cement kiln, D** (Anonymus 2009)	**Cemex cement kiln, Rüdersdorf, D** (Wirthwein 2008)	**Summary** "RDF premium"
Lower calorific value [MJ/kg]	11-24	21-26	22-25	**>22**
Particle size [mm]	<50	20-25	20-25	**20-50**
Oversize ratio [%]	-	<10	-	**<10**
Contamination ratio with inert materials [%]	-	-	-	**<1**
Chlorine content [%]	<0,6	-	<0,8	**<0,8**
Ash content [%]	<30	-	<10-12	**<12**

To produce these summarized RDF qualities certain technologies are available which ensure the specific quality demands, see Table 5.

Table 5 Technologies for RDF preparation

	RDF light	RDF classic	RDF premium
Lower calorific value [MJ/kg]	Screening	Screening/ Wind-shifting/ Ballistic separation	Material selection/ Screening
Particle size [mm]	Shredding	Shredding/ Screening/ Wind-shifting/ Ballistic separation/ Fine shredding	
Oversize ratio [%]	Shredding	Fine screening	
Contamination ratio with inert materials [%]	Magnetic separation	Magnetic separation/ Eddy current separation	
Chlorine content [%]	Material selection	Near infrared sorting/ Material selection	
Ash content [%]	-	Screening	Material selection

A plant design recommendation can be given according the outcomes shown in Table 5, see Figure 3. This plant shall be able to produce all three types of RDF and shows flexibility towards possible future changes of the quality demands as well as towards changes of the input material qualities.

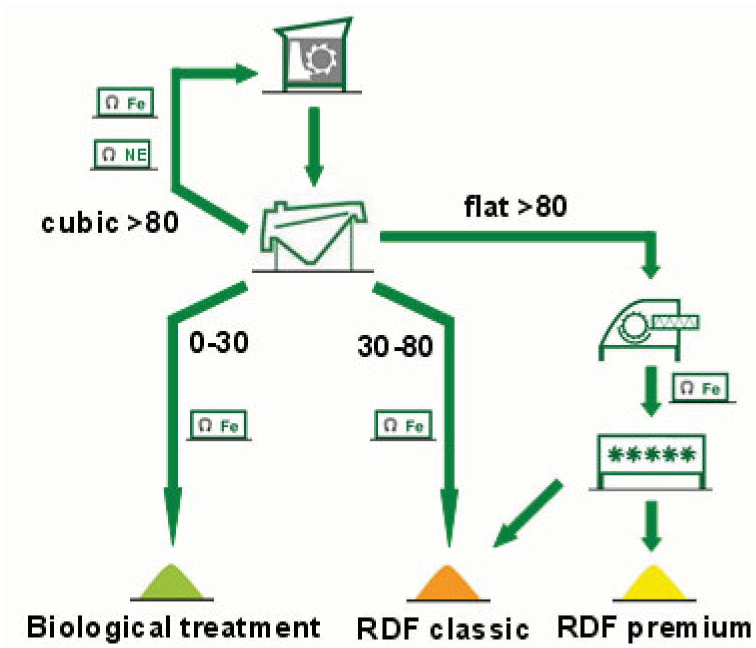

Figure 3 Ballistic-separator dominated RDF plant

The output rations of the ballistic-separator dominated RDF plant in Figure 4 show differences compared with the wind-sifter dominated RDF plant in Figure 2, e.g. the lack of a grid incineration fraction.

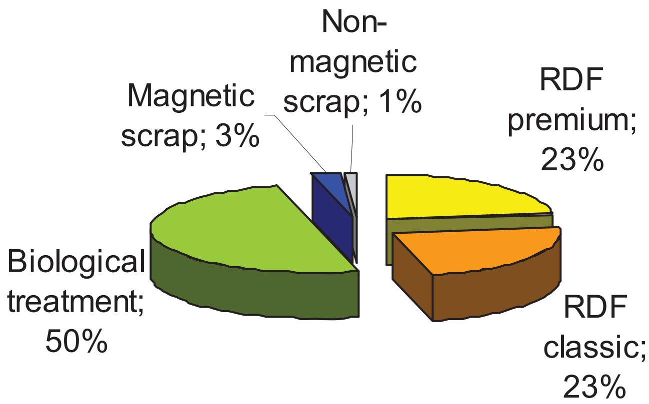

Figure 4 Output ratios of by-products of the ballistic-separator dominated RDF plant

Due to the reduced and different machinery a ballistic-separator dominated plant shows advantages related to a wind-sifter dominated plant. The differences in energy demand run up to -27%, in investment -23% and in operating costs -22%. Figures are shown in Table 6.

Table 6 Comparison of ballistic-separator dominated technology versus wind-sifter dominated technology

	Ballistic separation	**Wind sifting**
Specific investment [€/Mg]	35	43
Specific energy demand [kWh/Mg]	5,2	6,6
Specific operation costs [€/Mg]	18	22

4 Discussion

The advantages of a ballistic-separator dominated RDF plant is not only based on the replacement of the wind-sifter by a ballistic separator but additionally by use of an advanced pre-shredding technology reducing oversize >100 mm to <5wt%. Cubic materials from the ballistic separator can be recycled to the shredder after scrab separation. Each pre-shredding-cycle reduces the former cubic fraction to 50% by directing the other 50% to the undersize fraction of the ballistic separator. This prevents grid incineration fractions alike those produced with the wind-sifter dominated RDF technology.

Additionally found there were better scrap qualities in ballistic separator dominated RDF technology because metal wires which are mainly responsible for the adhesion of non-metal materials are separated to the flat fraction. Even they are metallic they do not harm the fine shredder for their thickness is low. After fine shredding they easily can be removed by usual magnet technology as they are now small pieces.

Pertinent machine development together with examination of the quality demands of RDF and by-products enables modern waste treatment plants to operate at lower energy demand and lower costs. Meanwhile two new RDF plants are built in Hagenbrunn, Lower Austria, A, and in Bernburg, Saxony, D, according the proposed ballistic-separator dominated RDF technology.

5 Literature

Anonymus;	2008	Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives. Official Journal of the European Union 22.11.2008 L 312/3.
Anonymus;	2009	Personel communications 2009. D.
Bandilla, A.;	2008	Ersatzbrennstoffeinsatz im Industriekraftwerk Rüdersdorf. Presentation and personal communication on 2008-04.29 at „Ersatzbrennstoffe für Industrieanlagen“, VDI-Tagung, Berlin.
Böhmer, S., Kügler, I., Stoiber, H. & Walter, B.;	2007	Abfallverbrennung in Österreich – Statusbericht 2006. Umweltbundesamt GmbH, Wien. ISBN 3-85457-911-X.
Bürgler, T.;	2008	Das industrielle Konzept der nachhaltigen Nutzung von Sekundärrohstoffen bei der voestalpine Stahl GmbH. Presentation on 2008-08-26 at „Effiziente Abfallbehandlungsmethoden der Zukunft“ in Wien, Institute for International Research, Wien.
Oetjen-Dehne, R. & Kalvelage, M.;	2007	Erfahrungen mit der Aufbereitung und Verwertung von Ersatzbrennstoffen aus Gewerbeabfällen. In Kühle-Weidemeier (ed.): Internationale Tagung MBA 2007. Cuvillier Verlag, Göttingen. ISBN 978-3-86727-237-7.
Prochaska, M., Raber, G. & Lorber, K. E.;	2004	Heizwertreiche Abfallfraktionen aus der mechanischen Abfallbehandlung (MA) und der mechanisch-biologischen Abfallbehandlung (MBA). Endbericht im Auftrag des Bundesministeriums für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, Wien.
Resch, M.;	2007	Personel communication 2007-06-28. Energie- und Abfallverwertungs GmbH, Graz.

Wellacher, M. & Pretzler, R.;	2007	Cold processing caloric commercial waste. Presentation on 2007-09-26 at "ISWA/NVRD World Congress 2007", Amsterdam.
Wirthwein, R.;	2008	Historie des Industriekraftwerks Rüdersheim. Presentation and personal communication on 2008-04-29 at „Ersatzbrennstoffe für Industrieanlagen“, VDI-Tagung, Berlin.
Zahlten, M.;	2008	Verfügbarkeit von Ersatzbrennstoffen im Wandel des Entsorgungsmarktes. Presentation on 2008-04.28 at „Ersatzbrennstoffe für Industrieanlagen“, VDI-Tagung, Berlin.

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Quality Improvement in RDF and Other Non-metallic Products through Magnet and Sensor Sorting

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Abstract

Solid waste has become a material source for various applications, such as Residue Derived Fuel (RDF), polymers, or wood for chip board production. The removal of components which reduce quality is essential for the widespread use of these materials. A recent feature of sensor sorting systems is magnetic separation, which has become a must for quality-assured RDF. State-of-the-art technologies include inductive sensoring, x-ray transmission and near infrared spectroscopy.

Keywords

Magnetic sorting, eddy current separation, sensor sorting systems, residue derived fuel, wood recycling

1 The Source of Raw Material

In addition to the recycling of raw material, the globally booming waste industry is concentrating increasingly on the use of the energy content of waste. In order to enable an extensive use as alternative fuel, quality assurance has to be a priority. This is the only way residue derived fuel (RDF) can be used as a real alternative to fossil fuel, irrespective of its origin, without risks in operation and without causing emissions. In Germany, this has already been carried out on a large scale and has led to the use of state-of-the-art sorting technologies in the production of RDF. In other countries, especially in the USA, the comprehensive energetic use of RDF is in the start-up phase.

Many other waste substances also have to be free of impurities, especially if the material is to be recycled. Some of these are wood for fuel or for use as chip board material, and also polymers. Slag from waste incineration should be free of metals, too.

Considerable amounts of high-quality materials can be made available if this potential is exploited. The waste bin is thus just one example of a source of raw materials.

2 The Process

Essential process steps in the treatment of waste material are digestion and shredding, classification into particle size classes and sorting. Residue derived fuel also has to be formed into briquettes for transport and dosing. This process is very sensitive to impurities. The main purpose of the classification is to make the subsequent sorting steps more efficient.

It is of virtually no importance whether the separated materials are the end product or the impurities during the set-up phase (fig. 1).

	Process Step:	Solution:	
1	shredding of waste		Standard
	grading into fine, medium and coarse grain sizes		
2	recovery of iron	suspended magnet separator UM/AM™	
3	recovery of nonferrous metals	nonferrous metal separator NES™	
4	recovery of polymers	near-infrared sorting system	
5	separation of metal-containing impurities (stainless steel etc.)	induction sorting system ISS™	Options
6	separation of other impurities (stones etc.)	x-ray sorting system XSS™	
	residue derived fuels		

Figure 1: General process diagram

However, the plant operation will be different here, because output and purity differ greatly according to the process principle. In simple terms, a high output can only be achieved with a low purity and vice versa. Differences may emerge here, depending on the method selected.

Coarse iron components are separated with the help of suspension magnets. Depending on the treatment's objective – recovery of metal or separation of metal as impurity – a magnetic drum or a permanent magnetic belt idler may be added to the process, before the eddy current recovers or separates the valuable nonferrous metals (fig. 2).

Sensor sorting systems follow traditional metal separation. Depending on the technology used, it is their task to recover polymers or separate them as impurity, but also to separate metals like stainless steel. In some cases they are also used to separate stones and glass.

Figure 2: Eddy current separator in an RDF plant

3 Sorting Solutions To Date: Magnetic Separation in the Broader Sense

The more sophisticated these machines are, the more successful they are in the sorting process. Particle sizes of 0 to 25 mm or 0 to 40 mm are processed frequently in residue derived fuel. This demands a great deal in terms of magnetic separation and from the eddy current separator.

3.1 Suspension Magnets

The main task of suspension magnets is to recover free, lightly bound marketable iron. Composite material like a nail in a piece of wood usually remains in the material flow, although this depends predominantly on the distance between magnet and material and on the magnetic forces. It is also important to emphasise that a suspension magnet has to be suspended lengthwise above the end of the belt and not at a different point across the conveying belt (fig. 3). This is due to the fact that, at the dropping point, the material is loosened up and the iron can move through this loosened layer without much resistance. The discharge area and all machine parts within the magnetic field have to be made from non-magnetic material, e.g. austenitic steel. This applies especially to the belt idler and the dividing plate at the dropping point. Otherwise, secondary magnets form and attract the iron particles, hindering their movement considerably.

Figure 3: Suspended magnet positioned lengthwise above dropping point

In a crosswise arrangement (fig. 4), the tare weight and, in particular, the weight of the overlying layers counteract the magnetic force of attraction. In this case, the iron recovery is drastically reduced.

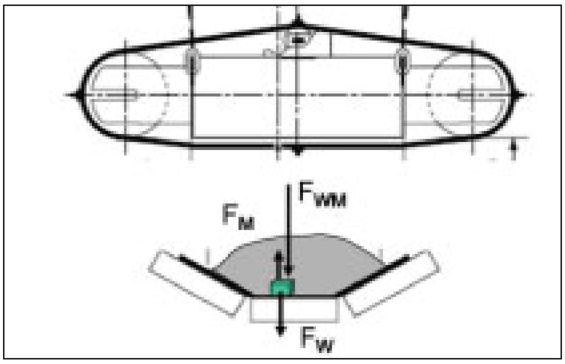

Figure 4: Load of conveyed material on an iron particle:
F_M Force of attraction, F_W: Weight,
F_{WM}: Weight of overlying material

The magnetic field should be sufficiently long in order to increase the time of exposure and to cover the whole width of the belt conveyor. This can be best achieved with rectangular coils.

3.2 Eddy Current Separators

The eddy current separator has been a standard method in waste treatment for about twenty years and can be considered a magnetic separator in the broadest sense, since the separating force is generated by an alternating magnetic field. The material, e.g. an aluminium tin, is repelled in the drop from a short conveying belt.

Therefore, different parameters have to be considered for purposes of selection and operation. The first important aspect is the particle movement at the discharge point, because bigger particles fall off the belt sooner than smaller ones due to their inertia, as shown in figure 5. The same applies to heavy and light particles. At this point, the eddy current has to alter the particle movement, no sooner and no later.

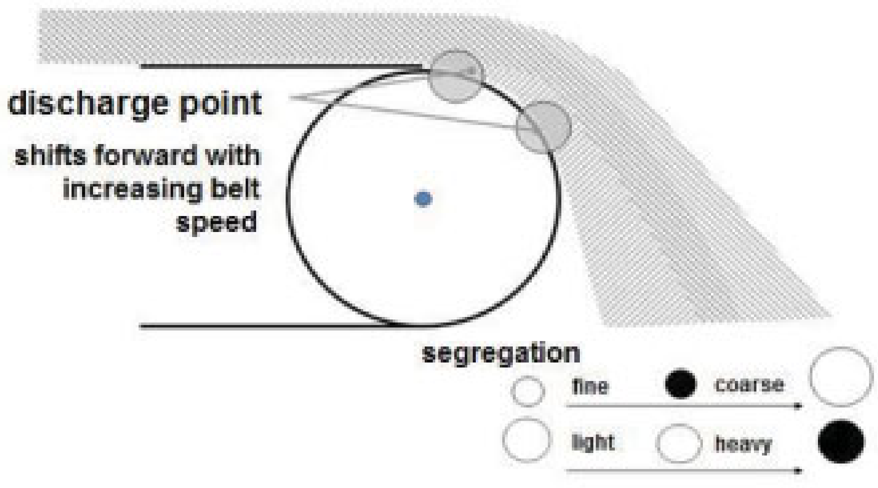

Figure 5: Particle behaviour at the discharge; the discharge point shifts

The finer the material, the later it drops off the belt and falls down in according proximity to the belt. With higher belt speeds, the material leaves the belt earlier. The effectiveness of the alternating magnetic field changes if it is distanced only slightly from the belt. This is why the point of force application of the eddy current separator has to be adjustable, especially if particle sizes of more than 50 mm are to be separated. The same applies to the speed of the belt. It can thus be concluded that effective sorting requires a narrow range of particle sizes.

Only eddy current separators with an eccentric pole system can fulfil these requirements; only these can be adjusted, which explains the wide success of this technology. In order to enable an eccentric arrangement, the belt fastener has to be very large (fig. 6).

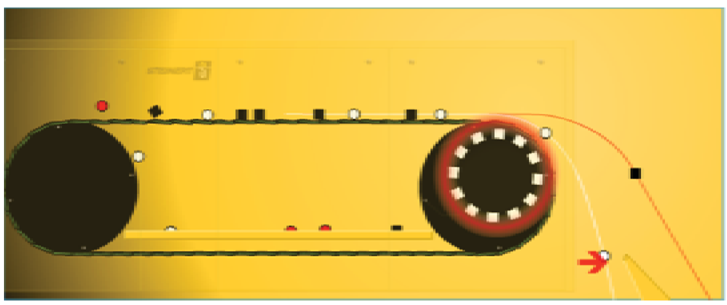

Figure 6: Eddy current separator with an eccentric pole system; adjustable; magnetic field only acts at the dropping point; red: iron particles can move freely

Since nonferrous metals are valuable, a high availability of the eddy current separator must be guaranteed. These machines can be sensitive when it comes to remaining iron.

If an eddy current separator with a centric system (fig. 7) is used, a high-frequency magnetic field acts around the whole belt fastener, attracts iron particles and causes them to rotate and bore, which produces a “singing” noise. The possible scattering of iron particles under the belt naturally wears out both the belt and the belt fastener.

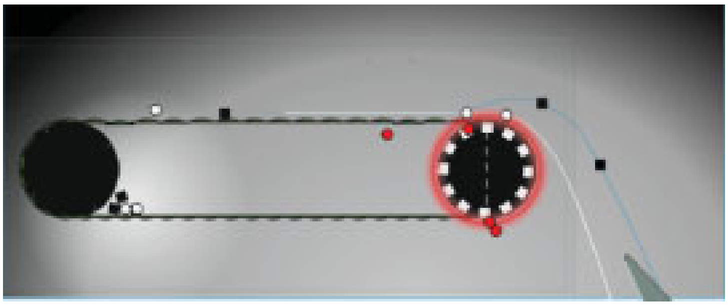

Figure 7: Eddy current separator with a centric pole system and magnetic field around the belt fastener; red: adhering iron particles.

In order to remove adhering iron particles from the belt, centric eddy current separators have several discharge strips on the belt. These throw the material under the eddy current separator, from which point it has to be removed manually.

Despite this, the durability of belt fastener and belt of eddy current separators of this kind is considerably reduced. Both components usually have to be replaced frequently.

Availability and separation efficiency also have economic advantages, as shown in the following table.

Table: Comparison of eddy current separators with eccentric and centric pole system

feed	10	t/h					
nonferrous material	4	%					
feed per annum	38.400	t/a	16h/d; 240d/y	2 layers			
	STEINERT eccentric		**others; centric**		**difference to STEINERT**		
Investment machine	85.000	€	60.000	€	-29	%	additional investment
Availability	95	%	92	%	-3	%	due to drum body and belt
Other investments, personnel, energy, depreciation		similar					
Replacement parts, personnel	3.500	€/y	13.500	€/a	286	%	2 drum bodies per year - centric
specific costs €/t	2,5	€/t	2,8	€/t	13	%	
Output	90	%	88	%	-2	%	due to adjustability
Purity	90	%	89	%	-1	%	due to adjustability
Production	1.313	t/y	1.244	t/y			
Value	720	€/t	712	€/t			
Total revenue	945.562	€/y	885.404	€/y	-6	%	
Total cost p.a.	96.768,0	€/y	109.056,0	€/y	13	%	
Profit p.a.	848.793,6	€/y	776.348,5	€/y	**-9**	**%**	
Annual difference	**72.445,1**	**€/y**					Advantage STEINERT

4 Sensor Sorting Systems open up New Possibilities

Near-infrared sorting systems follow classic metal separation, both in order to recover polymeric resources, and to separate impurities such as PVC. However, high-resolution near-infrared sorting systems can only remove part of the chlorine content along with the PVC. However, this step remains essential, because it is the only way to observe limit values.

Nowadays, additional sensor-based technologies represent another option. The most important technologies are the induction sorting system ISS and the x-ray sorting system XSS. All above-mentioned systems are in use today for residue derived fuel and other materials.

The indispensibility of effective metal separation can be seen very clearly in figure 8. The stainless steel, exposed to the briquetting press, can be recognised. The destructive action of such pieces cannot be overlooked.

Figure 8: Shredded wood with metal

The principle of sensor sorting systems is represented in figure 9. Sensors, in this case a multitude of metal detectors, measure certain material properties and control compressed-air nozzles that remove the detected particle from the material flow if necessary.

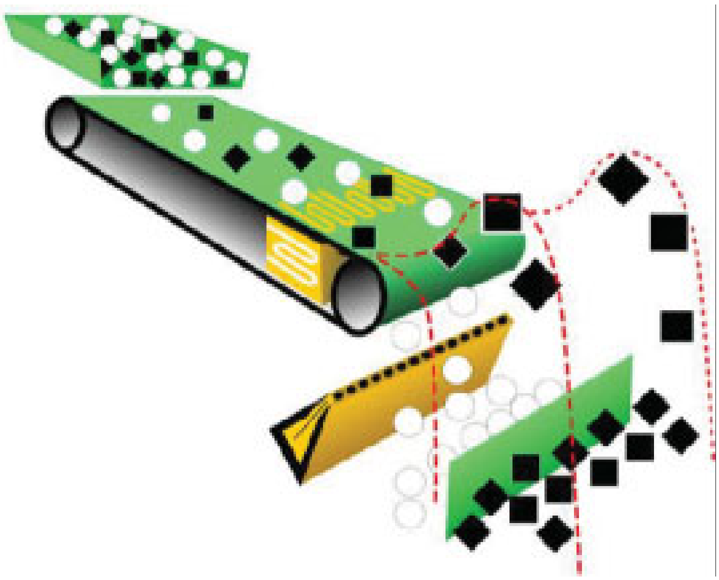

Figure 9: Principle outline of a sensor sorting system, Induction Sorting System (ISS)

If, for instance, an x-ray sorting system detects different materials, they can be sorted with the help of a calibration curve, as shown in figure 10.

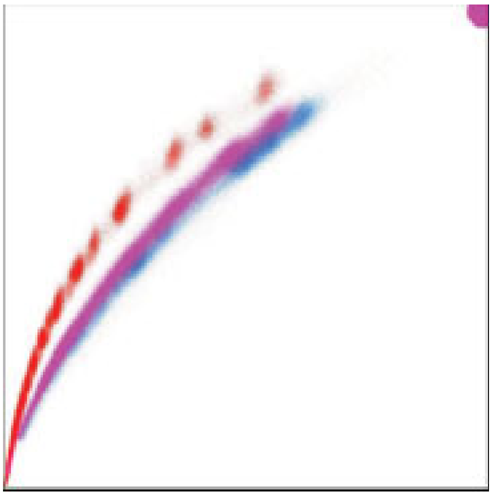

Figure 10: Calibration curves for distinction of materials through different intensities at different energy levels.

In the case of RDF and wood, this can be stones, PVC or rubber. The basis here is the transmission of particles by x-rays and the analysis of material specific attenuation of the exiting radiation on two different energy levels (Dual Energy). The heavier the chemical element, the larger the adsorption of the radiation becomes. Dual Energy compensates differences between atomic mass and material thickness and thus facilitates an evaluation regardless of thickness.

The material distinction is performed mainly on the basis of the atomic mass of the main chemical elements (fig. 11).

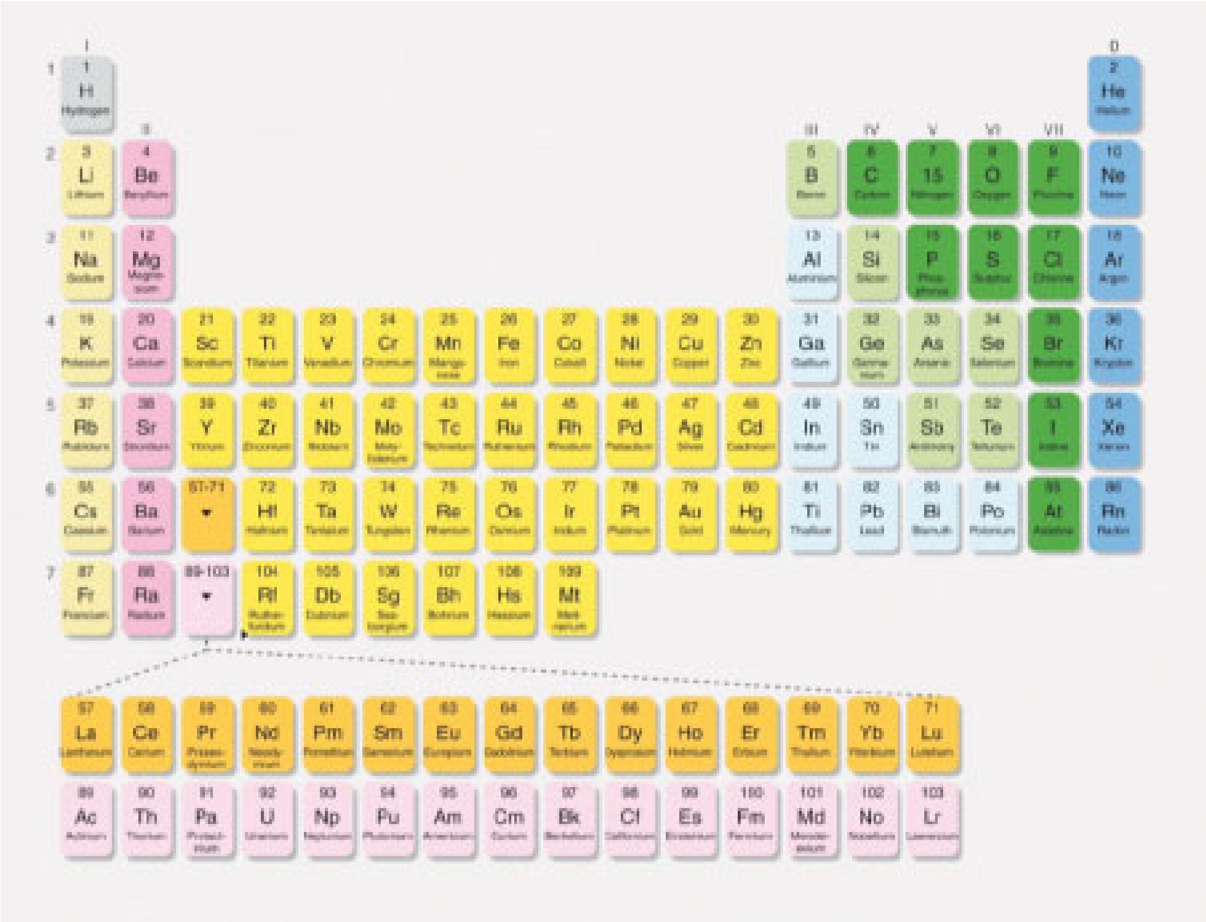

Figure 11: Periodic system of chemical elements as basis for the X-ray Sorting System (XSS)

An in-line arrangement of eddy current separation and induction sorting system is shown in figure 12 in a residue derived fuel processing plant in Germany. In this case, the induction sorting system was complemented by a near-infrared sensor technology, in order to separate remaining metals as well as PVC from packaging material.

Figure 12: View of an RDF plant with an eddy current separator on the left and an induction sorting system combined with a near-infrared camera on the right side

5 Conclusion

An understanding of the sorting steps and the product requirements allows the processes to be coordinated. However, this is based on the assumption that the technologies are understood at their interfaces and that they can be chosen freely. A selection of all the available sorting technologies makes this easier.

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New possibilities for fully automatic sorting of recyclables

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Abstract

New sensor technologies combined with intelligent software allows sorting of recyclables which could not be sorted automatically in the past.

Inhaltsangabe

Neue Sensortechnologien verbunden mit intelligenter Signalauswertung eröffnen völlig neue Perspektiven in der Aufbereitung von Werkstoffen.

Keywords

Waste sorting, optical sorting, sensor technology, multisensorsystems, MRF, cullet recycling, PET-bottle Recycling, scrap recycling

Wertstoffaufbereitung, Abfallsortierung, Optische Sortierung, Sensortechnik, Multisensorsysteme, MRF, Glasrecycling, PET-Recycling, Schrottrecycling

1 Sorting applications in the field of recycling are getting more and more complex

In a time of continuously increasing legal requirements about the degree of resource recycling, material sorting within recycling processes is becoming more challenging and complex and therefore requires highly effective detection and sorting systems.

1.1 Multi-sensor systems as a high-tech solution for difficult separation challenges

To meet these increasing demands and challenges, S+S Separation and Sorting Technology, a company specialised in the separation of mixtures of materials for over 30 years, has developed a modular system of conveying, sensing and separation units which can be implemented either as a stand-alone or a combined system, depending on specific demands. The user can choose between several sensors to meet individual separation challenge. S+S offers a segmented metal sensor, based on high frequency technology, able to detect all types of metal and to consistently locate their position on the conveying system. Several sensors of different segment width can be chosen, depending on the grain size of the material to be analysed. Typical examples of applications can be found anywhere from the separation of aluminium cans from a PET bottle fraction to the removal of metal particles from 0.6mm upward from open electronic waste. With regard to recycling of mixed waste types, this sensor offers a way to separate of remaining metal particles after the magnetic and Foucault current methods. To differentiate different types of metal, an additional version of the sensor is available, able for example to separate high grade stainless steel from a mixture of metals.

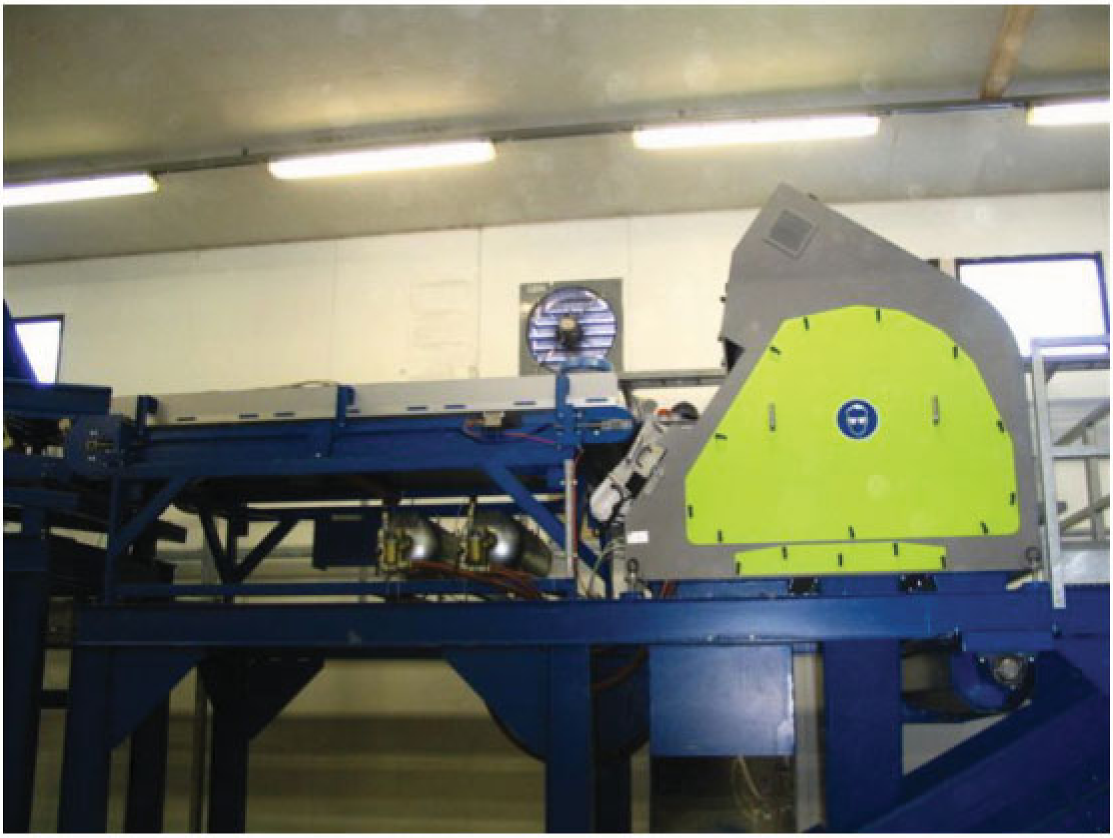
In the sorting process, it is often important to distinguish between transparent and non-transparent materials, for example, the detection of ceramic particles within the glass recycling process. For this purpose, S+S offers a special transmitted light sensor which scans the stream of material with high energy light to analyse transparency. A CCD camera module can also be utilised if not only transparency but also shape, colour and brightness are to be analysed to separate other fractions. Typical applications are the separation of pre-separated plastic bottle fractions or the sorting of mixed metals by colour, for example, copper, brass and aluminium. When optical characteristics are not sufficient to classify substances, a module applying „near infrared technology“ can be used for example to distinguish plastics based on their polymeric structure, to identify and separate them from a mixed waste stream.

Varisort X, X-ray based sensor system for difficult sorting applications

X-ray technology is also used to separate materials with only marginal differences in their chemical structure, which either cannot or only with difficulty be classified by applying conventional methods. A typical example material separation using x-ray technology is the separation of optically identical high temperature resistant glasses from normal bottle or flat glass and the separation of substances containing chlorine from substitute combustible fractions. The same technology is often applied in electronic waste recycling to separate monitor glass rendering the manual or semiautomatic separation of front and cone glass unnecessary.

1.1.1 Multi-sensor systems start a new chapter in recycling

Through intelligent implementation of the sensor systems mentioned above, either stand-alone or integrated multi-sensor systems, the majority sorting challenges of the future can be overcome.



Multisensorsystem Varisort MNC with three different sensors

A complete version of this presentation paper is available from the author via e-mail under peter.mayer@se-so-tec.com

Anschrift der Verfasser(innen)

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Feasibility of Acoustic Sorting for Black Materials in Solid Waste Processing

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Abstract

Municipal and Industrial Solid Wastes are generally collected as mixtures of different solid materials. In solid waste treatment plants the waste gets crushed, classified and sorted. Among these processes the sorting is the determining step in which materials with the same recycling attributes are concentrated and cleaned from impurities. During the last decade sensor based sorting like 3D cameras and Near – Infra – Red (NIR) sorting made a huge technical improvement and enabled its industrial implementation. One of the still remaining problem lies within the sorting of black materials like plastics and rubbers which are very difficult to sort by using conventional visual sensors. This results from absorption of NIR emissions. The black materials have different structures and acoustic emissions when an impact is given. By using the acquisition and analysis of the acoustic signals from the impact in frequency-domain, the characteristics and features of different materials can be extracted and then transferred to the sorting system as sorting criteria. The key device of acoustic signal acquirement and analysis is the Data Acquisition (DAQ) card. With the high development of signal processing technologies, the capacity, compatibility, stability and flexibility of a soundcard is already adequate for industrial measurements and its price is much lower than the professional DAQ cards. The Signal acquirement and analysis systems which are discussed in this paper are therefore based on computer soundcards.

Keywords

Sensor based sorting, Impact acoustic, Spectrum analysis, LabVIEW

1 Introduction

Each year billions of tons of solid waste are generated through human activities in the world. All of them need to be treated in order to avoid pollution and other hazards which probably happen. In addition to that, most of the solid waste can be utilized as a source for secondary raw materials, like metals, plastics, glass, paper, old tires, etc. By recycling and utilizing solid waste materials a lot of energy, resources and raw materials can be saved which leads to improvement of local and global environmental.

Waste is always collected and fed into waste treatment plants as a mixture of different solid materials. In waste treatment plants the mixture gets crushed, classified and sorted. Among these processes the sorting is the determining step in which materials with the same recycling attributes are concentrated and cleaned from impurities.

The sorting technologies can be divided into direct and indirect separation processes. In direct processes there are different selective interactions between the characteristics of single particles and the corresponding force field of the separator. One example for the direct process is the eddy current separation.

However, the colour, texture or volume of each particle could also be considered as sorting criterion but there is no sufficient force field by which the corresponding particles get sorted from a mixture stream. According to this a separation based on recognition and mechanical sorting is necessary and defined as indirect sorting process. For example in the manual sorting processes, the characteristics of the particles are detected by the human eye and the material groups are organized in the human brain. After the detection, information which has been processed in the human brain is used to initialize the sorting operation with the hand. Similarly the methodologies which are defined as sensor based sorting processes follow the same basic principles like hand sorting. Instead of human senses different technical sensors are developed and implemented [7]. Examples are cameras, microphones and even some senses that cannot be processed by humans such as NIR and microwave sensors. In the last decade the sensor based sorting by using 3D cameras and NIR sensors made a huge technical improvement and enabled its industrial implementation. One of the still remaining problems lies within the sorting of black materials like plastics and rubbers which are very difficult to sort by using conventional visual sensors. This results from absorption of Near–Infra–Red (NIR) emissions. The black materials have different structures and acoustic emissions when an impact is given.

Although the black materials have the same visual characteristics, they still have some different characteristics like the acoustic emissions by impaction on solid surface. According to our experiences, the acoustic signal of plastic, rubber, and mineral materials colliding with a solid surface can be easily distinguished by hearing. The modern acoustic sensors like microphones are much more sensitive than the human ear and together with rapid signal processing technologies the acoustic sorting of black solid waste in industrial scale can be realized. Some facilities using this system have already been developed and employed, such as the processing system for nut and wheat kernels.

Different from the metals, most of the acoustic emissions of plastics and rubbers concentrate in the auditory threshold i.e. the frequency range of 20 – 20,000 Hz. In this range the PC soundcard is a perfect signal acquisition and analysis system. With the high development of signal processing technologies, the capacity, compatibility, stability and flexibility of computer soundcards are already adequate for industrial measurements and their price is much lower than the one of professional DAQ cards. Through the installation of several soundcards in one PC, a multi – channel signal acquisition and analysis system can be established. The signals can be processed and analyzed by virtual equipment with the corresponding software LabVIEW. The feature “extraction of acoustic signals” is based on frequency domain analysis.

This paper summarizes the results of experiments, in which the impact behaviours of several kinds of plastics have been studied with self-built acoustical equipment by the Department of Processing and Recycling (IAR) of the RWTH Aachen University. The frequency – domain – based analysis are used to process the signals and the spectral features are introduced to recognize the different materials. Nearly all of the tested materials have their own spectrum according to different particle size except some abnormal impacts. The feature “information of acoustic signals” is sufficient and available for the sorting criterion.

2 Preparation of the Experiment

2.1 Construction of the Experimental System

In order to acquire the acoustic emissions of different materials, individual sample particles of each material are designed to fall from a defined height and then impact on a thick stone plate. The impact system is sealed in an empty medium – density fiberboard (MDF) case whose inner surface is covered by sponge material in order to avoid the influence of ambient noises.

The MDF case consists of 4 elements. The height of the case can be adjusted to be 600 mm, 750mm or 900mm for different falling heights. The outer dimension of this equipment is 300 mm in width and 300 mm in length, the thickness of the MDF plates is 15 mm. The inner dimension is about 270 mm in width and 270mm in length. The impact stone plate is made of nature stone for foot paths with the dimension of 200 mm in length, 200 mm in width and the thickness of 30 mm. The stone plate is placed in a steel bracket which is set in a 45° angle inside the system. The acoustic signals of impacts are acquired by the acoustic sensor i.e. the microphone which is placed at the ceiling of the inner space [1].

The reason for the selection of the impact plate material is the excellent stability of the stone plate and its vibration characteristics towards plastics and rubber. A metal impact plate has similar acoustic emissions and a wooden plate would be deformed and worn off in short period of time.

The sketch of the case is illustrated in figure 1 [1] and the installation of the whole equipment and the impact plate are illustrated in figure 2 and 3 [1].

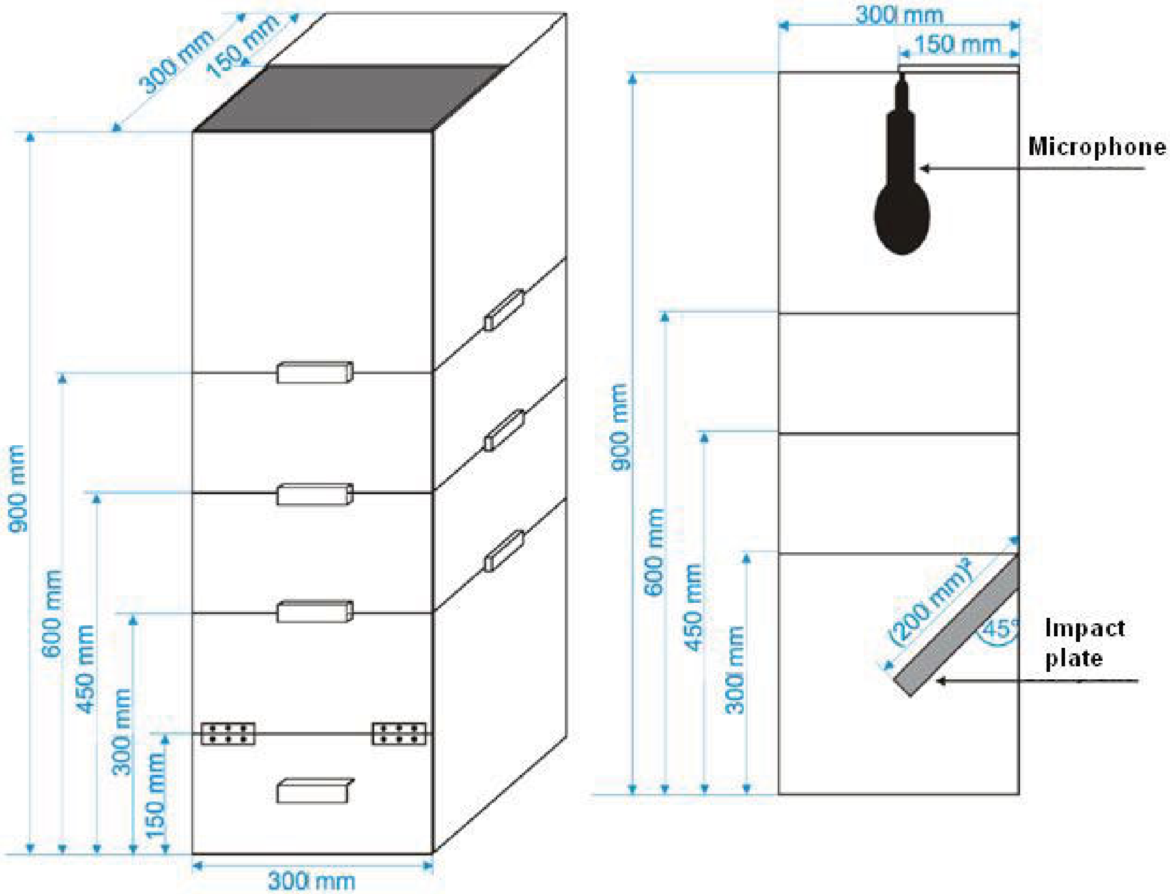

Figure 1 The Sketch of the experiment equipment for impact acoustics

Figure 2 Complete Equipment and the installation of microphone and impact plate

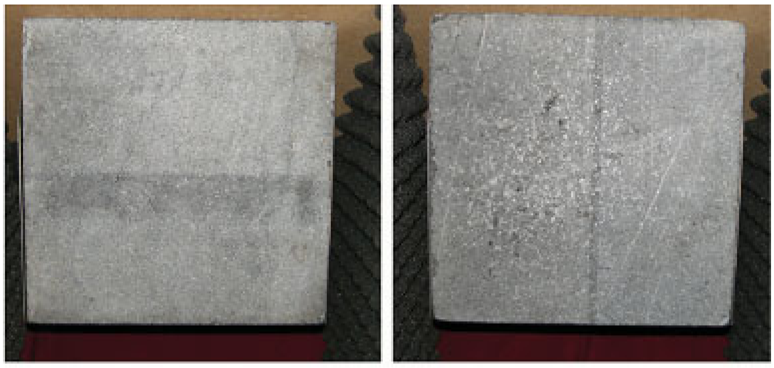

Figure 3 Impact plate for experiment (left: before experiment, right: after the experiment)

2.2 Demand of Software and Device

The original impact signals are acquired by a microphone and transferred to the computer. There they are saved and analyzed by the soundcard and LabVIEW. The professional DAQ cards which are available on the market like the device from National Instrument (NI) are expensive and the same functions can also be realized by standard soundcards of computer. The A/D and D/A capacity of soundcard are already adequate for industrial measurement and their prices are much lower than those of professional devices. Normally the precision of 16 bits soundcards is better than the 12 bits DAQ cards. The soundcards transfer the data by direct memory access (DMA) technology and result in massive reduction of the CPU occupation. The PCI bus technology allows the high speed data communication between soundcard and system and made the online analysis and real time manipulation by using virtual instruments possible. The key performances of soundcard are sampling rate and resolution. Currently the maximum sampling rate of a soundcard can reach up to 96 kHz, and the resolution can reach up to 32 bits and the maximum SNR reaches up to 114 dB. Normally, the function and operability of an external soundcard is better than the same of devices which are integrated in the common main – boards. Software updates are also more convenient for the external devices. The soundcard which was implemented in this project is an external soundcard, type of AUREON 5.1 USB MKII. The performances of this model are:

1. Sampling rate: 32, 44.1 and 48 kHz
2. Band width: 0 – 22.05 kHz
3. Resolution (number of samples pro sampling): 16 bit
4. Input connection: Line – in / Mic – in
5. Output connection: USB 1.1 / 2.0

The virtual instrument software which was used for data acquisition and analysis is LabVIEW (version 8.5). LabVIEW is designed for virtual instrument development. It is an advanced platform for industrial testing, measurement and manipulation. It includes almost all the common signal processing functions and lots of advanced signal processing toolkits. The virtual instrument (VI) program can be easily integrated with other hardware, Ethernet, BUS communicator and common databases.

2.3 The Method of Signal Processing and Analysis

The characteristic wave of acoustic signals can be expressed longitudinal wave which comes from a vibration source. The sound wave is transferred by media (air, water, iron, etc) as the continuous variation of amplitude, frequency, phase and some physicals. All the variations are detected by microphone and then converted to analog signals. The analog signals are converted to digital signals by the soundcard and then saved on the computer. Like the communication signal processing the analysis of acoustic signals can also be operated by frequency – domain analysis which is based on the Fast Fourier Transformation (FFT) method, hence the main feature of sound signals is the energy distribution according to frequencies. Standard methods for feature extraction are frequency spectrum, power spectrum and power spectrum density (PSD).

3 Configuration of the Device Parameters

3.1 Settings for FFT Analysis

In order to acquire the suitable signals which are available for FFT Analysis the soundcard must be set correctly. The utilization of FFT has also constrains which is called “Nyquist-shannon sampling theorem” or “Sampling theorem”. The constrains are:

1. The sampling rate must be at least twice higher than the band width of signal.
2. The number of samples must be 2^n (n is integer, always the bit number).
3. The sampling period must be the integral multiple of signal period.

The signals which do not fulfill the sampling theorem will cause the aliasing effect and leakage effect during the FFT analysis and generate errors.

3.1.1 The Aliasing Effect

In statistics, signal processing, computer graphics and related disciplines, aliasing refers to an effect that causes different continuous signals to become indistinguishable (or *aliases* of one another) when sampled. It also refers to the distortion or artifact when a signal is sampled and reconstructed as an alias of the original signal. If the sampling rate is not high enough the aliasing effect will be generated. The theory of aliasing generation is illustrated in figure 4.

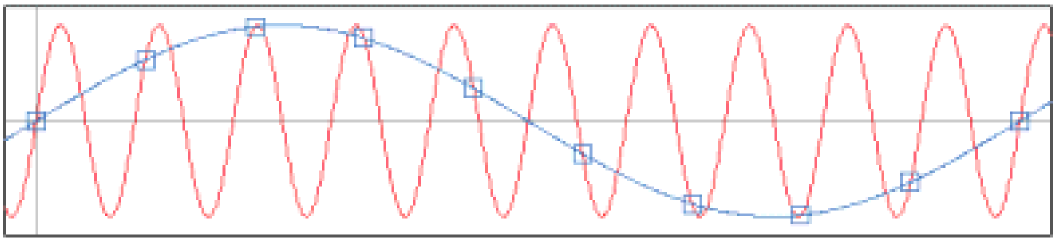

Figure 4 The generation of aliasing effect

In figure 4, it is shown that because of the low sampling rate the two different signals have the same sample values. It can directly influence the frequency spectrum and make it difficult to be recognized [7]. The influence of the aliasing effect in frequency domain is illustrated in figure 5.

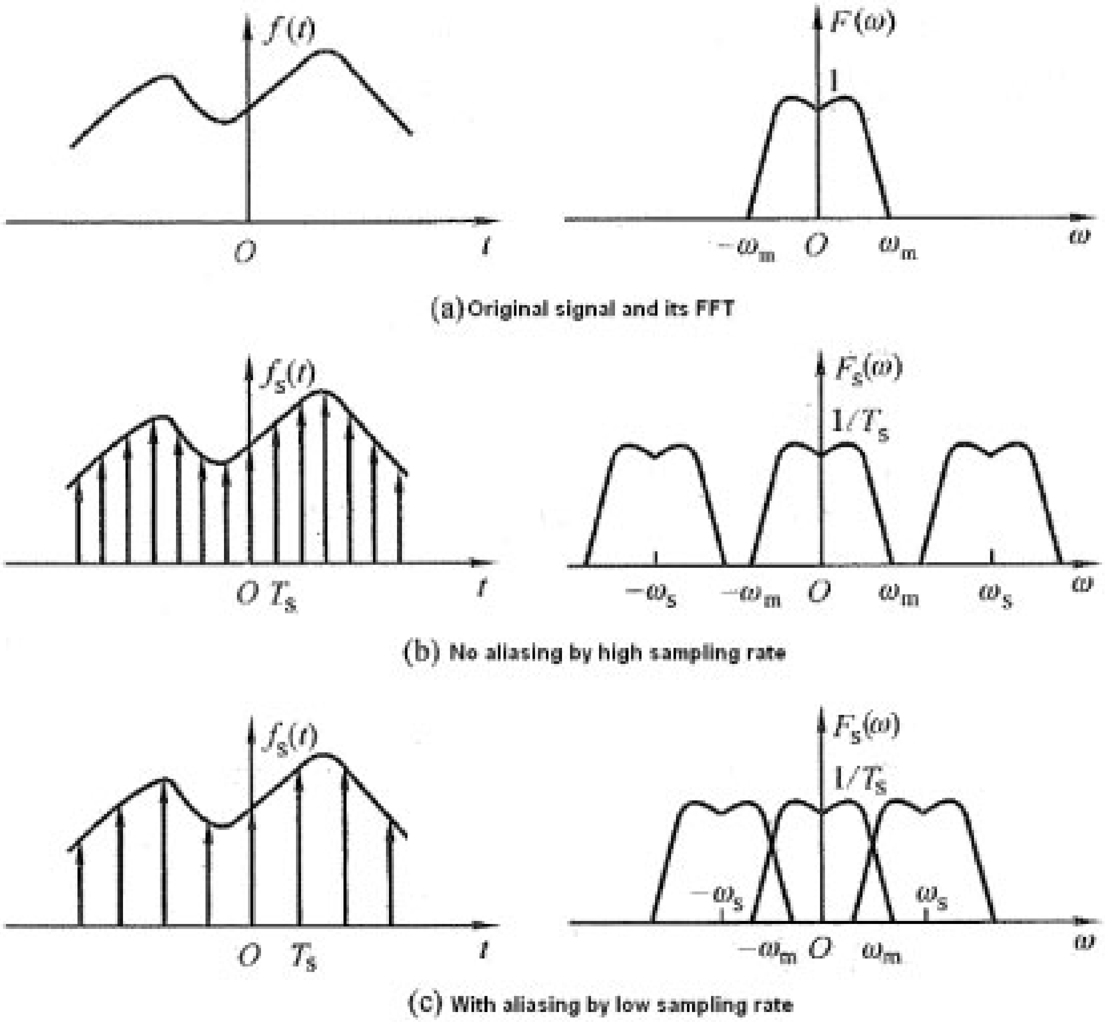

Figure 5 The aliasing in frequency domain and frequency spectrum

Figure 5 shows that because of the aliasing – effect the features which lay in the frequency spectrum are mixed and become more difficult to be recognized. Increasing the sampling rate to be a higher level can avoid or at least reduce this.

3.1.2 The Leakage Effect and Window Functions

The signals are acquired continuously but the available impact acoustic signals are non – continuous because the impacts of particles are discrete. The available signals need to be cut from the unlimited signal series i.e. the time function must be set to be limited in order to analyze the signals. The signal cutting process can be realized by the original signal *x(t)* multiply with a rectangular impulse *h(t).* Just like watching the signal through a rectangular window. The *h(t)* is called window function. The signal after cutting can be calculated as [6]:

$$x_1(t) = x(t)\,h(t) \tag{1}$$

The Fourier transformation of $x_1(t)$ can be calculated as the convolution of the *X(f)* and *H(f). X(f)* and *H(f)* are the Fourier transformation of *x(t)* and *h(t)* [6]:

$$X_1(t) = X(f) * H(f) \tag{2}$$

During the cutting process the distortion of the frequency spectrum is generated which is known as the “Leakage effect”. The generation of leakage effect is illustrated in figure 6.

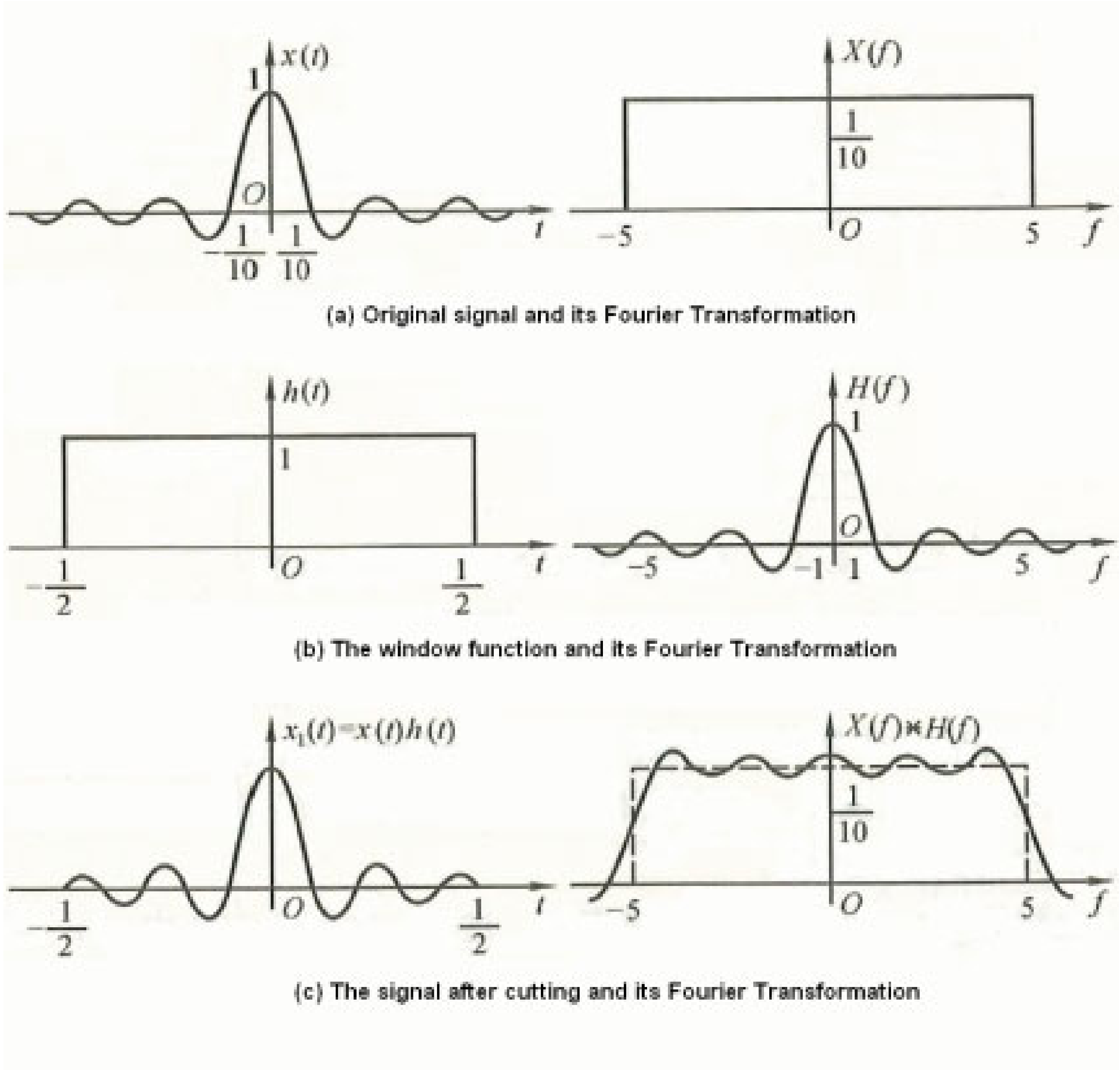

Figure 6 The leakage effect generated by rectangular window function

Figure 6 shows that the Fourier Transformation of the signal which was cut by a window function has the distortions on both band width and frequency spectrum. The band width is expanded and the spectrum has undulations. The expansion of band - width may further cause or intensify the aliasing effect and the spectrum distortion may conceal the information of the signal.

The leakage effect which is generated by truncation of the time – unlimited signals is inevitable. It can only be minimized by a selection of different window functions. The high distortion of the rectangular window is caused by the impulse and mutation in the time domain of this rectangular window function. The impulse in the time domain causes the low convergence in the frequency domain and the solution to this problem is to cut the signal by a gradual change window function. Many of such function have been developed, like the Hanning window, the Hamming window, the Blackman window and etc. These three kinds of window functions are illustrated in figure 7.

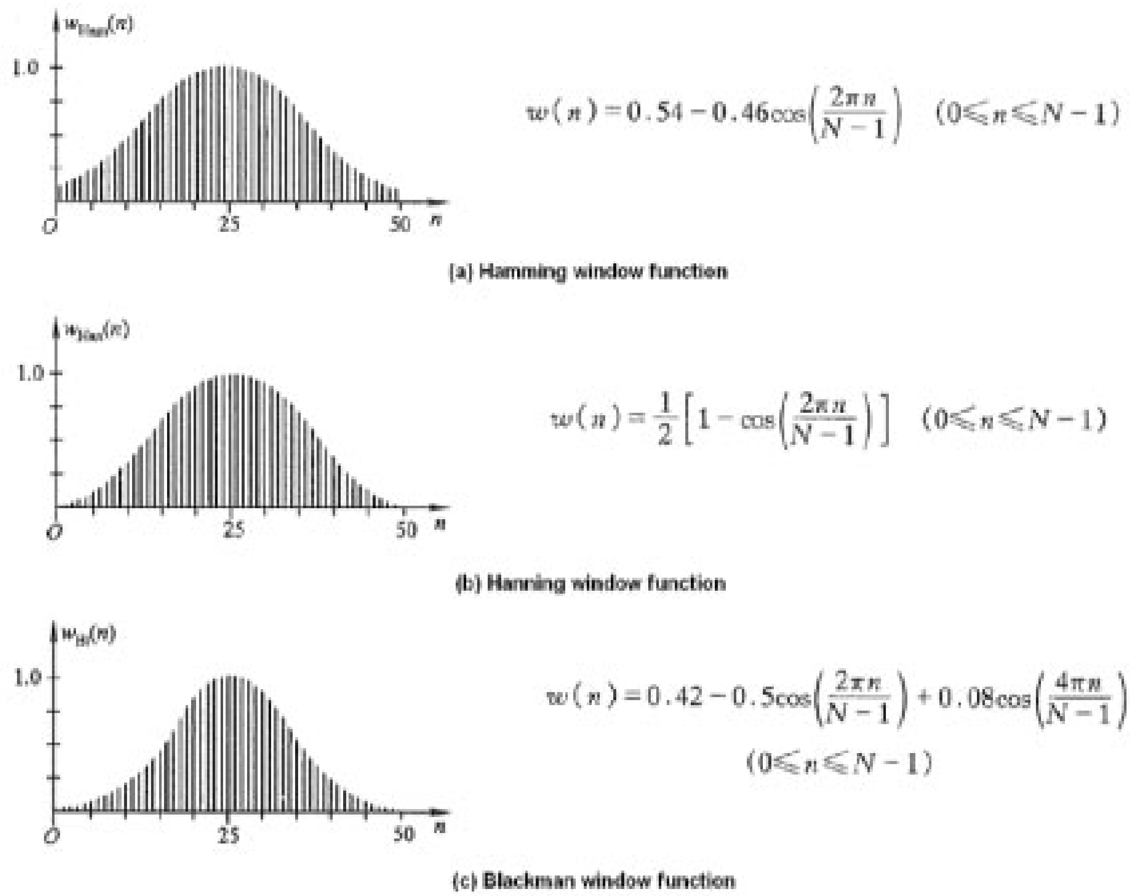

Figure 7 Three kinds of window functions

In these functions *N* represents the width i.e. the number of the samples in a discrete – time window function. Typically it is an integer power – of – 2, such as $2^{16} = 65536$. n is an integer with values $0 \le n \le N - 1$.

For a given window function, the intensity of the leakage distortion correlates with the side lobe attenuation in its own frequency spectrum. The ideal condition is that the heights of side lobes are zero and all the energy concentrates on the main lobe, which is impossible [6]. In reality the side lobe can only be minimized but not be avoided. For example the rectangular window and the Hanning window are compared in figure 8:

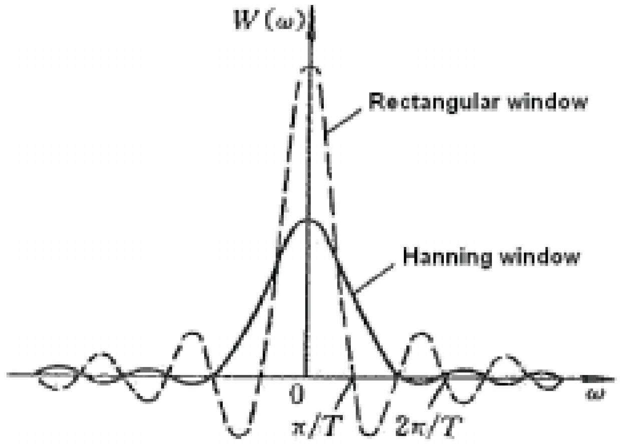

Figure 8 Comparison of Rectangular and Hanning window in frequency domain

It is illustrated that the side lobe attenuation of Hanning window is much more rapid than rectangular window and the corresponding energy leakage is much lower.

By setting of the sampling rate the number of samples and the selection of a suitable window functions with which the acquired acoustic signals can be cut and analyzed correctly, so that the results can also be available to be used as sorting criteria.

One constrain for FFT analysis is that the sampling period must be the multiple integral of a signal period. If the sampling rate and the number of samples are determined, the sampling period is also defined and it does not have to be the multiple integral of a signal period. This problem can cause a small leakage effect and its distortion behaves at the side lobes of the frequency spectrum. This is illustrated in figure 9:

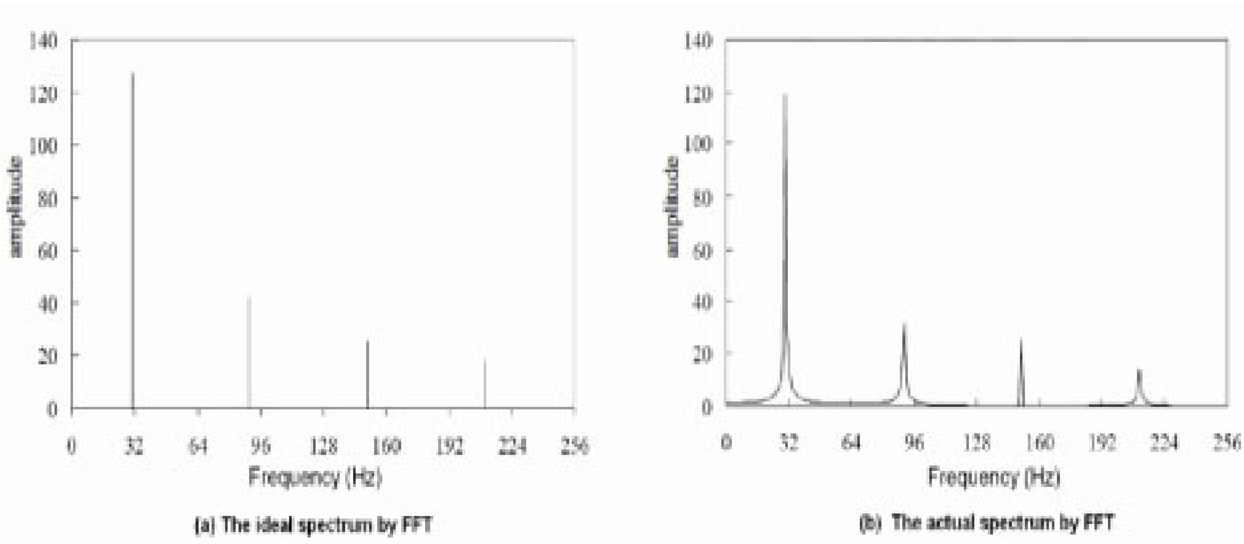

Figure 9 The Comparison of ideal and actual spectrum by FFT Analysis

Figure 9 shows that the ideal eigen – frequencies should be denoted by lines on the FFT spectrum but on the actual spectrum the eigen – frequencies are denoted by peaks because of the side lobes which are generated by wrong sampling periods. Normally this distortion is inevitable and in most cases it does not influence the feature extraction since the energy leakage by expansion of sampling period is very low and the position of eigen – frequencies cannot be aliased or changed. The most important constrains of FFT analysis is the sampling rate and the number of samples.

3.2 Configuration of Soundcard

According to the constrains of the sampling process, the soundcard must be configured before running experiments. The soundcard which is selected for this research has a band width of 0 – 22.05 kHz. Hence the sampling rate is set to be 44.1 kHz. The resolution of the soundcard is set to 16 bit in order to acquire enough information. The setting of the channels is mono. The window function which is selected for cutting the original signal is the “Hanning” window and it is realized by using software.

The setting and control of the sampling process is automatically controlled by LabVIEW software automatically. Using the sound and graphic toolkit one can easily start or close the soundcard and set up all the necessary parameters. The sound signals are set to be saved on the hard disk as “.wav” files, because this format of sound data is nearly universal for all acoustical software and its accuracy is also high enough for industrial measurements. The virtual signal acquirement instrument is illustrated in figure 10.

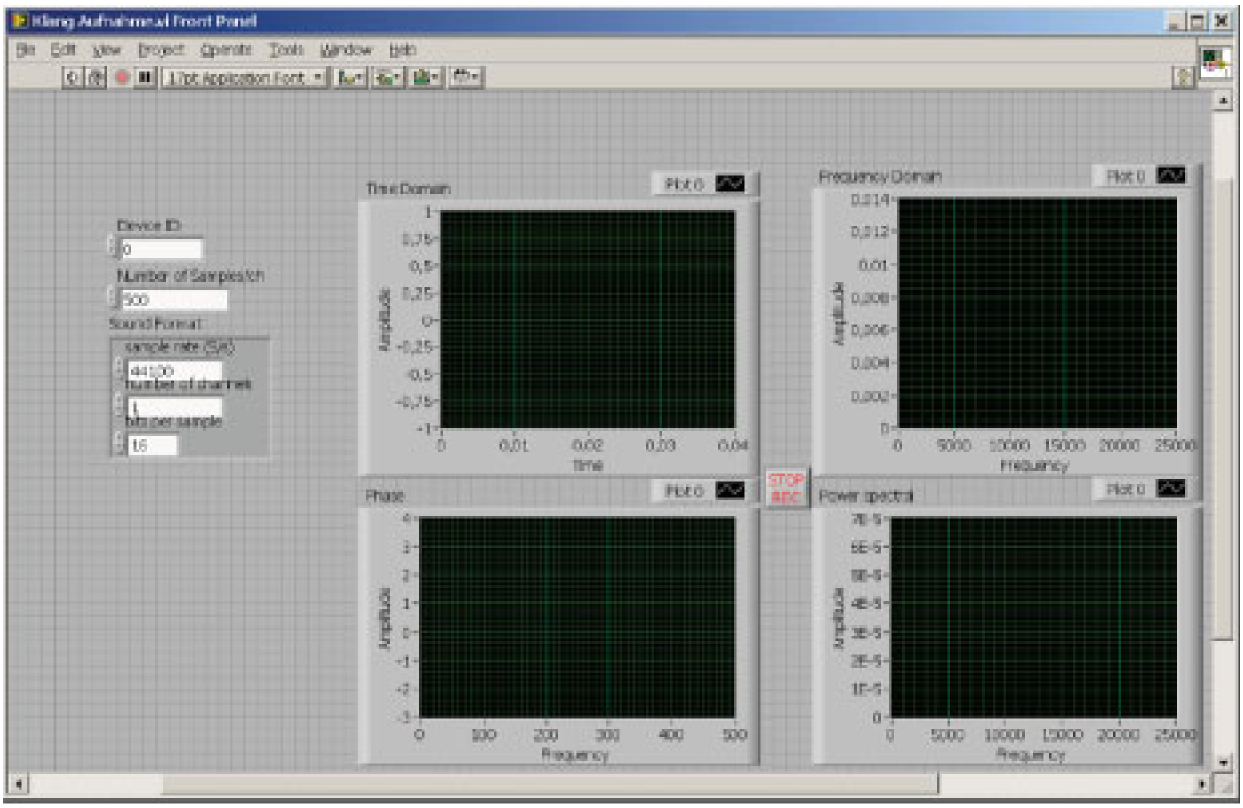

Figure 10 The front panel of signal acquirement program

On this panel, there is only one device (soundcard) installed. So the default device ID is zero. The sampling period is fixed by giving the “number of samples per / channel” and “sampling rate”. The number of channels is one and the resolution is 16 bit. The saving path of signal data is determined in the program but not on the front panel. The wave-form, phase and two kinds of spectrums are shown synchronously and continuously. One example of impact acoustic signal from ABS Plastic is illustrated figure 11.

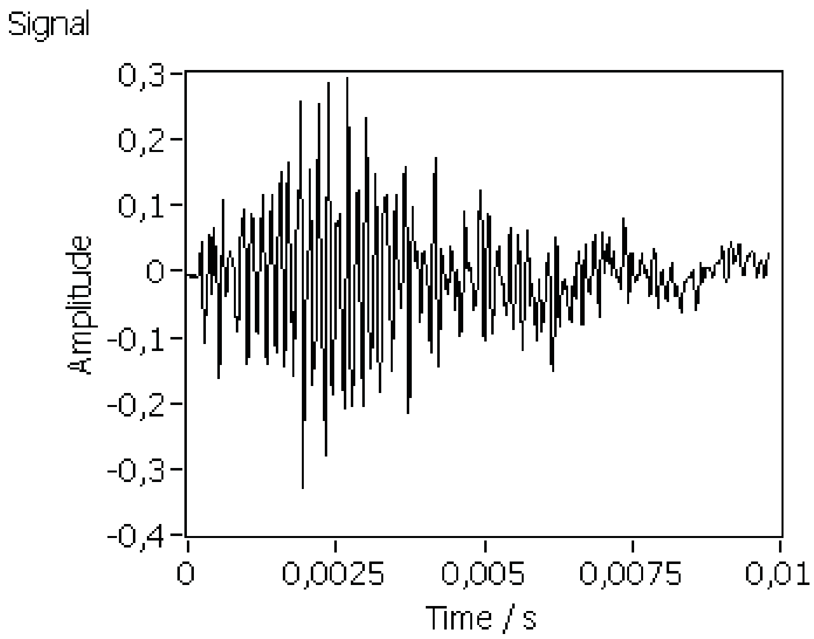

Figure 11 One example of impact acoustic signal from ABS plastic

4 Process of Experiment and Analysis of Results

This paper shows the results from several kinds of acoustic impact emissions from black material particles. The results show that using the FFT analysis the impact characteristics of each material have different features which can be used as sorting criterion. Not all the impacts are available for feature extraction, the abnormal impact such as the double or triple impacts which are caused by the shape of particles and the no – ringing impacts. The abnormal impacts are inevitable but can be minimized by regulating the shape of the particles and increasing the time of single particle impact (circulation of indistinguishable particles).

4.1 Selection of a suitable Shape for Particles

The crushing process of materials can only determine the particle size, the shape of particles are generated randomly. The impact process is also a random process so that the types of acoustic impact emissions of a single particle are different over a certain number of experiments. There could be several kinds of signals by one particle. The abnormal impacts are mostly generated by the irregular shapes of particles. Through this research it can be deduced that by increasing the particle size the probability of abnormal impacts increases. Too small particle on the other hand cannot generate signals with an adequate intensity of the. The suitable particle sizes are between 5 mm and 25 mm. The abnormal impacts which are caused by particle shapes are illustrated in figure 12.

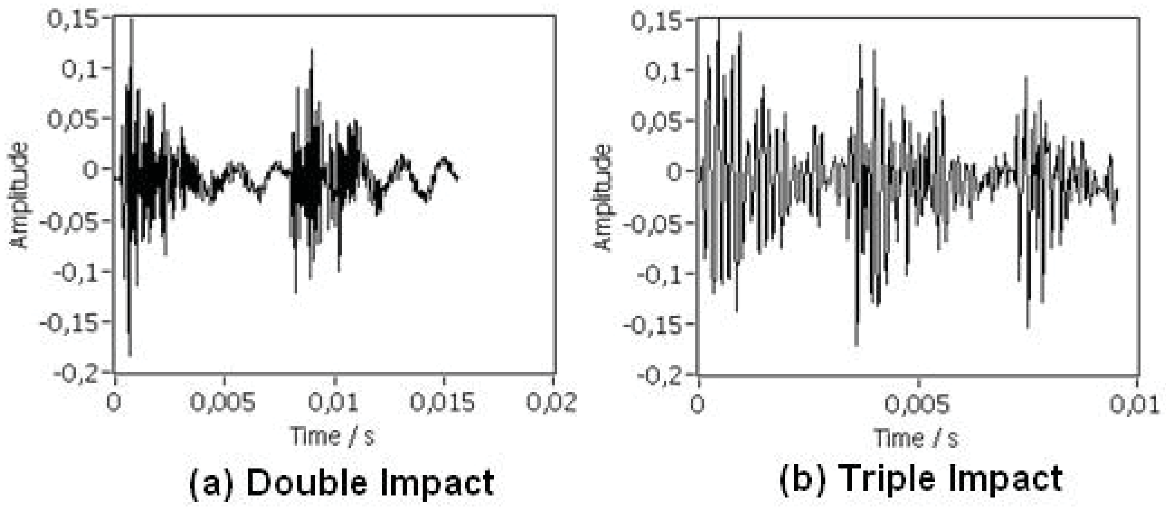

Figure 12 The abnormal Impacts generated by Particle Formats

The influence of multi – impact in frequency domain by FFT is the increasing of spikes of spectrums and further the decentralization of the features. For example the power spectrum of the signal which is shown in figure 12 (a) is shown in figure 13:

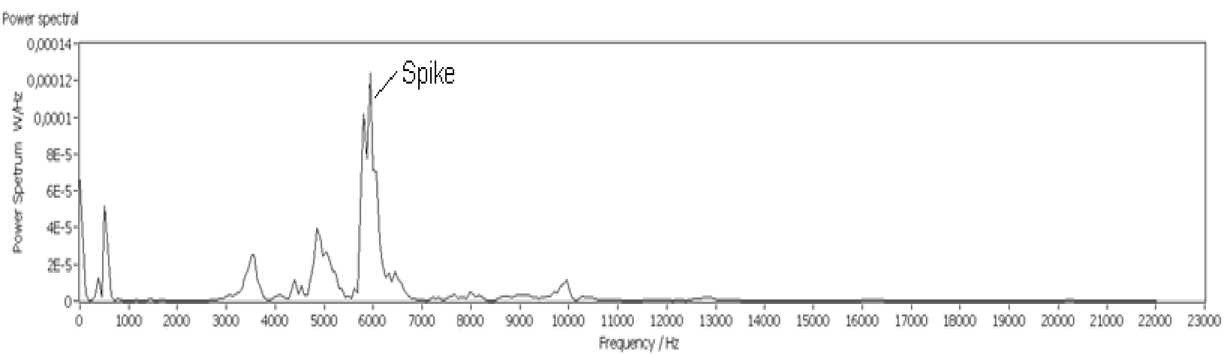

Figure 13 The influence of multi – impact on Power Spectrum

The feature of the signal in figure 12 (a) should have the highest peak in the range of 5,700 – 6,000 Hz. Due to the abnormal impact there are two peaks in this range and make this spectrum similar to the one of another material. This problem can confuse the program and lead to a wrong determination in sorting.

Except the multi – impact sometimes other abnormal impacts may occur. This refers to impacts without ringing. Sounds induced by impact can be separated into two major categories. The first is “acceleration” and the second is “ringing”. The acceleration component of the process controls the early time response of the time-dependent field pressures, whereas the subsequent time response is dominated by the free-vibration of the impacting bodies. Ringing sounds which control the response after the decay of the acceleration component is traditionally recognized as useful for the feature extraction [3]. The acceleration and ringing parts of sound signals are illustrated in figure 14.

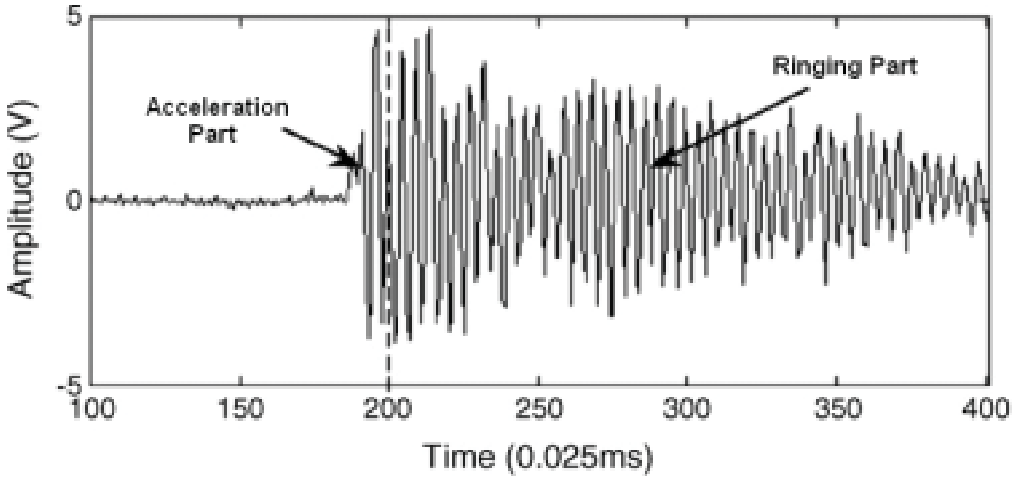

Figure 14 The acceleration and ringing parts of a sound signal

Moreover, the initial acceleration part of impact sounds can be further divided into two parts, from the impact plate and from the test object. If the particles are not correctly accelerated to vibrate, the ringing part will be very weak and most of the impact energy will be transferred to the impact plate. The result of the analysis will be the vibration spectrum of the impact plate. This kind of abnormal impact happens infrequently very seldom but cannot be ignored. The particles which impact the plate without ringing signal must also be determined and sent back to the raw material and impact again.

According to the research of all particle sizes the probability of multi – impact is about max. 30% and the probability of the impacts without ringing are about max. 5%. By using the particle with the size of 5 mm – 25 mm the multi – impacts can be reduced to 3% - 10% and the impacts without ringing can be reduced to about 2%.

4.2 The Feature of the Impact Plate

The energy distribution during the impact is also a random process. In which a part of the kinetic energy of the falling particles is transferred to the impact plate and causes it to vibrate. The vibration of the impact plate influences the spectrum of the acquired signal and leads to distortions. Hence the response feature of the impact plate during the impact process must be determined and then neglected during the FFT analysis.

The material, shape, size and thickness of the impact plate are fixed so that the response features of it should also be a fix value. The response features of the impact plate are determined by the analysis of the impact signals which are generated by different particles with different materials. The analysis was done by the sound processing software DEWESoft. The results are illustrated in figure 15:

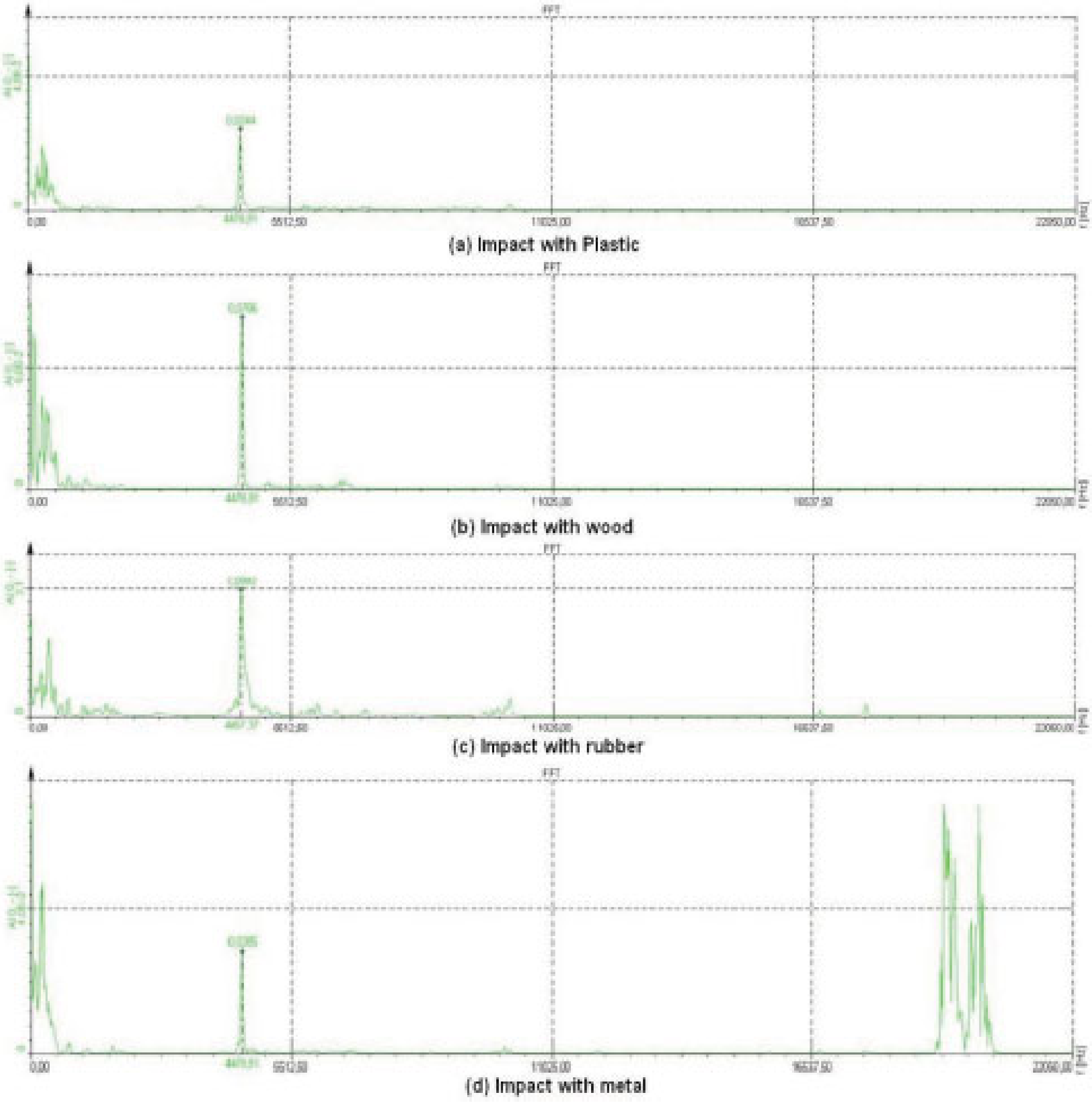

Figure 15 The FFT analysis of the eigen – frequencies of impact plate

In figure 15 the impact signal from different materials are analyzed and the results shown that the common feature are the peaks between 4,457.37 Hz and 4,478.91 Hz. In order to avoid distortions the peaks between 4,400 Hz and 4,600 Hz on the spectrum of signals can be ignored as the features of the impact plate.

4.3 Analysis of the obtained Results

In the time domain, each signal which is cut from the signal series contains about 500 points sampled at 44.1 kHz. To obtain the frequency – domain information, the power spectral of the feature is estimated with the Fast Fourier Transformation (FFT) calculation on the original time history.

The particles which are used for the experiment have the same particle size about 20 mm and the same thickness of about 2.5 – 3 mm. The plastic flakes are usually mixed together and then crushed into the same particle size. The particle size of 20 mm is suitable to avoid the abnormal impacts. In this experiment there are 3 different plastics in total which have been measured for min. 150 times and they all have one or more evident features in the frequency domain.

The 3 kinds of plastics are Polypropylene (PP), Styrene maleic anhydride (SMA) and Acrylonitrile butadiene styrene (ABS). The typical spectrums have been obtained and illustrated in figure 16 to 18.

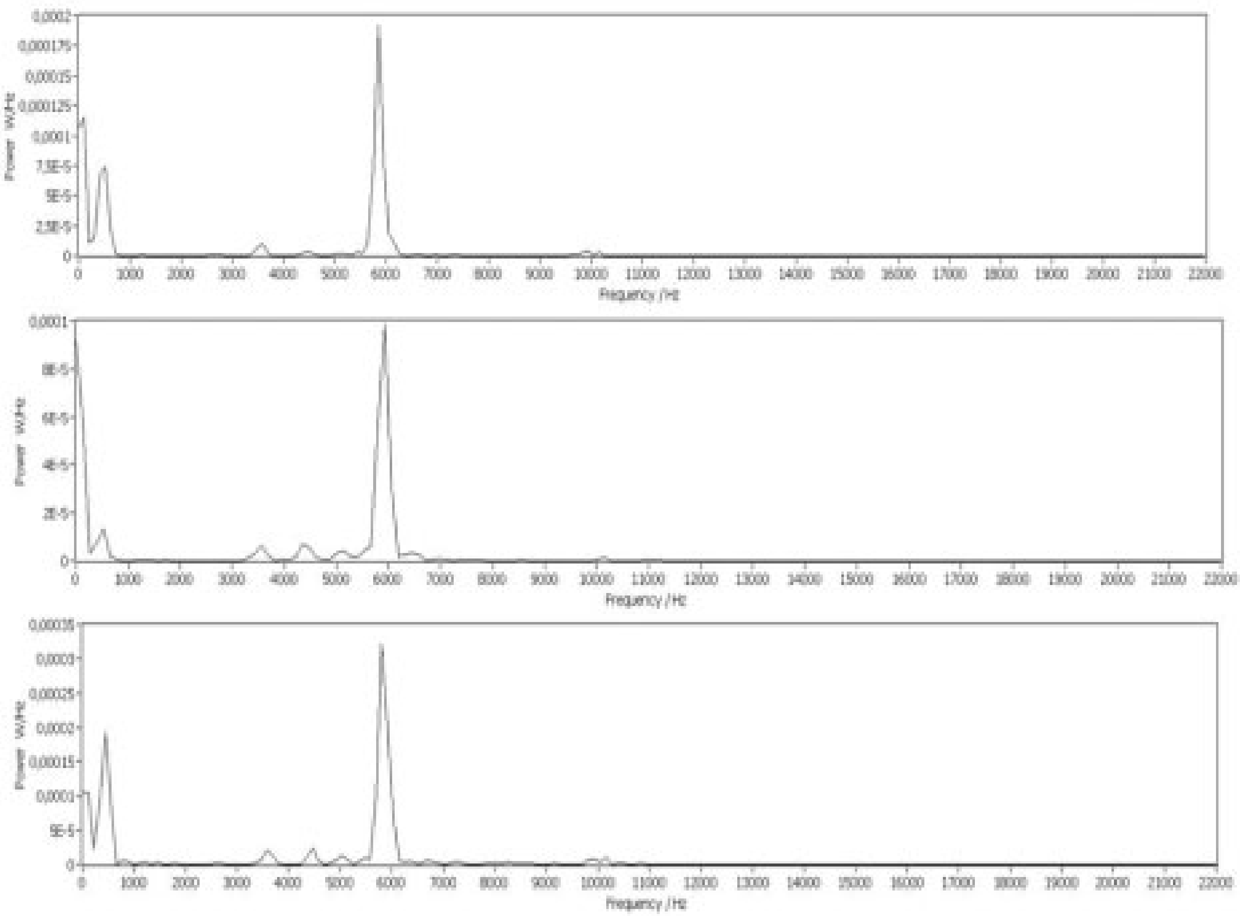

Figure 16 The power spectrum of Polypropylene (PP) pieces

Figure 16 illustrates that the spectral feature peaks of PP particles concentrate in the range of 5,700 – 6,000 Hz. Normally the main peak has not spikes and it is at least 8 times higher than other peaks. The peaks which locate in the range of 4,400 – 4,600 Hz must be ignored because it is the feature area of the impact plate. This feature has the probability of occurrence of about 62.5%.

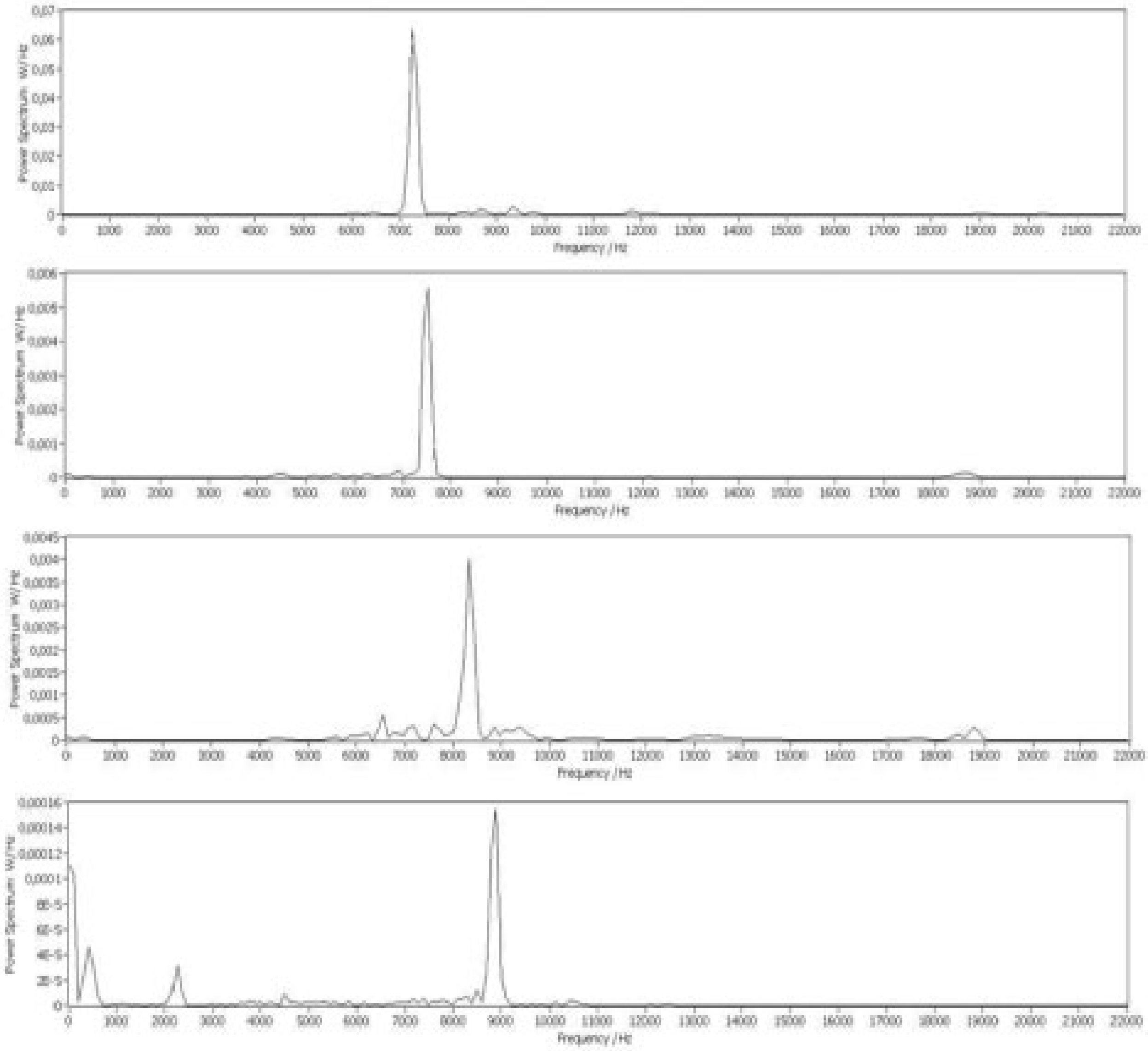

Figure 17 The power spectrum of Acrylonitrile butadiene styrene (ABS) pieces

Figure 17 illustrates that the spectral features of ABS particles are distributed in the range from 7,000 to 9,000 Hz. Normally the main peaks are smooth and do not have spikes. Sometimes there is not only one main peak but also the second or third high peaks on the spectrum. The main high peaks are always located in the range of 6,000 – 6,500 Hz and 7,000 – 9,000 Hz. The approximate probabilities of occurrence for the main peak areas are:

1. 7,000 – 8,000 Hz: 35%
2. 8,000 – 9,000 Hz: 25%
3. 6,000 – 6,500 Hz: 10%

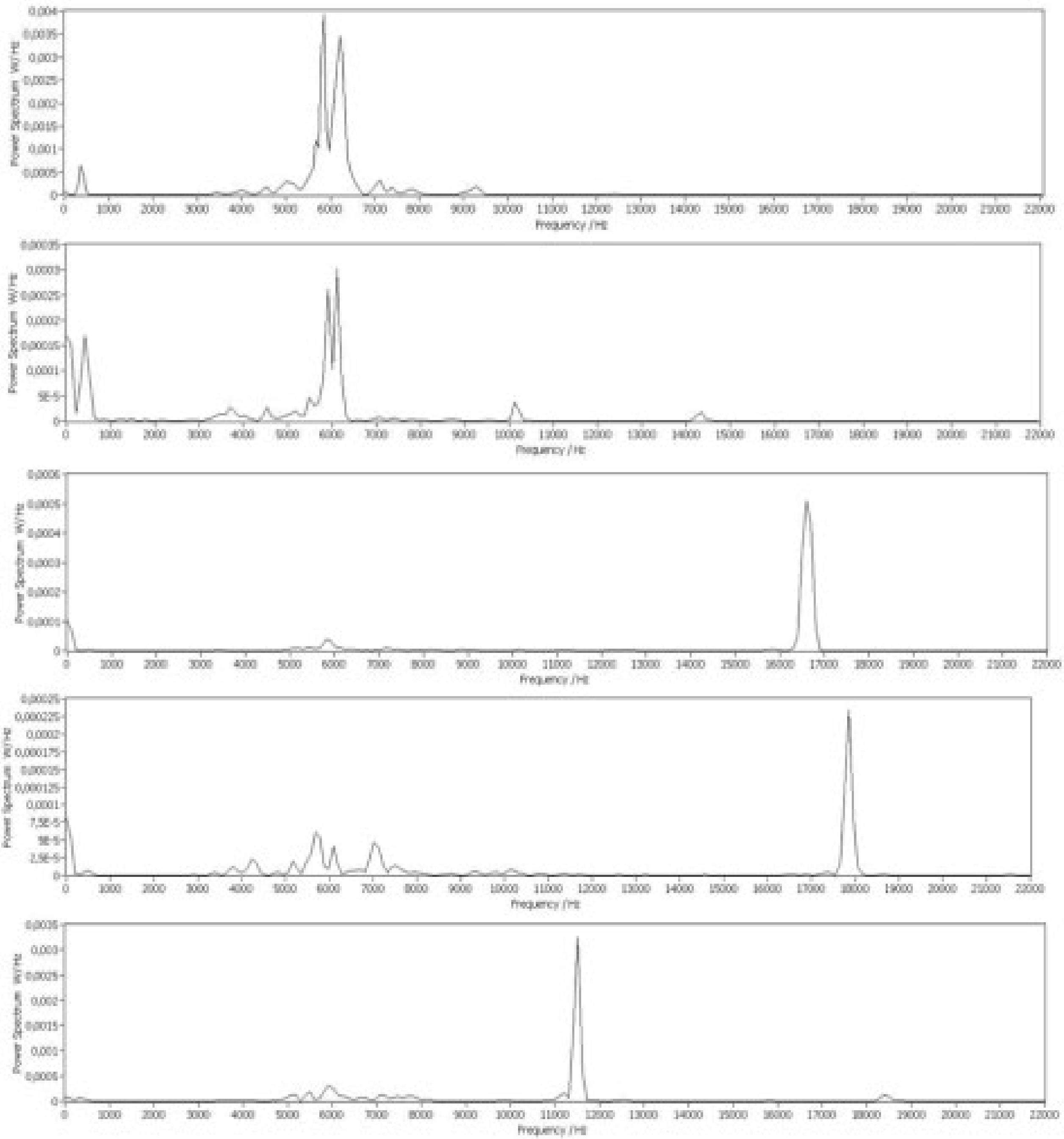

Figure 18 The power spectrum of Styrene maleic anhydride (SMA) pieces

Figure 18 illustrates that the spectral features of SMA pieces are more complicated than the others. There are two different cases:

1. There are double peaks locate respectively in the range of 5,700 – 6,000 Hz and 6,000 – 6,300 Hz. The valley which locates between the double peaks is in the range of 5,900– 6,100 Hz. In the range of > 10,000 Hz there are two or three small peaks. This case has a probability of occurrence about 30%.
2. The highest peak locates in the wide range of 11,000 – 21,000 Hz. Sometimes this range still contains another two or three high peaks. The common ground of

this kind of spectrum is that there is a small peak located in the range of 5,700 – 6,100 Hz. This case has a probability of occurrence about 30%.

5 Conclusion

In this paper the basic principles and concept for acoustic sorting technologies are introduced and the methods for acquisition and analysis of acoustic impact signals are also given, by using the soundcard and computer a signal DAQ and the analysis system can be easily established and through the methods based on the Fast Fourier Transformation the features of most impacts can be deduced and used in further as application as sorting criteria.

In this paper the equipment for acoustical research was introduced and actual experiments carried out with 3 different kinds of black materials have been summarized and the results illustrate that the features which are extracted from the impact signals are evident and can be easily distinguished from one another. In further work, the results could be used for technical applications. A real experimental system of acoustic sorting can be built based on this research.

6 Literature

Weranek, I.	2007	Studie über die Möglichkeiten Akustischer Einzelkorn Sortierung von Kunststoffen und Aluminiumschroten, Diplom Thesis, I.A.R. RWTH Aachen University, 2007.
Tong, F.; Tso, S.K.; Huang, M.Y.Y.	2006	Tile – wall bonding integrity inspection based on time – domain features of impact acoustics, Sensors and Actuators A Physics, Vol.132
Tong, F.; Xu, X.M.; Luk, B.L.	2008	Evaluation of tile – wall bonding integrity based on impact acoustics and support vector machine, Sensors and Actuators A Physics, Vol.134
Pearson, T.C.; Cetin, A.E.; Tewfik, A.H.	2007	Feasibility of impact – acoustic emissions for detection of damaged wheat kernels, Digital Signal Processing, Vol.17

Zhou, A.; Ma, H.	2005	SoundCard based data acquisition and analysis system in LabVIEW, Control and Automation, Vol.21
Zheng, J.; Ying, Q.; Yang, W.	2000	Signals and Systems, China High Education Publishing House, Beijing, ISBN978 – 7 – 04 – 007983 – 8
Killmann, D.; Scharren-bach, T.; Pretz, T.	2007	Perspectives of Sensor Based Sorting for the Processing of Solid Waste Material, Transcripts of International Symposium MBA, Hannover, Cuvillier Publishing House, ISBN 978 – 3 – 86727 – 237 – 7

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Multiplexed NIR spectroscopic Sensors and NIR spectroscopic Imaging: Two Solutions for Sensor based Waste Sorting in Comparison

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Abstract

Different systems for plastic sorting, which utilize multiplexed near infrared (NIR) sensors, have been established in the recycling industry, so far. They offer a high spectral resolution and a high dynamic range (16 Bit), so that even the smallest material differences can be detected. Besides identifying standard polymers like PET, PE, PP, PVC and PS these systems can also solve difficult sorting problems like the recognition of PET-bottles with PVC- or PP-labels. Belt widths of up to 4 meters are possible and colour sensors can be integrated into the optical systems, easily. A limiting factor is only the reduced spatial resolution because of the maximum number 64 tracks (corresponding 31mm pitch at 2m belt width) and the relatively low scan rate of up to 100Hz.

Recently hyperspectral NIR imaging systems, which work without optical multiplexers and handle 256 tracks at scan rates of up to 330Hz, have been developed. However, they have a reduced dynamic range of 12 Bit and detect only the shortwave NIR spectral range up to 1.7µm, which may limit the possible applications. At belt widths of up to 2 meters these new systems can be used for sorting standard plastics as well as plastic flakes >5mm.

The article compares the advantages and limitations of both systems and demonstrates the fields of use on the basis of practice-oriented examples.

Keywords

Plastic, sorting, hyperspectral, multispectral, imaging, near infrared, NIR, sensor

1 Plastic identification with NIR

Because all polymers consist of long chain molecules with recuring molecular groups, nearly all plastic types can be identified by the means of near infrared spectroscopy. If such a material is illuminated by a standard halogen lamp, the infrared radiation enters the sample and is multiply scattered in its interior, where interactions with the material occur. By the absorption of photons the sample molecules are excited to oscillate. A small fraction of photons finally reaches the surface again, is diffusely remitted by the sample and can be analysed by an NIR spectrometer. A quantum mechanical treatment of the molecules shows, that they can only oscillate on certain energy levels, from which follows, that they can only absorb certain photon energies (Figure 1) corresponding to certain wavelengths in the NIR absorption spectrum. Thereby, specific molecular groups absorb only certain spectral ranges resulting in absorption bands, which are specific for the material composition. Typically, the fundamental mode for the C-H stretch vibration is around 3500nm and the first and second overtones are around 1700nm and 1150nm, respectively (WORKMAN, WEYER). As indicated in Figure 1 with increasing order of the transition the absorption strength decreases and the bands are increasingly broadened. This property is essential when selecting the appropriate wavelength region and sensor for a specific application.

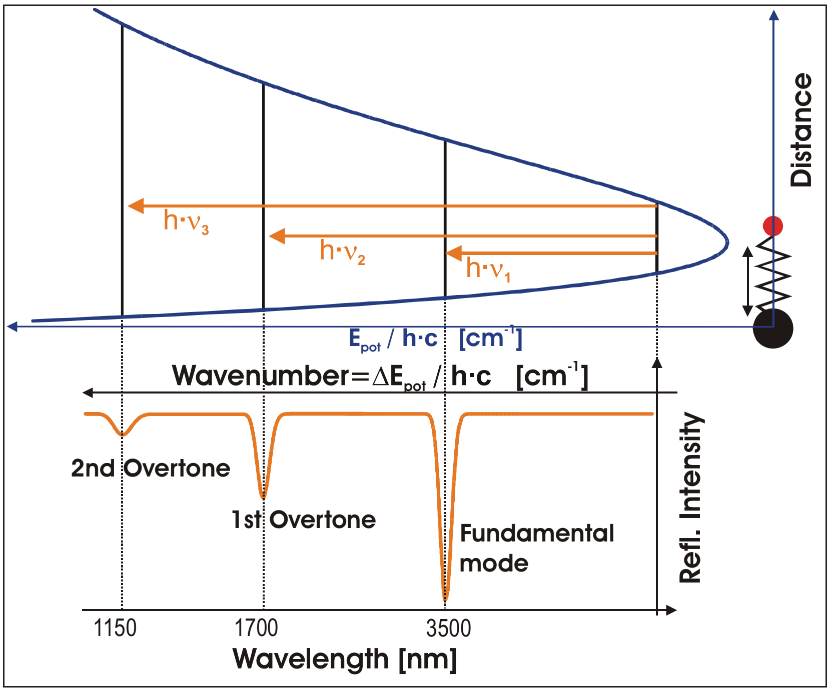

Figure 1: Schematic diagram of the vibrational modes and NIR absorption bands of a diatomic molecule.

Because the penetration depth of NIR radiation (1.1µm-2.0µm) into the standard polymer types can be up to a few millimetres, the plastic identification is widely independent of surface contaminations. Even labels made of other polymers can be penetrated, so that the material beneath can be detected, which is subject of the following.

2 NIR-sensors

The two devices under comparison are a Kusta 4004M multiplexed NIR spectrometer (MPL) and a KustaMSI 1.7 multispectral imaging (MSI) spectrometer from LLA Instruments, where the latter is based on the Helios 1.7 device from EVK DI Kerschhaggl. Both systems work with the well-established chemometric analysis routines (PLS, PCR, Neuronal Networks etc.) used so far as standard for identification with the Kusta 4004M multiplexers. This makes a direct comparison of the identification performance possible. Figure 3 illustrates the covered spectral regions of the MSI- and MPL-sensor on the basis of four spectra of the most common polymers.

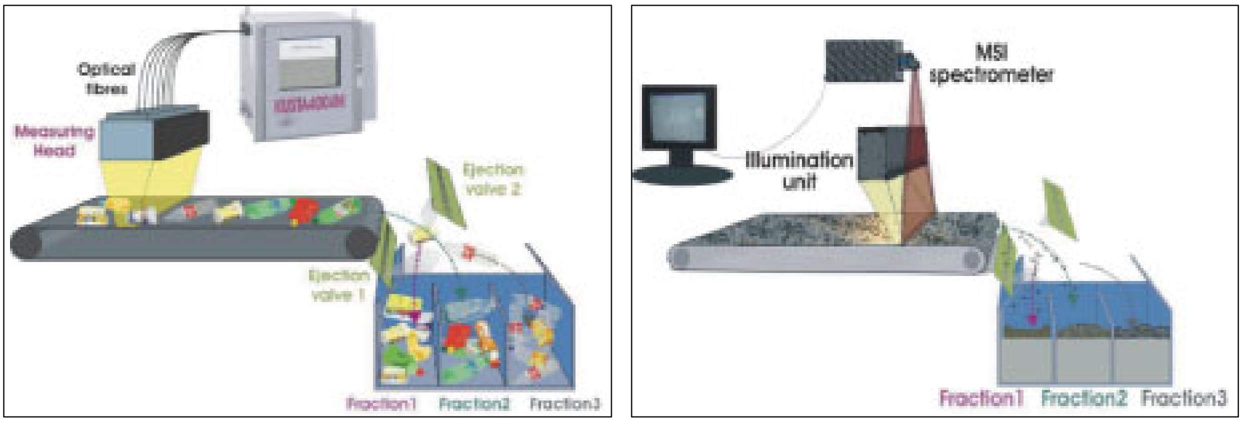

Figure 2: Schematic setup of the MPL system (left) and the MSI system (right).

Because the important 1st overtone vibrations of PVC and the Polyolefines (PE, PP), which are very strong and equipped with many details in shape, are not accessible to the MSI-sensor, the chemometric identification routines have to be trained mainly on the basis of the weaker and broader 2nd overtone vibrations. In contrast to that, the MPL-sensor covers the complete 1st overtone region, which makes the identification more sensitive and reliable.

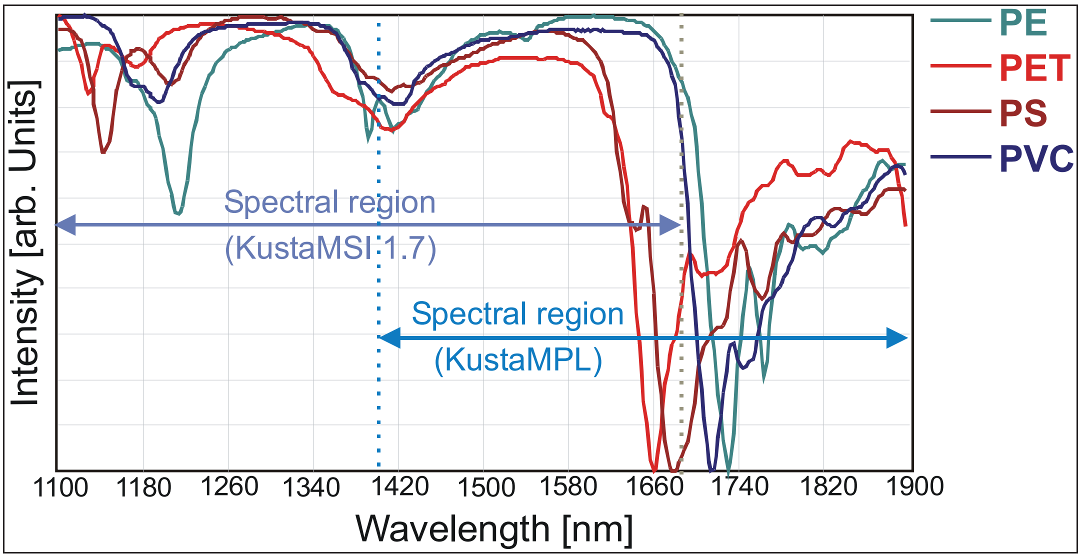

Figure 3: Spectral regions of KustaMSI and KustaMPL for spectra of common polymers.

3 Identification of PET-bottles with different plastic labels

In the recycling of household waste one of the most important sorting tasks is to recover polyethylene terephthalate (PET bottles). Typically they are labelled with printed foils of other polymers, where PP, PS, PVC, PE and paper are common. Depending on the process conditions and the demands of the final product, it may be of interest to sort out PET bottles with PVC-label. Especially for bottle-to-bottle recycling this is necessary, because during injection molding of PET (~280°C) the presence of PVC contaminations leads to the formation of HCl-gas, which destroys the polymer chains of the PET and leads to impurities in the recycled product. In contrast to that, when down-recycling to a product of lower quality, it will be of interest to recover as much PET as possible independent of the label.

In the following, this application is chosen for a comparison between the identification performance of the MPL- and the MSI-system. While both systems identify pure polymers with high accuracy, the evaluation of mixed-spectra, as they occur in the case described above, is a more demanding task. The test measurements were performed on a laboratory plant under the following conditions:

Table 1: Measuring conditions of the laboratory plant and theoretical values for MSI (grey)

	MPL	MSI	MSI (2m)
Belt speed	1.6m/s	1.6m/s	1.6m/s
Frame rate / scan frequency	50Hz	240Hz	240Hz
Resulting measurement distance in moving direction	32mm	6.7mm	17mm
Track pitch (perpendicular to moving direction)	32mm	3.1mm	8.3mm
Corresponding maximum belt width for 64 tracks (MPL) and 240 tracks (MSI)	2000mm	750mm	2000mm

In contrast to the MPL-system the track pitch is not variable for the MSI-system but depends on the used objective (f=8mm) and measuring distance. Because on the laboratory plant a belt width of 2000mm was not attainable with the available optics, the spatial resolution of the MSI-system is higher than it would have been under comparable conditions. For each type several hundred of spectra were recorded, on labelled and unlabeled parts of different plastic bottles. Subsequently, a partial least squares algorithm (PLS) was trained with the data, where it carefully was kept track of using exactly the same samples for the training of both systems. From the scores plots of the two methods (Figure 4) it can be seen that KustaMPL reaches a good separation between the three types, while PET+PVC and pure PET overlap slightly on KustaMSI. This effect is assumed to be due to the short wave NIR region covered by the MSI-sensor, where the important 1st overtone absorption bands of PVC (1.717µm) cannot be detected. A few of the PP-labels showed strong reflections leading to a large spread in the point clouds of PET+PP, where the MSI-system seems to be more sensitive to this effect. This can also be observed in the processed image of the bottles on the moving conveyor belt (Figure 5). At the MSI record two of the PP-labelled bottles have missing identification points on the label (light grey) indicating that these spectra could not be evaluated because of strong reflections.

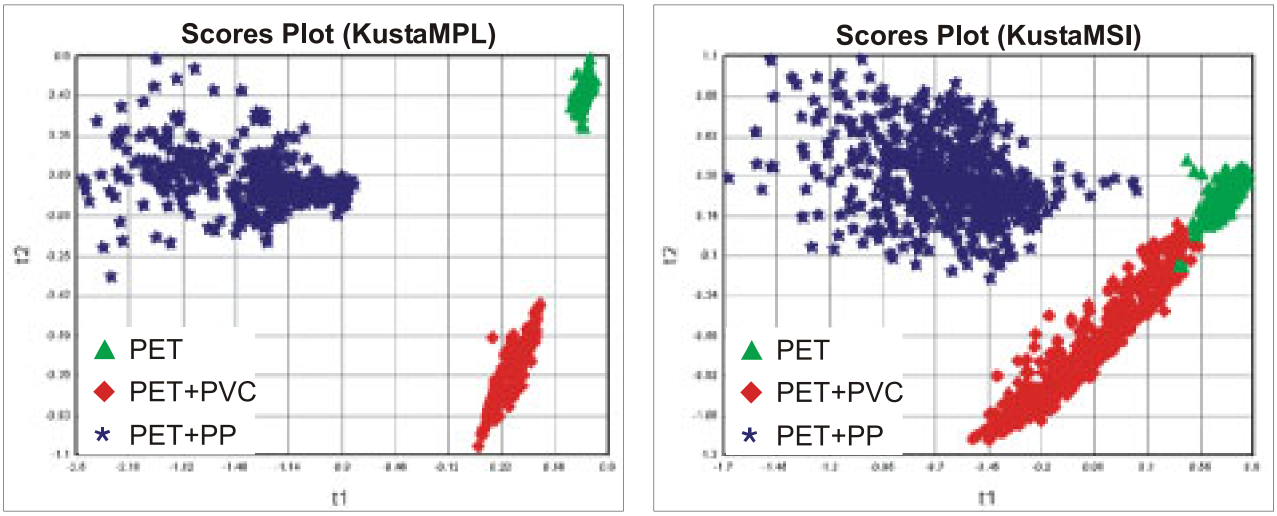

Figure 4: Scores plot of a PLS routine trained on PET bottles without label and with PVC- or PP-label for KustaMPL and KustaMSI.

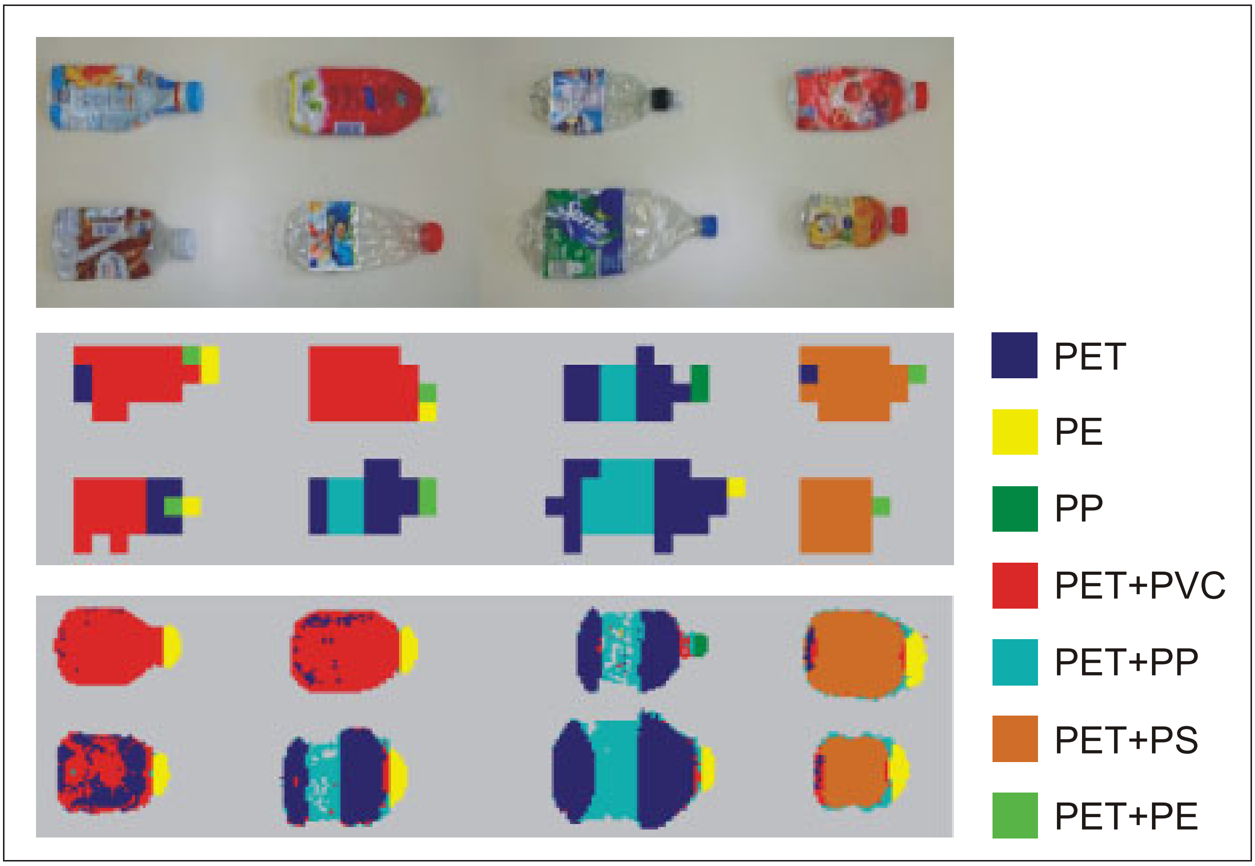

Figure 5: Process image (NIR identification) of PET bottles with different plastic labels and PE or PP-caps for KustaMPL (top) and KustaMSI (bottom). PVC- and PS-labels covered the complete bottle.

The MPL-system does not show this behaviour, because it averages over a larger measuring area (∅=32mm) and has a higher dynamic range (16bit). Remarkable is also, that the PE- or PP-caps are identified correctly not only by the MSI-system but also by the MPL-system, at least as mixed spectra PET+PE.

While the MSI-system identifies all samples correctly as PET bottles, the classification of the mixed spectra from the labels is ambiguous and shows some mixing between PET+PP and PET+PVC. This indicates that although pure plastics can be identified well with KustaMSI, the analysis of mixed spectra is limited in this application.

4 Combined NIR- and colour recognition with KustaMPL

Due to the modular setup, which combines an optical multiplexer with an NIR spectrometer, a colour sensor (RGB) can easily be integrated into the MPL devices. Figure 6 illustrates the principle of function: The multiplexer sequentially images each fibre cable (track of the measuring head) via a rotating mirror onto the entrance slit of the NIR spectrometer. Between both units a dichroic mirror couples out the visible range of the light and focuses it onto the RGB-sensor, while the near-infrared part passes unhindered to the spectrometer.

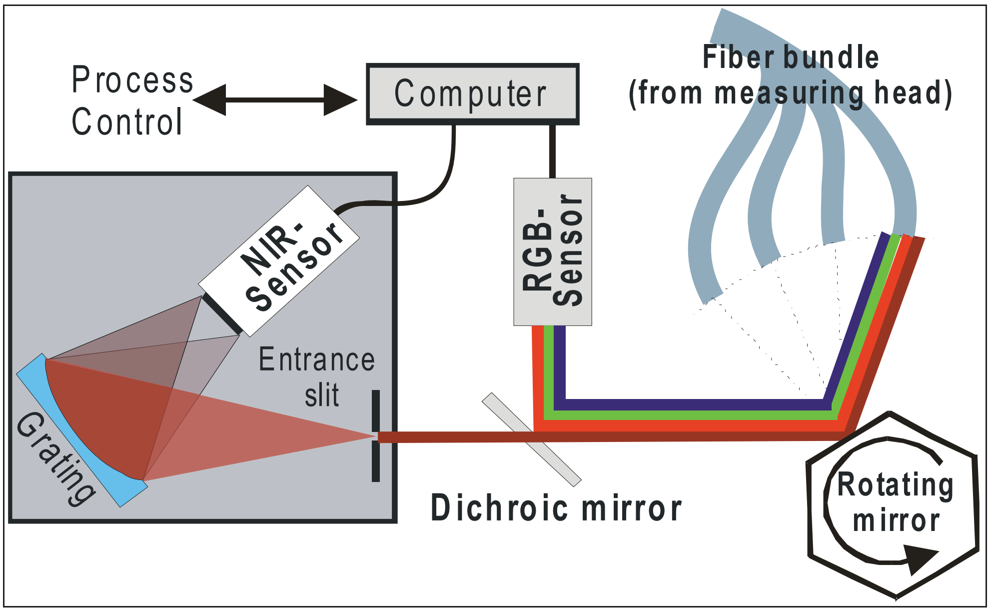

Figure 6: Schematic layout of the KustaMPL system with integrated RGB-sensor.

In contrast to other systems combining NIR- and RGB-sensors the present layout guaranties that both signals are detected exactly at the same time and the same position on the sample. The data is evaluated in a computer, where a PCR or PLS algorithm analyses the NIR spectrum as before, while the RGB data is converted into the HSV space (Hue, Saturation, Value). Because the hue parameter is a compact representation of the colour value and falls in the range 0° to 360° (“colour wheel”), the interpretation and definition of limits for the classes of interest is easy.

Below, the advantage of an additional colour sensor is shown for the application of sorting recycled paper. Because the absorption bands of cellulose and lignin (1600nm-1800nm) have to be evaluated, this sorting task can only be treated with an MPL system. The data was recorded in a recycling plant under process conditions (belt width 2.4m, belt speed 2m/s). In paper production even small fractions of cardboard reduce the brightness and lead to impurities in the final product, so that one important sorting task is to separate corrugated cardboard from newspapers and office papers. With the recorded spectra a PLS algorithm was trained, where the corresponding scores plot is shown in Figure 7. Obviously, the three types overlap slightly in the PLS scores space as well as in the HSV space. Because of that, neither sensor is capable of separating the three types alone. Especially the deinking loss of 10.5% (Table 2) is too high, when using only a single NIR identification. But with the following combination of the NIR- and RGB-results, the separation accuracy increases significantly:

- A measurement is classified as "CC", when the NIR- *and* RGB- result is CC.
- When the NIR-result is "OP" and the RGB-result is "CC", the measurement is re-routed to "CC" (this is possible, because there is no overlap between OP and CC in the HSV space)

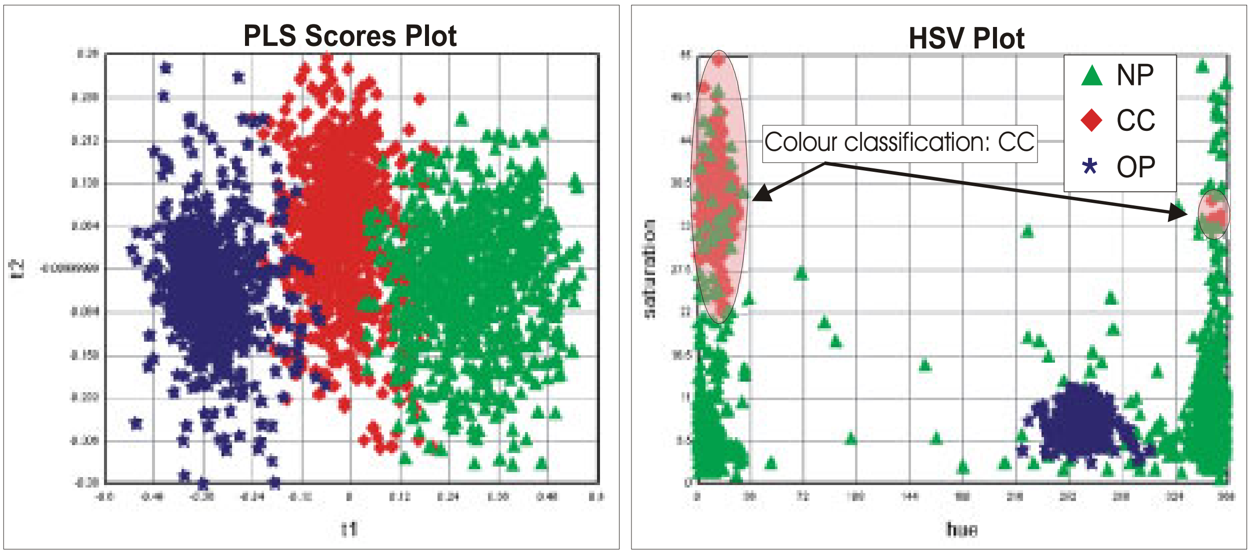

Figure 7: PLS scores plot and HSV plot for the separation of corrugated cardboard (CC), newspaper (NP) and office paper (OP).

Table 2: Classification results for the separation of CC, NP and OP.

	only NIR (without RGB-sensor) [%]	only RGB (without NIR-sensor) [%]	NIR- combined with RGB-sensor [%]
CC classified correctly	93.6	100	95.5
CC misclassified as OP	1.9	0	0
NP misclassified as CC	5.7	3.9	0
OP misclassified as CC	4.8	0	0

With this logical link the deinking loss (NP and OP misclassified as CC) is eliminated, while 1.9% of CC misclassified as OP is retrieved as CC.

5 Sorting of shreddered electronic waste (WEEE) with KustaMSI

The following investigation was performed with the KustaMSI system on the same laboratory plant and under the same measuring conditions described in section 3 (240Hz frame rate, 750mm measuring width). A multistage identification tree was developed, in which five different PLS methods were linked together to identify all important polymers occurring in shreddered electronic waste. The included plastic types were: ABS, PS, PA, PBT, PC, PE, PE, PMMA, POM, PP, PPE+SB, PUR and PVC.

To test the identification accuracy and the spatial resolution, different plastic particles of size <8mm were aligned in a regular grid of 20mm spacing. The test pattern was measured at a belt speed of 1.6m/s. In this application the high spatial resolution and frame rate of the MSI-system are essential. The processed NIR-image of the samples on the conveyor belt shows, that the particles are identified correctly and can clearly be separated from each other (Figure 8). Even ABS and PS, which have very similar NIR spectra due to their related chemical composition, are classified correctly. However, from Figure 8 it can be seen that the spatial resolution perpendicular to the moving direction is better than the resolution parallel to it. Most samples have a long drawn-out shape in the process image. Unfortunately, this effect is unavoidable because of the long integration time necessary for the MSI-sensor (~3ms). At a belt speed of 1.6m/s each particle moves 4.8mm during that time, what tends to “blur” the particles in moving direction.

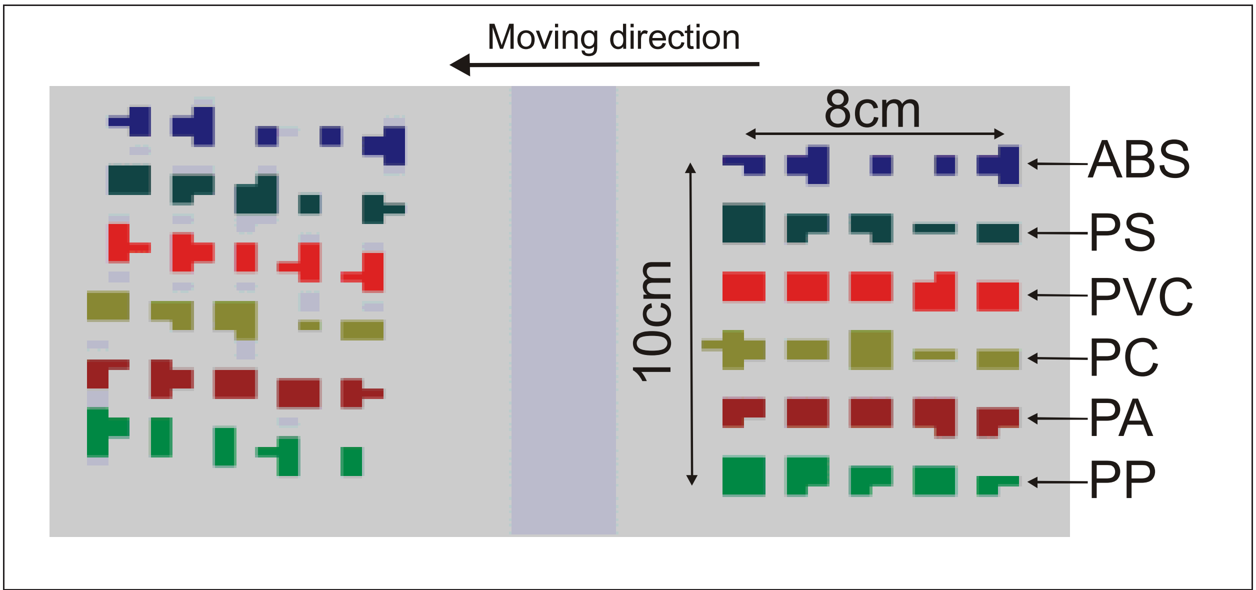

Figure 8: Shreddered plastic flakes (size 6-8mm) recorded with KustaMSI 1.7.

6 Conclusion and prospects

The spatial resolution of the multiplexed NIR system (KustaMPL) has been shown to be absolutely sufficient for sorting household waste and recycling plastics. Especially applications, where mixed spectra have to be evaluated, can better be treated with the MPL system. Here, the longer wavelength region covered and the higher dynamic range is necessary. The usage of fibre optics opens up the possibility to connect one device to different conveyor belts (master-slave configurations), so that up to four plastic types can be separated by one MPL system.

For the sorting of shreddered plastics with particle sizes <20mm the KustaMSI system is better suited, due to its high spatial resolution and frame rate. Because it is capable to separate even 6mm small particles, it is especially appropriate for the sorting of WEEE- and PET-flakes. Larger belt widths of up to 2m will be accessible to the MSI-system in the future by using folding mirror optics. Special NIR objectives are tested, to further increase the sensitivity and resolution.

References:

Jerry Workman, Lois Weyer 2007 "Practical Guide to Interpretive Near-Infrared Spectroscopy", CRC Press.

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Hyperspectral imaging detection architectures for polyethylene (PE) and polypropylene (PP) identification inside plastic waste streams

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Abstract

Since polymers are continuously replacing other materials in major consumer products, the consumption of plastic increases faster than the economy as a whole. One of the weakest points in the recycling system is the reuse of waste plastic. There are many kinds of plastics utilised in every day life: polyethylene (PE), polystyrene (PS), polypropylene (PP), polyvinyl chloride (PVC) and polyethylene terephthalate (PET). The most important polymers in the consumer goods and the least recycled plastics materials are the polyolefin's. The reason can be mainly attributed to the complexity of these wastes according to different polymers (rubber, foam, etc.) and polluting (not polymers) materials (wood, aluminium, copper, stones, glass, etc.) commonly present in plastic waste streams. In this paper an innovative sensing technology, based on an hyperspectral imaging (HSI) approach, is presented and discussed: i) to determine the quality of waste plastic feed and ii) to set up new sorting strategies for pure PP and PE recovery.

Keywords

Plastic recycling, plastic waste characteristics, polyolefin's, hyperspectral imaging, sorting, quality control.

1 Introduction

Analyses by the European Community (EC) indicate that besides their ecologic importance, raw materials and energy are also the most important competitiveness factors for EU industries. Therefore the need to increase recycling, improving at the same time the quality and homogeneity of recycled materials to minimize environmental pollution and usage of resources is thus a topical subject for the EC. There is a strong drive to recycle polymers from end-of-life products and avoid their ending up in land fills and waste incinerators because plastics recycling reduces CO_2 emission and saves resources.

The worldwide production of plastics was 230 million ton in 2005 (JOHANSSON, 2007). In Europe, 53.5 million ton were produced in total. Out of 22 million ton of post-consumer plastic waste in Europe in 2005, 53% was disposed, 29% was used for energy recovery and 18% was recycled (JOHANSSON, 2007). According to Directive 2004/12/EC on packaging and packaging waste, a recycling level of 22.5% should be achieved for plastics packaging by the end of 2008. New, more cost-effective separation technology can thus provide an important incentive to increase recycling rates.

Polyolefins constitute more than a third of the total plastics consumption in Europe, but they are the less recycled. There are many complex wastes rich in polyolefin, such as waste from electric and electronic equipment (WEEE), automotive shredder residue (ASR) or, simply, household waste (HW). Polyolefins are the largest group of thermoplastics, the term polyolefins means “oil-like” and refers to the oil feel that these materials have (GRAHAM SOLOMONS, 2001). They consist only of carbon and hydrogen atoms and they are non-aromatic. They are polymers of simple olefins (hydrocarbons containing one double bond per molecule) such as ethylene, propylene, butenes, isoprenes, pentenes and copolymers and modifications thereof. A characteristic common to all polyolefins is a non polar, non porous, low energy surface that is not receptive to inks and lacquers without special oxidative pre-treatment. The two most important and common polyolefins are polyethylene and polypropylene and they are very popular due to their low cost and wide range of applications.

Aim of this study is to evaluate the possibility to apply hyperspectral imaging based techniques to preliminary determine both the quality of feed and product streams in the recycling of plastic based post consumer waste and/or to develop innovative detection/sorting strategies specifically addressed to perform a preliminary recognition and a further separation of the different polyolefin’s materials.

2 Polyolefins characteristics and recycling

Polyethylene, usually indicated as PE, is probably the most popular plastic in the world. It is a very versatile material that makes grocery bags, shampoo bottles, children toys, and even bullet proof vests. Although its wide application field, PE has a very simple structure, the simplest of all commercial polymers, consisting of long chains of the monomer ethylene. A molecule of PE is thus nothing more than a long chain of carbon atoms, with two hydrogen atoms attached to each carbon: $[CH_2\text{-}CH_2]_n$. This type of PE is called linear PE, or HDPE (High Density Polyethylene), because the carbon chain does not have any branches. Sometimes some of the carbons, instead of having hydrogen attached to them, have long chains of PE. This is called branched PE, or LDPE (Low Density Polyethylene). Because of these short and long chains branching, chains do not pack into the crystal structure. Therefore LDPE has a lower density and less strong intermolecular forces than HDPE. For common commercial HDPE the melting point is typically in the range 120°C to 130°C and the density is between 930 kg/m^3 and

1000 kg/m^3. The melting point for average commercial LDPE is typically 105°C to 115°C and the density is between 915 kg/m^3 and 930 kg/m^3.

Polypropylene, usually indicated as PP, is a rather versatile polymer. It serves double duty, both as plastic and as a fibre. It is used to make things like dishwasher-safe food containers. As a fibre, PP is used for its characteristics (easiness to make it colourful and water absorption resistance) to make indoor-outdoor carpeting. Structurally it is a vinyl polymer with a linear structure based on C_nH_{2n}. PP is similar to PE only that on every other carbon atom in the backbone chain has a methyl group attached to it. Most commercial PP has an intermediate level of crystallinity between that of LDPE and HDPE. Its Young's modulus is also intermediate. PP has a melting point of 160°C and a density lower than 915 kg/m^3 (usually greater than 850 kg/m^3).

Currently available separation techniques, based on the difference in flotation properties in water, can be used to separate lighter types of plastic such as PP, HDPE and LDPE from the heavier types such as polyethylene terephthalate (PET) and polyvinyl chloride (PVC). Even so, PP, HDPE and LDPE together are both difficult to separate and chemically incompatible, so that the recovered product is a mixture allowing to produce low-quality recycling based plastics. To produce high-purity granulates from these concentrates, the mixture must be sorted very accurately, and to be economically and ecologically sound, most of the polyolefins should end up in a useful product.

Different separation techniques have been thus investigated in the past and are currently under study in order to exploit and/or try to enhance the low differences, in terms of chemical-physical attributes, of PE and PP. Experimental studies carried out by DAIKU ET AL. (2001), adopting electrostatic separation, demonstrated as an high grade for both PE (99.9%) and PP (99.5%) can be achieved, but with very low recoveries, 61.5% for PE and 54.8% for PP, for a throughput of a 1000 kg/h as maximum. The presence of pollutants on the surfaces, as well as that of finer particles, negatively affects the charging process and the further separation, strongly reducing the efficiency of the separation. A preliminary wet handling and a further drying of the plastic should be thus adopted. Such an approach is practically unacceptable from an economic point of view. The possibility to investigate a separation method based on the fact that PP and PE present different melting points was also evaluated. The PE with the lowest melting point will stick to a drum, when the surface of the drum has a temperature between the melting point of PP and PE. Even not considering the complexity of the separation unit, through such an approach only low quantities of products should be obtained. Furthermore this separation should be intrinsically batch, introducing further technical problems in common "continuous" waste plastics processing layout. Commercially available technologies in principle exist. An example is represented by the separation device proposed by TiTech Visionsort GmbH (TITECH, 2005), where the particles are scanned with near infrared and are separated into different types of material, like aluminium, PP, PE, poly(ethylene terephthalate) (PET) and polystyrene (PS). This type of separation equipment is widely applied in industry. The sorting architecture requires a relatively large minimum particle size, which is from 20 to 50 mm. Such dimensional limit represent a problem when finer particles have to be identified and sorted. For example the cap of a bottle is often made of PP or PE, being smaller than the required minimum particle size, PP and PE caps end up in the residue fraction and are only used for energy recovery. Furthermore this approach is not particularly suitable to separate black PP and PE, as in automotive polyolefins (BAKKER E.J. ET AL., 2008). A separation strategy based on the different density characteristics of the materials, i.e. sink-float process, could thus represent the easiest solutions to realise an effective separation with both high grade and recovery. Such a goal can be obviously reached if the difference in densities between the materials is large enough. This is how polyolefins are separated from PET in bottle recycling (BAKKER E.J. ET AL., 2008). About 80 mass% of the PP particles from shredder residue has a density lower than 910 kg/m^3, whereas virtually all of the LDPE has a density higher than 910 kg/m^3. For the HDPE more than 98 mass% has a higher density than 910 kg/m^3. A sink-float process with a density of 910 kg/m^3 would therefore give good results for the PP fraction. To get both a high grade PP fraction and a high grade PE fraction, it is necessary to remove the fraction between 910 and 930 kg/m^3. For a conventional sink-float process, this would require a separation in two steps. Another problem is the medium itself. Organic liquids (e.g., short chain alcohols) are used to produce a medium with a density lower than the density of water. This brings in economic and environmental problems (BAKKER E.J. ET AL., 2008). A valid alternative can be represented by a separation based on an emerging technology called Magnetic Density Separation (MDS) (BAKKER ET AL., 2007). MDS uses a strongly dilute mixture of water and ferrous oxide (nanometer sized ferrite particles) in a magnetic field. Such liquids derive their separation density from a combination of a magnetic field and gravity. The separation is realised achieving a lower apparent density than water by the combination of a gradient magnetic field and a magnetic liquid. An intriguing propriety of MDS liquids is that they have different separation densities in different layers of the fluid, according to different intensity of the magnetic field. In principle, this effect can be used to separate a complex mixture into many different materials in a single process step, using one of the same liquid. Other important advantages, linked to MDS liquids (composed by 99% water and 1% iron oxide), is that; i) they are environmentally harmless, in fact they can be used without the economic and environmental problems of organic liquids and ii) that they are very cheap to use, even if not fully recovered from the product materials.

Independently from the separation strategy adopted the need to operate a full control of the different plastic waste streams represent a key issue. Therefore a precise and online assessment of composition of the process stream is of the great importance for both the plastic recycling and plastic compounder industry in the transition to the recycling of post-consumer plastic wastes. The former needs it to monitor the plastic waste feed streams. The latter demands it for the most accurate (and fast) composition assessment of the different products, polyolefin based, resulting from the different separation stages constituting the recycling plant. Hence fast on-line assessment is a key point to increase the value of secondary polyolefins.

Actually PE or PP concentrates in terms of the concentration of the other polyolefin as well as non-polyolefin contaminants is carried out by hand-sorting and DSC (Differential Scanning Calorimetry) analysis of samples in laboratory. Other methods are CRYSTAF (Crystallisation Analysis Fractionation), FTIR-ATR (Attenuated Transmission Infrared Spectroscopy) and TREF (Temperature Rising Elution Fractionation). Neither of these methods is suitable and accurate for the required on-line quality assessment and therefore new sensor technologies should be developed to quantify the concentration of contaminants and particles size distribution in each of the products.

3 Hyperspectral imaging

Hyperspectral cameras are able to deliver a wide spectrum of information. Wavelength intervals are usually those ranging between (400-700) nm and (400-1000) nm and (1000-1700 nm). Several applications based on such a technology have been developed, both at research and application level, in several sectors as astronomy (HEGE ET AL., 2003), agriculture (MONTEIRO ET AL., 2007) (SMAIL ET AL., 2006), pharmaceuticals (RODINOVA ET AL., 2005) (ROGGO ET AL., 2005), medicine (FERRIS ET AL.,2001) (KELLICUT ET AL., 2004) and waste recycling (SERRANTI AND BONIFAZI, 2007), with particular reference to cullets (SERRANTI ET AL., 2006), fluff (BONIFAZI AND SERRANTI, 2006A), compost (BONIFAZI AND SERRANTI, 2006B). The technology can be used on-line and is cheap and powerful.

Spectra, with reference to this study, can be correlated to particles composition. Other parameters are also collected, as particles morphological and morphometrical attributes distribution, spatial and temporal fluctuations of the particles streams, etc. The development beyond the state-of-the-art will be to interpret the possibilities of hyperspectral imaging in determining the quality of feed and product stream in the recycling of post consumer plastic waste and translate the images into the parameters that are requested by recycling operation, both in terms of control strategies set up and product quality assessment.

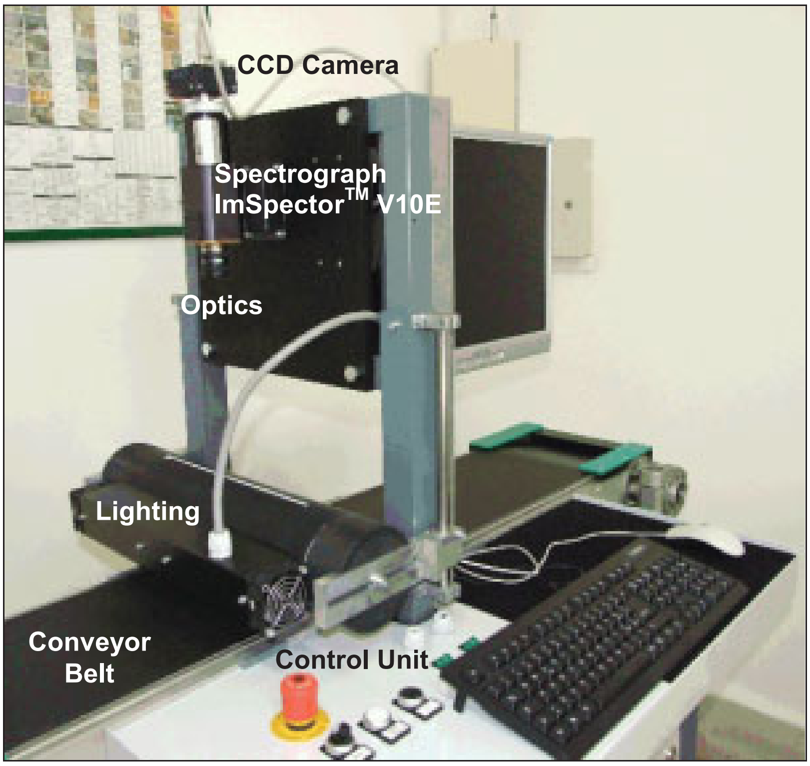


Figure 1 *Spectral scanner architecture utilised to acquire plastic waste particle spectra.*

4 Experimental

Tests have been carried out in order to verify the efficiency of the proposed approach in respect of: i) feed characterisation (particulate solids composition), ii) quality of the different flow streams resulting from specific processing actions (presence of contaminants and/or "pollutants") and iii) identification of PE and PP particles to set up new sorting strategies for their recovery. A specific hyperspectral detection based architecture was thus designed and realised at laboratory scale.

4.1 Laboratory set up, spectral acquisition and analysis

The spectral analyses have been carried out utilizing the detection architecture reported in Figure 1. The equipment assures a progressive and continuous horizontal translation of the sample and the "synchronized" acquisition (at a pre-established step) of the spectra. The sensing device being constituted by an ImSpector™ V10E working in the visible-near infrared spectral range (400-1000 nm), with a spectral resolution of 2.8 nm and a spatial resolution less than 9 µm (SSOM, 2008). Analysis have been carried out performing: i) a characterization of the "shape" of the entire detected spectra and/or identifying, at specific wavelengths, peaks or valley characterising the detected firm and ii) to verify, adopting a Principal Component Analysis (PCA) the possible correlation existing among detected spectra, sample textural attributes, presence, characteristics and localisation of the different materials and/or contaminants. A PCA is an orthogonal linear transformation of the data to a new coordinate system where the greatest variance by any projection of the data comes to lie on the first coordinate (first principal component, PC1), the second greatest variance on the second coordinate (PC2), and so on. PCA can be used for dimensionally reduction in a data set while retaining those characteristics of the data set that contribute most to its variance, by keeping lower-order principal components and ignoring higher-order ones.

4.2 Sample preparation

Waste product came from car dismantling after a shredding stage. Particle average diameter was less than 3÷4 mm. After sieving at 2 mm the retained product was hand sorted. Plastic was thus divided from other materials as: rubber, wood, stone and metal. In every mixture plastic constitutes the main material, contaminants are present only in small amounts. The plastic fraction was then subjected to a sink-float separation at a cut density of 1000 kg/m^3 in water. This approach was followed to separate polyolefins (float fraction: <1000 kg/m^3) from heavy plastics (sink fraction: >1000 kg/m^3). Sample was then subjected to several sink-float separation stages (using the static bath method at various cut densities in water and water-ethanol mixtures, at room temperature) to obtain classes of products characterized by different density distribution. The application of this separation strategy produced as result different products, that should be representative of: heavy plastic (density > 1000 kg/m^3), HDPE (density between 930 and 1000 kg/m^3), LDPE (density between 915 and 930 kg/m^3) and PP (density < 915 kg/m^3). The hyperspectral approach was thus applied: to investigate the sensitivity of the method in respect of both the waste plastic feed and the different flow streams resulting from processing stream to characterise, identify the different organic based materials (plastics, foams, rubber, tires, etc.) and contaminants (wood, finer fractions and metals).

5 Results

The acquired reflectance spectra for the particulate solids constituting the feed allow to identify the different materials constituting the plastic waste product resulting from car dismantling (Figure 2). Spectral plots clearly show as different materials present a different spectral signature (Figure 3). Unsorted plastics (PVC, PET, PE, PP, etc.), independently from their colours, are easily identifiable in respect of contaminants as wood, foam, aluminium, glass and tyre residues: wood shows an almost linear increase of reflectance in the wavelength range between 550 and 750 nm, foam shows a peak at 532 nm, aluminium shows a constant response in the NIR range (850÷1000 nm), finally glass and tyre residues are characterised by the highest and lowest reflectance between 650 and 750 nm, respectively.

Figure 2 *Example of different materials constituting the plastic waste product after the shredding phase of light fractions resulting from car dismantling.*

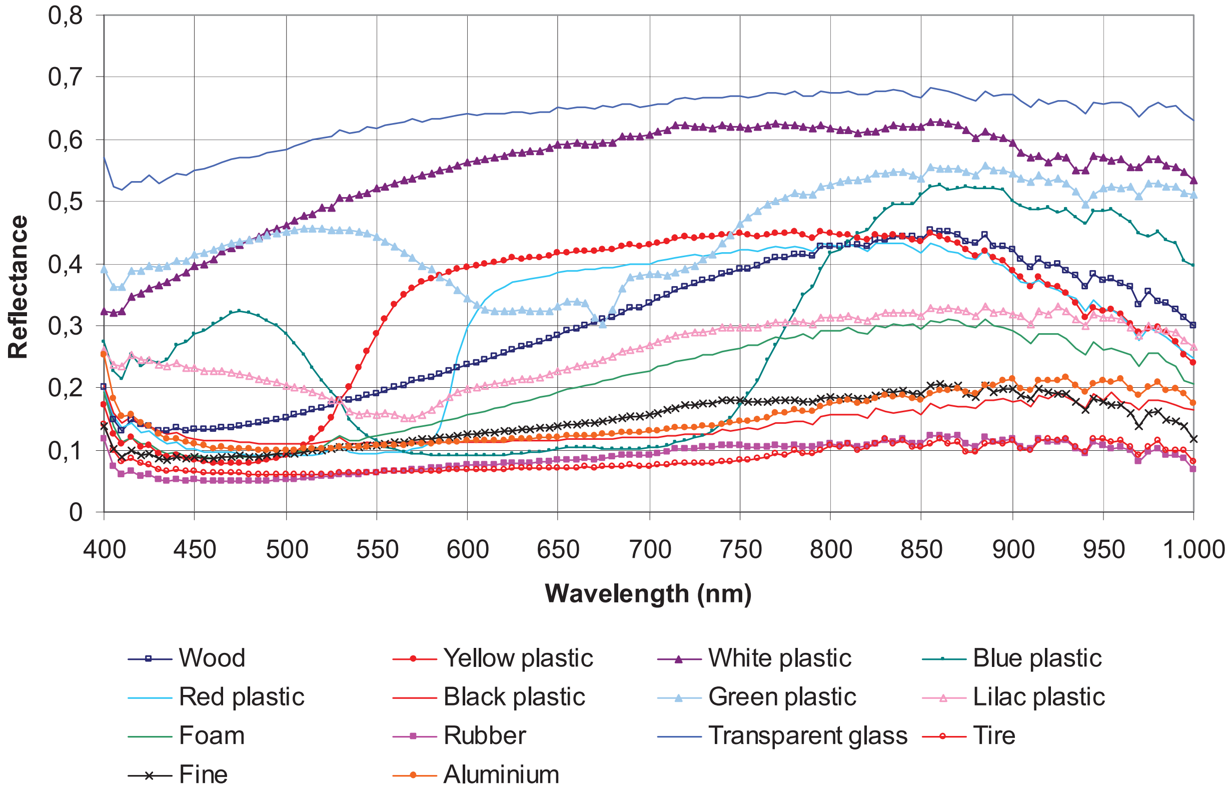
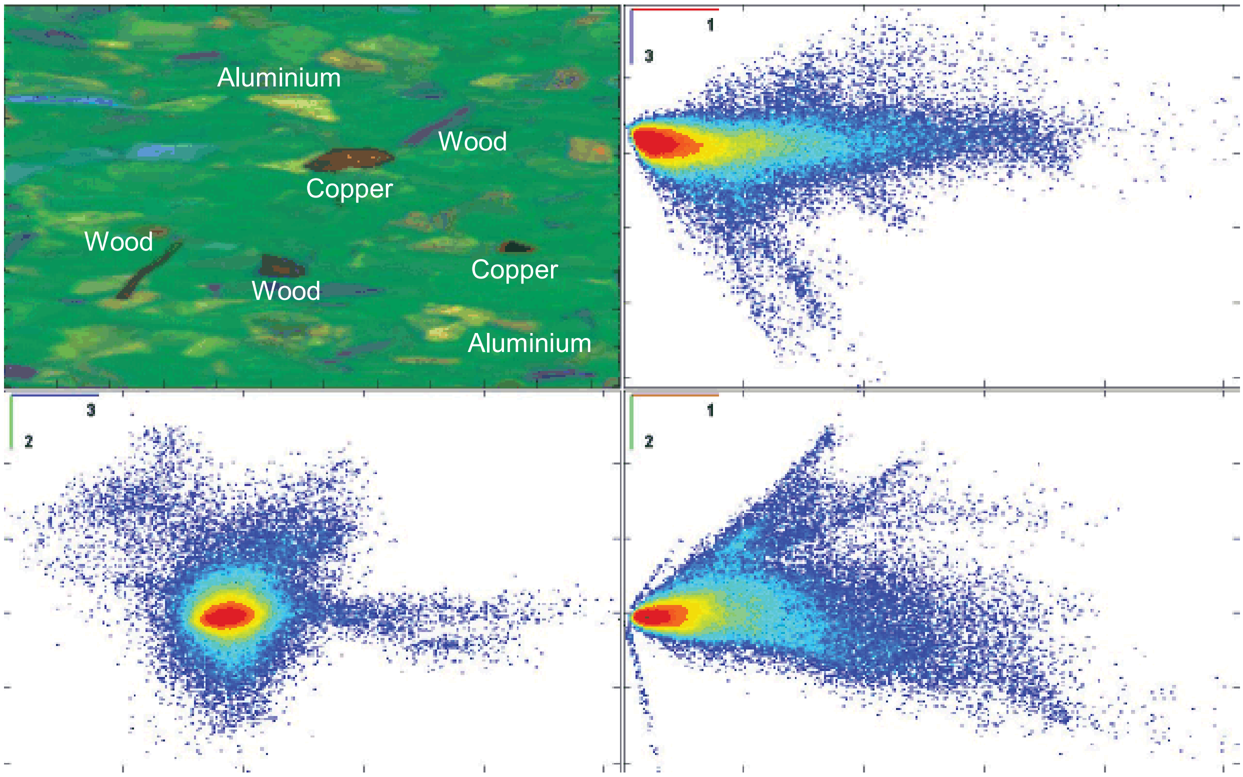


Figure 3 *Average reflectance spectra in the VIS-NIR field (400-1000 nm) of the different particulate solids present in the waste plastic feed, as resulting after car dismantling (shredding), detected by the hyperspectral imaging based architecture.*

4a



4b

Figure 4 *Plastic waste product containing different contaminants. 4a: hyperspectral image as acquired, 4b: corresponding false colour image (upper left corner) embedding the results of all the three score plots [1-3] [3-2] [1-2] related to PC1, PC2 and PC3 components as resulting from the application of the HPCIA. Contaminants can be easily identified thanks to the different colours of the particles.*

PCA applied to the images of plastic waste product, adopting an **H***yperspectral* **P***rincipal* **C***omponent* **I***maging* **A***pproach* (HPCIA), allows to identify pollutants (Figure 4). The analysis of the image related to PC1, PC2 and PC3 components permits, in fact, to detect presence, typology and position of different non plastic materials (contaminants). It is thus possible to quantitatively identify "undesidered particles" and, thanks to their topological assessment, to implement automatic sorting strategies for their removal.

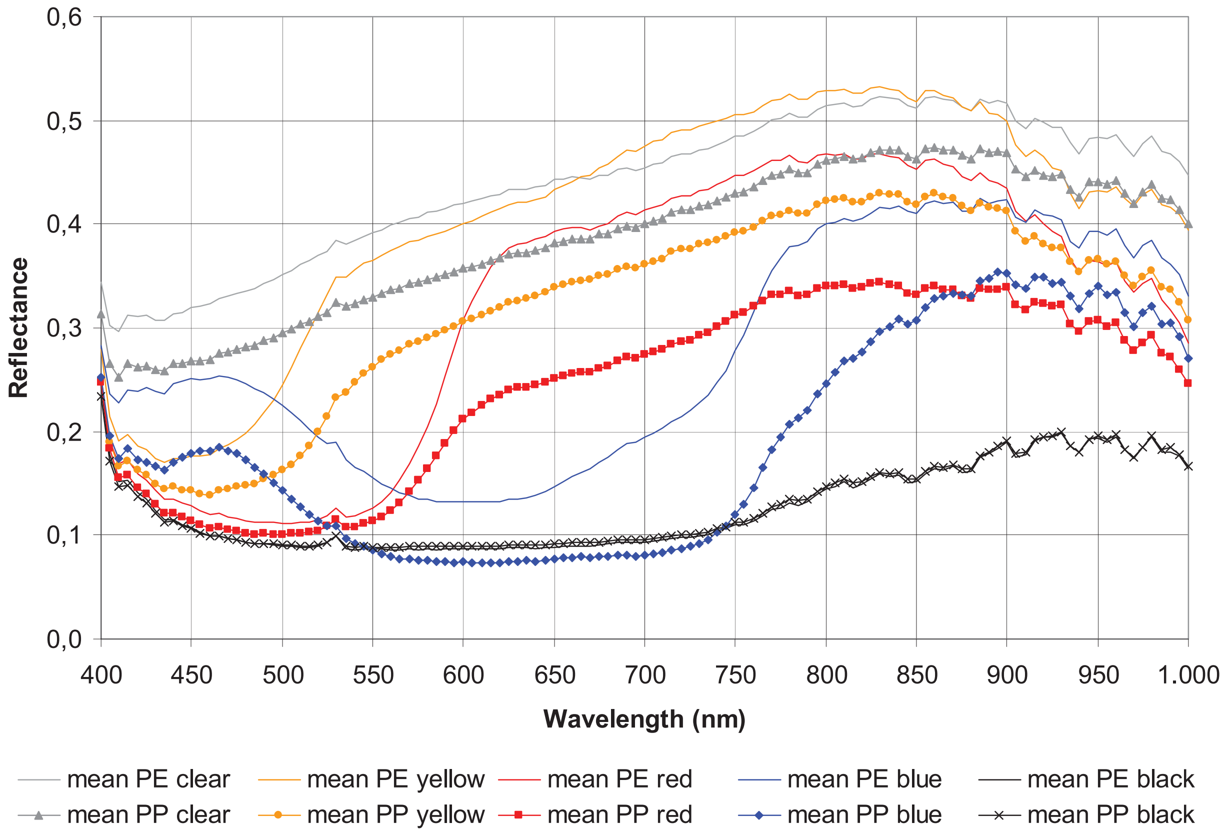


Figure 5 *Average reflectance spectra of polyethylene (PE) and polypropylene (PP), collected in the VIS-NIR field by the hyperspectral imaging device.*

The analyses carried out on different hyperspectral images of particulate products resulting from different processing actions and finalised to recover PE and PP also gave good results. Reflectance spectra for plastics belonging to the different classes of density have been compared in terms of average results, considering two groups of particles: those belonging to the density fractions (-1000 +960) kg/m^3, (-960 +930) kg/m^3, (-930 +915) kg/m^3 and those belonging to the classes (-915 +880) kg/m^{3}and less than 880 kg/m^3, that should be representative of PE and PP, respectively (Figure 5). Spectral plots showed as, for each class of colour, the reflectance level of PE particles is higher than that of PP particles. Such a result is valid for clear, yellow, red and blue particles, with the exception of black particles. A correlation can thus be established between particles reflectance and class of density. Reflectance level of particles increases with the increase of density. This result is quite important being utilised to set up and to apply innovative quality control strategies of PE and PP concentrated flow streams, according to PE and PP particles spectral signature (colour) and reflectance values (density).

6 Conclusions

The possibility to apply an hyperspectral imaging based approach to determine the quality of waste plastic feed and to evaluate the quality of recovered PE and PP particulate solids, resulting from recycling actions, was investigated.

Tests carried out on plastic waste feed results demonstrated as the proposed approach is quite efficient to detects contaminants on the base of the spectral response. The possibility to utilise an HPCIA approach to identify contaminants and their position in the flow stream opens interesting perspectives to develop and implement quality-control-sorting logics to remove contaminants.

The analyses carried out on PE and PP products, selected on the base of their colour, have been processed by a multi-stage-density-separation. Each product was thus analyzed, with reference to VIS-NIR (400-1000 nm) wavelength range, adopting the proposed HSI approach. Results showed as HSI allows to perform a recognition of the different classes of materials independently from their colour. The only exception is constituted by black particles, that cannot be recognized, at least on the base of the investigated spectral range. Further investigations will be carried out to evaluate, independently from the colour and surface status, how the different fillers, both in terms of typologies and quantities, can influence PE and PP particles spectral response. For black particles other regions of the spectrum should be investigated.

7 Literature

Bakker E.J., Rem P.C., Fraunholcz N.	2008	Upgrading mixed polyolefin waste with magnetic density separation, Waste Management, doi: 10.1016/j.wasman.2008.11.006
Bonifazi G., Serranti S.	2006A	Hyperspectral imaging based techniques in fluff sorting. The 21st Int. Conf. on Solid Waste Technology and Management: ICSWM 2006. 740-747. Philadelphia, PA, U.S.A.
Bonifazi G., Serranti S.	2006B	Compost quality control by hyperspectral imaging. Photonics Europe 2008. Proceedings of SPIE # 7003-81. Strasbourg, France.
Daiku H., Inoue T., Tsukahara M., Maehata H., Kakeda K.	2001	Electrostatic separation technology for waste plastics development of a high-purity type separator for plastics. The 2nd Int. Symposium on Environmentally Conscious Design and Inverse Manufacturing, December 11–15, Tokyo, Japan, 562–565.
Ferris D., Lawhead R., Dickman E., Holtzapple N., Miller J., Grogan S.	2001	Multimodal hyperspectral imaging for the non invasive diagnosis of cervical neoplasia. Journal of Lower Genital Tract Disease, 5(2), 65-72.

Hege E., O'Connell D., Johnson W., Basty S., Dereniak, E.	2003	Hyperspectral imaging for astronomy and space surveillance. Proceedings of the SPIE, 5159, 380-391.
Johansson J.E.	2007	Plastics – the compelling facts and figures. The 6th IdentiPlast Biennial Conference on the Recycling and Recovery of Plastics.
Kellicut D., Weiswasser J., Arora S., Freeman J., Lew, R., Shuman, C.	2004	Emerging technology: hyperspectral imaging. Perspectives in Vascular Surgery and Endovascular Therapy, 16(1), 53-57.
Monteiro S., Minekawa Y., Kosugi Y., Akazawa T., Oda, K.	2007	Prediction of sweetness and amino acid content in soybean crops from hyperspectral imagery, ISPRS Journal of Photogrammetry and Remote Sensing, 62(1), 2-12.
Rodionova O., Houmøller L., Pomerantsev A., Geladi P., Burger J., Dorofeyev V.	2005	NIR spectrometry for counterfeit drug detection: a feasibility study. Analytica Chimica Acta, 549(1-2), 151-158.
Roggo Y., Edmond A., Chalus P., Ulmschneider M.	2005	Infrared hyperspectral imaging for qualitative analysis of pharmaceutical solid forms. Analytica Chimica Acta, 535(1-2), 79-87.
Smail V., Fritz A., Wetzel, D.	2006	Chemical imaging of intact seeds with NIR focal plane array assists plant breeding. Vibrational Spectroscopy, 42(2), 215-221.
Serranti S., Bonifazi G., Pohl R.	2006	Spectral cullets classification in the mid-infrared field for ceramic glass contaminants detection. International Journal of Waste Management Research. 24, 48-59.
Serranti S., Bonifazi G.	2007	Solid waste materials characterization and recognition by hyperspectral imaging based logics. The 2nd Int. Symposium MBT 2007: Mechanical Biological Treatment and Automatic Sorting of Municipal Solid Waste. 326-336. Hanover, Germany.
Serranti S., Bonifazi G.	2008	Hyperspectral imaging applied to plastic recycling. Global Waste Management Symposium. Copper Mountain Conference Center, CO, USA.
SSOM	2008	Spectral Scanner Operative Manual (Version 2.0). DV Optics S.r.l., Italy. http://www.dvoptic.com/index.html
TiTech Visionsort GmbH	2005	Patent DE 29724853U.

Continuous Measurement of Waste Material Volume Flow

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Abstract

At the present time, volume flow rates in waste treatment plants are determined only discontinuously. With the aid of a contactless, sensor-based method the volume of the conveyed waste stream can be detected in real-time. In addition, information about the locations of the transported materials can be given. The data can be used to monitor and control aggregates. The procedure is applicable to all regular facilities of waste treatment plants.

Keywords

Controlling and monitoring of aggregates, laser triangulation, sensor based technology

1 Introduction

In disposal plants, waste material mass flows are usually determined by multiplying the mass flow rate during a defined period of time with the medium bulk density. Here, changes in the waste composition and short-term variations in the loading of the conveyor belt are not detected. Overload and idling of the conveyor belts are not considered in the overall result. Furthermore, no information can be given about the loading of the conveyor belts across their width.

The exact understanding of time-dependent loading conditions of the conveyor belts enables a rapid optimisation of the processes and their adjustment to current needs. As a result, the output of useful material can be raised and the quality of processed products can be increased to a higher degree.

A method for a detailed, time-dependent and low-cost measuring of volume flows on conveyor belts is being developed at the I.A.R [Department of Processing and Recycling]. With this method, volume flows are measured continuously and the current distribution of the waste material on the belt is indicated at the same time. The collected data can be evaluated statistically over periods of several months or it can be used for the direct control of aggregates. In the following, the technical background, the type of collected data and the possibilities of data usage are explained. Moreover, possible applications for volume flow measuring are introduced and an outlook on future developments is given.

2 Methods

2.1 Laser Triangulation

In a continuous volume flow measurement, height-related data is collected sensorially by a 3D camera. The examined surfaces have to reflect light diffusely. Glossy, reflective or transparent surfaces should be avoided. The underlying technology is based on the principle of laser light section triangulation. Figure 1 gives a schematic representation.

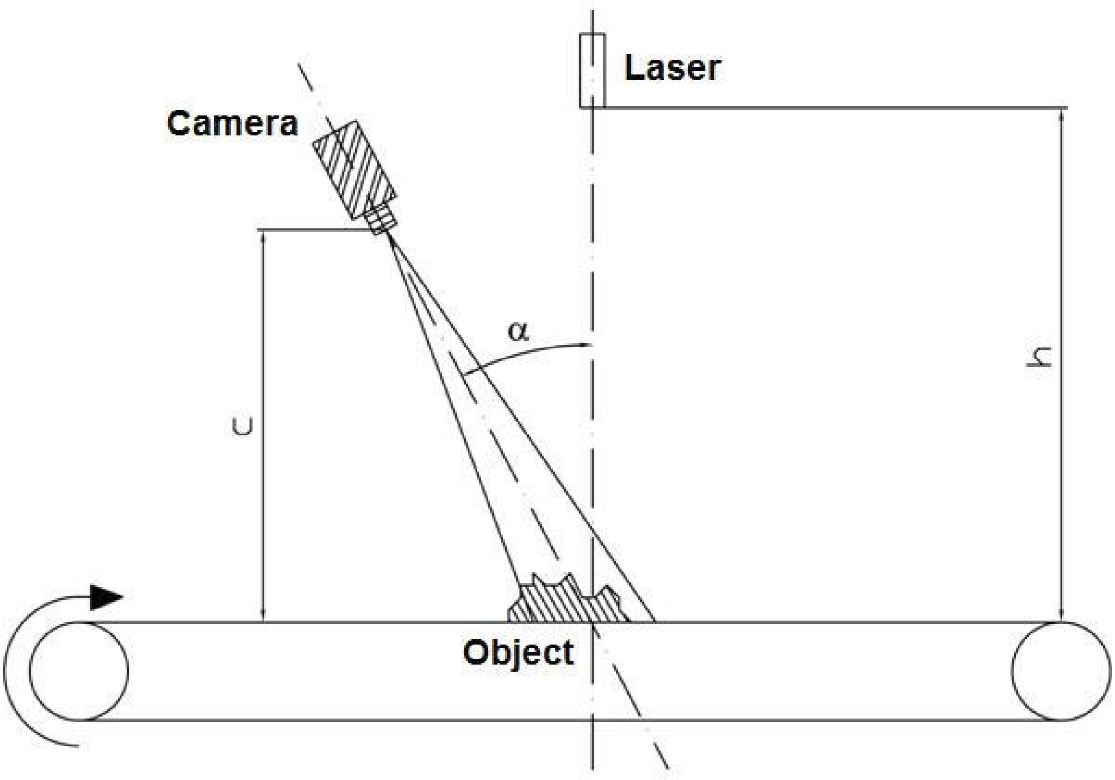

Figure 1: Measuring assembly for volume flow measurement on the basis of laser triangulation

In laser triangulation, a laser liner projects a “contour line” onto the material to be measured. The light of the line is reflected by the surfaces of the material and continuously recorded by a camera. The angle at which the light strikes the camera’s sensors serves to determine distances or heights of objects on the basis of trigonometric principles.

An evaluation software then develops a complete “contour image” from the several hundred pictures that the 3D camera takes per second. Together with trigonometric principles, this image can be used to determine the volume of the material and furthermore provides information about the waste distribution on the conveyor belt.

2.2 Measurement Setup

2.2.1 Laser

In order to generate the contour line, a laser liner is aimed vertically at the material flow. The focusable range of the laser lies between the belt surface and 40 cm above the belt surface. The costs for a laser liner with the necessary precision amount to about €100.

2.2.2 Camera

The position of the contour line varies according to the height of the loaded material. Therefore, the exact measuring of the contour line requires the measuring of the whole area above the conveyor belt. This requirement can be met by customary area cameras that are available from €250 to €1000.

The camera used at the I.A.R. has a VGA CMOS sensor and a frame rate of about 90 fps. With a conveyor belt width of one metre and a conveying speed of 0.5 metres per second, the highest possible resolution is about 8 mm^3 per voxel. The camera is connected to a PC via a gigabit ethernet interface.

2.2.3 Evaluation Software

The evaluation software was developed in the “LabVIEW” research environment by National Instruments (NI) and offers the possibility to create user- and application-oriented “measuring applications with analysis features”. At the I.A.R., a programme was written that combines the contour lines that are captured by the 3D camera into a continuous contour image. With the help of further algorithms, the volume and distribution on the belt surface are then determined.

2.2.4 Properties of the Measurement Setup

The measurement setup for the volume flow measurement is contactless and can be retrofitted to existing plant components. The basic setup is shown in figure 1. The distance of the laser from the belt surface depends on the focus and the aperture width of the laser optics and is at least twice the maximum loading height. The 3D camera is sighted so that it can capture the whole width of the conveyor belt as well as the space between the conveyor belt and the maximum loading height.

2.3 Data Acquisition

A complete data acquisition is achieved when the speed of the conveyor belt is adapted to the picture-taking rate of the camera. This rate depends on the line duration which in turn results from the exposure time, processing time and rest period.

The exposure time is set by the user depending on the brightness of the surroundings and the desired length of the conveyor belt to be covered by the picture. The longer the section of the conveyor belt to be observed, the longer the exposure time should be set.

With a frame rate of 90 pictures per second and a belt speed of 0.5 metres per second, height information of about 6 mm of the conveyor belt can be recorded with every picture. The recorded picture shows a blurred contour line composed by single surface contours that were captured during this time frame. The middle line of this blurred contour line is sufficiently accurate for the volume measurement and is used to generate the contour image.

The processing time that is necessary for the evaluation of the picture signals is constant for a set line length and takes a few milliseconds. The rest period is a variable parameter and fills the time before the next exposure.

The optical properties of most surfaces of the waste flow are suitable for the sensors of the volume flow measurement. Surface characteristics change the reflective properties of laser light. E.g. reflective, very dark, or transparent objects, are usually covered by surrounding dust to form a measurable surface.

3 Applications

3.1 Data Usage

The captured volume flow data can be used for plant monitoring in combination with a warning system for the personnel. The information about the volume flow helps to avoid failures and ensure the aggregates function properly. Additionally aggregates can be increased to a permanently high level of efficacy by optimizing the feeding volume.

Another possible application is the simultaneous use of a system for volume flow measurements at the input and output of aggregates. From this data, the current utilisation level of the examined aggregates as well as the current output can be determined. An overview of the possible applications is given in table 1.

Table 1 Possible applications of volume flow data

Aggregate	**Possible applications of volume flow data**
Classifier	Estimation of utilisation levels; prevention of overloads, blocking and idling periods
Sorter	Monitoring of input layer thickness; ensuring an even loading of the aggregates
Shredder	Prevention of overloads and idling periods

3.2 Classifier

The use of a continuous volume flow measurement at the inflow of classifiers can serve different goals. In drum screens, the information about the inflowing volume serves to estimate the current utilisation level and to avoid blockage, whereas in deck screens or sizers, overloads and idling periods have to be avoided.

3.3 Sorter

For sorters, an even feeding to the conveyor belt is required for an effective sorting. Here, the continuous volume flow measurement can be used for monitoring the layer thickness as well as the distribution of waste material on the width of the conveyor belt. Further examples are given in the following table 2.

Table 2 Overview of possible applications of volume flow measurement in sorters

Sorter	**Possible applications of volume flow measurement**
Magnetic separator	Monitoring of layer thickness; monitoring of material distribution
Sensor-based sorting	Securing of a monolayer; monitoring of material distribution
Air classifier	Monitoring of loading at the material inflow
Eddy current separator	Securing of a monolayer; monitoring of material distribution

3.4 Shredder

Apart from the use of volume flow measurement in classifiers and sorters, the use in shredding aggregates is also advantageous. By monitoring the supplying belts, both shredder overloads and underloads can be avoided. This ensures that the shredders are always fed with an optimum amount of shredding material (per time unit).

4 Prospective Outlook

At the moment, essentially two methods are used for estimating volume flows. The first one determines the total volume with the help of the throughput per time unit. The second option is to measure the material mass being processed e.g. with a belt scale and to determine the volume with the help of the average bulk density during a certain time period. Both methods are not suitable for real-time evaluation of volume flows and can only be used for plant controlling under certain conditions.

A continuous volume flow measurement on the other hand offers the possibility of supporting the control of the plant through a direct data transfer between the measuring equipment and the different aggregates. In the case of uneven volume flows, counter measures can be taken, e.g. by adapting the feeding of the material. Other advantages of controlling volume flow through measurement derive from the sorting of material flows for sensor-based sorting machines.

5 Conclusion

Continuous volume flow measurement is based on the principle of laser triangulation and is one of the sensor-based methods. The measuring device consists of standard components – a laser liner, an area camera with a frame rate of about 90 fps, and evaluation software that can be adjusted to the individual needs of the user. The measuring setup is contactless and can be retrofitted in existing plant components. The costs for the measuring setup amount to about €1000.

For the volume flow measurement, several hundred parts of contour data per second are recorded as “contour lines” and are combined into contour images by the evaluation software. This provides information about the volume flow and the distribution of material on the conveyor belt. Even difficult surfaces can be recorded thanks to the dusty waste surroundings. The resolution per voxel is accurate down to cubic millimetres.

Information about the volume flow can be gained at the input and the output points of all typical aggregates in waste processing plants. The possible applications of the data are diverse and include mainly plant monitoring and controlling. This encompasses the estimation of utilisation levels, the avoidance of overloads and the monitoring of layer thicknesses. Information about volume flows can be used in the future for plant controlling.

6 Sources

Jähne, B.	2005	Digitale Bildverarbeitung. Springer Verlag, Berlin Heidelberg New York, ISBN 3-540-24999-0
Killmann, D.; Pretz, T.	2008	Einsatz von Multisensorik in sensorgestützten Sortiersystemen. Beitrag im Tagungsband zur 9. Depo-Tech-Konferenz. VGE Verlag GmbH, Essen, ISBN 978-3-86797-028-0
Killmann, D.; Pretz, T.	2008	Dritte Dimension zeigt neue Perspektiven auf. Recycling Magazin 12/2008, ISSN 1433-4399
National Instruments	2009	Homepage www.ni.com/labview; accessed: February 2009

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Modeling of waste management processes so as to increase the efficient use of natural resources – outlook and future demands

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Abstract

Since the ban on placing untreated waste in landfill sites (Technical Instructions on Municipal Waste) came into force in June 2005, the increasing number of material waste streams in need of coordination has led to increased complexity of the recycling and disposal structures in the waste management and recycling industry, whereby the issues of material and energy efficiency are gaining importance. An approach to analyzing and optimizing these complex processes is offered in a project currently being undertaken at Bremen University of Applied Sciences in collaboration with partners from the industry itself. Here, as the basis for the development of software applications, a material flow model for the waste management and recycling industry is being developed for the purpose of supporting material waste flow management and thus helping to lay the foundations for better resource and cost efficiency in this industry.

Keywords

Modeling, waste management processes, resource efficiency, energy efficiency, material efficiency, material flow analysis.

1 The need for action

Against the background of complex recycling and disposal structures in the waste management and recycling industry, with its numerous material waste streams in need of coordination, which have developed since June 2005 (when it became illegal to simply landfill untreated waste, Technical Instructions on Municipal Waste), estimating the efficiency of different material streams has increasingly grown in importance. Since this time it has been necessary to treat waste in biomechanical or thermal waste treatment plants. Material, energy and cost efficiency will place big demands on the waste management industry in the coming years. For companies which operate a number of different waste recycling, processing and treatment plants, there is a need for them to be able to manage various material streams within or between the different plants, whereby considerable potential exists in many areas for optimization, especially in the more efficient use of material and energy contained in the available waste streams. However, at the moment, only partial solutions are available for controlling the processing and disposal networks. There are a number of different models available, each of which fails to provide a comprehensive view or, for various processes, does not include the relevant parameters, e.g. EASEWASTE (compare KIKEBY, J. ET AL.). The complexity of a corresponding, closed, comprehensive solution is compounded by a number of factors in the waste management system itself, whereby, economic, legal and specifically local factors are particularly important, as shown in the following Figure1.

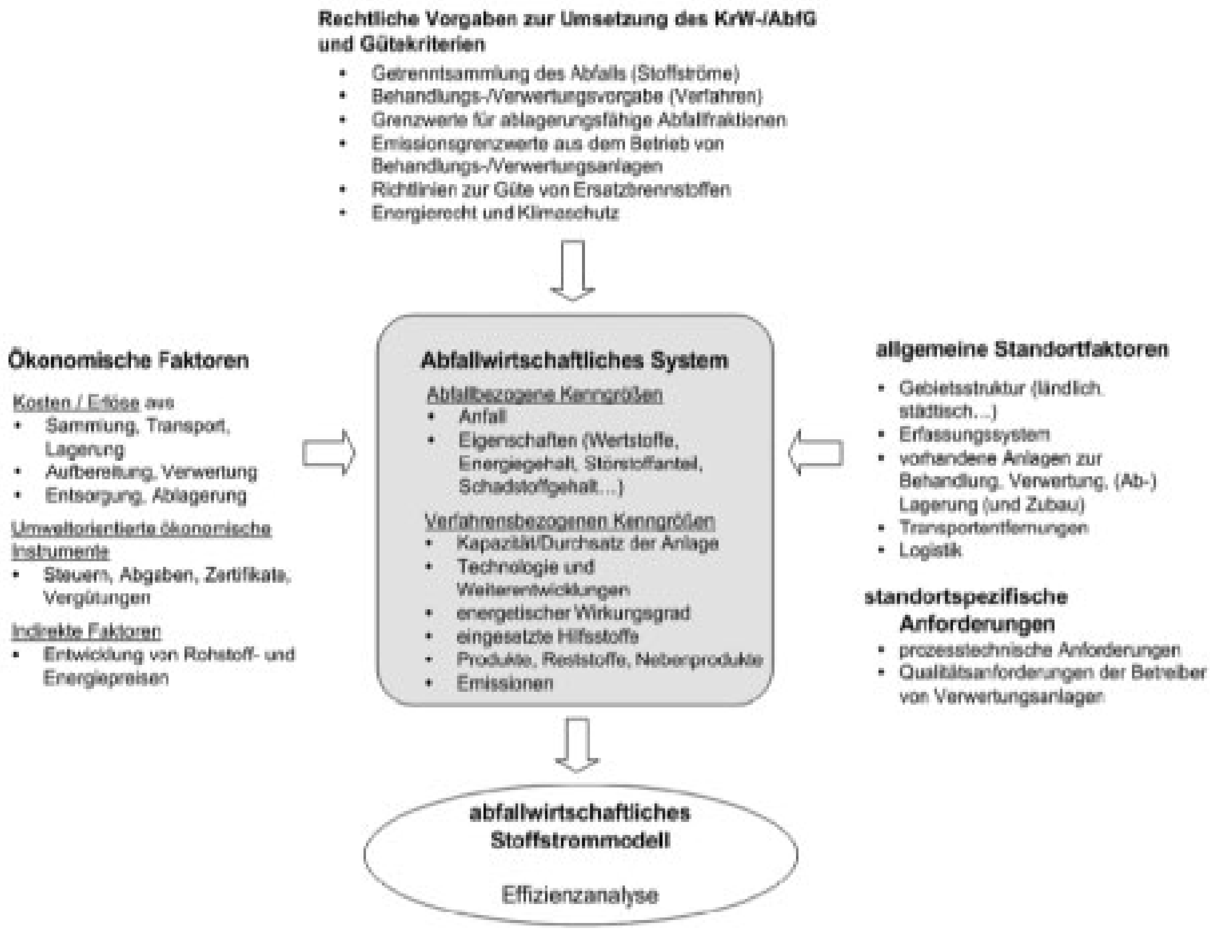

Figure 1: Basic conditions and factors in the recycling industry

The reason that comprehensive solution packages are lacking is to be seen in the fact that since implementation of Technical Instructions on Municipal Waste a material stream specific waste management industry has developed. From this, new demands emerge: for example, the course of waste processing is greatly influenced by the type, origin and composition of the waste in question. While in the models currently available, composition of the waste, i.e. the classification of fraction-specific parameters characteristic of a particular waste material stream are inadequately assessed. For companies in the waste management industry, however, it is of interest to be able to include in their assessment any factors, such as contamination limits, quality demands or surcharges related to waste quality, which influence the material flow process.

An additional problem is the large amount of raw data, which can hardly be made use of on a daily basis on account of a lack of analytical tools for modeling such material streams, despite there being a clear need for it if plants are to be successfully optimized, in respect to medium-term planning, as well as in respect to daily operations, so as to maximize both material and energy efficiency, and reduce costs (e.g. disposal services). In cooperation with local partners from the interested (software and waste management) industries, the hope is to improve this situation.

2 Project description

2.1 Aims

A current project at Bremen University of Applied Sciences is aimed at solving outstanding problems by facilitating contacts between different interest groups, thus increasing efficiency, and, in collaboration with IKrW, Ecologix and other industry sector partners, developing a material flow model for the waste management and recycling industries. The approach focuses on methods of waste treatment and processing, and characterization of the waste in question. The project involves cooperation between well-known industry sector partners (e.g. Nehlsen, swb AG) located in and around the city of Bremen, thus ensuring that the individual parts of the model fit together to form comprehensive solution. This includes features such as methods for calculating regenerative CO2, a material and ecological balance sheet, and technical simulation of planned plants. Of importance for the economics and daily operation of a plant are questions of changing material input parameters and the influence these have on output (increased emissions, waste in need of disposal, etc).

This project, supported by the European Regional Development Fund and the support program, Applied Environmental Research, of Bremen state, attempts to analyze and describe, using suitable parameters, the material streams of the waste management and recycling industry, along with the treatments and processing involved, and present them in a material flow model. In this way it is hoped to discover optimization potential for increasing energy, material and cost efficiency. The result will be the provision of a material flow model for the input of data, representation, evaluation and optimization of material waste flows in the waste management industry.

The particular aims of the project involve the unified characterization and classification of different kinds of waste according to their utility and contamination with pollutants, and data collection on material streams of the waste management and recycling industry, so as to facilitate optimization of treatment selection and plant operation (e.g. bio-mechanical plants, incineration plants, recycling parks) within particular companies or regions. The discovery and presentation of any potential to optimize the utilization of energy and recyclable materials contained in particular waste streams will also be integrated. In addition, by providing an overview of the distribution of pollutants in a particular waste management system, the model will facilitate assessment of its environmental relevance, thereby helping to assess both the economic (e.g. material and operating costs) and the ecological (e.g. emissions) situation.

The project is aimed at providing a basis for the development of software applications which will support material flow management in the waste management industry and form a solid foundation on which to build a sustainable waste treatment, recycling and energy-producing industry. The results of modeling and developing a material flow management system will also have wide-ranging effects on the whole value creation chain. Besides improvements in material and energy efficiency, technical innovations in respect to automation and efficient transport in the logistics sector (waste management logistics processes) are also expected from this project, thus contributing to the environmentally friendly development of the regions.

2.2 Development of a waste characteristic

However, for such modeling a important basis is currently lacking: a process-related, easily usable and with data substantiated waste characterization (description). For production-specific wastes, commercial waste and processed fractions of municipal waste no such description is available. All we have is a comprehensive base data set for domestic waste.

Because of the different approaches taken up until now in collecting data, there are limits to the extent that different data sets can be compared with each other or applied to situations other than the one they were collected in. However, against the background of a need to assess material distribution, and for information relating to the concentration or depletion/degradation of certain substances (e.g. pollutants) in the waste in question, such a characterization is of great importance and an essential aim of modeling. To facilitate this, standardization of the approach to data collection is called for, along with a definition of what data are necessary and a method of deducing the required parameters from the data collected. The end result is a characterization for different kinds of waste, according to utilization and pollutant content, which is implemented in the system.

The properties of the waste are essentially determined by its material group composition. These fractions of the heterogeneous waste can be characterized by corresponding parameters. Thus, for example, particle size and bulk density are important parameter for mechanical processes effecting material separation. Also, ferromagnetic and surface properties are used for the separation of metal and plastic fractions. The aim is to separate high calorific waste fractions and through further conditioning produce a fuel from them. The requirements for such substitute fuels depends on the kind of combustion involved, the firing equipment and the kind of regular fuel that might normally be used. Essentially, the decisive parameters are: calorific value, chlorine content, heavy metal content, particle size and the content of interfering substances (compare ECKARDT 2005). The first three named parameters, in particular, are dependent on the composition of the waste input, while the latter parameters can be readily achieved through subsequent diminution and metal separation. Particularly plastics, papers, boards and composite materials, with their high calorific values, should be enriched in the substitute fuel. However, plastics and composites are often sources of chlorine and heavy metals, the content of which fluctuates greatly, depending on the particular plastics or composites involved (compare KOST 2001 AND ROTTER 2002). Thus, in order to determine the composition of various kinds of waste, it is meaningful to be able to recognise and characterize different classes of plastic.

Table 1: material parameters and their influence on utilization

Material parameter	Thermal utilization	Bio-mechanical treatment
Particle size	X	X
Bulk density	X	X
Surface properties		X
Ferromagnetism		X
Calorific value	X	X
Chlorine content	X	
Heavy metal content	X	X
Interfering substances		X
Ash content	X	
Water content	X	X
Organic substance	X	X
Particle size	X	
C, H, O, N, S	X	

By thermal utilization the relevant parameters can be deduced from the material composition and chemical-physical properties of the waste. Physical properties are ash content, water content, and the content of organic substances. Combustion related properties are determined by calorific value, material composition, bulk density and particle size. Carbon, hydrogen, oxygen, nitrogen, chlorine and sulphur content are relevant to estimating emissions.

It is clear that a multitude of different material properties are necessary in order to adequately describe a waste fraction in view of the technical processes that provide a possible solution.

3 Case study: Optimization of a waste-fueled power station

From the perspective of those operating thermal waste treatment plants, their main objective is in achieving a economically and ecologically optimal result. While keeping to the emission limits that are laid down, the most important factors influencing the plant's operating condition are:

- optimal energy coupling out,
- high availability of boilers and
- high through-put rates.

These factors, alongside the available technology and design of the plant, are influenced above all by the properties of the fuel being burned. The decisive material parameters relating to the waste have already been mentioned, but also of decisive importance are economic parameters (e.g. the price paid for taking the waste and disposal costs).

From the above it follows that the choice of waste mixture as fuel for a plant also allows one to control its operation, from which the question arises as to which waste fractions permit optimal use of plant design and technology? Because of the complexity of all the variables, this optimization problem can only be solved using computer software. The following figure shows just a part of the material flow analysis model.

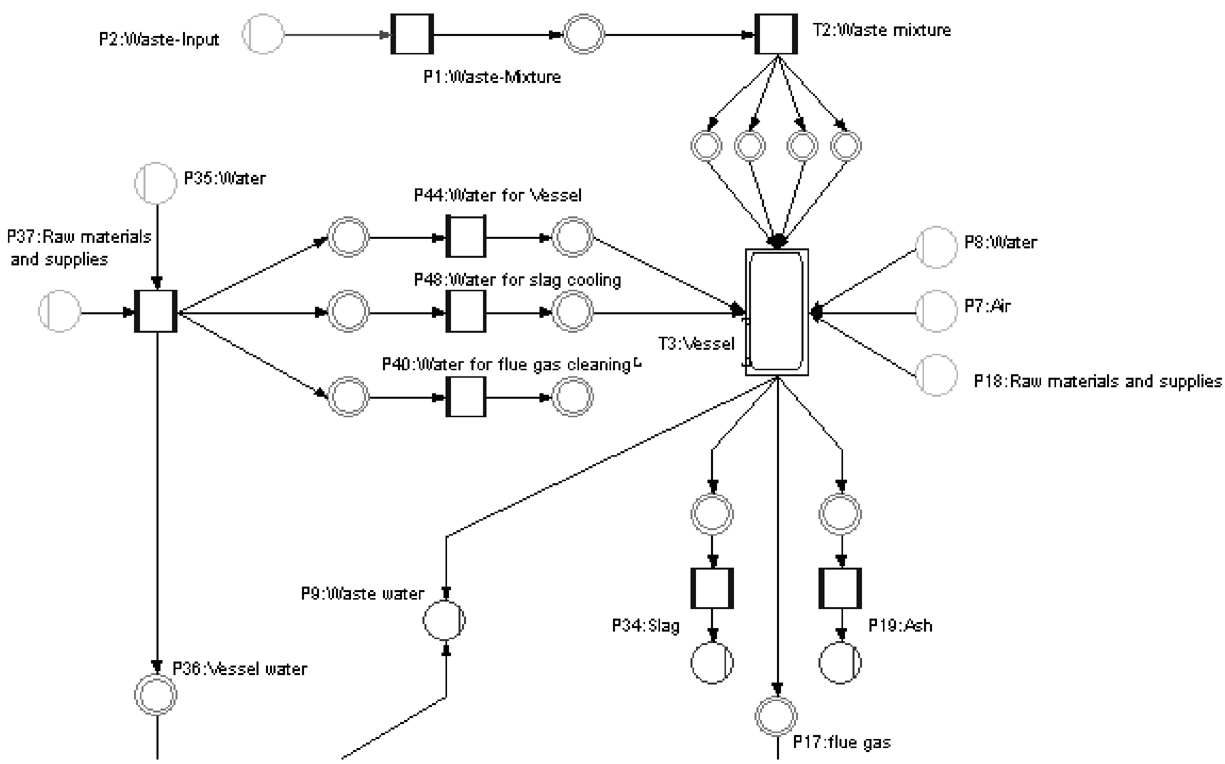

Fig 2: material flow analysis model for a thermal waste treatment plant

In modeling a thermal waste treatment plant, emission limits and other constraints have to be taken into account. Through-put on the boiler grate is calculated in relationship to the calorific value of the waste fraction and the thermal output chosen. Via the selected thermal output, a specific amount of steam is produced, which is decisive for the possible yield of thermal and electrical energy.

The result of an initial estimate shows waste fractions with relative low calorific values, ash and heavy metal content, along with a high price for taking the waste, to be the most favored fractions for waste incineration. However, such criteria alone do not suffice when working out optimal plant operation. It is decisive that emission limits and other constraints are taken into account (e.g. max. furnace heat liberation).

Within the framework of a Bremen University of Applied Sciences development project, an attempt was made to support, using models, optimization of a waste-fueled power plant operated by Abfallbehandlung Nord GmbH in Bremen (now the swb AG). To this end, the plants processing units, along with all the relevant material and energy streams and cost factors were diagrammatically represented in a model (see Fig. 2). The waste being fed into the plant was fractioned according to waste type and characterized with actual measurements, supplemented with data from the technical literature (also see SCHMIDT ET AL., 2008).

Table 2: Results of model calculation for waste-to-energy power plant by variation of waste input

	Scenario 1	Scenario 2
Waste input [Mg]	491,000	500,000
Calorific value of waste fraction [MJ/kg]	11.8	11.6
Max incineration capacity [Mg]	493,000	502,000
Slag [kg/Mg]	242	257
Ash [kg/Mg]	15.9	16.9
Residue RGR [kg/Mg]	29.4	31.9

In the first scenario, a total of ca. 491,000 Mg was incinerated in the plant, whereby the waste input had a calorific value of ca. 12 MJ/kg. In the second scenario, waste input was varied to the extent that ca. 95,000 Mg of high calorific fraction was replaced with sewage sludge (75% dry substance), shredder light fraction and residue from the sorting of commercial waste. In order to arrive at roughly the same calorific value as before, in this scenario 500,000 Mg of waste were incinerated (compare Table 2).

The results based on this model showed the following:

- Increase in revenue from the waste thanks to a higher through-put of 10,000 Mg compared with Scenario 2.
- Increased operational costs due to need for more additives in scrubbing flue-gases, because of higher levels of pollutants, mainly contained in the sewage sludge and shredder light fraction, in the waste mixture burned in Scenario 2.
- Increased disposal costs due to greater content of ash and slag in Scenario 2.

This example illustrates the complex interrelationships involved in waste incineration. It was possible to show that the models which have been developed reflect these interrelationships well and can be helpful in optimizing the operation of a waste-fueled power plant.

In order to make a final determination of optimal operating conditions for a waste-fueled power plant, one also needs additional methods of optimization from business studies/commercial informatics. A software tool developed at University of Pforzheim within the framework of a project dedicated to the "combination of optimization methods and material stream analysis for the improvement of material utilization", named KOMSA, was thus applied in this project, to see if it was capable of providing a solution to its optimization problems. The goal was to produce a mixture of waste from a selection of waste fractions with different waste parameters, taking into account required emission limits and other constraints, for optimal operation. With the help of optimization algorithms contained in the optimization prototypes, different waste mixtures were automatically produced until the optimum composition for the waste-fueled power plant was found. For this case study, the numbers were anonymized, so that they didn't correspond to any real situation. In Figure 3, possible economic operation results are shown - and with them the optimization potential – in relationship to the composition of the waste. The graphic also shows the optimization methods used and the necessary calculations.

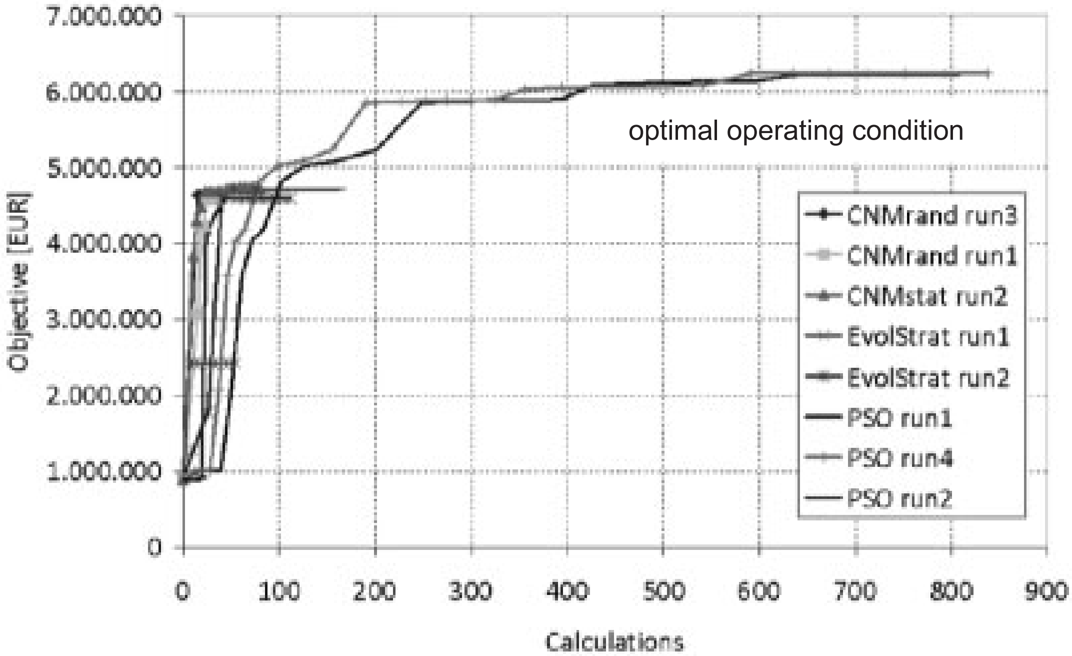

Fig. 3: Anonymized representation of the results from six optimization alogrithms.

With this combination of optimization methods and material analysis, the waste and corresponding material, energy and cost streams can in future be used as a basis for prompt assessment and optimization of efficiency in waste management systems and strategies.

4 Literature

Eckhardt, S.	2005	Anforderungen an die Aufbereitung von Siedlungs- und Produktionsabfällen zu Ersatzbrennstoffen für die thermische Nutzung in Kraftwerken und industriellen Feuerungsanlagen. Dissertation, Technische Universität Dresden in Kooperation mit der Hochschule Bremen, in: Beiträge zu Abfallwirtschaft/Altlasten, Band 41, Dresden 2005
Kikeby, J. et al.	2006	Environmental assessment of solid waste systems and technologies: EASEWASTE, In: Waste Management & Research 2006, 24, S. 3-15
Kost, T.	2001	Brennstofftechnische Charakterisierung von Haushaltsabfällen. Dissertation, Technische Universität Dresden, in: Beiträge zu Abfallwirtschaft/Altlasten, Band 16, Dresden 2001
Rotter, S.	2002	Schwermetalle in Haushaltsabfällen - Potential, Verteilung und Steuerungsmöglichkeiten durch Aufbereitung. Dissertation, Technische Universität Dresden, in: Beiträge zu Abfallwirtschaft/ Altlasten, Band 27, Dresden 2002
Schmidt, A. et al.	2008	Bilanzierungsmodelle für thermische Abfallbehandlungsanlagen zur Bewertung von optimalen Betriebszuständen, in: waste to energy - Conference Proceedings, 2008 HVG Hanseatische Veranstaltungs-GmbH, Bremen, Germany, S.61-65

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Recyclables and Sorting Plants on the Market – Special Aspects of Antitrust Law, Public Procurement Law and Fiscal Law

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Abstract

This article presents a survey on questions arising in the fields of antitrust law, public procurement law, and fiscal law, when contracts of recyclables (incl. sorting) are drafted.

Keywords

Recyclables, sorting plants, antitrust law, public procurement law, fiscal law

1 Introduction

Waste disposal services often constitute challenges for public contracting authorities and private waste management enterprises with regard to antitrust law, public procurement law and fiscal law. In particular, this also applies to the disposal of recyclables and the sorting thereof.

In accordance with antitrust case law, a (tender) market is not declared open before a public contracting authority calls in a third party for the provision of a service (cf. e.g. Federal Cartel Office, decision of 16 May 2007, file no. B 4 – 90003 – Fa – 8/07, margin no. 61). This is especially important for Germany, where waste disposal is a sovereign function. Owners and producers of waste can only dispose of waste within certain limits. In principle, private owners of both waste for disposal as well as waste for recycling are obliged to hand over waste to public waste managers (the so-called *Überlassungspflicht*), while owners of other kinds of waste have to meet that obligation only for waste for disposal (for a detailed examination see KUNIG/PAETOW/VERSTEYL, 2003, § 13 margin no. 1 et seq.). Defining these categories in a given case is highly controversial – considering the economic interest of the "service providers" – and shall not be discussed in detail here (for a detailed examination see WENZEL 2008). However, it should be pointed out that, within the framework of pending appeal proceedings, a fundamental decision of the Federal Administrative Court is expected concerning some important issues, notably on § 13 (1) sentence 1 German Waste Avoidance, Recycling and Disposal Act [KrW-/AbfG, *Kreislaufwirtschafts- und Abfallgesetz*] (on the issue of individual recovery of waste) and possibly also on § 13 (3) sentence 1 no. 3 German Waste Avoidance, Recycling and Disposal Act [KrW-/AbfG, *Kreislaufwirtschafts- und Abfallge-*

setz] (on the issue of commercial collections) (file no. 7 C 16.08; following OVG Schleswig-Holstein [Administrative Appeals Tribunal of Schleswig-Holstein], ruling of 22 April 2008, file no. 4 LB 7/06].

To the extent that the waste is handed over to public waste managers, the latter has to fulfil its waste management duties pursuant to § 15 (1) KrW-/AbfG. The public waste managers may exercise general discretion concerning organisation, meaning that they can decide whether they want to provide the relevant waste disposal services themselves or appoint third parties in accordance with § 16 (1) sentence 1 KrW-/AbfG (for a detailed examination of the assets and drawbacks as well as the prerequisites of the different organisational structures see GAßNER/SIEDERER 2003, margin no. 393 et seq.) In the event that the public waste manager provides the entire waste disposal services itself, three consequences apply: firstly, no public procurement procedure is required, secondly, the (tender) market as object of regulation required for the application of antitrust law is missing and thirdly, no fiscal issues arise, as the sovereign function is (as yet!) tax-exempt. From the state and municipal viewpoints respectively, the following issues arise only if a third party is called in and appointed for waste service provision.

The following paragraphs therefore deal with special aspects of public procurement law as well as antitrust law and fiscal law. Antitrust legislation and public procurement law, which, as legal fields, are now anchored firmly within the Act Against Restraints of Competition (cf. §§ 1 et seq. and §§ 97 et seq. GWB *[Gesetz gegen Wettbewerbsbeschränkungen]*) are supposed to guarantee and result in competition free from discrimination. Antitrust law is supposed to prevent or restrict monopolies and oligopolies and to provide the Federal Cartel Office with strong powers of intervention and regulatory powers, whereas public procurement law regulates that invitations to tender are competitive and include basic duties of the public contracting authorities. Both main protagonists are subject to judicial or quasi-judicial control (cf. §§ 63 et seq. and §§ 107 et seq. GWB respectively).

2 Public Procurement Law

The public contracting authority is obliged to call for tenders for disposal services pursuant to § 98 GWB as it is either the original owner or producer of the waste or is legally obliged to dispose of recyclables of third parties and does not provide the service itself (for a more detailed discussion see BYOK/BORMANN 2008, 843). With respect to public procurement law, the contracting authority is de facto faced with the following issues that regularly lead to arguments with tenderers in the process of inviting tenders for recyclables and sorting services.

2.1 Special Aspects concerning Recyclables

§ 8 no. 1 of Award Rules for Services, part A [VOL/A, *Verdingungsordnung für Leistungen/Teil A*,] defines a set of requirements which need to be considered in the specifications for tenders, which in turn constitute the centrepiece of the so-called CADO (Contract Award Documents). To this end, the service shall be described "precisely and exhaustively" so as to guarantee an equal appreciation of all tenderers and thus comparability of the tenders (paragraph 1). Additionally, all conditions relevant to price calculation have to be indicated (paragraph 2) and the contractor shall not be burdened with any "rare venture" (paragraph 3). This is why special importance is attached to the quantitative and qualitative description of the recyclables in inviting tenders for disposal services of recyclable material. Quantities, for instance, can be erratic and influenced by conditions over which the contracting authority has no influence. The contracting authority is, however, expected to draw up authoritative quantity forecasts. By establishing quantity frames of +/- 10 %, the tenderers can calculate and indicate their fees based on that quantity information. The qualitative description of the recyclables is particularly important if further recovery is carried out in plants that must observe a certain quality. If the invitation to tender concerns quantities at transfer points that have already been recorded and/or have been pre-treated, the interfaces between the respective partial performances also have to be clearly defined, as, on the one hand, unsuccessful or delayed transfers or acceptances of quantities of recyclables may result in follow-up costs (especially incidental damages) and, on the other, there is no direct contractual relationship with the respective contractor of the partial service to the effect that the contracting authority must solve any respective problems.

To the extent that the recyclables have a positive market value at the time of the transfer to the contractor or as a result of the invitation to tender for waste disposal services, tender prices must be retrieved and assessed carefully, as problems concerning the comparability of the prices may arise from offsetting the proceeds with the fees. With respect to fiscal issues, this may even lead to incomparable tenders and thus to a breach of the above-mentioned requirements pursuant to § 8 no. 1 (1) sentence 2 VOL/A (see chapter 4.2; see also decision of the Public Procurement Chamber of Brandenburg at the Economics Ministry of 28 January 2008, file no. VK 59/07). The provisions pursuant to § 15 VOLA shall also be examined very carefully, determining whether the services are to be assigned at fixed prices or allowing for potential price adjustments.

To the extent that proceeds can be generated from recyclables and that their acquisition is not an exclusive sovereign function, the question of how competitive activities by the contractor may be prevented in order not to alter quantity or provoke a loss of proceeds may arise for the public contracting authority. Pursuant to a recent decision of the Higher Regional Court of Rostock [OLG, *Oberlandesgericht*], any universal non-competition clause aimed at banning the contractor (or a business connected to it) from competing for the same object of service in the field of waste disposal is illegal for the duration of the contract (decision of 6 March 2009, file no. 17 alloc. 1/09). According to this legal opinion, the contracting authority should at least ask to contractor to supply information on how the latter plans to rule out the aforementioned negative consequences of a commercial waste collection, if necessary.

2.2 Special Aspects concerning Sorting Plants

As far as waste management issues are concerned, the sorting is carried out with the aim of achieving a superior quality of waste disposal and/or with the business interest of gaining an economic advantage from this process. This advantage can, however, only be realised if the sum of the proceeds from the partial fractions minus the sorting costs does not exceed the proceeds of the unsorted total fraction (in the past this was not regularly the case with waste paper). Using sorting plants can be an obligatory or optional object of service. If the use of sorting pants is an obligatory component of the total service, the question arises whether the procurement may be carried out by lots pursuant to § 5 VOL/A. In this case, the definition of the interfaces (transfers before and after sorting) must be especially precise.

If the sorting plant is itself the subject of a call for tender, a distinction must be made between construction (Award Rules for Public Works Contracts, Part A – VOB/A, *Verdingungsordnung für Bauleistungen, Teil A*) and service (VOL/A) with respect to public procurement law. Public-private partnerships are only possible following a call for tender, and are only of limited economic interest with respect to follow-up and additional orders, this since the amendment of ECJ jurisdiction for want of in-house capabilities (cf. judgement of 11 January 2005, file no. case C-26/03, “City of Halle”).

3 Antitrust Law

Firstly, the concept of market definition shall be discussed, as the definition of the relevant market legally precedes all further examination with respect to antitrust law. A basic distinction has to be made between the so-called merger control (§§ 35 et seq. GWB), which is more and more frequently the case due to the increasing concentration in waste management, and the general antitrust regulations banning anti-competitive agreements, collusive behaviour, anti-competitive behaviour etc. (cf. Federal Cartel Office, decision of 6 May 2004, file no. 10 B 97/02 – “Waste Paper Disposal”).

3.1 The Legal Market Definition Concept

An antitrust test is de facto especially important with co-operations, be it on a simple contract basis, or as a consortium / joint bidders, or institutionalised (e.g. within the scope of a public-private partnership).

An antitrust market definition is generally made on two, occasionally also on three levels: as a relevant product market, a geographical market and a temporal market (if the market is not permanent).

The so-called demand market concept has been developed to define relevant product markets. It is based on the possibility to substitute products from a functional perspective from the supplier's point of view. The relevant product market comprises all goods that are so close to each other in terms of their characteristics, their economic purpose and their price range that a sensible consumer regards them as being interchangeable to satisfy a certain demand and thus weighs them against each other (cf. Federal Supreme Court [BGH, *Bundesgerichtshof*], judgement of 14 October 1995, file no. KVR 17/94, "Oven Market").

The geographical market is defined by a geographical description that is based either on political borders (federal states, administrative districts, towns, or municipalities) or on specific radii around points of reference (e.g. plant location), established on the basis of regular analysis of municipal tenders (see also LOTZE/MAGER 2007, 244).

3.2 Markets for Recyclables and the Sorting of Recyclables

While analysing Federal Cartel Office case law concerning antitrust issues in waste management, it can be pointed out that the product market definition generally contains two points of view: On the one hand, the fraction serves as a characteristic (e.g. waste paper, packaging, pre-treated municipal waste etc.), and, on the other, individual waste disposal processes are considered (e.g. collection, transport, sorting etc.). Based on the demand market concept set out under paragraph 3.1, the waste disposal services for the product market definition in question are subject to thorough analysis. In practice, the following aspects are of particular importance: term of the contracts, quality and quantity of the waste, purity of variety, removal intervals, vehicles used, other equipment and personnel (cf. e.g. Federal Cartel Office, decision of 16 May 2007, loc.cit.). Notably, the following product market definitions have been made with respect to antitrust case law: collection and transport of light packaging, sorting of light packaging, recycling of pre-treated municipal waste, sorting and recycling of waste paper, collection and transport of waste glass. In some cases, there have been divergent decisions of the Federal Cartel Office and the OLG Düsseldorf, which is in charge of judicial control. The Higher Regional Court Düsseldorf questioned, for instance, the inclusion of waste incineration plants and mechanical-biological treatment within the same product market (cf. decision of 4 September 2002, file no. Kart 26/02 (V)), whereas the Federal Cartel Office proceeded on that very assumption (cf. decision of 17 March 2006, file no. B 10-141/05).

The geographical market definition requires a case-by-case review. Whereas general nationwide markets could be found on rare occasions only, a geographical market regularly spreads up to 100 km around one plant or municipality, including a federal state or a number of federal states (cf. e.g. “Northern New Länder”, Federal Cartel Office decision of 17 March 2007, file no. loc.cit., margin no. 90).

Sorting services and sorting plants also face special challenges. Technically, the interchangeability of sorting services is most relevant for product market definition, i.e. whether the respective sorting plant is only capable of treating particular waste fractions (cf. Federal Cartel Office decision of 22 June 2006, file no. B 10-90003-FA-155/05). As regards the geographical market definition, there is a direct link between the catchment area of a sorting plant and transport costs, which in turn depend on the weight or density of the material to be sorted and also on the specific transport costs (especially fuels and tolls).

As a rule of thumb the following conclusion can be drawn: the smaller the geographical market, the higher the probability that an antitrust issue will arise, as, in terms of the relevant product and geographical market, more importance is attached to the order or enterprise subject of the antitrust test, which thus leads to an increased market share.

4 Fiscal Law

There are two basic issues with respect to fiscal law: privileging sovereign functions, while its legitimacy is doubted with respect to competition law, as well as the turnover tax base when offsetting the proceeds and the fees. Other issues, such as provision of reserves, cannot be discussed in great detail here (cf. Federal Fiscal Court judgement of 21 September 2005, file no. X R 29/03).

4.1 Privileges of Sovereign Enterprises

Sovereign enterprises are not subject to corporate tax pursuant to § 4 (5) sentence 1 Corporation Tax Law [KStG, *Körperschaftsteuergesetz*]. As the Federal Fiscal Court [BFH, *Bundesfinanzhof*] recently pointed out, this provision is to be construed narrowly (cf. BFH judgement of 29 October 2008, file no. I R 51/07). Distinguishing between a sovereign enterprise and a commercial enterprise is also difficult with respect to waste management practice (cf. e.g. BFH decision of 6 November 2007, file no. I R 72/06, concerning waste disposal within the framework of the so-called Dual System in accordance with § 6 (3) Regulation on Packaging [VerpackV, *Verpackungsverordnung*]. Here, at least domestic waste disposal is acknowledged as a sovereign enterprise (BFH judgement of 23 October 1996, file no. I R 1-2/94). This is basically justified by the obligation to hand over waste to public waste managers (and "obligation to accept", respectively), as the definition of a sovereign enterprise (the decisive factor being the exercise of a sovereign function) indicates that "functions that are peculiar to and reserved to legal persons governed by public law. This is characterised by the exercise of public functions that derive from state authority, serve public purposes, and that a beneficiary has to accept based on legal or official order" (BFH loc.cit.). If exertion of public authority under federal state regulation is reserved to individual federal states, a sovereign enterprise pursuant to § 4 (5) sentence 1 KStG can only be presumed "if the market is regionally limited with respect to the provided service in a way that excludes restraints of competition on taxable enterprises in other federal states or EU member states."

Trade tax (§ 2 (1) GewStG, *Gewerbesteuergesetz*), real estate tax (§ 3 (1) GrStG, *Grundsteuergesetz*), as well as the turnover tax privilege all follow this classification (cf. § 1 (1) no. 1 in conjunction with § 2 (1) sentence 1, (3) sentence 1, Turnover Tax Law [UStG, *Umsatzsteuergesetz*]), so that waste management services provided in practice by an owner-operated municipal enterprise are, for instance, tax-free, whereas if a private waste management enterprise is appointed as a third party, 19 % turnover tax applies (cf. also BFH judgement of 15 December 2007, file no. V R 63/05). When comparing (re-)municipalisation and privatisation models, this leads to a de facto cost advantage for municipal enterprises which may (partly) compensate the private model's cost advantages due to e.g. sub-minimum wages paid to the personnel.

Associations of the private waste management industry criticise this form of privilege on a political level and have attempted to make this the subject of a European Commission appeal procedure with reference to ECJ jurisprudence (judgement of 16 September 2008, case C-288/07) – parallel to the unsuccessful motions of the FDP [German Free Democratic Party] in the German parliament (of 21 September 2006, printed matter of the Bundestag no. 16/2657 and of 19 June 2007, printed matter of the Bundestag no. 16/5728). The Commission has issued an intermediate information indicating doubts about this legal opinion (of 8 January 2009, the European Parliament, file no. E-6246/08). A final decision is pending.

4.2 Turnover Tax and Turnover Resembling a Barter Transaction

Outside of the sovereign realm (see chap. 4.1), waste disposal services are subject to turnover taxation. Determining the tax base (cf. § 10 UStG) can become a difficult issue if proceeds can be generated from the recycling material (for a detailed examination see: THIMM 2008). An example: a waste disposal service generates costs of 100 €; proceeds to the amount of 50 € can be generated from the recycling material left in charge of the service provider. If the fee reduced by the amount of the proceeds is taken as the tax base, the bid price is reduced by 9.50 € (100 ./. 50 = 50 x 1.19 = 59.50 €). A different result is reached when the costs are taken as tax base and the proceeds are only deducted from the gross amount (100 x 1.19 = 119 - 50 = 69.00 €). Against this problematic backdrop, the Federal Ministry of Finance issued a statement on 1 December 2008 (ref. no. IV B 8-S 7203/07/10002) commenting on the application of the principles of turnover resembling a barter transaction [*tauschähnlicher Umsatz*] and explaining the individual requirements (including the minimum limits). To determine the tax base you generally take the economic value of the recyclable material. In case of barter transactions with additional payment, this payment then has to be added. So if a waste owner pays 5 € for a waste disposal service and the economic value of the waste left in charge of the service provider is 20 €, a turnover of 25 € is chargeable (5 + 20 = 25 x 1.9 = 29.75 €). The statement urges the fiscal authorities not to object to parties to a contract entered into before the 1 July 2009 who assume that there is no turnover resembling a barter transaction for a transitional period until 31 December 2010.

5 Summary and Outlook

Without knowledge of public procurement law, antitrust law and fiscal law, any contracting parties risk concluding a contract on the disposal of recyclable material which is not legally compliant. Considering the increasing deregulation of recyclable disposal services and the decreasing participation of public contracting authorities associated with it, the importance of public procurement law certainly decreases. At the same time, an increasingly complex public procurement law that is more risky for the contracting authority, “motivates” them to return to providing waste disposal services (for which a call for tender had as yet been obligatory) themselves. Admittedly, an amendment of public procurement law, supposed to strengthen the legal certainty in that matter, will come into force very soon (for a more detailed discussion see V. BECHTOLSHEIM 2009). It remains to be seen whether this goal can be reached in practice. At the same time, antitrust law gains in importance in deregulated markets in order to maintain material competition. In this, antitrust case law tends to adopt regional markets that generally increase the probability of the relevance of co-operations or mergers for competition law based on a market share that is increasing correspondingly. However, an analysis of municipal calls for tender to define relevant markets is far too short-sighted, as here (especially concerning waste paper management and scrap metal recycling services provided in so-called commercial collections) market shares have been won back by competitors with direct contact to waste owners. These market shares are not taken into account in the assessment, thereby encouraging the formation of oligopolies in the waste disposal management industry. Fiscal law poses bigger legal problems in the case of the positive market value of recyclables and therefore also poses bigger economic risks in case of wrong decisions if the tax rates exceed the usual profit margins. Considering the increasing deregulation of recyclable waste disposal services, the issue of tax equity has gained in importance, no doubt resulting in yet another cost item for the owner of waste. It is worth considering whether fiscal law should, in particular, privilege recycling and therefore contribute to the fulfilment of (true) waste management objectives – thereby regaining the true meaning of "fiscal law".

6 Bibliography

v. Bechtolsheim, C.	2009	„Sachstand Vergaberechtsnovelle und abfallwirtschaftliche Ausschreibungspraxis", in: Müll und Abfall 2009, no. 2, pages 69-77.
Byok, J., Bormann, G.	2008	„Aktuelle Rechtsfragen zu der öffentlichen Auftragsvergabe in der Entsorgungswirtschaft", in: NVwZ 2008, no. 8, pages 842-848.
Gaßner, H., Siederer, W. (eds.);	2003	Handbuch Recht und Praxis der Abfallwirtschaft. Lexxion Verlag, Berlin, ISBN 978-3830503415.
Kunig, P., Paetow, S., Versteyl, L.-A.	2003	Kreislaufwirtschafts- und Abfallgesetz. Kommentar. 2nd ed. C.H.Beck Verlag, München, ISBN 978-3-406-49857-2.x
Lotze, A; Mager, S.	2007	„Entwicklungsmarkt der kartellrechtlichen Fallpraxis im Entsorgungsmarkt", in: WuW 2007, no. 3, pages 241-252.
Thimm, D.	2008	„Tauschähnlicher Umsatz in der Entsorgungswirtschaft – Ein Problemaufriss", in: AbfallR 2008, no. 4, pages 182-187.
Wenzel, F.	2008	„Überlassungspflichten für Verwertungsabfälle aus privaten Haushaltungen – Regel oder Ausnahme? - zugleich eine Anmerkung zu OVG Schleswig-Holstein, Urteil vom 22.4.2008 – 4 LB 7/06" in: ZUR 2008, no. 9, pages 411-418.

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Reliable determination of element contents in heterogeneous waste fractions

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Abstract

Recently a particle based procedure has been developed to characterize chlorine content in heterogeneous waste fractions by sorting analysis and fractionated chemical analysis. The procedure generates reliable results including variances within a few hours. At the same time the development of mobile RFA analysis allows on-site analytical characterization. The combination of sorting analysis and RFA elemental characterization may offer the opportunity for an on-site multiple elements characterization within a short period of time.

For testing those opportunities a RDF has been characterized not only by sorting but also by RFA analysis. The results show that the elements lead, cadmium, antimony, chromium and zinc are distributed extremely heterogeneous as known for the element chlorine. For every single element different “levels of preferred concentrations” occur. Therefore the result of a chemical analysis is strongly depending on the number of high load contributors reaching the sample and their particle weight.

Based on statistical demands the necessary sample size can be calculated. For every single element a different sample size is needed. On the other hand for a defined sample size the reliability of evidence varies from element to element.

The attempt to achieve a fast and reliable on-site-analysis can only deliver a screening. Producing reliable results either need an extremely high number of single “shots” or very small particle sizes. The mobile RFA may ideally be used in cases where huge load contributors have to be identified in order to get separated.

Inhaltsangabe

Die sortieranalytisch unterstützte Bestimmung des Chlorgehaltes von Abfällen ermöglicht eine schnelle Bestimmung unter Angabe des Vertrauensbereiches. In Verbindung mit tragbaren RFA-Schnellanalysatoren ergibt sich ggf. die Möglichkeit, innerhalb weniger Stunden für 30 chemische Elemente Gehalte und Vertrauensbereiche zu ermitteln.

Die Vorgehensweise ist an einem gut definierten Ersatzbrennstoff erprobt worden. Im Ergebnis zeigt sich, dass die Elemente Blei, Cadmium, Antimon, Chrom und Zink ähnlich heterogen verteilt vorliegen wie das Element Chlor. Für jedes Element sind verschiedene „Konzentrationsfenster“ unterscheidbar. Ein gemessener Analysenwert hängt damit entscheidend davon ab, wie viele Artikel aus den jeweiligen Konzentrationsfenstern in der Analysenprobe vorhanden sind und wie schwer die Artikel sind.

Aus der Stückzahlhäufigkeit der jeweiligen Frachtträger kann auf die erforderliche Probenmasse zurückgeschlossen werden. Dabei zeigt sich, dass zur Erreichung vergleichbarer Aussagesicherheiten für jedes Element eine spezifische Probenmasse erforderlich ist. Im Umkehrschluss ergibt sich für eine definierte Probenmasse elementspezifisch eine unterschiedliche Aussagesicherheit.

Der Zielsetzung einer Vor-Ort-Analytik mit der mobilen RFA kann im Rahmen einer orientierenden Analyse entsprochen werden. Eine exakte Analyse benötigt entweder eine extrem hohe Zahl an Messpunkten oder aber die Zerkleinerung des Materials auf sehr kleine Korngrößen. Die mobile RFA findet ihr Einsatzgebiet in erster Linie bei der Identifikation einzelner großer Frachtträger. Hier leistet sie sehr wertvolle Dienste.

Keywords

Elementgehalte; Heterogene Abfälle; Aussagesicherheit; Sortieranalysen; RFA-Schnellanalysatoren; Vor-Ort-Analysen; Qualitätssicherung; Inputkontrolle; Mindestprobenmasse

Element Contents; heterogeneous wastes; reliability; sorting analysis; mobile RFA analysis; on-site-analysis; quality assurance; input control; sample size definition

1 Introduction

Within the last years a particle based procedure has been developed to characterize heterogeneous waste fractions by sorting analysis which has been presented and published in scientific literature [KETELHUT 2006, KETELHUT 2008]. It has been shown that for characterization of elemental contents the results are determined by three factors:

- The portion of “load contributors” in the sample
- The ratio of average particle weights of load contributors and all particles
- The difference between element concentration in load contributors and background

Using this procedure the determination of the chlorine content in heterogeneous wastes can be done very fast and efficiently compared to chemical analysis. In addition the statistical framework like average, mode, mean and standard deviation can be defined precisely. This clearly exceeds the actual standards followed in chemical analysis.

At the same time the development of mobile RFA analysis has reached a level that the market offers on-site analytical characterization within a few seconds. The combination of sorting analysis and RFA elemental characterization may offer the opportunity for an on-site multiple elements characterization.

For testing those opportunities a RDF has been characterized not only by sorting analysis but also by RFA analysis. The results are presented here.

2 Sorting Analysis

A well known RDF with a d_{95} < 50 mm has been sampled by 15 single samples of 2 liters each for a whole day of production. During sorting analysis the material was separated into the fractions:

- Ferrous-Metal
- Non-ferrous Metal
- Minerals
- Organics (paper, cardboard, wood, biomass)
- Non-halogenated Ppolymers (NFT)
- Halogenated Polymers (Chlorine Load Contributors, FT)
- Fine Grain < 15 mm

The diversification of plastic for chlorine content was done by “Beilstein-testing”.

From the sorted fractions particle-mass distributions were developed by single parts weighing. Based on these distributions the mass contents of the fractions can be calculated using the statistically defined particle portion distributions.

The sample showed the following characteristics:

080910 X-Ray testing	Weight [g]	No. of Parts in Sample	Average Weight [g]	Percentage of No	Percentage of Mass > 15 mm	Percentage of Mass total	Percentage of Mass stat.	Cl Conc.	Cl Load	Percentage Cl-Load
Ferrous Metal	0,0	0	0,0	0,1%	0,0%	0,0%	0,0%			
Non-ferrous Metal	51,8	109	0,5	3,8%	2,5%	1,5%	1,9%			
Minerals	52	13	4,0	0,4%	2,5%	1,5%	1,5%			
Organics	701	993	0,7	34,3%	33,5%	20,6%	20,7%	0,3%	0,1%	4,1%
Polymers halogen.	234	147	1,6	5,1%	11,2%	6,9%	6,5%	19,8%	1,3%	81,0%
Polymers non hal.	1.052	1.629	0,65	56,3%	50,3%	30,9%	30,7%	0,4%	0,1%	6,8%
Sum sorted	2.090	2.891	0,72	100,0%	100,0%	61,4%	61,3%	2,4%	1,5%	91,9%
< 15 mm	1.315					38,6%	38,6%	0,3%	0,1%	8,1%
Total	3.405					100,0%	100,0%	1,6%	1,6%	100,0%

The chlorine content of the sample can be prognosticated as a cumulative frequency distribution using the chlorine contents gained from fractionated analyses in the past and the mass contents of the fractions based on the results of the actual sorting analysis.

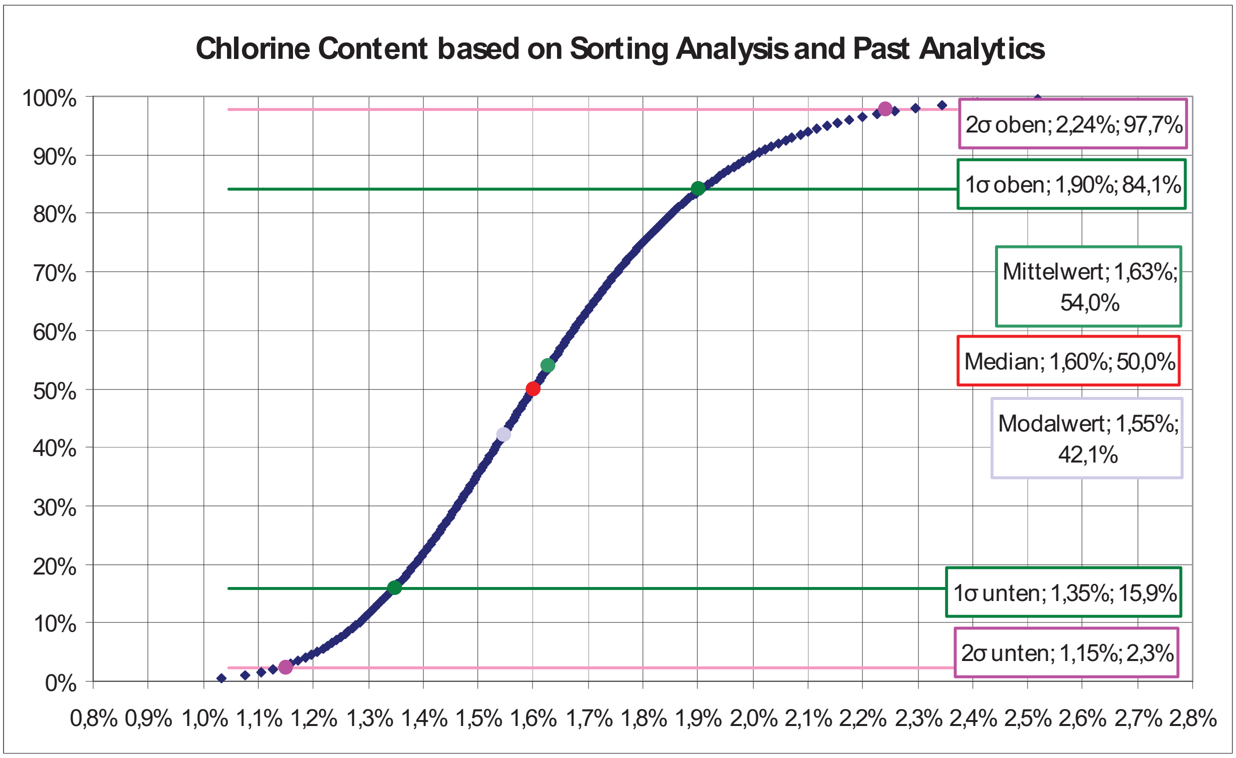

Figure 1: prognosis of the chlorine content

3 RF-Testing

The RF-Analysis was done by Mr. Stefan Rutsch from UBeRU (Rutsch Environmental Consulting) with a RF Spectrum Analyzer of the series XL3t 900 of Thermo – NITON which is marketed in Middle Europe by AnalytiCON Instruments GmbH.

From the organic fraction and from both of the plastic fractions a certain number of single particles were analyzed by RFA and weighted. The fine grain was analyzed by multiple “shots” on the whole fraction’s surface.

In total 299 Analyses were conducted.

- Organics 53 particles
- Non-halogenated plastics 85 particles
- Halogenated plastics 131 particles
- Fine Grain < 15 mm 30 shots one fraction’s surface

The measured number of particles did not correspond to the particles portions. Both of the metal fractions as well as the Minerals were not analyzed.

3.1 Results Chlorine

Chlorine was found in 287 out of the total of 299 single analyses.

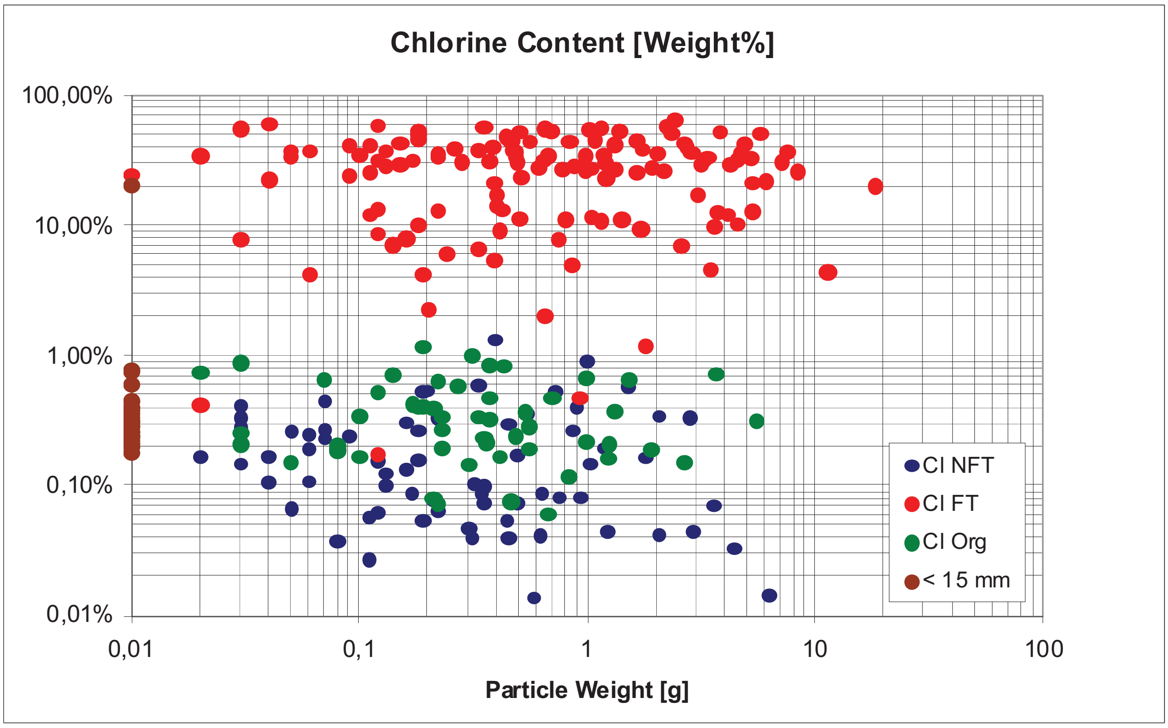

Figure 2: overview results for chlorine

Compiled as a cumulative frequency distribution the values look like this:

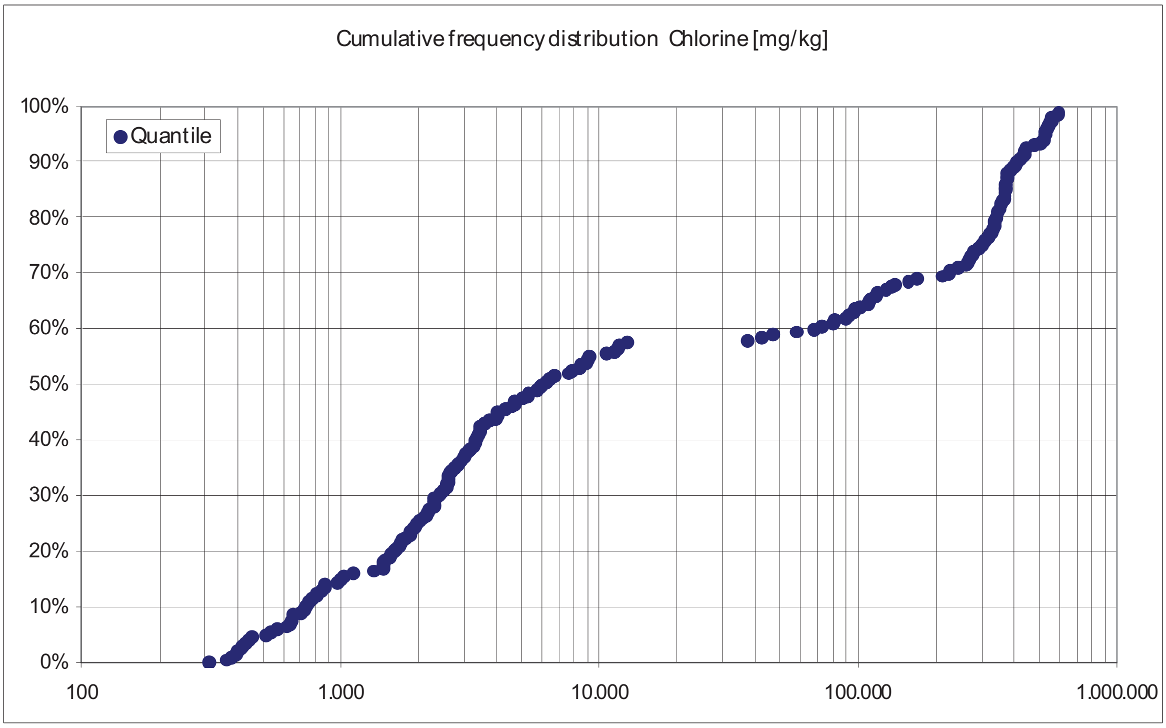

Figure 1: chlorine results as cumulative frequency distribution

It is obvious that the element chlorine is distributed in the very heterogeneous way. Especially striking is the gap between 2% and 4% chlorine content (20,000 and 40,000 mg/ kg). On this gap the differentiation between load contributors and background is based. The detailed analysis reveals that behind the found distribution four single distributions might be hidden:

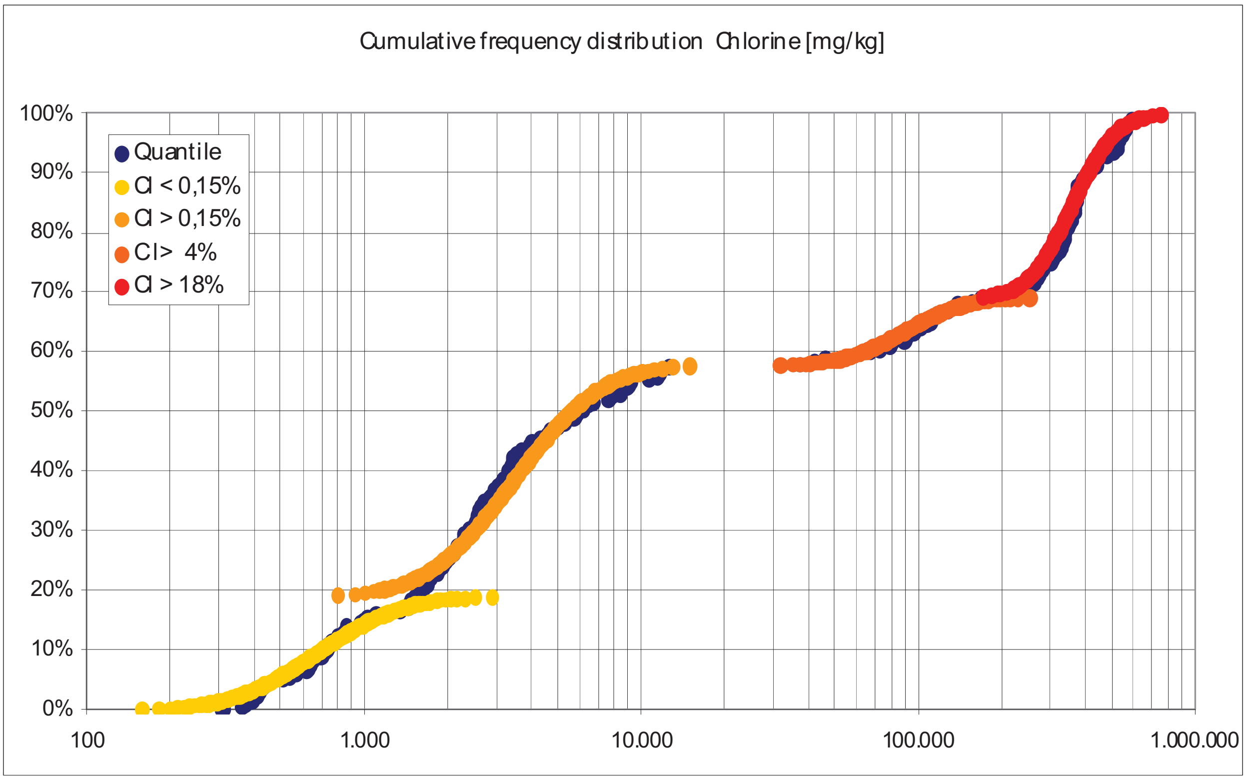

Figure 3: approximation of the distribution of chlorine values by four single distributions

Chlorine values > 18% are found in the halogenated plastics. A single value of 22% was also in the measurement in the fine grain <15 mm. The average of the single distribution is around 37.4%. The expected value for the occurrence of highly chlorinated articles is about 3.5%. It is likely to be PVC.

The orange curve approximates chlorine concentrations from 4 to 18%. It shows a relatively broad spectrum. The average chlorine content is close to 10%. Even these particles are found exclusively in the group of halogenated polymers. The frequency of occurrence of these particles is in the order of 1.3%. Several halogenated rubber products can be found here.

The chlorine levels below 2% can also be divided into two groups. The boundary concentration is in this case 0.15% respectively 1,500 mg/kg. Values below 1,500 mg/kg are mainly found in non-halogenated plastics and in some organic particles. Most results for the fine grain and a variety of measurements of organic particles are located in the range 0.15 to 0.8% chlorine. The mean of this distribution is approximately 0.4%.

For a reliable analytical testing (+/- 20% deviation from the true value) it is recommended reach a sample size that ensures to have at least 100 different load contributors in the analytical sample. If this number is significantly under-run the measurement is very much influenced by the stochastic weight of load contributors in the sample. For this RDF a sample for chlorine testing should comprise at least 7,500 articles > 15 mm.

3.2 Results Lead

67 out of 299 analyses show results for lead.

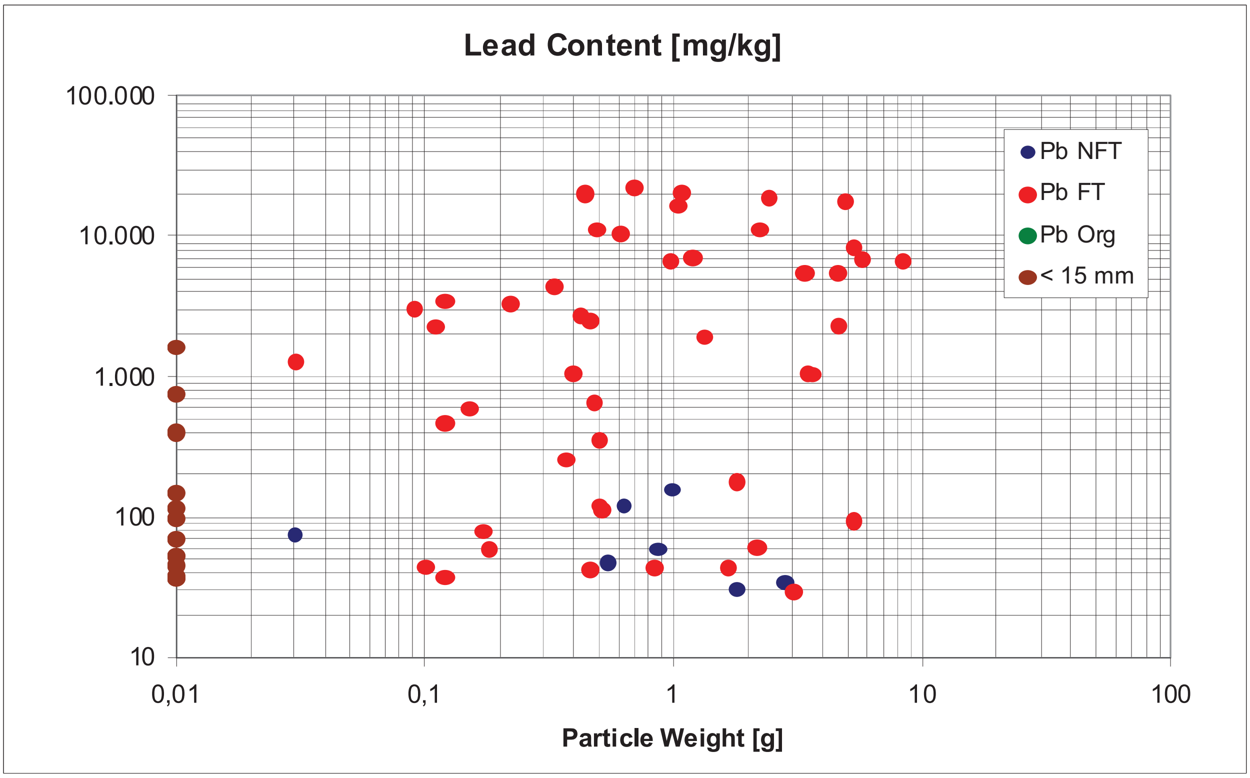

Figure 4: overview results for lead

Even the results for lead seem to belong to different uses resulting in distinguishable distributions. Lower concentrations are around 70 and up to 200 mg/kg. They are found in plastics and in the fine grain. Lead contents above 200 mg/kg are mainly found in halogenated polymers, which is not a surprise as lead compound are used as standard stabilizers in PVC. In addition three out of thirty shots on the fine grain delivered values above 200 mg/kg,

Around 1.2% of all articles have a lead content of > 200 mg/kg, so a reliable sample should at least cover 8,500 articles.

3.3 Results Cadmium

Based on a detection limit of 10 mg/kg cadmium was detectable in 44 measurements.

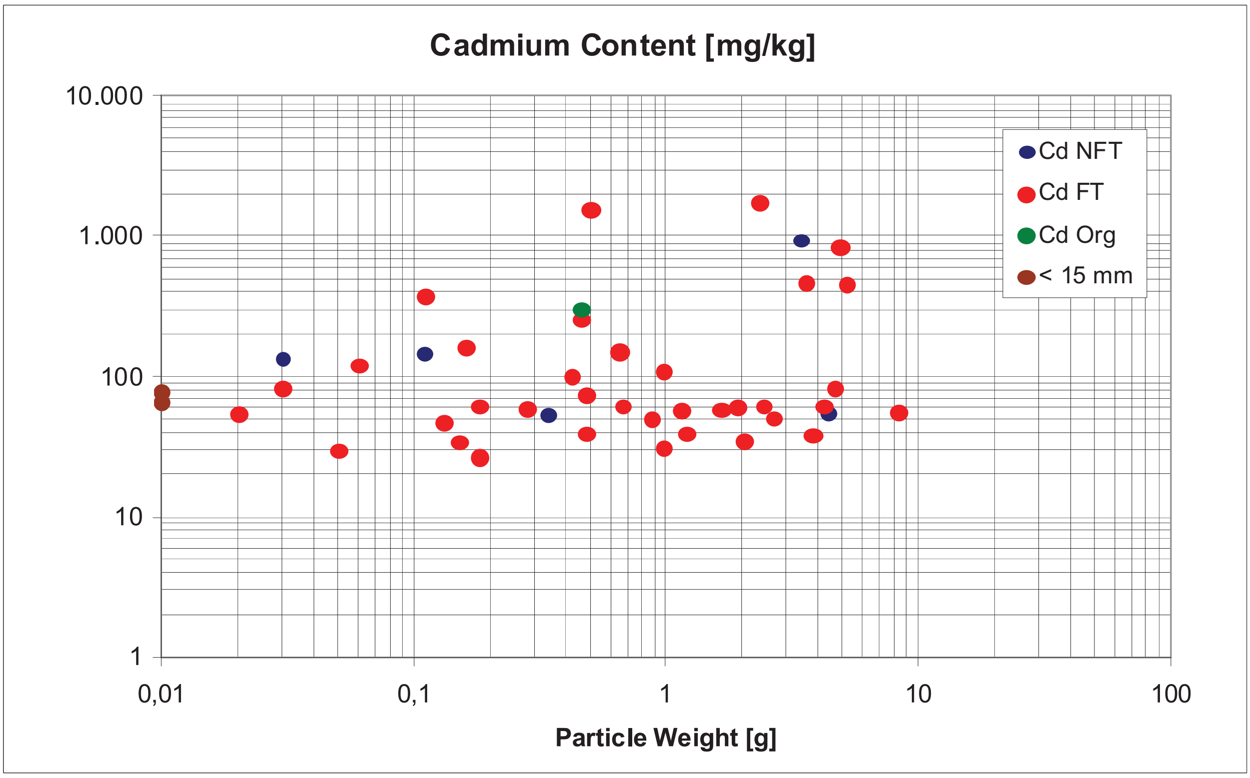

Figure 5: overview results for cadmium

Results < 80 mg/kg comprise 26 out of 44 positive results. 22 out of these were found in halogenated polymers. The average cadmium content is around 50 mg/kg. In the range up to 160 mg/kg six halogenated and two non halogenated polymers showed results.

The range form 160 up to 500 mg/kg covers 5 values. Apart of 4 findings in halogenated polymers an organic particle showed this kind of high cadmium concentration. Concentrations above of 500 mg/kg were found in further four articles. Again three out of the four were halogenated plastics.

Cadmium concentrations above 500 mg/kg are very seldom. In order to ensure the presence of around 100 particles of this type a sample should not contain less than 13,000 articles > 15 mm.

In small samples the presence of particle with a high cadmium load can significantly influence the analytical result.

Cadmium has been used for pigmentation and as an additive for PVC. Despite the decreased use in Europe it can still be found in waste fractions.

3.4 Results antimony

The element antimony was detectable in 61 out of 299 analyses.

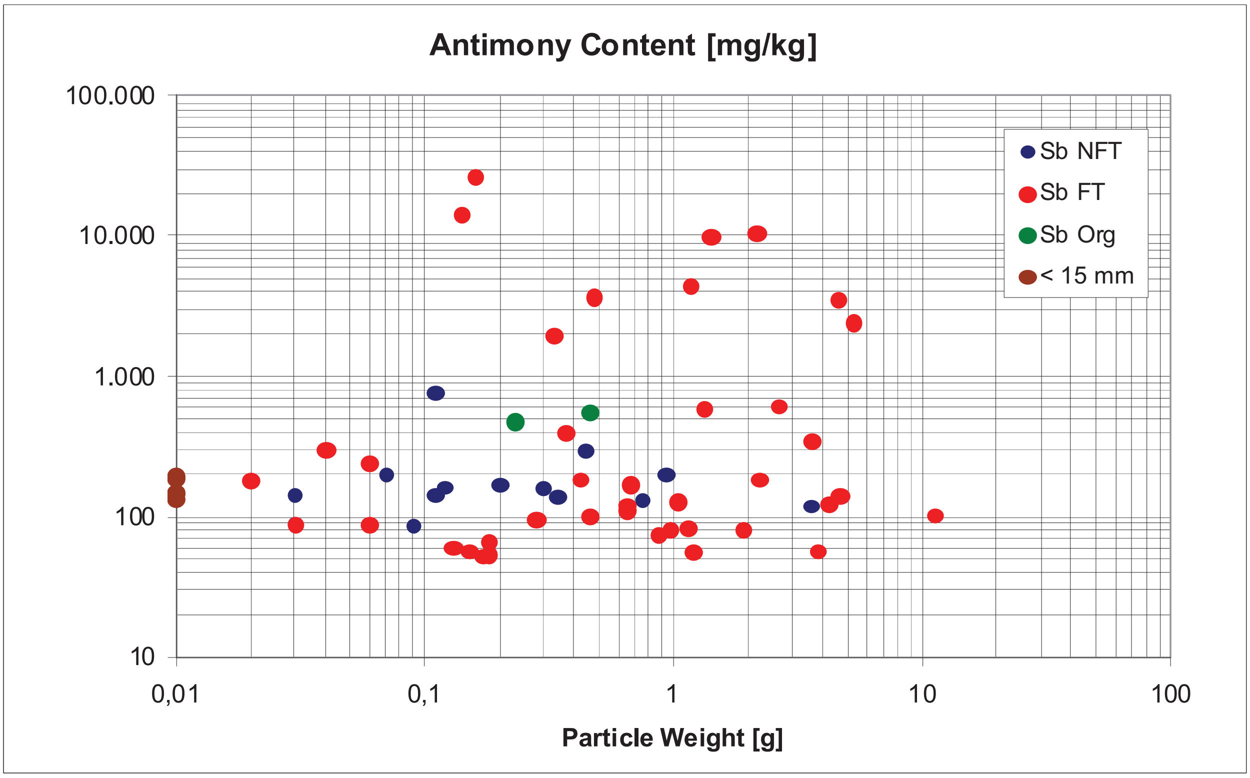

Figure 6: overview results for antimony

Two third of the measured results are related to concentration below 200 mg/kg. They belong to all fractions except the organic fraction. 20% of the values are located between 200 and 800 mg/kg. Here apart of the polymer fraction two organic articles appeared to contribute some antimony load.

The region above 800 mg/kg was only reached from halogenated polymers. Very likely this arises from the use of antimony trioxide as flame retardant, where either polybrominated compounds or even PVC have a synergistic function.

Only three out of one thousand articles contain antimony in such high concentrations. This is why especially for antimony very huge sample sizes are needed. In this case it is recommended to go for a sample size of > 32,000 articles > 15 mm.

It is very likely, that the reported difficulties to generate reproducible results in antimony testing [FLAMME 2009] have to do with these rare parts providing a very high antimony load.

3.5 Results chromium

For chromium we revealed 110 analyses above the detection limit.

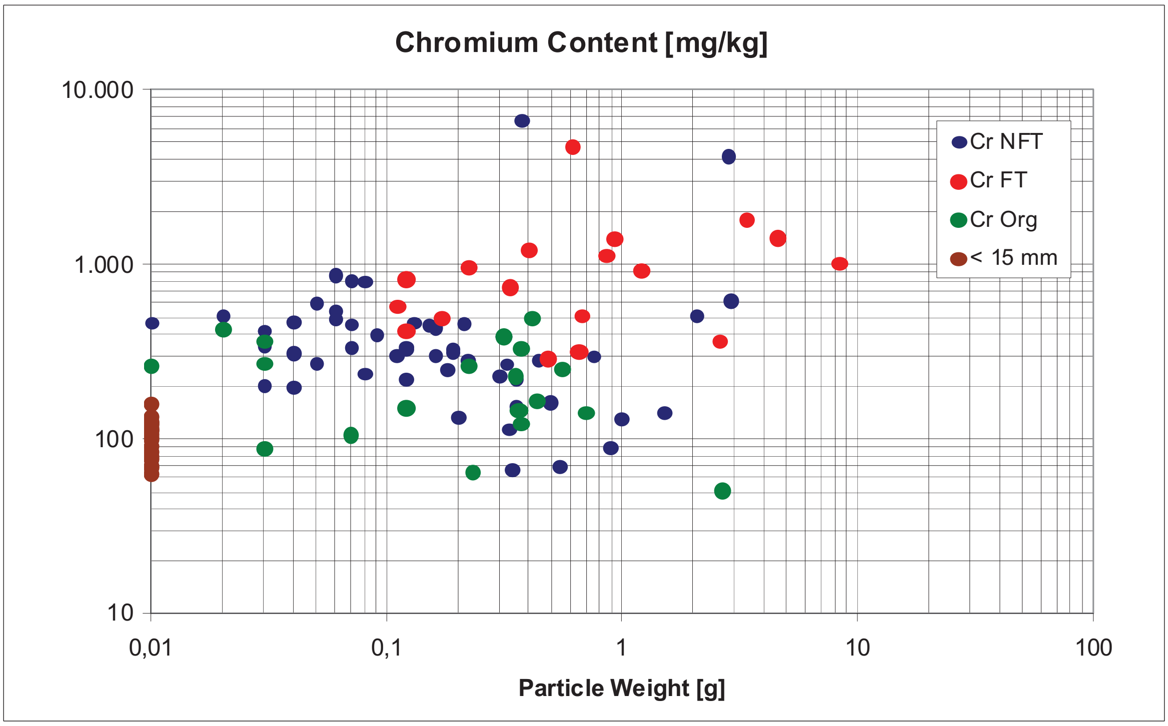

Figure 7: overview results for chromium

Obiously these results belong to different application of the element.

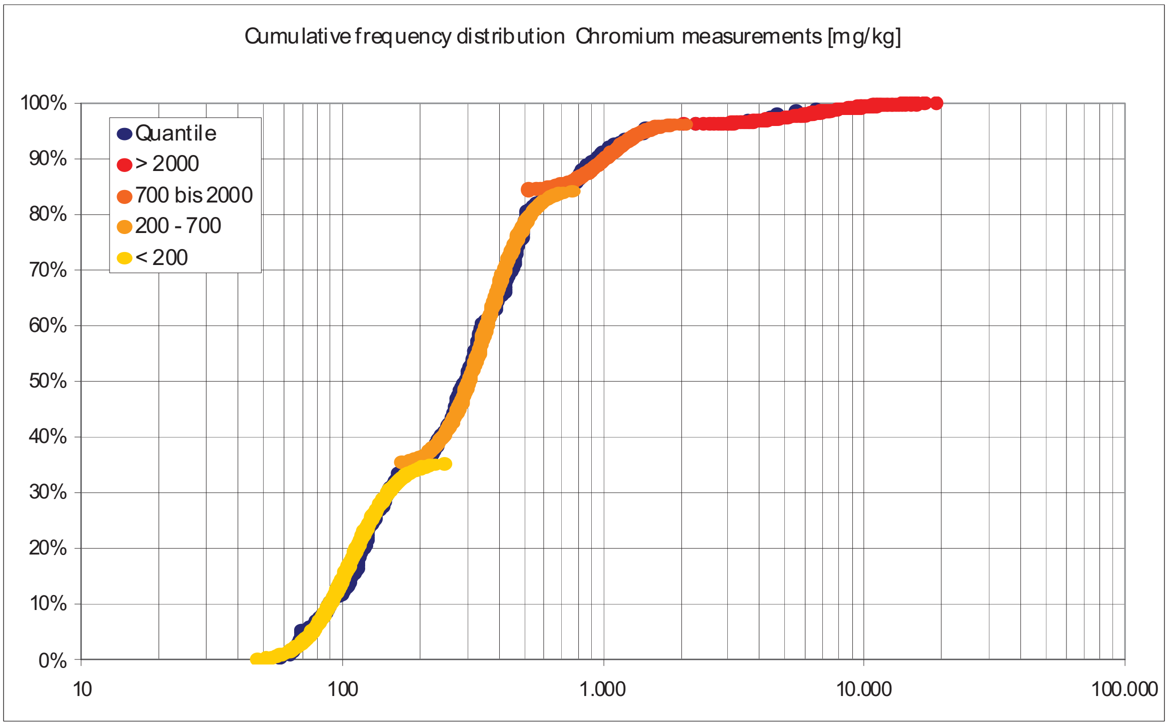

Figure 8: approximation of the distribution of chromium values by four single distributions

Around 30% of the results show values below 200 mg/kg. They belong to organic particles and non-halogenated polymers. Almost 63% of the values fit in the region between 200 and 700 mg/kg. Here we find a comparable amount of organic particles and a huge quantity of non-halogenated polymers.

Concentrations above 700 mg/kg are only found in polymers. Halogenated polymers do not attract specific attention.

The expected value for the quantity is around 5%, so a 5,000 piece sample will be large enough for the delivery of reliable results.

High concentrations may indicate the use of chromium pigments.

3.6 Results zinc

With respect to zinc 60% of all measurements led to results.

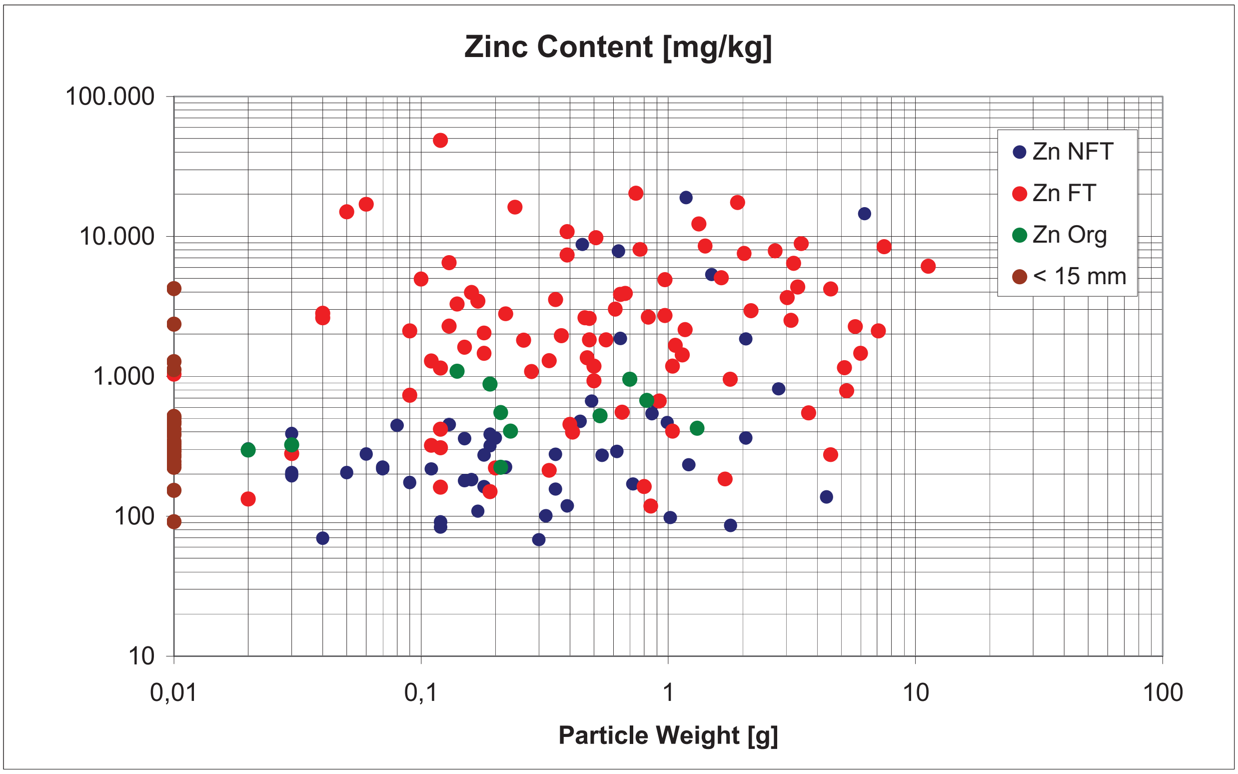

Figure 9: overview results for zinc

The cumulative density distribution allows the conclusion that the values belong to three different distributions.

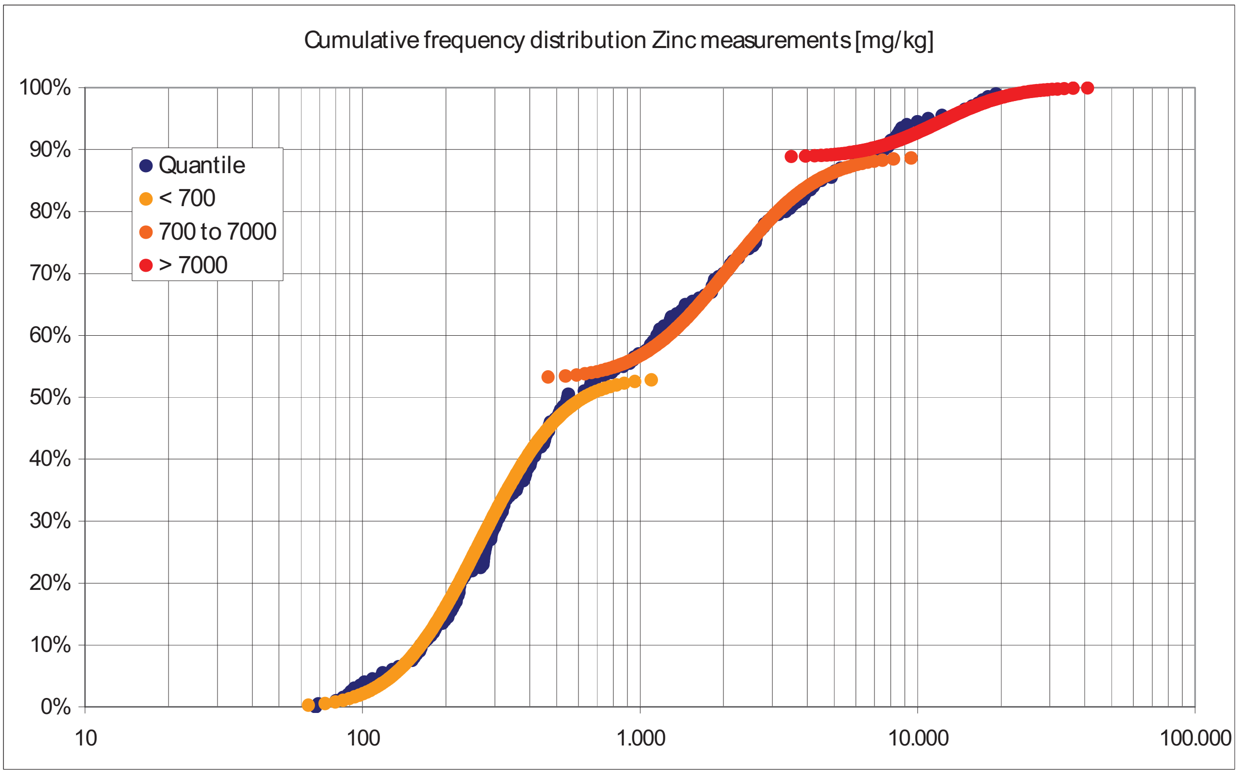

Figure 10: approximation of the distribution of zinc values by three single distributions

Almost 80% of all results stay below 700 mg/kg. The values affect primarily organics and not halogenated polymers. Results between 700 and 7,000 mg/kg are found for halogenated polymers and less for organics and non-halogenated polymers. Values exceeding 7,000 mg/kg were contributed from halogenated polymers and some other polymers.

Seven out of one hundred articles provide a significant zinc load. This leads to comparably small sample sizes.

Zinc is widely used in chemical additives. White pigments and fillers may contain zinc as well as the standard additives for PVC.

4 Load portions and recommended sample sizes

A comparison of the load contributed by the different levels of concentrations shows that more than 50% of the total element load comes from very less particles with very high element concentrations.

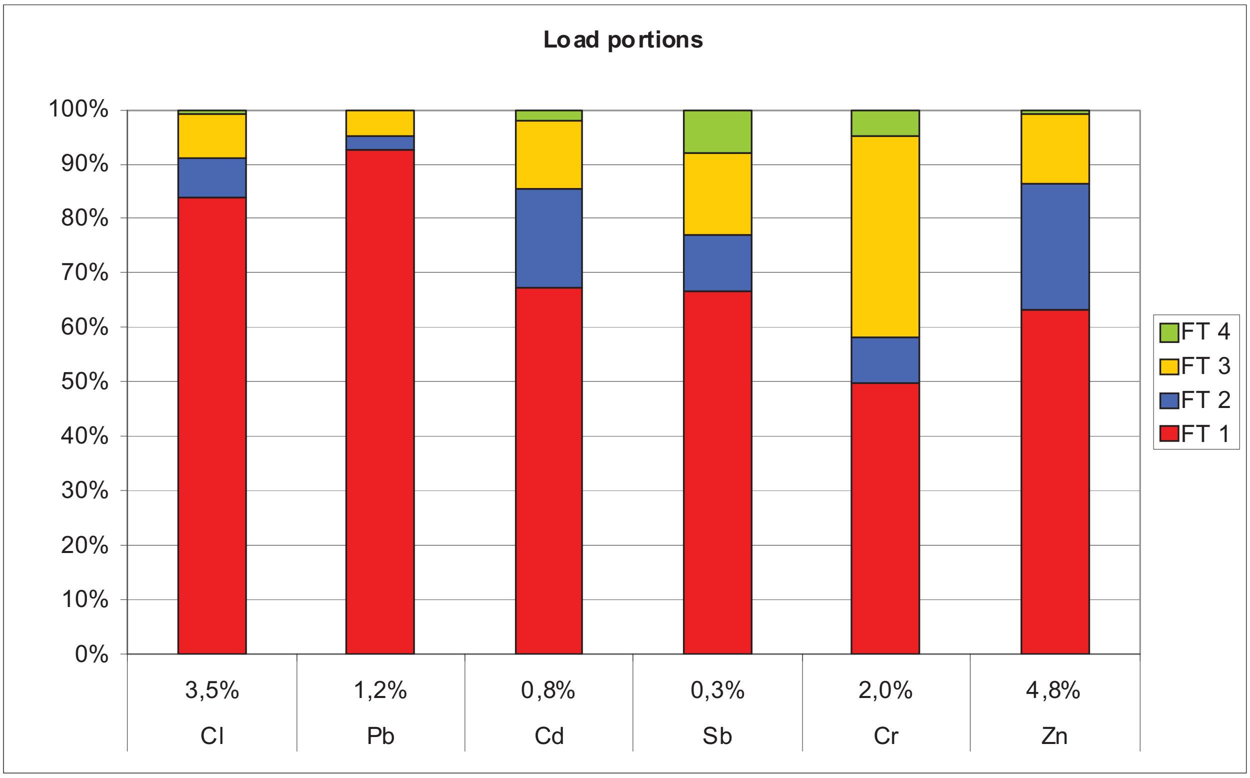

Figure 11: load contributions from different levels of concentration

While the load contribution from the highest concentration levels is around 50% for chromium it reaches values between 60 and 70% for the elements zinc, antimony and cadmium.

Regarding chlorine more than 80% of the total load is contributed by PVC. Concerning lead the portion may even reach 90%.

This makes clear that the concentrations measured in a single analysis for different elements have different reliabilities or to say it the other way round: for reaching a certain level of liability a specific sample size is needed for every single element.

The following figure compares the recommended sample sizes for this RDF based on the requirement to ensure the presence of 100 load contributors for the specific element.

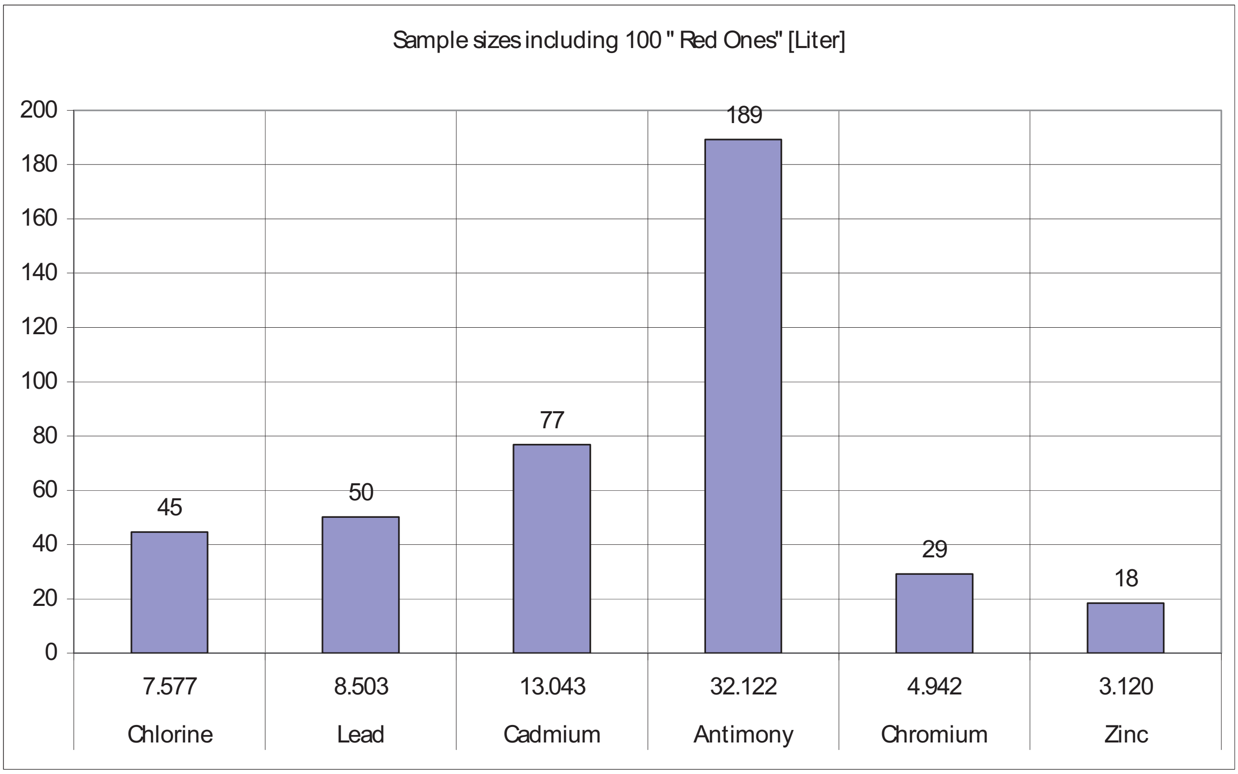

Figure 12: recommended sample sizes for different elements

The comparison shows that for an RDF with a d_{95} < 50 mm sample sizes below 20 Liters should not be used at all. Sampling 50 Liters will lead to acceptable results for zinc, chromium, lead and chlorine, while the generated values for cadmium and especially antimony will not be on the same level of liability. These values can easily under- or even overestimate the true element content.

In this case to produce a reliable analytical result for antimony 190 Liter of material is necessary. This 190 Liter must not be reduced without previous grinding to a smaller particle size.

Combining RF-Analysis and sorting analysis leads to very interesting findings concerning different sources for elemental loads. The attempt to achieve a fast and reliable on-site-analysis did not reach the target. For the particle sizes we have found here, RF-analysis can only deliver a screening. Producing reliable results either need an extremely high number of single “shots” or very small particle sizes.

The mobile RFA may ideally be used in cases where huge load contributors have to be identified in order to get separated.

5 Literature

Flamme, Sabine	2009	Analyse der Schwermetallgehalte von Ersatz-brennstoffen – 1678. In: Müllhandbuch digtal, MuA Lfg. 1/09. Berlin: Erich Schmidt Verlag GmbH & Co. 2009
Ketelhut, Ralf	2006	Abfälle sauber definieren: physikalische Parameter In: Müll und Abfall 1/2006, page 35 ff, chemische Parameter In: Müll und Abfall 2/2006, page 84ff
Ketelhut Ralf	2008	Chloranalytik in heizwertreichen Abfällen - nicht mehr (als) nötig!, Part 1 in: Müll und Abfall 1/2008, page 25 ff, part 2 in: Müll und Abfall 2/2008, page 80 ff

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Municipal solid waste composition and assessment: a case study in Kocaeli, Turkey

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Abstract

Composition of municipal wastes as well as projection of waste-generation and -disposal rates is need to plan and implement disposal and recycling activities. The primary objectives of the study are to characterize and evaluate the recycling potentials of the municipal solid waste. Waste sorts were conducted during the summer and winter of 2008 at the City of Kocaeli. A detailed physical sampling protocol was outlined. Weight fractions of 17 waste components were quantified from all geographic areas that contribute to the Kocaeli Sanitary Landfills. Each region was divided into four groups, i.e., low-income, middle-income, high-income and commercial district. Comparisons of solid waste generated between locations and seasons were conducted. The composition of the entire waste stream was organic wastes (38 – 41%), recyclable items (26 – 38%), combustible wastes (15 – 22%), hazardous wastes (1 – 2%), and others (3 – 12%).

Keywords

Municipal solid wastes, solid waste composition, recycling

1 Introduction

Turkey covers an area of 780,580 km^2 with a population of 67.8 million according to the 2000 population survey. According to the recent survey conducted by the State Institute of Statistics (SIS), 28.5% of municipal solid waste (MSW) collected from municipalities was disposed in engineered sanitary landfills. While 63.4% of MSW was deposited in municipality dumps improperly constructed without bottom linings and leachate/gas collection systems, 5.9% was open dumped, 1.2% composted, and 1.0% was open burned (SIS, 2005). In 1991, there was no sanitary landfill; and the same institute reported that over 90% of MSW was disposed in non-engineered city dumps. Currently, there are more than 30 engineered sanitary landfills in Turkey. Kocaeli is located in the Marmara Region, between 29.960°E longitude, 40.790°N latitude, surrounded by Sakarya from its east and southeast, Bursa on the south, The Izmit gulf, Yalova and The Marmara Sea and Istanbul on the west, and the Black Sea on the north. It is located on an important crossroad binding Asia to Europe (Figure 1). Kocaeli with a population of 1.5 million is one of the largest commercial and industrial centres of Turkey. It is divided into 7 regions and 44 sub-regions. Each region has its own municipality. Each sub-regional municipality is responsible for collection and transportation of solid wastes generated within its region. These sub-regional municipalities are working under the supervision of regional municipalities. Kocaeli has undergone a dense industrialization since the 1960s, which was followed by a rapid increase in population and an irregular urbanization. The city has a state-of-the-art sanitary landfill designed and constructed by German engineers in 2000.

Figure 1 *Turkey's map and the location of the city of Kocaeli*

Waste composition is critical in the planning, design, and operation of solid waste management systems. Waste composition should be carried out as a first step in solid waste management since management entails the handling, processing, and conversion of materials (SAVAGE AND DIAZ, 1997). In addition, any waste management plan must be related to a specific waste composition (HASSAN ET AL., 2000). MSW composition varies substantially from country to country and even region to region within a city due to the amount of community recycling activities, banned items, etc. Therefore, there is no substitute for a local analysis and a comprehensive MSW composition is necessary for every municipality. In the beginning of 2008, Turkish Ministry of Environment and Forestry has started a nationwide survey and asked to every municipality in Turkey to collect and compile data on their MSW characterization. This paper discusses the results of MSW composition data obtained in summer and winter of 2008 for the city of Kocaeli.

2 Methodology

Waste composition study has been carried out for 25 sub-regional municipalities (out of 44) having populations more than 5,000. The MSW samples are taken from four different regions within each sub-district, i.e., low income, middle income, high income and commercial areas. Waste is sorted into 17 category namely kitchen wastes, paper, cardboard, cardboard boxes, plastics, glasses, metals, bulky metallic wastes, electronic wastes, hazardous wastes, yard wastes, other non-combustibles, other combustibles, other combustible bulky items, other non-combustible bulky items, and miscellaneous wastes. The constituents of each waste group are provided in Table 1.

Table 1 Main waste classification

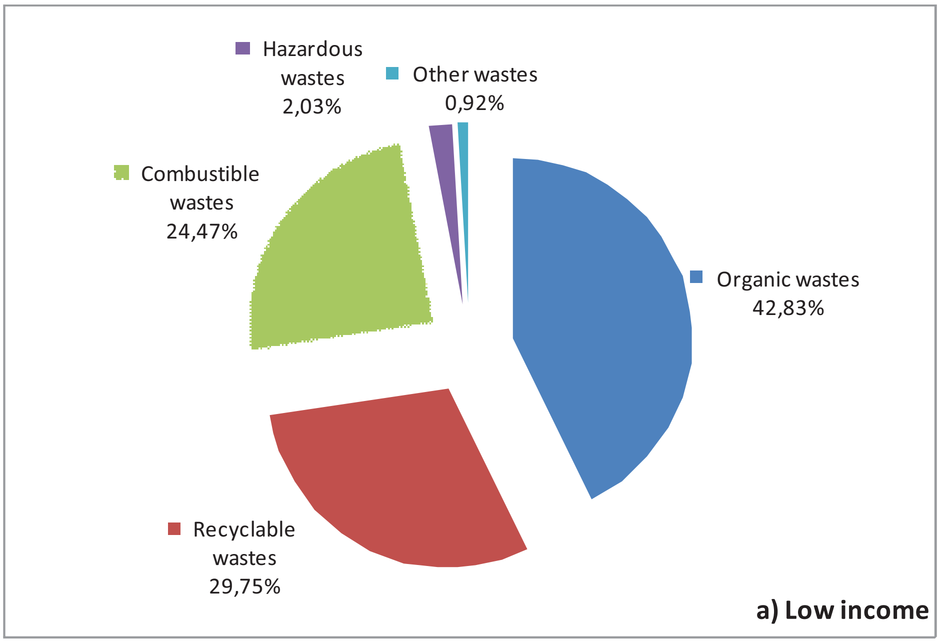
Waste class	Waste components	Waste constituents
Organic	Kitchen wastes	Food wastes, bread, fruits, vegetables
	Yard wastes	Yard trimmings, leaves, grass, crop residues
Recyclable	Paper	Newspaper, magazines, office paper
	Cardboard	Milk boxes, juice boxes
	Cardboard boxes	Various types of cardboard boxes
	Plastics	HDPE, PET, PVC, Film plastic
	Glasses	Clear bottles, colored bottles, flat glass
	Metals	Ferrous metals, aluminium cans
	Bulky metallic wastes	Metal cabinets, metal tables
Combustible	Other combustibles	Textiles, wood, diapers, shoes, rugs
	Other combustible bulky items	Furniture, wooden cupboard
Hazardous	Electronic wastes	Computers, radios, phones
	Hazardous wastes	Batteries, detergent boxes, medicine bottles
Others	Other non-combustibles	Rock, concrete, soil, dirt, brick, ceramics
	Other non-combustible bulky items	Refrigerators, washing machines
	Miscellaneous	Remainder/composite
	Ash (only in winter)	Ash from coal burning

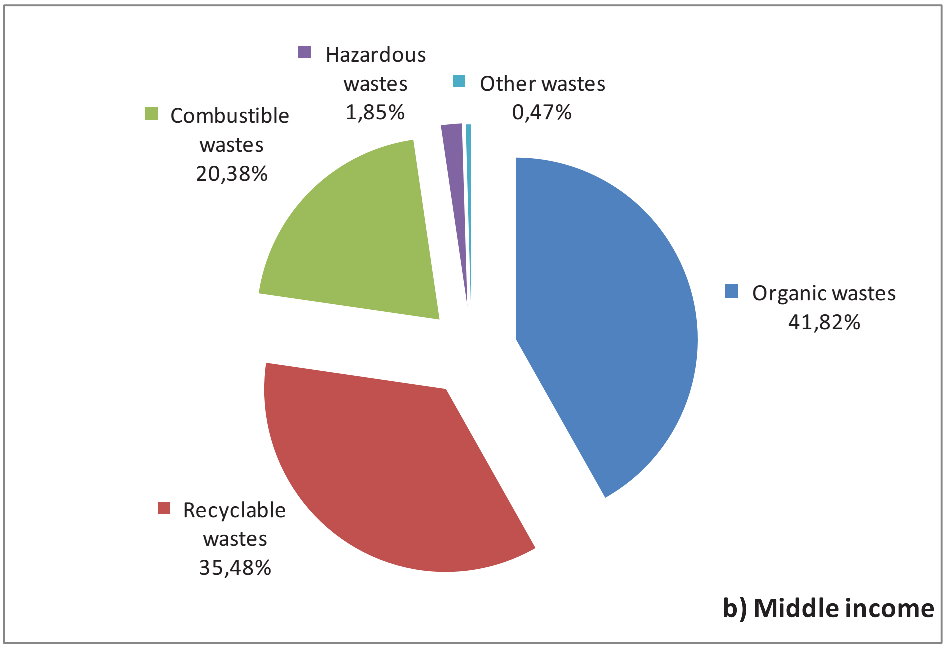
The sampling is repeated in summer and winter of 2008. Approximately 1 m^3 of samples are taken from the collection vehicles at disposal sites. To carry out the analysis, the wastes in the samples are sorted according to the 17 categories listed in Table 1. In the sorting process, each type of waste is placed in its appropriate container (see Figure 2). At the completion of the sorting, each container and its contents are weighed (gross weight). Gross and tare (empty container) weights are recorded. The difference between the two weights is the net weight of the individual type of wastes. In winter, the amount of ash resulted from household coal burning is separately determined. The ash amount is determined with the use of manually manipulated screens. The screens have square openings of 1 cm2. After bulky wastes are sorted, composite waste is placed on the screen. The screen is shaken until particles of refuse no longer pass through the openings. Material remaining on the screen (oversize) is collected and re-sorted. The material that has passed through the screen (undersize) is considered as ash.

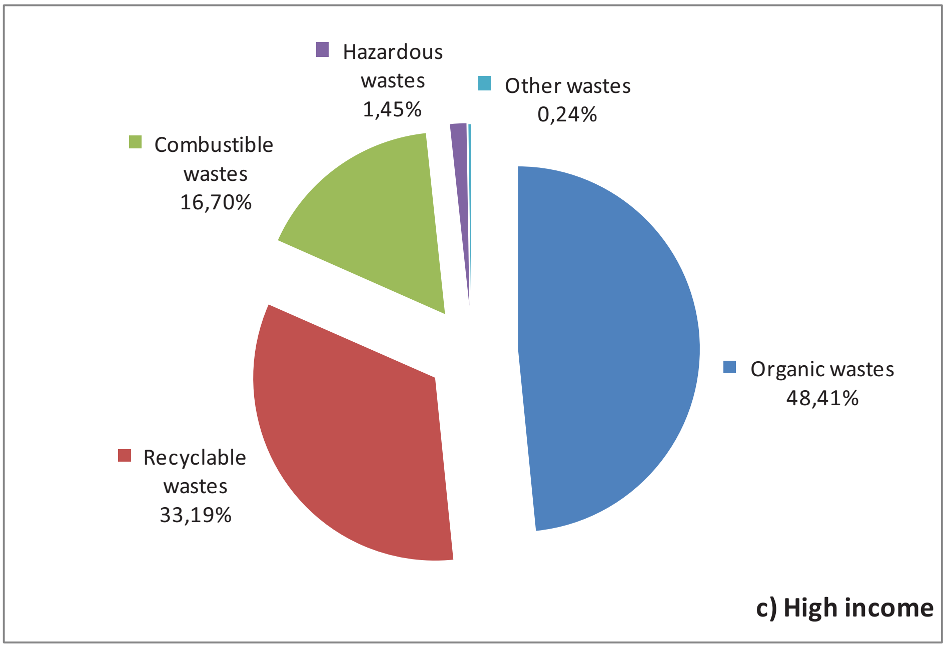
Figure 2 MSW Sorting process

3 Results and discussion

The waste components sorted are further grouped under 5 different main categories depending on their physical, chemical and biological properties. These are organic wastes, recyclable wastes, combustible wastes, hazardous wastes and other wastes (Table 1). The break-down of the main waste classes and their average percentage distribution for different socio-economic categories in 25 sub-districts of Kocaeli are given in Figures 3 and 4. Solid waste compositions in summer and winter have been found to be relatively stable. Organic wastes always comprise the highest portion, followed by recyclable wastes and combustible wastes. In Kocaeli, organic wastes account for about 42 – 49 % of the total waste streams in summer and 34 – 44 % in winter. Maximum rates of organic waste discard occurred in summer due to greater availability of fruits and vegetables. On the other hand, recyclable wastes account for 30 – 40 % in summer and 21 – 36 % in winter. Although the comparison of national waste statistics may not be a simple task, due to the difference in compositional classifications and the manner in which the data were collected, solid waste composition in Kocaeli has been found to be quite similar to that in other major metropolitan cities of Turkey, e.g., Istanbul, Izmir, Bursa, Adana (METIN ET AL., 2003; BERKUN ET AL., 2005), and those in major cities in the developing countries, but very different from those in cities of the developed countries in the world (UNEP, 2005). The organic wastes in Kocaeli almost doubled the percentage in the major cities of developed countries. The amounts of other wastes are substantially increased in winter due mainly to high rates of ash production from coal use for space heating.







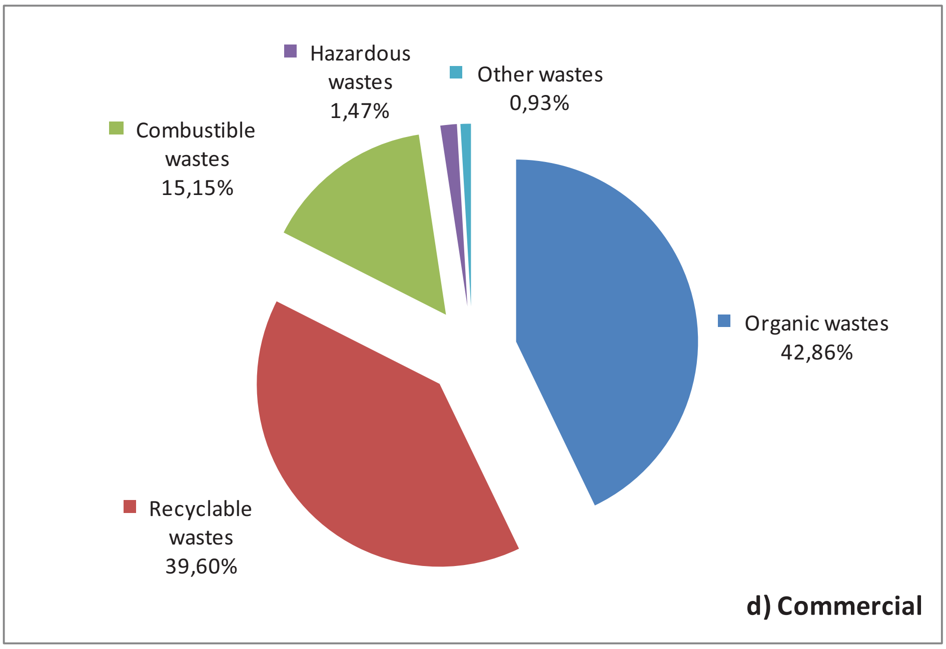
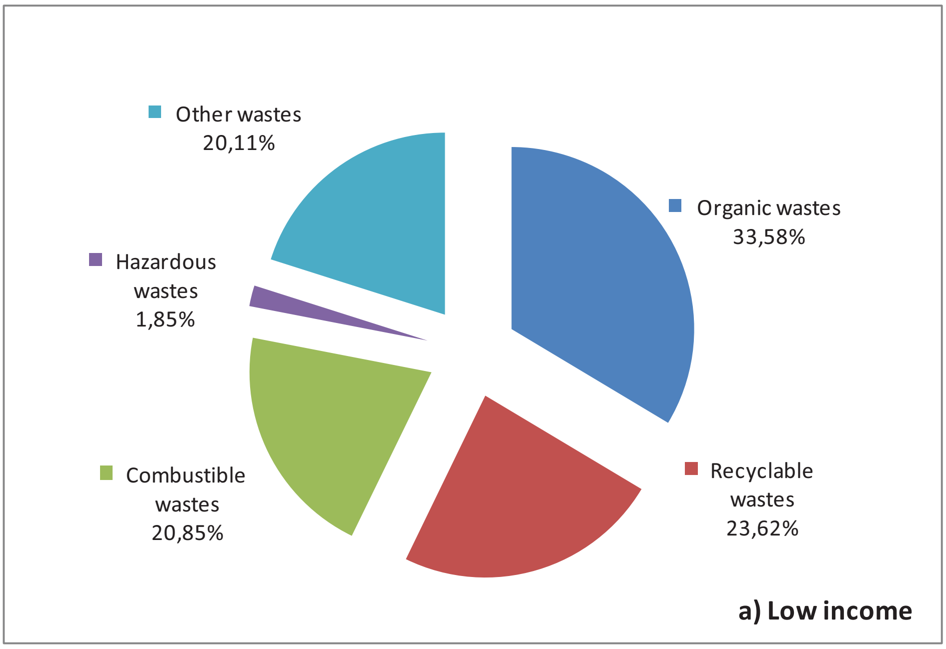
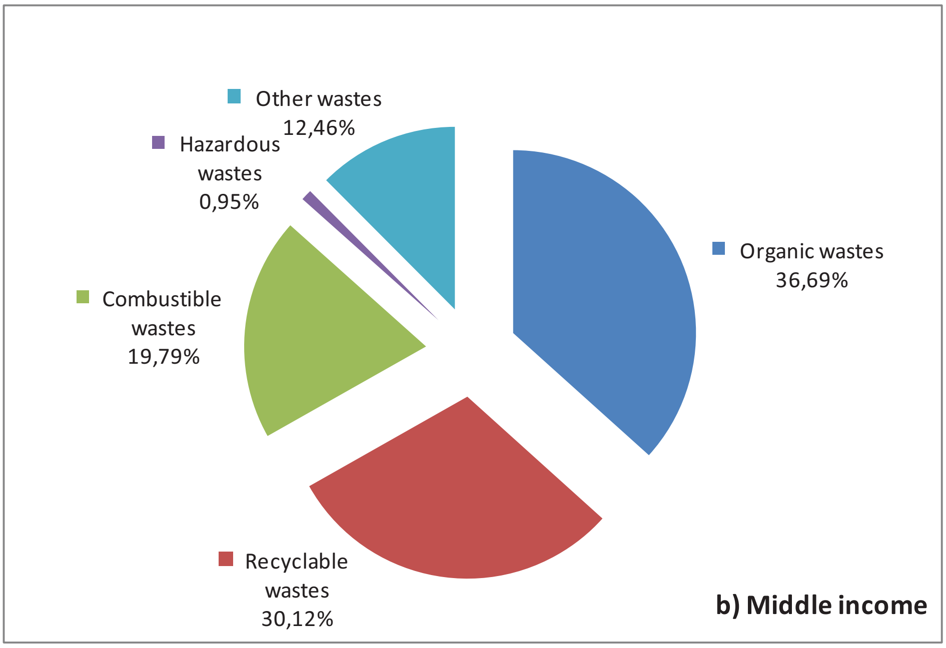


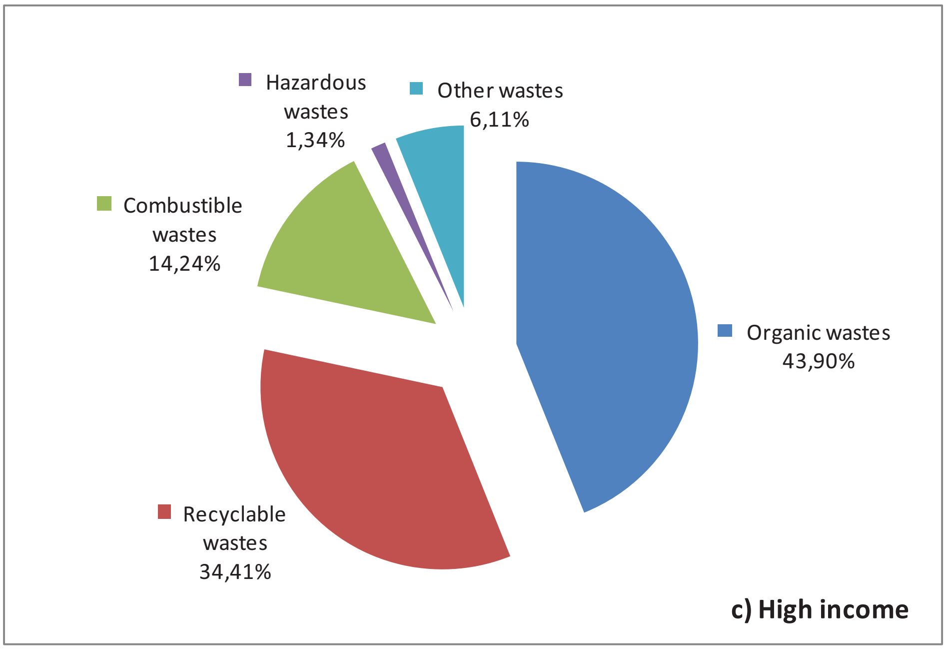
Figure 3 Average MSW compositions for Kocaeli in sumer

Recycling may sometimes be far more costly than originally anticipated. Collection and handling costs have always formed a large component for material recycling, and the quality of waste materials separated for recycling has frequently been inadequate for direct resale (BAI ET AL., 2002). Although there is no comprehensive recycling program carried out by the central municipality in Kocaeli, there are several success stories achieved by few sub-regional municipalities in the past. In general, recyclable materials are collected mainly by individuals (scavengers) under non-hygienic conditions and sold to private companies. At present, the key players are scavengers, middlemen and traders. Currently, an integrated solid waste management strategy is under preparation for the central municipality. This anticipated strategy has a state-of-the-art recovery plant and a MSW baling and packing plant.

Since paper, plastics, glass and metals have been the most commonly separated waste materials for recycling purposes, the average percentage distribution of these individual components in recyclable wastes are provided in Table 2. It can be noted that the percentage of plastics in the recyclable wastes is relatively high. This is due to fact that plastics rather than paper is widely used in packaging in Turkey. The increase in the amount of plastics in summer can be explained by the fact that it is very common using drinking water in disposable plastic bottles.







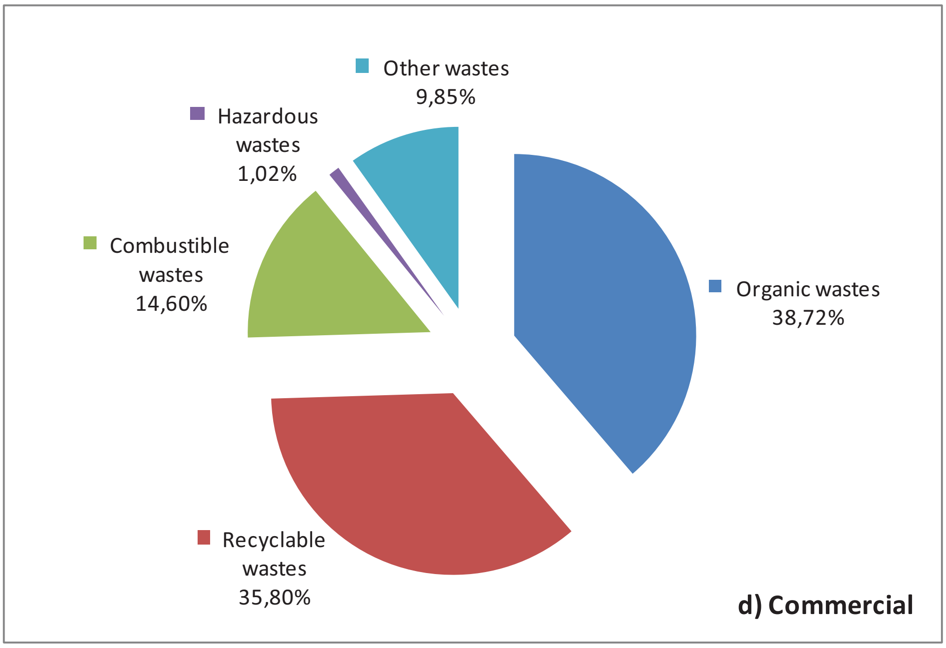


Figure 4 Average MSW compositions for Kocaeli in winter

The average per capita MSW generation in Turkey is assumed to be 0.95 kg/person-day (Metin et al., 2003). Therefore, Kocaeli's daily MSW production amounts to 1425 metric tonnes (0.5 million metric tonnes per year). The average amounts of paper including cardboard and cardboard boxes, plastics, glass, metals including bulk metallic wastes are 61550, 75650, 18100, 7550 tonnes per year, respectively. The average buying prices at source for paper including cardboard and cardboard boxes, plastics, glass, metals including bulk metallic wastes are determined as about € 60, 115, 25, 100 $^{-1}$, respectively (METIN ET AL., 2003).

Table 2 Average recyclable waste components

Recyclable waste components	Percent by weight		
	Summer	Winter	Average
Paper	5.88	4.33	5.11
Cardboard	2.61	2.75	2.68
Cardboard boxes	4.65	4.38	4.52
Plastics	16.11	14.15	15.13
Glasses	3.81	3.43	3.62
Metals	1.30	1.65	1.48
Bulky metallic wastes	0.01	0.04	0.03

Thus, the total potential economic value for separating recyclable materials from the waste stream at source in Kocaeli is about € 3.7, 8.7, 0.5, 0.8 million y^{-1}. Due to technical, economic and management constraints, no country is able to recycle 100% of their recyclable wastes. If it is assumed that 75% of the recyclable wastes could be recycled, the estimated total revenue from selling recyclable wastes at source is about € 2.8, 6.5, 0.4, 0.6 million y^{-1}. At this 75% level, the estimated potential revenue from recyclable wastes is about € 10.3 million y^{-1}.

4. Conclusions

For the protection of conservation of natural sources in Kocaeli, MSW recycling must be provided. In addition, the above-mentioned estimates clearly indicate the economic potential for recycling of wastes in Kocaeli. Separation of MSW components at the source of generation is the most effective way to achieve the recovery and reuse of recyclable materials. Kocaeli should have its own MSW management strategy since the differences in solid waste composition have a great impact on the system of solid waste management. Recyclable waste collection centres should be created to encourage recycling. A price, even in a small amount, paid especially for used papers, glasses and metal products can motivate the delivery of these materials to the collection centres.

5. Acknowledgements

Thanks are due to the Metropolitan Municipality of Kocaeli and the Izmit Waste and Residue Treatment, Incineration and Recycling Co. for their financial support.

6. Literature

Savage, G.M., Diaz, L.F.	1997	Solid waste characterization in the United States. Proc., 6th Int. Landfill Symp., Sardinia, Italy, 253-261.
Hassan, M.H.	2000	Waste recycling in Malaysia: problems and prospects. Waste Management and Research, 18, 320-328.
Bai, R., Sutanto, M.	2002	The practice and challenges of solid waste management in Singapore. Waste Management, 22, 557-567.
Metin, E.	2003	Solid waste management practices and review of recovery and recycling operations in Turkey. Waste Management, 23, 425-432.
Berkun, M.	2005	Disposal of solid waste in Istanbul and along the Black Sea coast of Turkey. Waste Management, 25, 847-855.
SIS	2005	Municipality Solid Waste Statistics, Office of the Prime Minister, Ankara, Turkey.
UNEP	2005	Solid waste management. United Nations Environment Programme. ISBN: 92-807-2676-5.

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Ergebnisse von Vergleichsuntersuchungen verschiedener europäischer Parameter zur Bestimmung des biologischen Stabilisierungsgrades

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Results of comparative studies of various European parameters for determining degree of biological stabilization

Abstract

Base for the comparison of various European parameters for determination of biological stability degree of products of biological treatment of residual waste, were investigations conducted on different plants for biological treatment in Europe. Samples of the input material, of intermediate products and the output material were taken and the following parameters were investigated: BM100, SRI, DR4, ASTM, PDRI. The results of laboratory tests were statistically evaluated to find out correlations between the different-parameters.

Inhaltsangabe

Ausgangspunkt für den Vergleich verschiedener europäischer Parameter zur Bestimmung des biologischen Stabilisierungsgrades von Rotteprodukten waren Untersuchungen auf zehn verschiedenen Abfallbehandlungsanlagen für Resthausmüll in Europa. Auf diesen Anlagen wurden Proben des Rotteinputmateriales, von Rottezwischenprodukten und des ausgerotteten Materiales gezogen und auf folgende Parameter untersucht: BM100, AT4, DR4, ASTM, PDRI. Die Ergebnisse der Laboruntersuchungen wurden statistisch verrechnet und überprüft, inwieweit Korrelationen zwischen den untersuchten Parametern bestehen.

Keywords

Resthausmüll, Mechanisch-biologische Abfallbehandlung, MBA, biologische Stabilisierung, AT4, DR4, ASTM, PDRi, BM100

Municipal solid waste, mechanical-biological treatment, MBT, biological stabilisation, SRI,

1 Introduction

The results of the comparison of different biodegradability indices are derived from sampling and analysis from various MBT plants in Europe. The scope of the investigations was to determine the performance of these plants and to establish correlations between different stability parameters.

Following stability parameters, which are used in different countries, were applied:

➢ Biochemical Methane Potential (BM100)	UK
➢ Dynamic Respiration Rate (DR4)	UK
➢ Static respiration rate (AT4)	Germany, Austria
➢ Potential Dynamic Respiration Index (PDRI)	Italy
➢ Test Method for Determining the Stability of Compost (ASTM)	USA

2 Stability tests

In the following the investigated stability test are shortly described.

Biochemical Methane Potential (BM100)

The BM100 test determines the biodegradability of organic wastes under anaerobic conditions by measuring the production of biogas. This method is based on the Blue Book method for measuring the biodegradability of sewage sludge by anaerobic digestion (SCA 1977).

Under anaerobic methanogenic conditions the decomposition of organic carbon proceeds by producing biogas (CH_4 + CO_2) from the organic carbon. The amount of biogas production therefore measures directly the C mineralised. The test is set up in a small vessel containing the test substrate, a mineral aqueous medium and an inoculum of methanogenic bacteria taken from an active anaerobic digester. The test is monitored by collecting the biogas produced and recording its volume, which is then adjusted to standard temperature and pressure. The test is incubated for an extended period until gas production ceases which may be up to 100 days or more. The test therefore measures the complete biodegradation of the waste (ENVIRONMENT AGENCY, 2005).

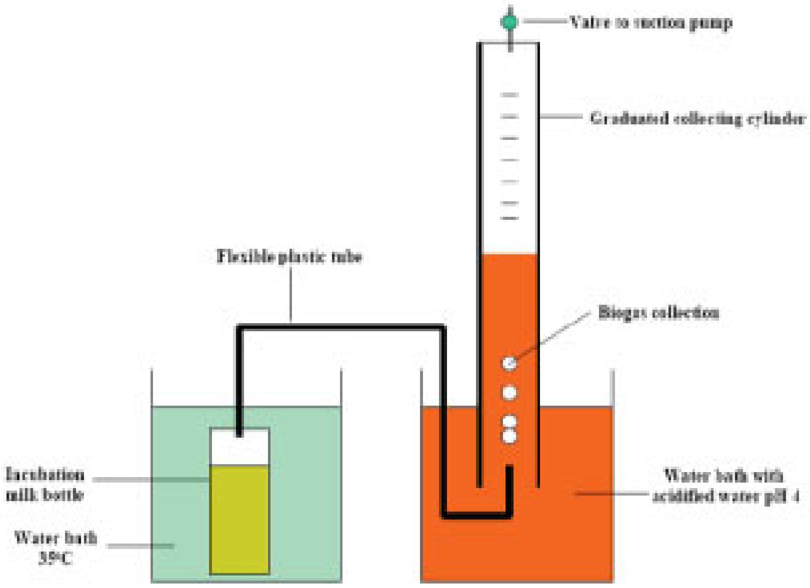

Figure 1: Schematic of BM100 method set up

Dynamic Respiration Rate (DR4)

The dynamic respiration test is an aerobic method of determining organic waste biodegradability based on the standard methods (ASTM D5975-96, ISO 14855:1999). This test method provides a measure of the biodegradability over 4 four days of any solid organic waste whether it is composed of readily biodegradable (raw) organic matter or treated stabilised or poorly bio degradable organic matter.

The DR4 or dynamic respiration index is a reference to the method description where the test is aerated by passing air through the waste. This definition is used to differentiate the method from those where aeration is by diffusion of air into and out of the test material, which are referred to as SRI or static respiration index.

At the beginning of the test, the sample is mixed with a mature compost that provides a good source of microbes (seed) able to degrade the test material. The mixture is incubated under aerobic conditions by aerating the mixture in a vessel through which air is blown. The microbes degrade the test waste producing CO_2 as the decomposition product, which is evolved and found in the exhaust gas stream of the system. The CO_2 production is then measured as a measure of the biodegradability of the test material and converted to oxygen consumption units. The test may also be monitored directly by the consumption of oxygen as an alternative to monitoring CO_2 production (ENVIRONMENT AGENCY, 2005).

Static respiration rate AT4

The static respiration rate was determined according to the method specified in the German *"Ordinance on Environmentally Compatible Storage of Waste from Human Settlements and on Biological Waste Treatment Facilities"* which translates the EU landfill directive into German law and specifies the requirements of waste before it can be landfilled.

AT4 is the cumulative oxygen consumption. The evaluation period is 4 days, and it begins following the initial lag phase. The lag phase has ended when the mean oxygen consumption, expressed as a 3-hour mean, reaches 25% of the value that results as the 3-hour mean in the region of the largest increase in the oxygen consumption within the first 4 days.

The weight of the oxygen consumed during the lag phase is subtracted from the weight of the oxygen consumed throughout the entire test (lag phase + 4 days), and it must not be more than 10% of the overall value. If this condition is not fulfilled, determination may not be carried out. Measurements must be recorded on an hourly basis.

Reporting units are on both on a dry matter (DM) and loss on ignition (LOI) basis, i.e. mg O/kg DM and mg O/kg LOI respectively.

Potential Dynamic Respiration Index (PDRI)

The test was conducted according the "Adani" method in the laboratory of Prof. Adani.

The Potential Dynamic Respiration Index (PDRI) is the result of the dynamic respirometric test which is a biological test measuring the hourly consumption of oxygen used in the biochemical oxidation of easily biodegraded compounds contained in an organic matrix by microorganisms, in conditions of forced air insufflation in the sample.

The Potential Dynamic Respiration Index (PDRI) expresses the value of biological stability of the sample standardized according to the main chemical-physical parameters. This standardization guarantees the best aerobic microrganism growth conditions, producing excellent conditions for their activity for the purpose of measuring the potential microrganism activity capable of degrading the organic substance (ADANI, 2004).

ASTM Test Method for Determining the Stability of Compost

The ASTM test was the basis for developing the DR4 test. The key difference is that the DR4 test is operated at 35 °C whereas the ASTM test is conducted at 57 °C.

This test method covers the stability of a compost sample by measuring oxygen consumption after exposure of the test compost to a well-stabilized compost under controlled composting conditions on a laboratory scale involving active aeration. The compost samples are exposed to a well-stabilized compost inoculum that is prepared from municipal solid waste or waste similar to the waste from which the test materials are derived. The aerobic composting takes place in an environment where temperature, aeration and humidity are monitored closely and controlled. This test method yields a cumulative amount of oxygen consumed of volatile solids in the sample over a four day period. The rate of oxygen consumption is monitored as well.

The test method is applicable to different types of compost samples including composts derived from wastes, such as municipal solid waste, yard waste, source-separated organics, biosolids, and other types of organic wastes that do not have toxicity levels that are inhibitory to the microorganisms present in aerobic composting systems (ASTM COMMITTEE ON WASTE MANAGEMENT, 2004).

3 Correlation calculations

The stability test methods employed for this project use different units in terms of the mass base to which the biological activity (gas yield or oxygen consumption) is related to:

- UK tests (BM100 and DR4) results are related to the LOI of the BMW[1] (BM100 = l gas/kg LOI BMW; DR4 = mg O_2/kg LOI BMW)
- SRI/AT4 and ASTM result is related to the dry matter of the whole sample (not BMW) (SRI/AT4 = mg O_2/g DM)
- Italian PDRI result is related to the LOI of the whole sample (not BMW) (PDRi = mg O_2/(kg LOI x h))

This means that the results are related to different parts of the waste that are to be assessed. For the determination of correlations between the different tests all results have to be converted to the same base unit. It was felt that the dry matter of the whole sample was the most suitable base because different types of waste can be directly compared using the same base.

[1] BMW = Biodegradable Municipal Solid Waste

4 Tested MBT plants and sampling

4.1 Overview of tested MBT plants

Over the last 4 years samples were taken from several operational MBT facilities across Europe.

The capacity of the plants ranges from 40,000 to 300,000 tpa. The plants were commissioned between 2001 to 2006 and

The composting technologies employed represent the main relevant processes currently used in MBT facilities:

- tunnel-composting system
- table windrow system (see Figure 3) and
- composting bays (see Figure 3)

Samples from Anaerobic digestion processes were only taken from a few facilities and are not included in this evaluation.

In total 15 plants were tested but not all data are presented in this paper as some of the data are confidential.

In all plants an upfront mechanical treatment is in place prior to the biological treatment process so that only part of the total waste input is biologically treated. The input in the biological treatment was typically less then 80 – 100 mm and the capacity of the biological treatment rages from 25,000 to 150,000 tpa. All processes work with forced aeration and the process time for biological treatment ranges from 10 to 70 days. This wide range is due to the fact that in some tested plants the main focus is on biological drying of the waste, which require shorter process period.

Figure 2: Unloading of a composting tunnel

Figure 3: Table windrow

Figure 4: Composting bays

4.2 Sampling

Samples were taken from different stages in the biological process.

For the actual sampling following procedure was used:

At least 10 sub-samples were taken for each sample. For input samples these samples were taken over a period of several hours to get a representative mixture of the waste of that day. Samples from the composting process were taken during turning or emptying of a tunnel or a batch. This was not always possible for the interim samples for which the outside of a windrow was removed using a front-end loader to reach a representative part of the batch. Samples were then taken randomly from the cross section of the windrow. The sample size depended on the type of waste. For the composting material which is usually sized less than about 80 mm, sub-samples of 10 to 15 ltr were taken.

All sub-samples were then combined and thoroughly mixed. To reduce the volumes for removal to the laboratory, “coning and quartering” was used.

5 Results of correlation tests

In the UK, both the general approach and the parameters used to assess the performance of MBT are different to those used in continental Europe. As there is only little data available for comparison of results from the test requirements in Germany/Austria and the parameters used (mainly SRI - in Germany referred to as AT4, and PDRI in Italy) both the UK parameters and SRI and PDRi have been analysed.

As explained in section 3 all results have been converted to be related to the dry matter content of the total sample.

In Figure 5 to Figure 8 the correlation between the SRI/AT4 (on the x-axis) with the other stability parameters on the y-axis are shown (BM100, DR4, PDRI and ASTM).

The coefficient of determination (R^2) shows a straight forward linear correlation of 0.83 between the SRI and the BM100 and 0.82 between the SRI and the PDRI. The coefficient of determination for the correlation between the SRI and the DR4 and the ASTM are lower at $R^2 = 0.68$ and 0.56 compared to the parameters listed before.

While there are some differences in the robustness and accuracy of these biological parameters, in general are parameters are suitable to be used to determine the reduction of the biodegradability over the course of a composting process. This means in turn that all these parameters can be used to determine the effect of the MBT process on the biodegradability of the output materials. As a practical consequence an agreement with, for example, a technology supplier could be arrived at where the acceptance of a plant could be based on the SRI/AT4.

What needs to be agreed for any parameter is a sufficient number of samples and test results and a procedure to eliminate outliers (tests which have been failed due to the vulnerability of the test method). For ongoing monitoring, a rolling average of the last 4 results could be a reasonable approach.

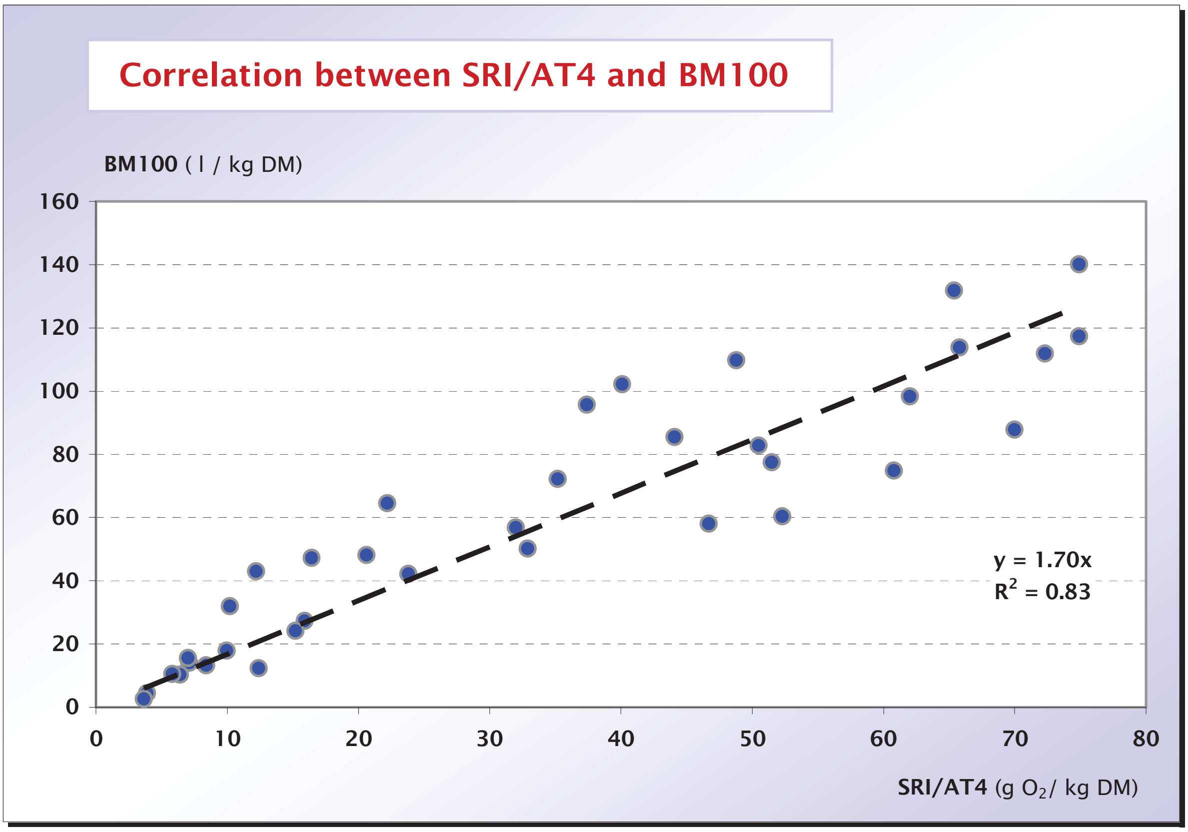

Figure 5: Correlation between SRI/AT4 and BM100

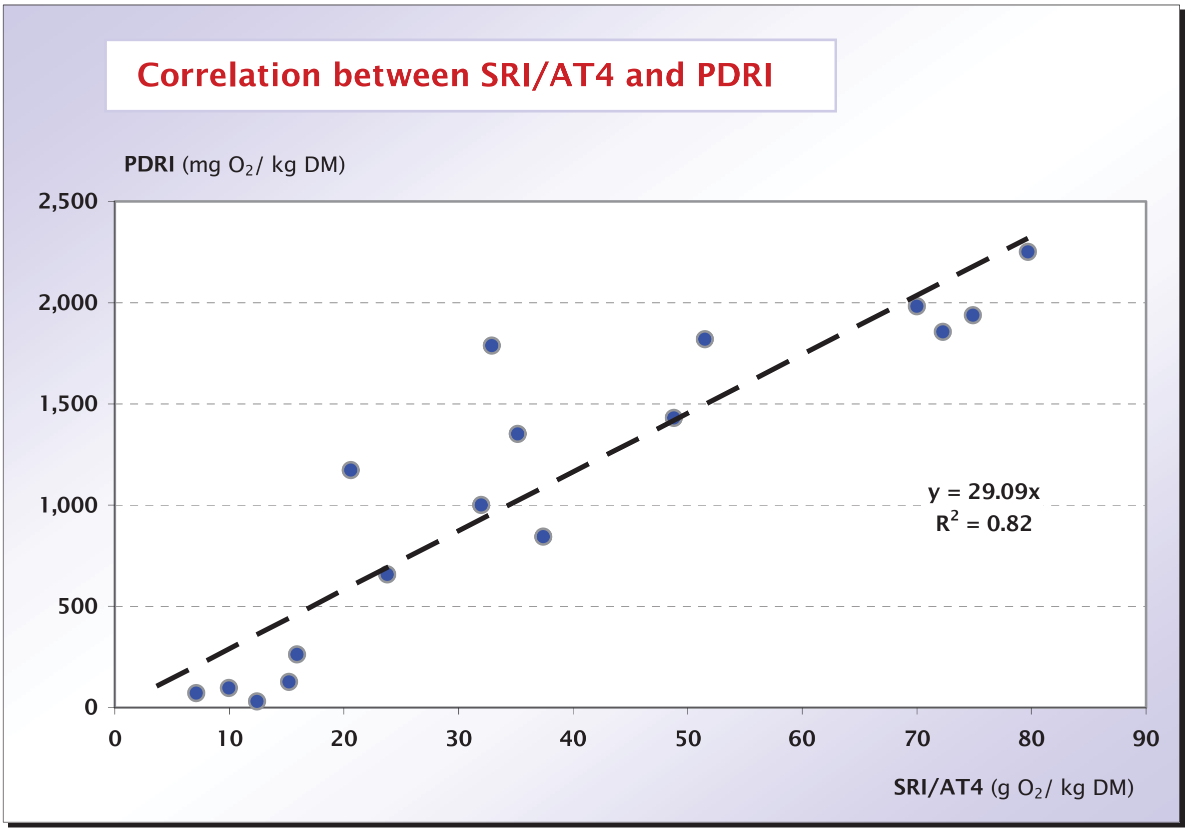

Figure 6: Correlation between SRI/AT4 and PDRI

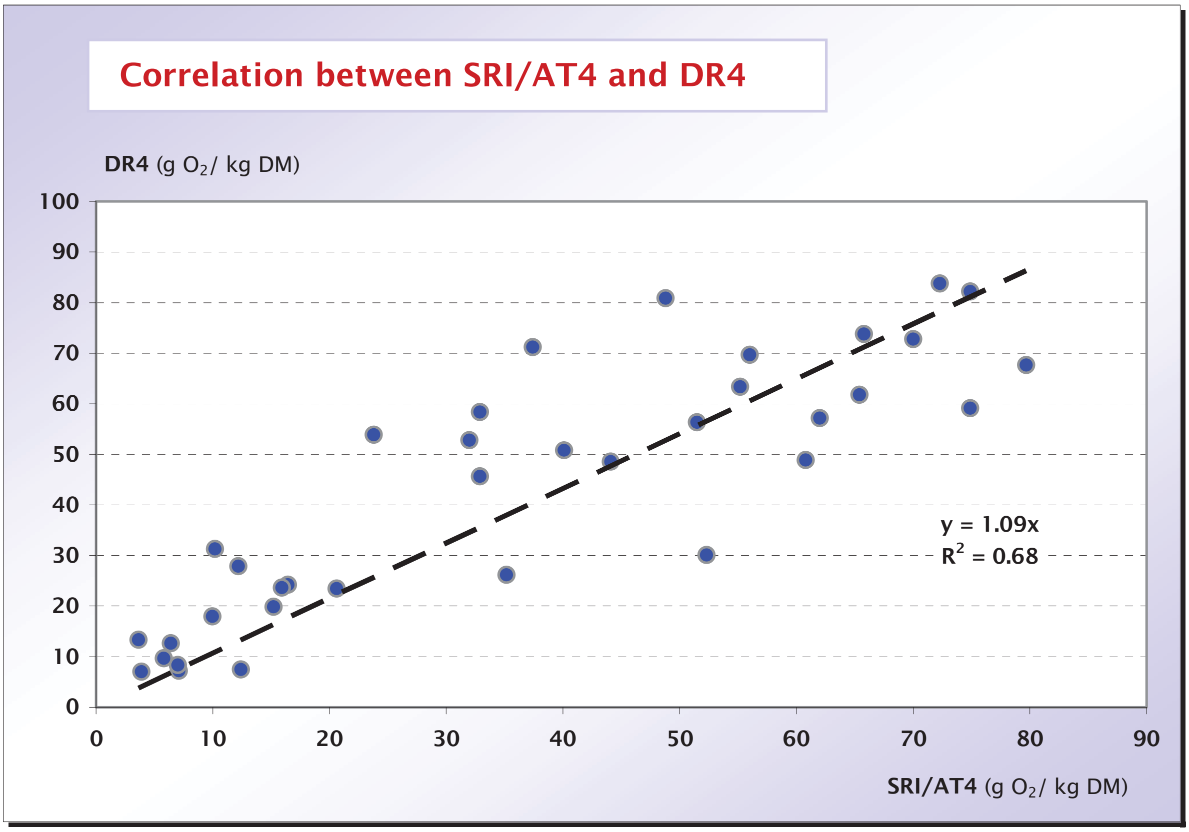

Figure 7: Correlation between SRI/AT4 and DR4

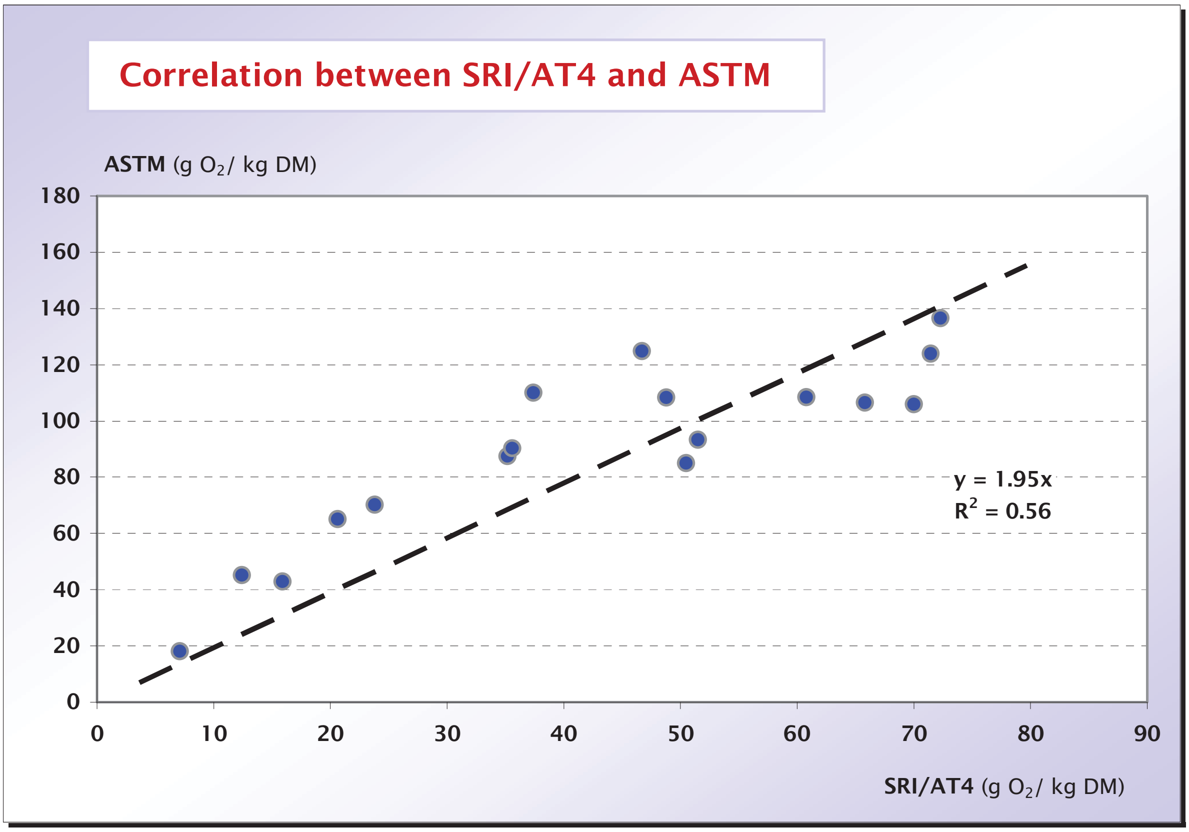

Figure 8: Correlation between SRI/AT4 and ASTM

6 Literatur

Adani, Fabrizio: Di.Pro.Ve. (Department of Vegetal Production) - Universitàdegli Studi di Milano (University of Milan)	2005	Determination of the Biological Stability of Waste and Compost using the Dynamic Respiration Index (Di.Pro.Ve. Method) developed by the "Scientific Group for biomasses studies"
ASTM Committee on Waste Management	2004	Standard Test Method for Determining the Stability of Compost by Measuring Oxygen Consumption
Environment Agency UK	2005	Guidance on monitoring MBT and other pre-treatment processes for the landfill allowances schemes (England and Wales)
Federal Government of Germany	2001	Ordinance on Environmentally Compatible Storage of Waste from Human Settlements and on Biological Waste-Treatment Facilities

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Evaluation of the biodegradability of organic waste by the means of impedance analysis

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Abstract

The biodegradability and consequently the stabilization degree of biologically treated waste is a required parameter to provide the evidence of the fulfillment for the German Waste Storage Ordinance (AbfAblV, 2002). The in appendix 2, AbfAblV recommended test procedures RA_4 (Respiration Activity over 4 days) and GF_{21} (Gas Formation over 21 days) takes at least 4 or 21 days respectively. Moreover, despite uniform regulation, obtained analytical results show a strong dispersion of the values particularly with regard to different laboratories.

Within this work basics for a new microbiological approach, the impedance analysis, are examined for the evaluation of the biodegradability. A clear correlation resulted in the case of impedance measurement and biodegradability. In addition the impedance values can be converted with appropriate regression equations into the standard parameters RA_4 and GF_{21}. Hence, it seems suitable, that organic waste samples may be controlled within a day on their depositing ability according to AbfAblV or the efficiency of the biological treatment processes could be examined by impedance analysis.

Keywords

Biodegradability, Composting, Municipal Solid Waste, Impedance, Microbial Population Dynamic, RA_4, GF_{21}. MBT

1 Introduction

In the course of the past ten years, stricter ecological requirements became effective to national and European regulations concerning the disposal of wastes.

Since January 2004 in Austria and, June 2005 in Germany the deposition of untreated waste is not allowed by law. Wastes for deposition must be pre-treated thermally or mechanical-biologically and have to fulfil the stability criteria of the Waste Storage Ordinance (AbfAblV, 2002). Hence this decreases the volume of the deposited waste, the biological activity in the organic portion as well as the quantity of gas emissions and landfill leachate.

An important and essential parameter for verification of the deposits ability is the biodegradability of the waste treatment output material.

In practice, the estimation of the biodegradability, determined by RA_4 or GF_{21} is associated with uncertainties and discomfort. Firstly, their long test duration: RA_4 takes at least four and GF_{21} up to 21 days. Secondly, the margin of errors is high. In interlaboratory tests it was determined that significant fluctuations, impede their experiences or quality standards (Bockreis, 2006).

Both methods RA_4 and GF_{21} essentially cause concern on the indirect determination of the microbial activity. In order to establish a new method, which reduces the test duration time and the error sources, the impedance analysis is investigated in this work. To be able to better explain the impedimetric results, the classical germ number determination was carried out too.

2 Background

Numerous studies describe the cell number of different microorganisms during the rotting process. There are many involved and cultivatable microorganisms known and in the newer development microorganisms are identified with molecular-biological methods (Ryckeboer, et al., 2003). Some authors appraise the development of microorganism's population to the biodegradability (Herrmann, et al., 1997); this work will prove these theses.

The classical cultivation methods for germ number counting are economical from the expenditure for material and supplies point of view, but not suitable due to the time expenditure. Molecular-biological methods are however cost-intensive and only feasible under trained laboratory personnel. An alternative method for the estimation of the stability of organic material on basis of microbiological populations should be more economical, more simple and faster than the standard methods RA_4 and GF_{21}.

Impedance analysis is an economical and fast microbiological method for germ number counting. This method is used particularly for sterility controls and germ number counting in the foodstuffs industry and in health care for drinking water quality control (Futschik, et al., 1995). Isolated applications within the range of the wastewater and/or sludge characterization are known likewise (Weichgrebe, et al., 2004).

The impedance measurement is an automated method with an increasing application in various fields of the biology (Cady, et al., 1978). It is generally recommended as a high-speed method for estimation of microbial contamination. In contrast to classical cultivation procedures, it is not necessary to wait for the appearance of a macroscopic visible colony. The germ number can be derived from the electro-chemical changes in the nutrient solution that is involved with microbiological metabolism. The online determination of this measurable signal shortens the analysis duration to a few hours.

An impedance-measuring instrument detects the change in the conductivity of the nutrient solution, which is caused by growth of the microorganisms. The theoretical relation of the electrode-electrolyte interface during bacterial growth is shown below:

$$\left|Z_{1,2}\right| = \sqrt{\left(G_m + 2G_i\right)^2 + \left(1/\pi \bullet f \bullet C_1\right)^2} \qquad (1)$$

Electrical circuit equivalence between two electrodes. G_m – medium conductance, G_i – interface conductance, C_i – capacitance of each electrode, f - frequency (Guan, et al., 2004).

At the two electrodes, which are immersed into a nutrient solution, an alternating current (AC) is applied. Metabolic products created during the bacterial growth modify the ionic concentration, which, in turn, results in conductivity changes of the nutrient solution. Such modification is proportional to the concentration of viable microorganisms (Guan, et al., 2004). The recording and evaluation of the measured values occur through a computer with specific software. The conductivity represents as function of the incubation durance, the media impedance curve. This curve, resulted from the metabolic activity of the microorganisms, is very similar to the normal, bacterial growth curve.

According to the manufacturer of the impedance measurement device (SY-LAB Geräte GmbH, Neupurkersdorf / Austria), the parameter Impedance Detection Time (IDT) is used for the evaluation of the impedance measurement. IDT corresponds to the point of the beginning of the exponential growth in the normal growth curve of the microorganisms. With appropriate calibration, IDT is also used for rapid determination of the germ number.

3 Research Objectives

The decomposition of organic substance is a very complex microbiological process. Today there are numerous investigations over the composition of the microbial communities in solid waste or compost (Ryckeboer, et al., 2003), (Harutaa, et al., 2005). However, the function of individual species, populations and their contribution to the process of decomposition, are not well known. Moreover, in the most works data are achieved with classical, cultivate-based methods, where the difference is observed only between mesophilic and thermophilic microorganisms. The examined groups of microorganisms are mostly limited to total cell count, fungi and actinomycetes. The comparison between the results of different research groups is often difficult, because no standardized investigation methods were used in their experiments.

Several microorganism groups were suggested to be suitable an indicator for biodegradability of organic materials. Although we can certainly assign specific microorganisms to different degrees of decomposition, en suitable method to determinate the biodegradability could not be developed.

One aim of this investigation was to study the microbial population dynamics during composting and determining the stability level of the product by microbiological approaches.

In the first part of this work, all samples were examined simultaneously with standard methods to determine the biodegradability (RA_4, GF_{21}, organic dry matter (ODM) and self-heating) and microbial methods in order to evaluate correlations between the stabilization degree and the microbial population dynamics. Investigations on changes in the germ number of different microbial groups were accomplished during organic waste (OW) composting. The dependence was examined between germ number and the stabilization of the organic material. Further, the suitability of impedance analytics was examined as a high-speed method. Appropriate growth media for impedance analytics were tested.

In the second part of the work, the data was transferred to residual waste (RW) from the Mechanical-Biological waste Treatment. The impedimetric approach could be used for the examination of the deposit ability according to AbfAblV with appropriate calibration. The calibration was carried out with material from a full-scale MBT-facility.

4 Methodology

4.1 Treatment Process and Sampling

Actual OW was taken from a full-scale composting facility (aha, Lahe). It consists of a mix of organic waste (kitchen and garden waste) and a small amount of horse manure and wood shavings. The total duration of the composting amounts to 13 weeks, with 6 weeks of intensive-rotting (with aeration) and 7 weeks maturation.

RW was taken from a full-scale MBT facility (RABA, Bassum) for municipal solid waste. The input for the plant consists of household similar trading waste and municipal solid waste. In the mechanical waste treatment iron and non-ferrous metals are sorted out. In the following rotary sieve drum, the material is separated into 40 and 60 mm fractions. The fine fraction of 0 to 40 mm is stabilized in a wet fermentation process. The 40 to 60 mm fraction is treated for 8 weeks along with the fermentation residues aerobically by an intensive rotting and 6 weeks maturation afterwards.

Three samples of about 3 kg were taken from the middle and the sides of the pile, every week after turning the material. For analysis, the samples were mixed and briefly hand sorted to remove large inert material, such as metal and glass. According to the ASA Standard, the samples were milled up to 10 mm (Rohring, et al., 2007). For the microbiological analyses eluates were made from the solid material. Therefore, 50 g of the material was made up to 1 L with physiological saline solution and suspended for 1 h in an overhead shaker.

4.2 Selective Media and Incubations Conditions

For the investigation of individual microorganism groups, selective growth media were used. Total germ count: Nutrient Broth, Difco (NB) and SY-LAB 001B (SY); Gram-positive: Phenylethyl Alkohol Agar, BBL (GP); Gram-negative: NB-Medium with SDS (GP); Actinobacteria: Actinomycete Isolation Agar, Difco (AI); *Arthrobacter:* CT-Medium according to Tanaka (CT); Lactobacillales: MRS-Agar, Fluka (MRS); Cellolytic group: CMC-Medium according to Ryckeboer (CMC); Fungi: Sabouraud Pepton-Agar (SAB). The selective growth media were used without changes for the impedanceanalytic and plate count.

The incubation occurred in the mesophilic range at 30°C. Duration of incubation varied depending on the microorganisms group for the plate count between 2 to 5 days and for the impedance-analytic between 1 to 10 hours.

5 Results and Discussion

5.1 Plate Count

The partial results of the germ counting are shown in Figure 1. In comparison to the determination of the germ number the simultaneously analyzed Biodegradability (RA_4) is shown.

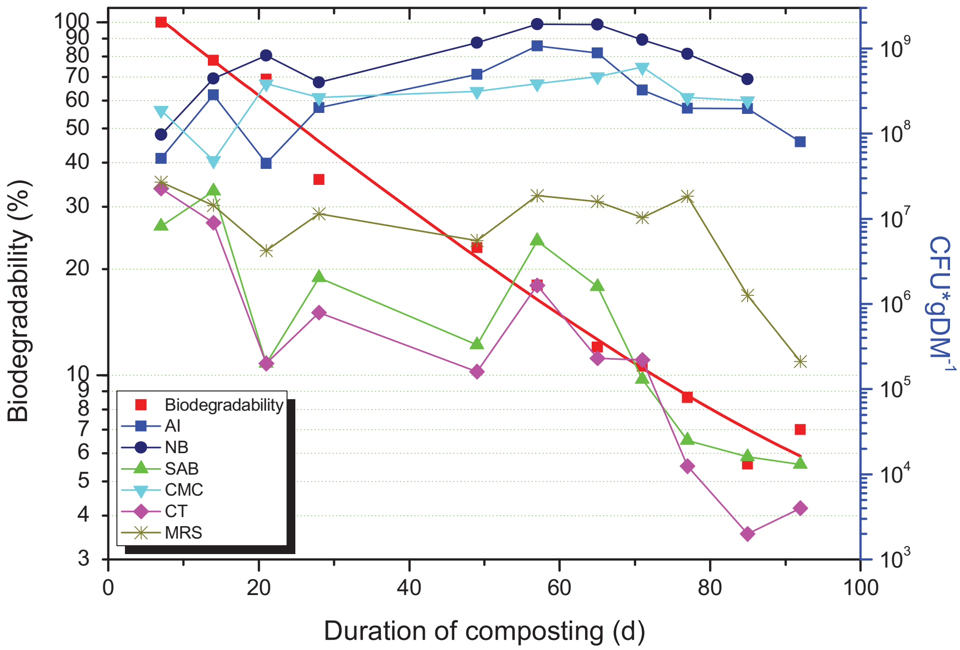

Figure 1: example for Germ count biodegradability (RA_4) AI – Actinomycetes, NB – total germ count, SAB - Fungi, CMC – Cellolytic MO´s, CT – Arthrobacter, MRS – Lactobacillales.

The thermophilic phase last from day 3 to 25, with temperature until 70°C. For all investigated microbial groups the effect of the temperature is stronger than influence of the biodegradability.

None of the tested microorganism groups show a suitable correlation with the biodegradability (measured by RA_4). Similar results also arise for the correlation with parameter GF_{21} (data not shown). A weak correlation is present by the Lactobacillales, fungi and *Arthrobacter* group. Only in the last phase of composting, the germ number could be an indicator for biodegradability.

Due to the strong heterogeneous microorganism's community in solid waste, only a weak correlation was observed between the results of germ count and impedimetric approach (data not shown).

5.2 Impedimetric Approach

For the impedimetric approach, the same selective growth media were used. The results are shown in Table 1.

Table 1: Established correlations between IDT and biodegradability, by screened groups of microorganisms. Key: strong – R^2 > 0,8; present R^2 0,8-0,5; absent R^2 < 0,5.

Group of microorganisms	Correlation of IDT and biodegradability	
	OW	RW
Total germ count	strong	present
Gram-positive	not tested	strong
Gram-negative	not tested	strong
Actinomycetes	strong	present
Arthrobacter	strong	not tested
Lactobacillales	present	strong
Cellolytic microrganisms	absent	not tested
Fungi	strong	present

A strong correlation of IDT and biodegradability show the groups of actinomycetes, *Arthrobacter* and fungi in OW, and Gram-positive, Gram-negative and Lactobacillales in RW. The growth media with a strong correlation may be used to evaluate the biodegradability of the dry residue according to AbfAblV. Just as well to estimate the compost maturity.

The relation of the IDT-value (total germ count) to RA_4 and GF_{21} is shown in Figure 2.

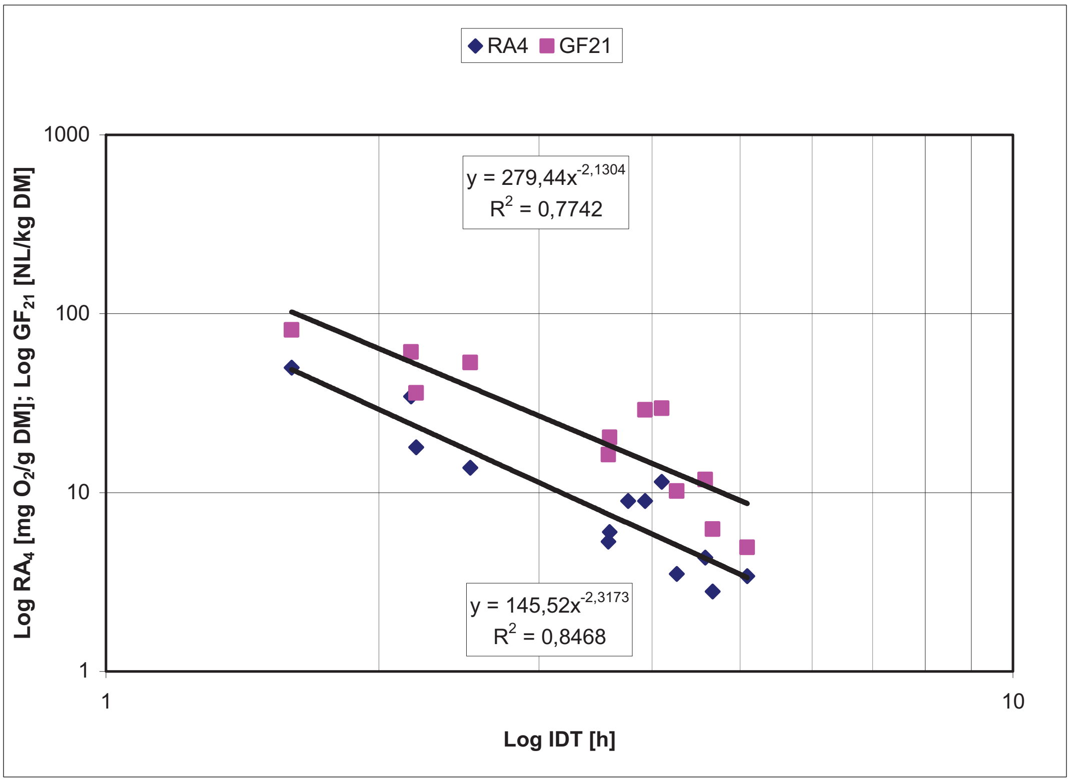

Figure 2: IDT in correlation with RA_4 and GF_{21} (organic waste).
Growth media for total germ count used.

IDT can be converted as follows into the RA_4:

$$RA_4\,[mgO_2\,/\,gDM] = 141{,}52 \bullet IDT\,[h]^{-2{,}3173} \tag{2}$$

GF_{21} can be estimated with the following equation:

$$GF_{21} = [NL\,/\,kgDM] = 279{,}44 \bullet IDT[h]^{-2{,}1304} \tag{3}$$

6 Conclusions

The use of impedance analysis provides a method to define microbial activity during waste treatment processes. In this study, samples of a composting plant and of a waste treatment process on a full-scale facility were examined by impedance analysis along the process operation. For this organic waste (OW) and residual waste (RW) were investigated in particular.

As expected rapid changes in germ number were observed during the waste treatment. According to other works different microbial groups are related to different stages of degradation. Nevertheless, no clear correlation between the germ number and the biodegradability was determined. The germ count is not suitable to determine the biodegradability clearly, because it is primarily dependent on the rotting temperature of the organic material. Only in the last phase of rotting, where no more self heating is observed, the germ number can be used as an indicator for the biodegradability.

On the other hand, a clear correlation resulted in the case of impedance and biodegradability. We suppose that the impedimetric signal is primarily dependent on the activity of the microorganisms and the composition of the microbial community in the waste sample, but further investigations are necessary.

Impedimetric analysis of stabilised composts may provide a method for evaluation maturity and stabilisation of varied composts. However, more important is the application for RW. The feasibility of evaluating the biodegradability and stabilisation degree of a waste sample with impedance analytics is shown. The analysis is suitable for aerobically or anaerobically treated wastes. Full stream fermentation was not examined so far. With the regression equation, it is possible to convert the IDT values into RA_4 and GF_{21}. The period to obtain the analytical results by the means of impedance analytics shortens to 1-24 hours in contrast to RA_4 and GF_{21} with 4 and 21 days respectively. The definite duration time depends on the activity of the sample.

IDT seems to be an attractive alternative against RA_4 and GF_{21}, which helps the operator to control and to observe the waste treatment process quickly and easily. Nevertheless, to establish such a method, further investigations are necessary and are under progress.

7 Acknowledgements

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8 Literature

Bockreis, A.	2006	Schwankungsbreiten bei der Analytik von Zuordnungskriterien (AbfAblV). Niedersächsisches Ministerium für Umwelt und Klimaschutz.
Cady, P. [et al.]	1978	Electrical impedance measurement: Rapid method for detecting and monitoring microorganisms. In: Clinical Microbiology. Volume 7, Issue 3, pp. 265-272.
Futschik, K., Pfützner, H.	1995	Electrode and Media Impedance for the Detection and Characterisation of Microorganisms. Proceedings RC IEEE-EMBS & 14th BMESI.
Guan, J.-G., Miao, Y.-Q., Zhang, Q.-J.	2004	Impedimetric Biosensors. In: Journal of Bioscience and Bioengineering. Volume 97, Issue. 4, pp. 219-226.
Harutaa, S. [et al.]	2005	Microbial diversity in biodegradation and reutilization processes of garbage. In. Journal of Bioscience and Bioengineering. Volume 99, Issue 1, pp. 1-11.
Herrmann, R.F., Shann, J.F.	1997	Microbial Community Changes During the Composting of Municipal Solid Waste. In: Microbial Ecology. Volume 33, Issue 1, pp. 78–85.
Rohring, D. [et al.]	2007	ASA-Standard/RAL-RG 504. Standardisation of sample collection, treatment and analytics of parameters according to Waste Storage Ordinance (AbfAblV) In: Müll und Abfall. Volume 39, Issue.12, pp. 585-587.
Ryckeboer, J. [et al.]	2003	A survey of bacteria and fungi occurring during composting and self-heating processes. In: Annals of Microbiology, Volume 53, Issue 4, pp. 349-410.
Weichgrebe, D. [et al.]	2004	Electrochemical Oxidation of Drug Residues in Water by the Example of Tetracycline, Gentamicin and Aspirin. In: Water Scince Technology. Volume 49, Issue 4, pp. 201-206.

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Lösungsansätze zur Vermeidung von Fehlbefunden bei der Bestimmung der Reaktivität von MBA-Materialien

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Reactivity of MBT-Waste - A new approach to identify failures of biological tests

Abstract

The "Austrian Landfill Ordinance" (BGBl. II Nr. 39/2008) (BMLFUW, 2008) provides requirements for the disposal of wastes. Limit values regarding reactivity such as respiration activity and gas generation sum (by incubation test) or gas evolution (by fermentation test) have to be met before landfilling. In Austria respiration activity AT_4 < 7 mg O_2 g^{-1} DM (dry mass) and gas generation sum GS_{21} (gas evolution GB_{21}, respectively) < 20 Nl kg^{-1} DM are stipulated. In 2004 Austrian Standards for these parameters were established. Sometimes reactivity is underestimated by biological tests when the microbial community is affected by environmental conditions during the test (e.g. dryness, insufficient oxygen supply, production of metabolic products). Gas generation sum and respiration activity in general feature a good correlation. Due to this fact, lower findings can be identified by determination of both parameters. On the one hand this approach serves as security and on the other hand these tests are very time consuming (4 and 21 days resp.). Thus, it was aimed for, to develop new analytical tools for the determination of reactivity parameters. Fourier Transform Infrared (FT-IR) spectroscopy was used as a non-destructive method to predict reactivity parameters and to identify errors resulting from inhibiting effects on biological tests. The development of prediction models that allow an accurate interpretation of FT-IR spectra, was based on multivariate data analysis. For parameter determination a partial least squares regression (PLS-R) was applied. A series of MBT-materials was subjected to infrared spectroscopic investigations and biological tests. This paper presents the comparison of the results obtained by the developed prediction models and by biological tests (respiration activity and gas generation sum). The procedure of error identification is demonstrated.

Inhaltsangabe

Die mechanisch-biologische Behandlung von Restmüll ist eine mögliche Behandlungsmaßnahme zur Stabilisierung der Abfälle vor ihrer Ablagerung. In Österreich sind als Kriterien zur Beurteilung der Stabilität die Atmungsaktivität (AT4) und die Gasbildung (GS21 bzw. GB21) vorgeschrieben. Die Deponieverordnung begrenzt die AT4 mit 7 mg O2 g-1 TM und die GS21 mit 20 Nl kg-1 TM. In Österreich muss die Einhaltung beider Grenzwerte nachgewiesen werden. Aufgrund von Störungen der biologischen Tests sind Unterbefunde möglich. Die beiden Parameter AT4 und GS21 stehen in direktem Verhältnis zueinander. In der Praxis hat sich daher gezeigt, dass die Forderung nach der Analyse beider Parameter sehr wichtig ist, um Fehlbeurteilungen durch Unterbefunde bei einem der beiden Tests ausschließen zu können. Da beide Parameter jedoch sehr zeitaufwändig sind, wurde nach neuen, schnelleren Bestimmungsmethoden gesucht. Dabei fiel die Wahl auf die Infrarotspektroskopie, die in zahlreichen Branchen als Routineanalytik in der Qualitätskontrolle eingesetzt wird. Sie zeigt die chemische

Zusammensetzung des Materials und lässt die Beurteilung der Reaktivität aufgrund der chemischen Zusammensetzung, unabhängig von biologischen Tests zu. Zur einfachen Bestimmung der Reaktivitätsparameter mittels FT-IR wurden Vorhersagemodelle entwickelt. Dafür wurden alle österreichischen MBA-Anlagen beprobt und von den Proben sowohl die Atmungsaktivität als auch die Gasbildung bestimmt, sowie parallel dazu ein Infrarotspektrum aufgenommen. Für die Modellerstellung wurde eine Partial Least Squares Regression (PLS-R), ein Verfahren der multivariaten Datenauswertung, verwendet. Sowohl die Atmungsaktivität als auch die Gasbildung können mittels des erstellten PLS-R Modells über das Infrarotspektrum bestimmt werden. Die Modellparameter der Modelle sind für die Atmungsaktivität unter Berücksichtigung von 220 Proben ein Korrelationskoeffizient r^2 von 0,92 und ein Vorhersagefehler von 3,9 mg O2 g-1 TM. Für die Gasbildung wurden im derzeitigen Modell für 62 Proben ein Korrelationskoeffizient r^2 von 0,82 und ein Vorhersagefehler von 8,4 Nl kg-1 TM erreicht. Es konnte gezeigt werden, dass Unterbefunde in den biologischen Tests durch die Bestimmungen mit der Infrarotspektroskopie (Vorhersagemodelle) vermieden werden können.

Keywords

Mechanisch-biologisch vorbehandelter Abfall (MBA), Atmungsaktivität, Gasbildung, Fourier Transform Infrarot Spektroskopie, Multivariate Datenauswertung, Partial Least Square Regression (PLS-R)

Mechanically-biologically pretreated waste (MBT), respiration activity, gas generation sum, Fourier Transform Infrared Spectroscopy, multivariate data analysis, Partial Least Square Regression (PLS-R)

1 Introduction

The Austrian Landfill Ordinance requires limit values for respiration activity (AT_4) < 7 mg O_2 g^{-1} DM and gas generation sum GS_{21} (gas evolution GB_{21} resp.) < 20 Nl kg^{-1} DM. In 2004 Austrian Standards (OE-NORM S2027-part 1 to 3) for these parameters were established. A good correlation between GS_{21} and AT_4 has been demonstrated by BINNER ET AL. (2007). The correlation coefficient for 70 samples was r = 0.94. In Austria both, respiration activity and gas generation sum (or gas evolution) have to be determined to assess the quality of the MBT-output. In practice biological tests sometimes underestimate the reactivity due to unfavorable conditions for the microbial community. Thus, determination of both parameters confirms the conformity of the results obtained. Several effects that have a negative impact on biological tests have been observed in the past. Due to acidification very reactive materials often feature long lag-phases during the anaerobic test. In these cases, GS_{21} does not allow a correct interpretation. On the other hand during the respiration activity test metabolic products are generated and antagonize aerobic decomposition. Anaerobic conditions, insufficient oxygen supply or running dry during the biological treatment process can lead to lower findings too (BINNER, 2007). Adoptions of the OE-NORM-methods help to prevent such errors. Pre-aeration of samples after wetting results in shorter lag phases and higher degradation rates during the aerobic test (BINNER, 2003).

However, the number of incorrect results obtained by biological tests can be minimized, but not completely avoided (BINNER, 2006). Thus it is aimed for to apply new alternative methods that are capable to assess the reactivity of MBT-output directly via the chemical composition, avoiding the time-consuming biological tests. Accordingly, Fourier Transform Infrared (FT-IR) spectroscopy has been carried out.

Infrared spectra illustrate the plot of absorbed infrared radiation versus wavenumbers caused by interactions of infrared radiation with matter. Infrared spectroscopy has shown to be a valuable tool for the characterization of waste with several applications in waste science (POLLANEN ET AL., 2005; SMIDT ET AL., 2002; SMIDT AND MEISSL, 2006). An infrared spectrum reflects the chemical composition of the whole sample. Infrared spectroscopy has been applied to describe changes at a molecular level (ZHANG ET AL., 2005) during the biological treatment of organic waste (SMIDT ET AL. 2005, ZACHEO ET AL., 2002). Each infrared spectrum consists of many data points providing information on the material. Multivariate statistical methods are necessary to handle such huge data sets. Furthermore it should be pointed out that recording of an infrared spectrum takes only about 15 minutes compared to the “Sapromat” test that lasts at least 4 days or the anaerobic test that requires 21 days. The objective of the study was to develop a new analytical tool for reactivity determination of MBT-waste by means of FT-IR spectroscopy and multivariate data analysis (Partial Least Squares Regression). Prediction models for respiration activity and gas generation sum should allow verification of equivocal data obtained by biological tests.

2 Material and Methods

2.1 Materials, sampling and sample preparation

Samples originated from different Austrian MBT-plants. Sampling took place according to Austrian Standards OE-NORM S 2123-1. Representative fresh samples were shredded to a particle size of 20 mm. Respiration Activity was determined using these fresh samples. For spectroscopic investigations a representative subsample (about 1 kg of the original fresh sample) was oven dried (105°C), and in a first step prepared by a cutting mill (Retsch SM 2000), then ground by a centrifugal mill Retsch ZM 1000 and by a vibratory disc mill and screened through 0.63 mm to provide an appropriate particle size according to Austrian Standards for chemical analyses.

2.2 Biological tests

Respiration activity was measured for a 4-day-period (AT_4) in a Sapromat (Voith Sulzer). According to OE-NORM S 2027-1 the oxygen uptake (mg O_2) was recorded and referred to one gram of dry mass (g DM). GS_{21} was determined by the "Incubation Test" according to OE-NORM S 2027-2.

2.3 Infrared spectroscopic investigations

FT-IR absorbance spectra were recorded by a Bruker (Ettlingen, Germany) FT-IR spectrometer (EQUINOX 55) equipped with a DTGS detector. Two mg samples were mixed with 200 mg KBr (Aldrich; 22,186-4; FT-IR grade) and homogenized by pestle and mortar. The 13 mm KBr pellets were prepared under vacuum in a standard device under a pressure of 75 kN cm^{-2} for 3 minutes. Thirty-two scans per sample were collected in the wavenumber range 4000-400 cm^{-1} in transmission mode at a spectral resolution of 4 cm^{-1}. The collected spectra were ratioed against air as background.

For multivariate data analysis spectra were vector-normalized.

2.4 Multivariate data analysis

Multivariate data analysis was carried out using the OPUS 5 Quant software package (BRUKER Optics, Germany). For parameter prediction a partial least squares regression (PLS-R) was used.

For the PLS-R the preprocessed (vector-normalized) infrared data were regressed against the calibration components, and by means of full cross-validation with one sample omitted a significant number of PLS components was obtained.

3 Results and Discussion

3.1 Infrared spectroscopic investigations

Figure 1 shows the development of FT-IR spectra during decomposition of municipal solid waste. Changes during the process are marked by arrows. The band assignments have been published by several authors (CHEN, 2003; SMITH, 1999; SOCRATES, 2001; SMIDT AND SCHWANNINGER, 2005; SMIDT AND MEISSL, 2006). The indicator bands of the FT-IR spectrum reflect the reactivity of the sample and can reveal "lower findings" obtained by the biological test. Multivariate data analysis, especially parameter prediction, is a promising way to use FT-IR for practical purposes due to the fast and easy handling and maximum information. By means of partial least squares regression (PLS-R) a multivariate regression model from a known corresponding X and Y data set is established. Based on an established model prediction of new data (Y-values) is possible only by measuring X-values.

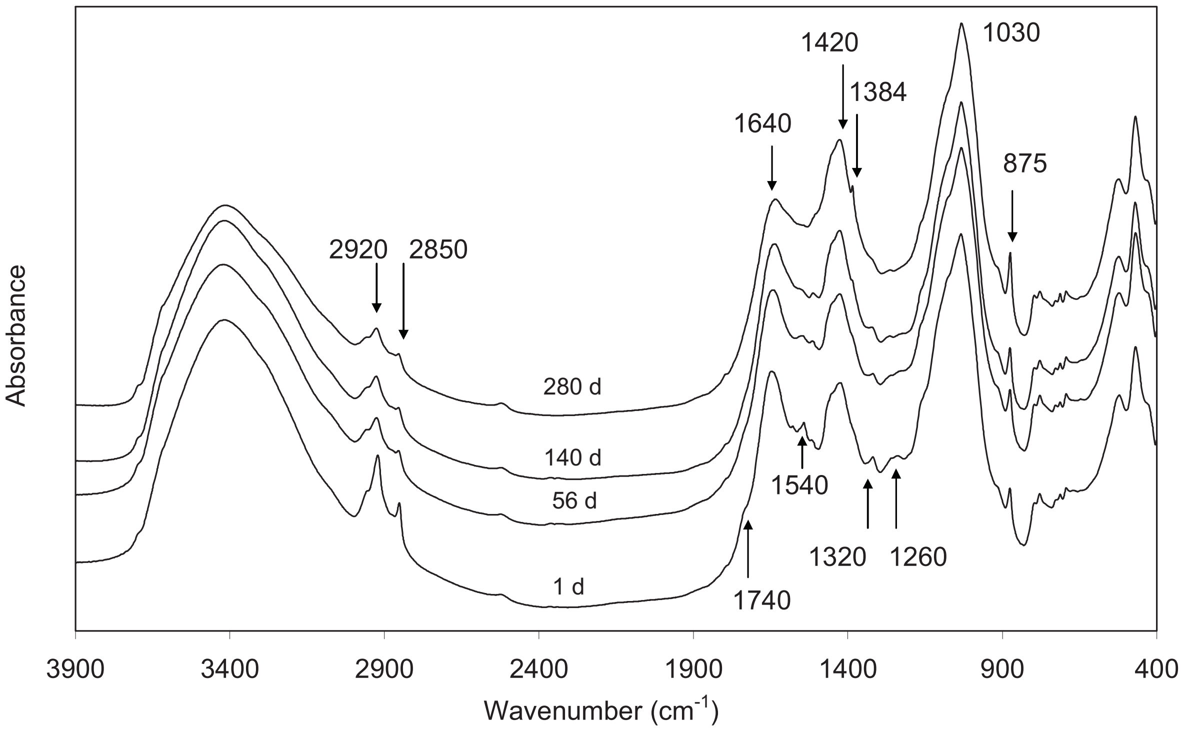

Figure 1 Development of infrared spectra during decomposition of municipal solid waste

3.2 Development of prediction models for stability parameters such as respiration activity and gas generation sum

3.2.1 Gas generation sum

Gas generation sum by incubation test is used to determine reactivity of MBT-waste under anaerobic conditions. The possibilities of errors by incubation test are acidification of materials, or H_2S formation during the test, which is toxic for anaerobic microbes. Thus, it was aimed for, to develop new analytical tools for the determination of reactivity parameters Therefore, FT-IR spectroscopy by means of multivariate data analysis was selected. In Figure 2a the correlation for gas generation sum by incubation test and by FT-IR spectra up to gas generation sum of 120 Nl kg^{-1} DM is carried out. The correlation is not satisfactory. There are only few very reactive samples with a correct gas generation sum. The samples above 70 Nl kg^{-1} DM seem to be underestimated by the model. Thus, a model without these 5 samples was developed illustrated in Figure 2b. This model shows a good correlation for prediction of gas generation sum. It is hypothesized that FT-IR spectra and the gas generation sum show a linear correlation only up to 70 Nl kg^{-1} DM. For the prediction model 62 samples were used ranged from 0.1 to 70 Nl kg^{-1} DM. The coefficient of determination was 0.82 with a mean error of prediction of 8.4 Nl kg^{-1} DM.

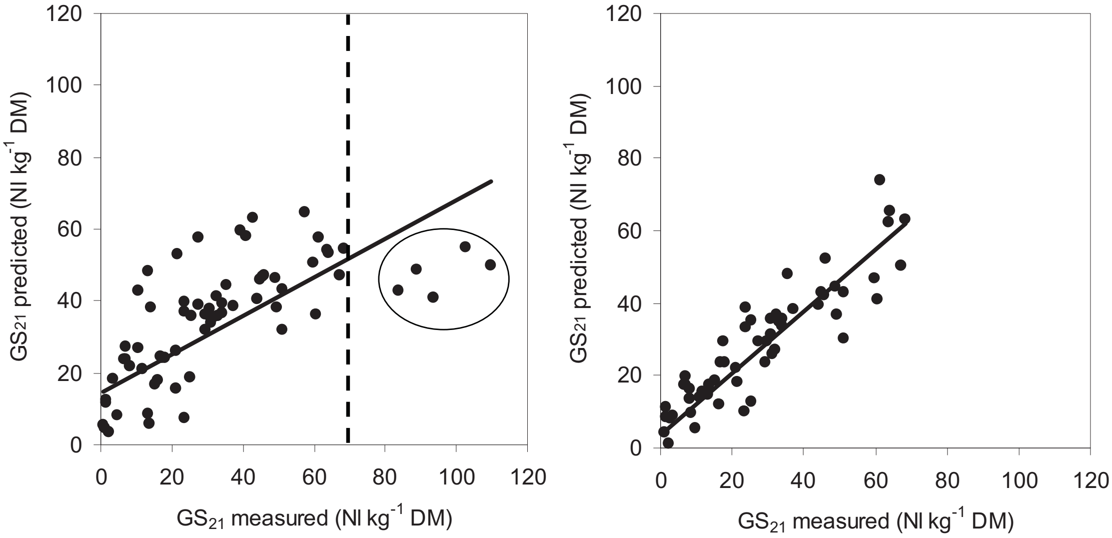

Figure 2 PLS-R model for gas generation sum (a) 0-120 Nl kg^{-1} DM and (b) 0-70 Nl kg^{-1} DM

3.2.2 Respiration activity

Respiration activity is used to determine the reactivity of MBT-waste under aerobic conditions. The possibilities of errors during the test are falling dry of material during the biological treatment process and air supply restrictions. Again FT-IR spectroscopy was used to determine the reactivity. The developed PLS-R model for respiration activity (AT_4) by means of FT-IR spectroscopy and multivariate data analysis is shown in Figure 3. The PLS-R of respiration activity was carried out using 220 calibration samples distributed in the range 0.1 to 55 mg O_2 g^{-1} DM with a mean error of prediction of 3.9 mg O_2 g^{-1} DM.

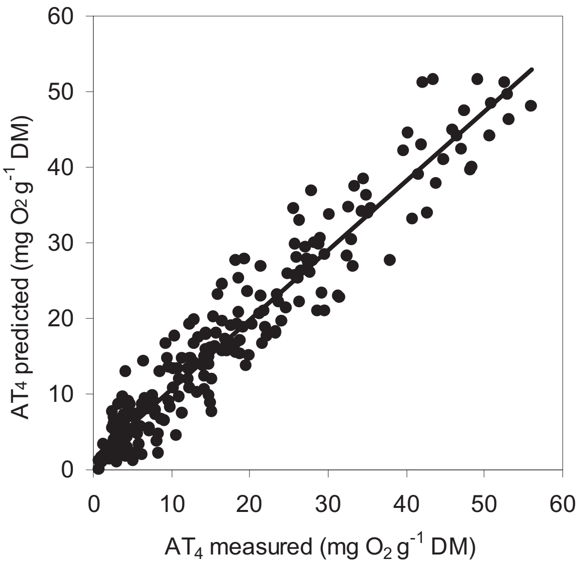

Figure 3 PLS-R model for respiration activity

3.2.3 Model validation

Furthermore the models were carefully validated and their stability and robustness were proven by an independent test set. For validation the data was divided randomly in a calibration set and a test set. The sets additionally were used vice versa. If the developed models are valid and stable they show equal model parameters. For the presented models it was successfully proven. Details of validation are not shown in this paper.

3.3 Identification of questionable results obtained by biological tests and provision of reliable results using FT-IR spectroscopy

3.3.1 Identification of failed biological tests

To prove the correlation between respiration activity and gas generation sum (BINNER ET AL., 2007) for FT-IR spectroscopy, the same 62 samples were predicted by the developed models and analyzed by Sapromat and incubation test. For comparison reason the values measured by Sapromat and incubation test of these 62 samples are also shown in Figure 4. It can be seen that the correlations are similar to each other.

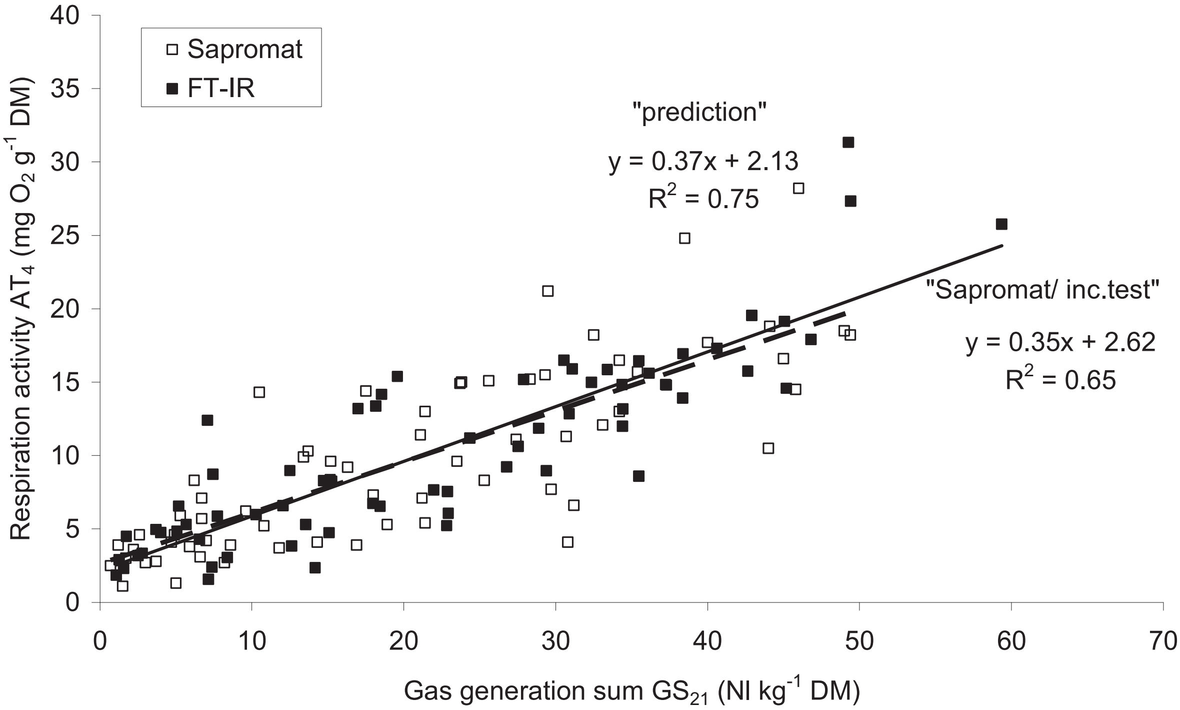

Figure 4 Correlation of respiration activity and gas generation sum by "Sapromat" and "incubation test" resp. predicted by the PLS-R models.

To illustrate the potential of the method, the models were applied to several samples supposedly underestimated by the Sapromat or incubation test in order to predict respiration activity and gas generation sum. It was assumed that there were lag phases or biological restrictions to degradation (falling dry during MBT process, formation of metabolic byproducts) during the tests. In Figure 5 the correlation of respiration activity and gas generation sum is shown. The biological tests were carried out using the conventional analytical methods as Sapromat and incubation test. Marked samples showed problems during one of the biological tests.

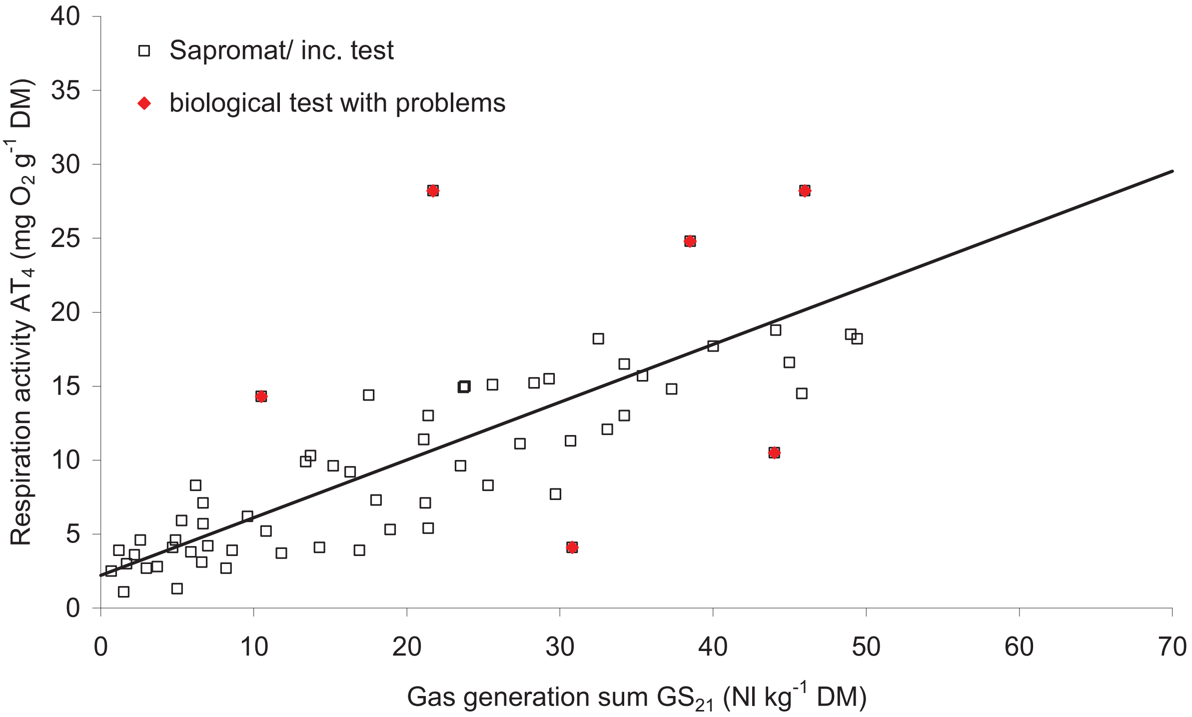

Figure 5 Correlation between gas generation sum (GS_{21}) and respiration activity (AT_4); samples with problems during the biological test are marked

3.3.2 Application of the developed prediction models

Due to the fact that samples marked in Figure 5 do not show good correlation of gas generation sum and respiration activity it is hypothesized that one of the biological test failed. Therefore, first the respiration activity was determined using FT-IR spectroscopy by means of the developed model. The results are illustrated in Figure 6. The two samples below the correlation line were underestimated by the Sapromat test. It is hypothesized that the respiration activity is underestimated by the Sapromat because material fell dry during MBT-process. The other samples compared to the Sapromat show similar results (marked by cycles). It is supposed that the gas generation sum of these samples is underestimated due to acidification. Thus, the gas generation sum was also predicted using the FT-IR model. The results are shown in Figure 7. All samples above the correlation line shift to a higher value of gas generation sum. All presented samples predicted by FT-IR models show good correlation between respiration activity and gas generation sum. These results demonstrate the applicability of FT-IR for determination of respiration activity (AT_4) and gas generation sum (GS_{21}).

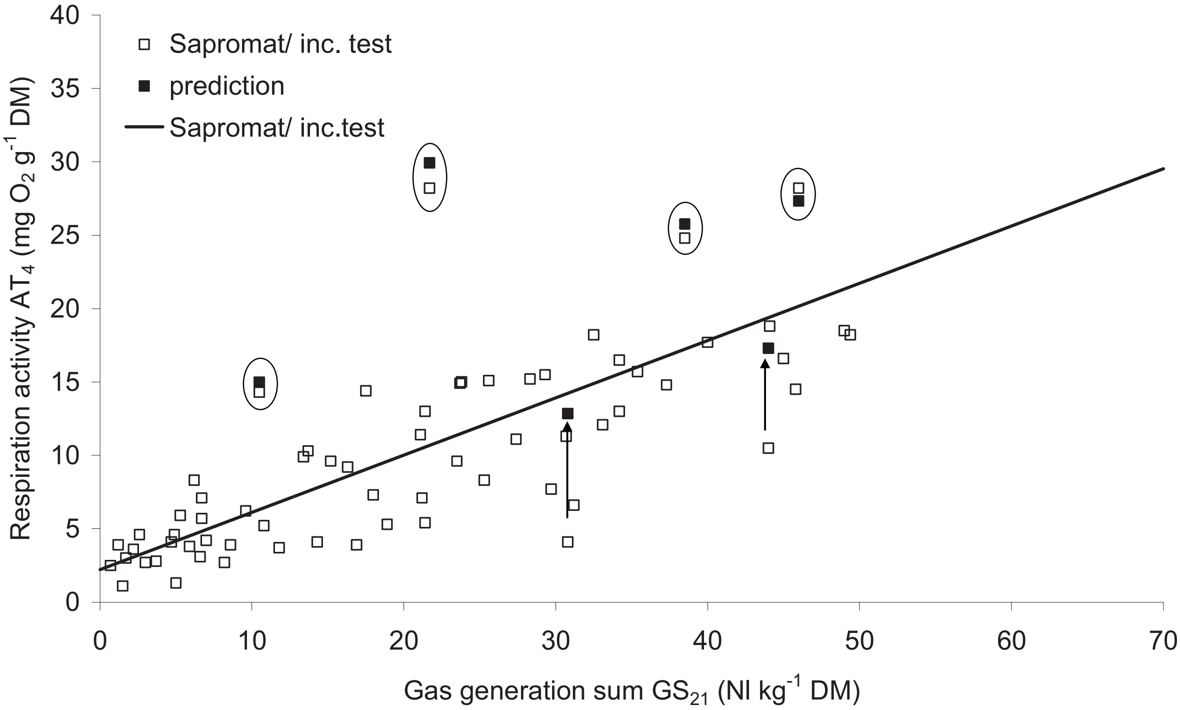

Figure 6 Prediction of the respiration activity of the sample set showing problems during the biological test

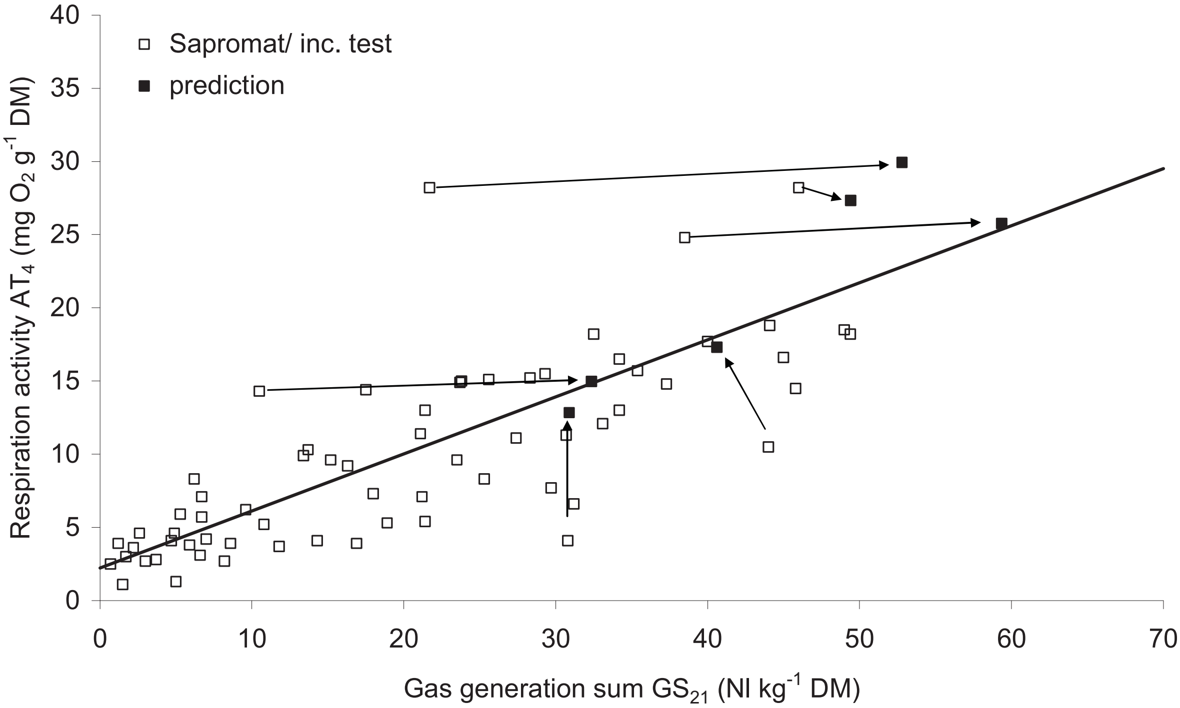

Figure 7 Recalculation of the sample set using prediction models for AT_4 and GS_{21}

4 Conclusion

The biological parameters gas generation sum within 21 days (GS_{21}) and respiration activity within 4 days (AT_4) are regulated by the "Austrian Landfill Ordinance" (BMLFUW, 2008) for reactivity determination of MBT-waste. Extreme lag phases during respiration activity test produce lower findings, occurring mainly in untreated wastes or those undergoing only brief biological treatment, as well as in the presence of disadvantageous environmental conditions (poor oxygen supply, falling dry) during the MBT process. The pre-aeration of samples (prior inserting samples in the reaction bottles and exposure to air for 4-6 hours) allows microbes to get adapted to the actual conditions (this shortens lag-phases). On the other hand aeration in between the test period of 4 days, allows repressing metabolic products to leave the test system, which increases activity. These adoptions may help to minimize lower findings but it does not ensure to avoid them completely. Thus a new analytical method the Fourier transform infrared spectroscopy (FT-IR) by means of multivariate data analysis (PLS-R) was developed. The results obtained demonstrate that this approach provide further support to biological tests due to the lack of effect produced by lag phases or toxic effects on the FT-IR spectrum. Furthermore it should be pointed out that the time consuming biological tests respiration activity and gas generation sum could be carried out efficient and rapid by means of FT-IR spectroscopy only in a few minutes. The results demonstrate that using a combination of different determination methods reliable results for biological reactivity of MBT-waste can be achieved.

5 References

BMLFUW	2008	Austrian Landfill Ordinance: Verordnung des Bundesministers für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft über Deponien (Deponieverordnung 2008) BGBl. II Nr. 39/2008
Binner E., Meissl K., Tesar M.	2007	Assessment of MBT-Waste – A new approach to avoid failures by measuring respiration activity. In: Proceedings of SARDINIA '07 – 11th International Landfill Symposium, Vol. I, Cagliari, Sardinia, Italy
Binner E.	2006	Beurteilung der Reaktivität von Abfällen - Anwendbarkeit der für mechanisch-biologisch behandelten Restabfall entwickelten Methoden bei anderen Abfällen. In: Matthias Kühle-Weidemeier (Eds.): Abfallforschungstage 2006 „Auf dem Weg in eine nachhaltige Abfallwirtschaft", Cuvillier Verlag, Göttingen, Germany
Binner E.	2003	Assessment of MBP-Waste - Misinterpretations of Respiration Activity. In: Proceedings of SARDINIA '03 – 9th International Landfill Symposium, Vol. I, Cagliari, Sardinia, Italy

Chen Y.	2003	Nuclear Magnetic Resonance, Infra-Red and Pyrolysis: Application of spectroscopic methodologies to maturity determination of composts. Compost Science and Utilization 11, 152–168
Meissl K., Smidt E., Schwanninger M.	2007	Prediction of Humic Acid Content and Respiration Activity of Biogenic Waste by Means of Fourier Transform Infrared (FTIR) Spectra and Partial Least Squares Regression (PLS-R) Models, Talanta 72, pp. 744-799
Pollanen K., Hakinnen A., Reinikainen S.P., Rantanen J., Karajalainen M., Louhikultanen M., Nystrom L., Pharamaceut J.	2005	Spectroscopy Together with Multivariate Data Analysis as a Process Analytical Tool for In-line Monitoring of Crystallization Process and Solid-state Analysis of Crystalline Product, Journal of Pharmaceutical and Biomedical Analysis 38, pp 275-284
Smidt E. and Schwanninger M.	2005	Characterization of waste materials using FT-IR spectroscopy – Process monitoring and quality assessment. Spectroscopy Letters 38, 247–270.
Smidt E. and Meissl K.	2006	The applicability of Fourier transform infrared (FT-IR) spectroscopy in waste management, Waste Management 27, pp. 268-276
Smidt E., Eckardt K.U., Lechner P., Schulten H.R., Leinweber P.	2005	Characterization of Different Decomposition Stages of Biowaste Using FT-IR Spectroscopy and Pyrolysis-field Ionization Mass Spectrometry, Biodegradation 16, pp 67-79
Smidt E., Lechner P., Schwanninger M., Haberhauer G., Gerzabek M.H.	2002	Characterization of Waste Organic Matter by FT-IR Spectroscopy: Application in waste science, Applied Spectroscopy. 56, pp 1170-1175
Smith B.	1999	Infrared Spectral Interpretation. CRC Press, London, New York, Washington; DC, Boca Raton.
Socrates G.	2001	Infrared and Raman Characteristic Group Frequencies. Tables and Charts. John Wiley & Sons Ltd, Chichester.
Zacceo P., Ricca G., Crippa L.	2002	Organic Matter Characterization of Composts From Different Feedstocks, Compost Science and Utilisation 10, pp 29-38

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Small scale co – composting plants to recycle sewage sludge and green waste.

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Abstract

In Europe the progressive augment of the production of sludge from municipal wastewater treatment plants has recently led to a growing attention about management of this type of solid matrix. European Directives and Italian guidelines stimulated reuse of sewage sludge on agricultural soils or in composting factories encouraging the restitution to the biogeochemical natural cycles of recovered material. Nevertheless current Italian law on wastes suggests that sewage sludge must be subjected to the general regulation of waste and sometime public opinion suspect about the sludge recovery practice prevails on the convincement concerning a more convenient waste management. A joint project by the University of Udine together with Poiana waterworks will test a new system to compost sewage sludge from wastewater treatment plants. The project aims to build a pilot composting plant to process sludge from the wastewater treatment plants.

Keywords

Sewage sludge, green waste, pilot composting plant, soil, quality standards, bench top, biocell

1 Introduction

In municipal and industrial wastewater treatment plants the decrease of biodegradable substances with the activated sludge technology and the elimination of organic and inorganic particulate produce high quantity of primary and secondary sludge. In the past ten years the production of sludge from municipal wastewater treatment plants (MWTP) in Europe has progressively increased (from 8 x 10^6 tonnes in 1998 to 10^7 tonnes in 2007) and represents an ever growing problem because of the concomitant rise in landfilling costs. Nowadays depending on both geographical localization and technologies of disposal, a range of charge from 380 to 750 euro per tonne (on dry mass basis) can be assumed (Andreottola et al., 2008).

In the municipal and industrial wastewater treatment plants, the separation of organic and inorganic particulates by sedimentation and the treatment of biodegradable substances by biological technology, produce high quantity of primary and secondary sludge. Sewage sludge in a treatment plant contains an high fraction of water with a little percent of solid material and, even after drying out, water can remain greater than 60 – 70% by weight. As a consequence an high volume of material must be managed to the final disposal with considerable costs. Many researchers assume that production of sewage sludge will increase in the next years because of treatment requirements connected to actual regulations (particularly in Europe) and new wastewater treatment plants constructions in emerging Countries (ANDREOTTOLA ET AL., 2008).

1.1 European and Italian Legislation about sewage sludge

In the recent past European Directives and Italian guidelines stimulated reuse of sludge from municipal wastewater treatment plants on agricultural soils or in composting factories. The most important European guideline is the Council Directive 86/278/EEC of 12 June 1986 on the protection of the environment (specifically of the soil), when sewage sludge is used in agriculture. This Act introduces quality standards for soil and sewage sludge when they are applied in agricultural terrain with the aim to regulate their correct use and to prevent probable harmful effects on soil, vegetation, animals and humans. In particular this Directive introduces specific requirements about concentration of heavy metals, kind of treatment to apply and analysis to carry out on sludge and soil before application, specifying areas where the use of sludge is prohibited. This perspective encouraged the restitution to the biogeochemical natural cycles of recovered material that, if considered only waste, could have heavy ecological and economic costs to disposal in landfill or in thermodestruction plants (GENEVINI, 1996). Furthermore the demand of preserving carbonious supply and fertility elements for the soils, together with a more convenient waste management prevailed on the public suspect (sometime strong opposition) about the sludge recovery practice.

Given the statements of the Italian regulation about the agricultural reuse (D.Lgs. 27 January 1992, Nr. 99), the current regulation on wastes suggests that sewage sludge from wastewater treatment plants must be subjected to the general regulation of waste, where it is applicable, and in particular when the sludge has to be considered a residue at the end of the complete process of the wastewater treatment plant. The last upgrade of the mentioned guideline (given by the D.Lgs. 16 January 2008, Nr. 4) underlines the opportunity of reutilization of sewage sludge only if the reuse is appropriate and sewage sludge are recovered as new raw material.

About 10 years ago a critical revision of the Directive 86/278/EEC was planned in order to accomplish some new targets in sludge recovery question and to improve the existing situation about sludge management, starting from the principles declared in Article 175 of the EC Treaty on environment protection. As a result in 2000 the 3rd draft of "Working document on sludge” was developed and published by European Commission's Environment Directorate-General with the aim to promote the use of sewage sludge in agriculture, to ensure safety of land application and to harmonize sludge quality standards (RIZZARDINI AND GOI, 2009). The document introduces standards for limit values for concentrations of heavy metals and organic compounds that should restrict the use of sewage sludge in agriculture and provides suggestions for good practices in the treatment and land application of sewage sludge (EUROPEAN COMMISSION, 2000).

1.2 Sewage sludge as a raw material: need of characterization

This material is rich in plant micro and macro - nutrients (e.g. about 5% of nitrogen, 3% of phosphorus and 0.5 % of potassium) and organic matter; as a consequence it could be used as fertilizer or to increase soil organic carbon contents. In particular humified organic matter in sewage sludge may improve both physical - chemical properties of soil and biological characteristics. Some effective agronomical quality of sludge with high organic content are recognized only after treatment and under specific safety requirements. Nevertheless direct land application remains the most important alternative for sewage sludge disposal, in particular for sludge produced by small or medium size wastewater treatment plants, with minor pollution by hazardous compounds and located close to the disposal site (SPINOSA, 2001). Land application of treated sewage sludge achieves a complete reuse of its nutrients and organic carbon at a relatively low cost. Therefore, this practise should become a preferred management option where there is available land and the quality of sewage sludge meet regulatory requirements. Intensive energy cropping and forest production using biosolids can help us to meet the ever-increasing demand for renewable energy, which can eliminate the contamination potential for food sources, a common social concern about land application of biosolids (WANG ET AL.). However, there are several factors that hinder sludge application on soil, for example the nitrate leaching risk or the presence of potentially dangerous for the environment as well as for human health (e.g. heavy metals and organic contaminants such as PAH, PCB and dioxins). From this point of view there is a need to characterize sewage sludge and to adopt international and standardized methods (e.g. ISO, CEN) to uniform analysis.

2 The project

The geographical area under study is part of the Friuli Venezia Giulia Region in the north-east of Italy, which is characterized by little communities on a alluvial plain characterized by porous terrains. Wastewaters are collected and treated by several small - scale treatment plants, mainly of activated sludge type. The Poiana waterworks society is in charge of the whole management of the water cycle in the area, from captation to depuration. The society manages 31 plants of similar potentiality serving several small municipalities, as well as an Industrial District. Until now sewage sludge from Poiana wastewater treatment plants was partly applied to agriculture by soil incorporation and partly landfilled. Up to now, land applications were massively employed complying with the regulations and technical and managerial requirements.

Currently Italian Legislation provides a relatively simple way to agricultural use by characterization of sewage sludge with a frequency of analysis defined on plant size basis. As well the monitoring of soil quality interested by land application is completed by simple testing.

The University of Udine together with Poiana waterworks have drawn a joint project to test a new system to compost sewage sludge: the aim is to plan, build and test a pilot composting plant to process sludge from municipal wastewater treatment plants. It may consist in a filter press to dry sewage sludge and also in a tank where green residual products (e.g. leafage or discard of pruning) are added to sludge, complying the proportion established by the Italian regulation (max 33% on dry weigh basis). In a second time a traditional aerobic treatment will be applied to the mixture of dry sludge and leafage to obtain a mixed compost. In this way a self sustained management of sludge produced by Poiana waterworks plants is proposed in order to reach several advantages: I) a decrease of disposal costs, II) an increase in value of waste, III) elimination of problems around disposal of recovered organic waste, and IV) the possibility to market organic certified fertilizers of high quality. As a consequence Poiana project proposes to design an internal sludge management protocol coming from the new recent approaches regarding quality of sewage sludge, with particular attention for composition and possible content of persistent organic pollutants produced by both industrial discharge and households.

In the first part of the project there was the quantification of the mean annual production of liquid sewage sludge of 10 urban and domestic plants chosen on the plant capability basis, types of water treatments and possible intrusions from agro - industrial activities. In order to obtain a good quality compost, sewage sludge is selected and treated complying with the „Working document on sludge“: analysis include hygienic, biological and inorganic parameters defined by the Horizontal Project Team (http://www.ecn.nl/horizontal). After this first step of analysis a composting test on lab scale is planned: a good quality sewage sludge will be mixed with green residues in a bench top reactor monitoring chemical and microbiological reactions to perform the best final compost mixture. The process-design results will be applied to a larger scale in the pilot composting plant to produce an high quality compost from sludge and green waste material. This final compost will be tested to evaluate its chemical, physical and agronomical attitudes.

3 Literature

Andreottola, G.;	2008	Minimizzare i fanghi di depurazione. Strategie integrate nel trattamento delle acque reflue. Università degli Studi di Trento, Trento. ISBN 978-88-8443-238-4.
European Commission;	2000	Working document on sludge, 3rd draft. http://ec.europa.eu/environment/waste/sludge/pdf/sludge_en.pdf.
Genevini, P.L.;	1996	La tossicità dei fanghi di depurazione. Presenza di xenobiotici organici. Fondazione Lombardia per l'Ambiente. ISBN 88-8134-020-8.
Rizzardini C.B. and Goi D.;	2009	Considerations About European Directives and Italian Regulation on Sludge from Municipal Wastewater Treatment Plants: Current Status and Future Prospective. The Open Waste Management Journal, Vol 2 pp 17-26 (10). Bentham Open, ISSN: 1876-4002. DOI: 10.2174/1876400200902010017.
Spinosa, L.;	2001	Evolution of sewage sludge regulations in Europe. Water Science & Technology, Vol 44 No 10 pp 1-8. IWA Publishing 2001, ISSN 0273-1223.
Wang, H.L., Brown, S.L., Magesan, C.n., Slade, A.H., Quintern, M., Clinton, P.W., Payn, T.W.;	2008	Technological options for the management of biosolids. Science and Pollution Research, Vol 15 No 4 pp. 308-317, many ref. Springer Berlin, Heidelberg. ISSN 0944-1344. DOI: 10.1007/s11356-008-0012-5.

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Municipal Solid Waste bio-drying viability in different countries

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Abstract
In the sector of biological - mechanical treatments of Municipal Solid Waste the bio-drying process followed by an adequate use of Refuse Derived Fuel can fulfill the EU requests regarding landfilling of a lower quantity of materials with a higher stabilization rate and a low lower heating value. In this paper the experimental and modeling results of bio-drying pilot plant runs are presented from the point of view of mass and energy balances taking into account the waste composition in different countries around the world. The results are useful for the decision-makers who must understand the viability of bio-drying in different case studies.

Keywords
bio-drying, LHV, MSW, organic fraction, RDF, selective collection.

1 Introduction

Waste management is one of the most important problems on the carpet in the world. The recent European Union regulations for a new concept of sanitary landfill point out the importance of a good waste management for landfilling a lower quantity of material with a higher stabilization rate and a low lower heating value. The optimal scenario is related to the presence of only not recyclable materials in the residual municipal solid waste (the waste that is not selectively collected).

In the sector of biological - mechanical treatments (MBT) the bio-drying process followed by an adequate use of Refuse Derived Fuel (RDF) seems to fulfill to these requests. This strategy can became a current/future option not only for the EU countries but also for the low and medium income countries, in particular for the new emerging countries as China and India.

In fact, bio-drying is a process which follows mainly the reduction of municipal solid waste humidity by exothermal reactions of organic substances with the lowest conversion of organic Carbon. The use of this process could be a temporary strategy before the implementation of a waste-to-energy plant: in a first step, bio-drying could help to decrease the impact of Municipal Solid Waste (MSW) to be landfilled; in a second step, an energetic valorization of the bio-dried (and refined) material could be implemented both in dedicated plants and in co-combustion options.

In the field of MBT, the presence of a separation unit as a first stage has been a typical approach in the past: after a mechanical sorting the waste stream was divided in biodegradable materials (aimed to Stabilized Organic Fraction generation) and non-biodegradable materials (aimed to RDF generation). This approach has been named “two-stream” option. Today the one-stream option is more and more applied (in Italy some initiatives aimed to convert existing two-stream plants into one stream plant are under discussion). In this way the preliminary separation stage is avoided and all the waste is biologically treated for obtaining a bio-dried material. Post-treatment of refining can allow the production of RDF used for alternative options (as a fuel for co-combustion in thermal power plants and cement kilns).

In this paper starting from the results of a research developed between the University of Trento (Italy) and the Politehnica University of Bucharest (Romania), some considerations regarding the viability of MSW bio-drying in different European countries at high/medium/lower organic fraction content are presented. Latin American and Asiatic case studies are also analyzed referring to very high organic fraction content in the MSW [Zhang et al., 2008a,b]. These case studies are compared with the ones where the selective collection plays an important role concerning the viability of bio-drying [Apostol el at., 2005].

2 Material and methods

In order to characterize the behavior of bio-drying when applied to different MSW, the experimental runs were made at Trento University were a biological pilot plant (Figure 1) was available [Rada 2005]. The biological reactor is an adiabatic box of 1m^3. For having real data concerning the variations of weight, the biological reactor is placed on an electronic balance.

Figure 1 Biological reactor

The necessary air is first filtered for protecting the blower then introduced and dispersed in the biological reactor through a diffuser. The air flow crosses upward the waste from the lower part, favoring the exothermal reactions and goes out of the biological reactor from the upper part. The biological reactor is equipped with pipes for interception and collection of condenses (leachate) that is formed on the walls of the biological reactor. In the biological reactor, four temperature probes were set: one on the diffuser (to measure the temperature of air in entry),one on the piping of discharge (to measure the temperature of process air on exit of the reactor) and two probes put on the vertical (to measure the temperature in the waste).

The experimental runs were performed reconstructing the MSW composition (Figure 2) case by case. In this paper the dynamics of generation and collection of waste is taken into account for each case.

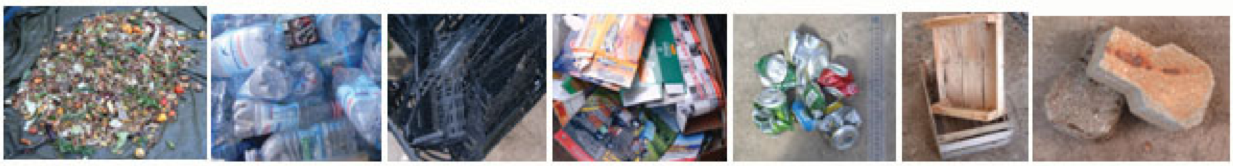

Figure 2 Waste fractions

Presently MSW for the East European, Latin American and Asiatic cases, is collected as is: generally no selective collection is activated, apart from few simplified experiences that are based on the principle of collecting only material ready to be sold (paper, PET, etc.). For this reason the percentage of the organic fraction for those cases is high: 50% or much more (70%).

For the Central and Southern Europe cases, where the selective collection is implemented, the percentage of organic fraction in the residual MSW can vary for instance from 21% to 8% in function of the efficiency of the organic fraction selective collection.

In order to characterize the behavior of bio-drying when applied to those cases a bio-chemical model was used [Rada et al., 2007]. This model is useful to assess the characteristics of bio-dried material and RDF during the process.

However in some countries the production of MSW will have a significant increase in the next decades, thanks to the economical development. The bio-drying process can adapt to the new composition of MSW only if the organic fraction content in the MSW keeps significant.

3 Results and discussion

The main parameter characterizing bio-drying is the mass loss. In Figures 3 and 4 the dynamics of mass loss during the bio-drying process is reported. Mass loss depends on water evaporation and volatile solids consumption. The concept of bio-drying is the maximization of evaporation (also the water generated by bio-chemical oxidation of hydrogen present in the volatile solids) and the minimization of volatile solids consumption.

Typical lasting of bio-drying is two weeks. After that period the residual putrescible volatile solids are not enough to support the process with adequate results: the effect of evaporation is interesting if related to availability of heat generated from bio-chemical oxidation, on the contrary drying should not be obtained by increasing the air flow.

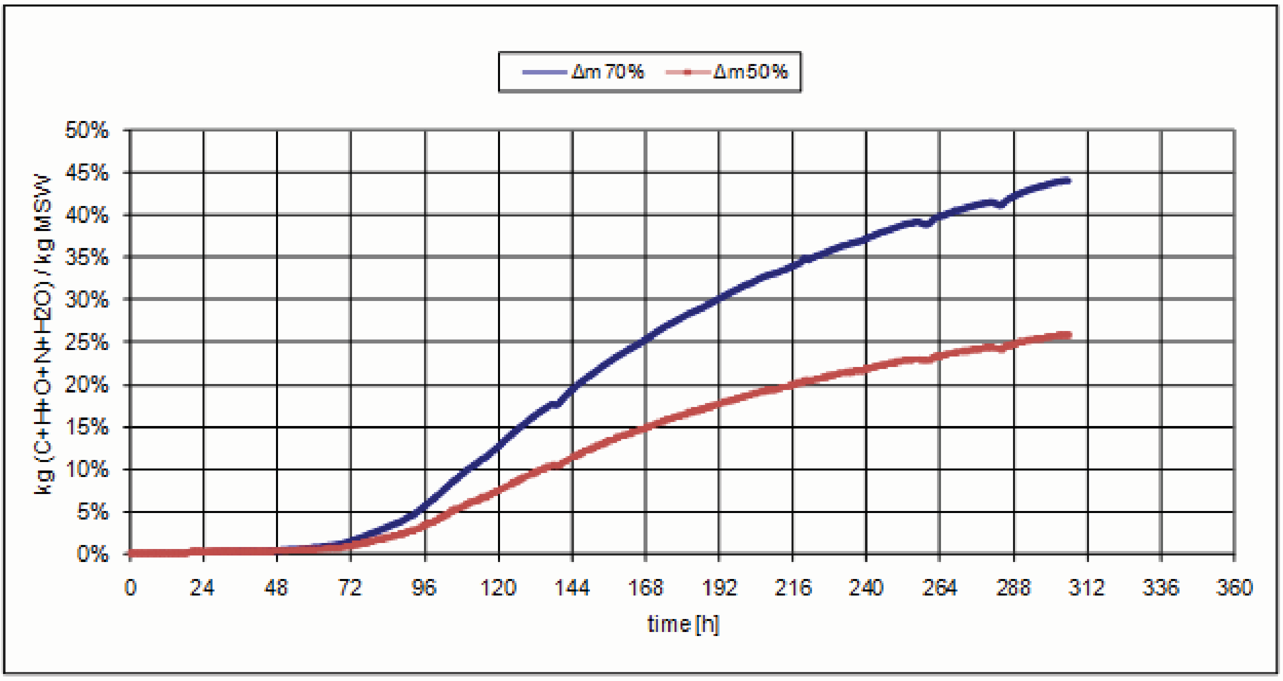

Figure 3 Mass loss dynamics during the bio-drying runs

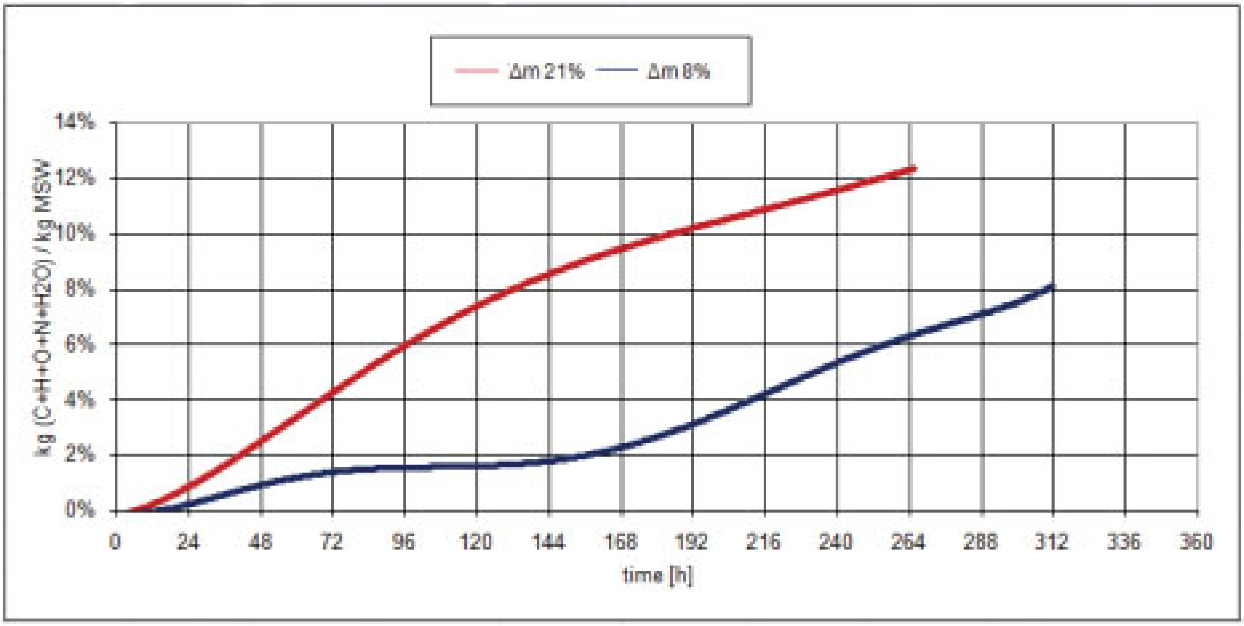

Figure 4 Mass loss dynamics during the bio-drying runs

Taking into account the dynamics from the Figures 3 and 4, it can be underlined that process is more interesting when the organic fraction content in the MSW is higher: the effect of a higher mass loss is a higher concentration of the initial energy content of waste in a lower mass. As a consequence the LHV of the bio-dried material increases (without an overall energy generation). From country to country it must be taken into account the viability of using the bio-drying process depending on the organic fraction content that depends also on the selective collection efficiency.

Table 1 LHV for each waste (treated and not treated)

OF	MSW	Bio-dried mat	RDF
70%	6939	10860	11377
50%	8616	10470	11632
21%	12464	14196	16765
8%	13495	14699	18601

The increase of lower heating values for the MSW to bio-dried material and to RDF (obtained from the bio-dried material without inert, glass and metals) is significant when is high (50%) or very high (70%). On the contrary when the organic fraction is low (21%) or very low (8%) thanks to the selective collection the viability of the process is not so good as in the first cases. Indeed a direct mechanical treatment for RDF generation applied to the MSW after the selective collection could be more suitable having also positive effect on the economical balance.

In Table 1 lower heating values for RDF refer to solutions with zero streams to be landfilled: all the separated materials after bio-drying are recycled. However, where industrial districts are available and need RDF with higher LHV (20 MJ/kg) additional post-treatment on RDF must be planned. This solution will generate a little part of material that can be landfilled or treated in other plants (vetrification) if landfilling must be avoided.

As explained a bio-drying strategy could avoid landfilling having an improvement in terms of greenhouse effect related to the loss of fugitive biogas from landfilling. It is clear that a use of RDF in industrial districts in countries where the control of off-gas lines is not adequately developed could create significant problems from the environmental point of view.

4 Conclusions

Viability of MSW bio-drying is very clear where the content of organic fraction in the MSW is high enough to support the full development of the process. On the contrary, low organic fraction contents give negligible results in term of changes in the energy characteristics of the treated material.

The variation of the lower heating value can transform the waste not suitable for combustion into a product for industrial applications. In spite of that the adoption of bio-drying must take into account the local organization of environmental controls and the existence of a market for the materials separated after bio-drying.

Some advantages of bio-drying could be related also to a decrease of transport costs when MSW presents an initial high organic fraction content: indeed the decrease of weight can be significant.

5 Literature

Zhang, D.Q., He, P.J., Jin, T.F., Shao, L.M.	2008a	Bio-drying of municipal solid waste with high water content by aeration procedures regulation and inoculation. Bioresour. Technol. 99, 8796–8802.
Zhang, D.Q., He, P.J., Shao, L.M., Jin, T.F., Han, J.Y.	2008b	Bio-drying of municipal solid waste with high water content by combined hydrolytic–aerobic technology. J. Environ. Sci. 20, 1534–1540.
Apostol T., Cemin A., Panaitescu V., Rada E.C:; Ragazzi M.	2005	Una proposta per un indicatore di efficienza dalla gestione integrata dei rifiuti, Rifiuti Solidi, Anno XIX, N.4 Luglio -Agosto, pp. 213 -220, ISSN: 0394-5391.
Rada E.C.	2005	Municipal solid waste bio-drying before energy generation, PhD, University of Trento and Politehnica University of Bucharest
Rada E.C., Franzinelli A., Taiss M., Ragazzi M., Panaitescu V., Apostol T.	2007	Lower Heating Value dynamics during municipal solid waste bio-drying, Environmental Technology, vol. 28, pp.463-469, 2007.

Two Approaches to Fuel Gas Production from Plastic Waste: Gasification with Air and Gasification-smelting Process with Multi-blowing Oxygen

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Abstract

Since 2005, DEKONTA has been working on a research project "Progressive Methods for Transforming Waste into Secondary Energy Source". One part of the project is focusing on gasification of municipal plastic waste. Two main approaches of plastic waste gasification were studied: (i) gasification process with air and (ii) gasification-smelting process with oxygen. Pilot-scale tests were performed at testing units in Brno / Czech Republic (University of Technology, Institute of Power Engineering - gasification with air) and in Kashima / Japan (Sumitomo Metals, Corporate Research &Development Laboratories - gasification with oxygen). In both tests, pre-treated plastic waste was used as input material. Obtained results showed that gasification represents a technically feasible approach to utilizations of municipal plastic waste as alternative energy source. Economic parameters of gasification process have become more and more competitive in consequence of rapid and continuing increase of fossil fuel costs.

Keywords

Gasification, Alternative fuel, Plastic waste

1 Introduction

Approximately 200 000 tons of plastic packages were generated in the Czech Republic in 2007 (EKO-KOM, 2008). Only 50 % is recycled as secondary material (mainly PET). The remaining portion of plastic waste stream is mostly landfilled. Possibilities for recycling of the remaining plastic waste are limited because of its heterogeneity, varying of its composition in time and content of impurities complicating potential utilization as raw material or energy source. The main problem related to direct consumption of the plastic waste as alternative fuel is relatively high content of chlorine. Chlorine rising during incineration process may negatively affect quality of both consumer´s production (e.g. cement, steel etc.) and technological equipment (e.g. corrosion by hydrochloric acid).

Thermal gasification is the chemical conversion of organic solids and liquids into a synthetic gas under very controlled conditions of heat and availability of oxygen. The synthetic gas formed by gasification is composed primarily of H_2 and CO. Applying thermal gasification to plastic waste is a relatively new development. Gasification process can transform the calorific value of the plastic waste to synthetic gas which can be utilized by chemical industries, the energy sector and so on.

Two approaches to gasification of plastic waste were tested in the framework of the research project “Progressive Methods for Transforming Waste into Secondary Energy Source”: (i) gasification with air and (ii) gasification with multi-blowing oxygen.

2 Plastic waste samples for pilot-scale gasification tests

Plastic waste material prepared for gasification tests was shredded to the size - 5 mm. Chemical composition of the tested material is presented in Table 1.

Table 1 Chemical composition of tested plastic waste

Component	Content	
	Gasification with air	Gasification with oxygen
Combustible matters (% w/w)	80.1	74.4
Fixed carbon (% w/w)	13.0	9.3
Ash (% w/w)	5.4	12.7
Moisture (% w/w)	1.45	3.5
C (% w/w)	46.6	56.6
H (% w/w)	7.6	17.2
O (% w/w)	36.9	9.0
N (% w/w)	1.17	0.7
Total S (% w/w)	0.15	0.3
Total Cl (% w/w)	0.67	2.2
CaO (% w/w)	1.29	3.0
SiO_2 (% w/w)	1.49	3.5
AL_2O_3 (% w/w)	1.13	2.7
Calorific value ($MJ.kg^{-1}$)	32.96	23.19

3 Gasification with air

Gasification with air as gasifying medium is a complex thermal and chemical conversion of organic matter into synthetic gas under oxygen deficiency conditions. Calorific value of produced gas is usually relatively low due to high content of nitrogen (more than 50 %); the other main constituents of the gas are CO, CO2, H_2, CH_4, higher hydrocarbons and impurities. Tar and dust are the main factors limiting the use of fuel gas.

Pilot scale tests of plastic waste gasification with air were carried out at a fluidized bed atmospheric gasifier with stationary fluidized bed called Biofluid 100 - see Figure 1. The gasifier is installed in the Institute of Power Engineering, University of Technology, Brno, Czech Republic (SKÁLA ET AL., 2007).

The unit is usually operated within temperature interval 750 °C - 900 °C. Process temperature control is carried out by modifying the fuel to air ratio. Consumption of gasified waste is normally 15 - 25 $kg.h^{-1}$ (max. 40 $kg.h^{-1}$), air flow is normally 25 - 35 $m^3.h^{-1}$ (max. 150 $m^3.h^{-1}$). The content of solid particles in produced gas is normally between 0.5 $g.m^{-3}$ and 3.0 $g.m^{-3}$ and the content of tars varies from 1 $g.m^{-3}$ to 5 $g.m^{-3}$ depending on fuel used and operating conditions.

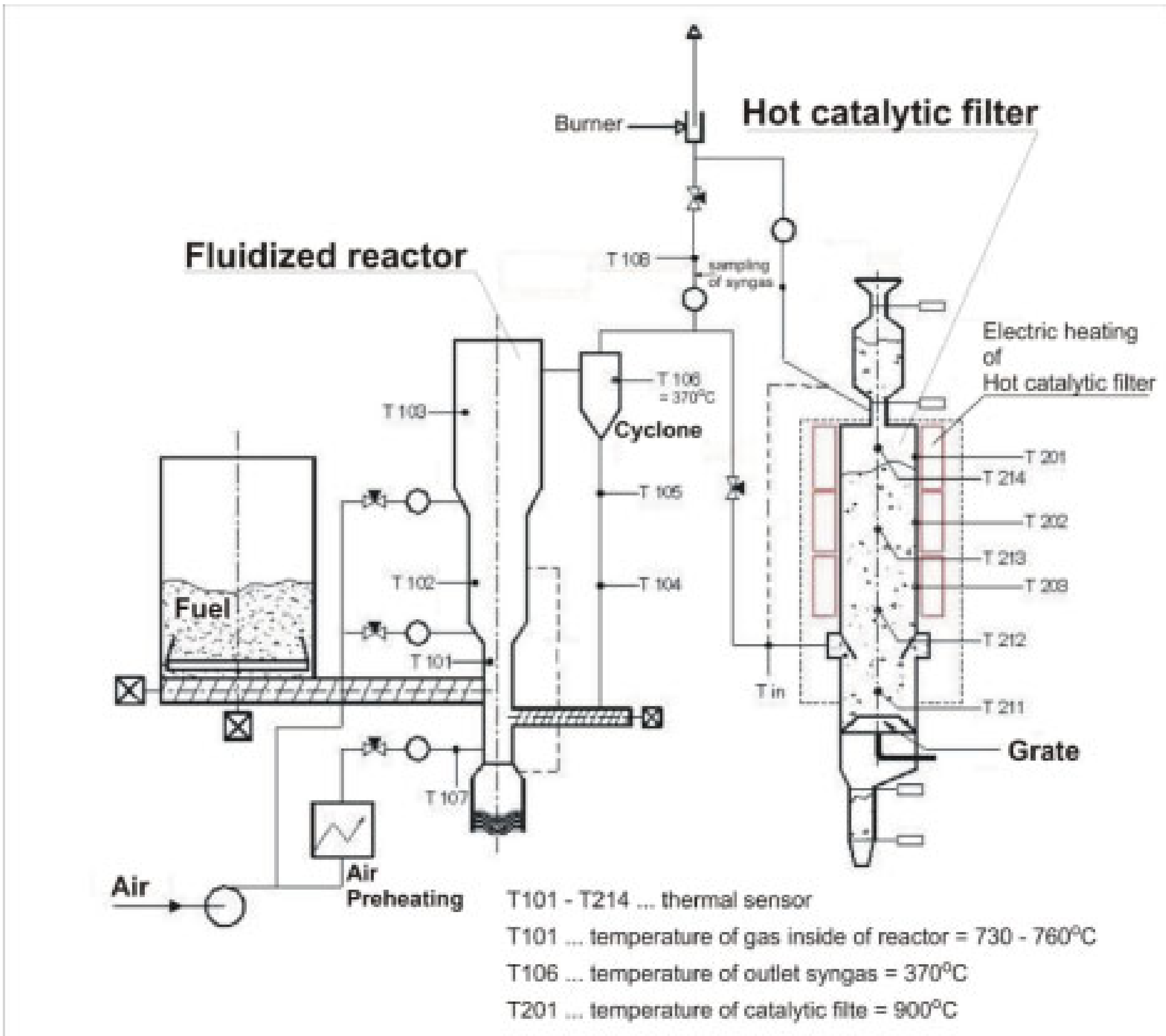

Figure 1 Gasifier Biofluid 100 - General view and simplified technological scheme

Shredded plastic waste is fed to the gasifier from a storage tank with a screw feeder. Compressed air is delivered to the gasifier as primary air ensuring partial oxidization of fuel and creating the fluidized bed. In a cyclone, dust particles are separated from the produced gas stream which is consequently combusted in a burner equipped with a small stabilizing natural gas fired burner. Ash is periodically discharged from the gasifier to ashbin by means of a specially-designed moving grate.

Gas quality measurement is carried out in two ways. One consists of an on-line monitoring of gas composition with simultaneous collection of gas samples to glass containers.

The pilot-scale gasification test was carried out in May 2007 under the following operational conditions:

- Consumption of plastic waste: 12 $kg.h^{-1}$
- Operational temperature: 730 - 760 °C
- Volume of gasification air: 29 $m^3.h^{-1}$

Based on achieved results (see Table 2), the following conclusions were made:

- Gasification of plastic waste with air is technically possible, synthetic gas with the calorific value of approx. 2 300 $kcal.m^{-3}$ can be produced.

- Generated synthetic gas contains: 63.6 %N_2, 10.8 % CO_2, 8.5% CO, 4.8 % H_2, 4.3 % CH_4, 4.0% ethylene; the total content of all other compounds (ethane, acetylene, propane, propene, benzene etc.) is approx. 4 %.

- Relatively high contents of dust (average concentration approx. 5 $g.m^{-3}$) and tar products (average concentration approx. 18 $g.m^{-3}$) were observed in the produced synthetic gas. Though content of both dust and tar products can be reduced by optimization of the gasification process parameters (size of shredded waste particles, gasification conditions etc.), especially the content of tar in produced syngas is considered as a main problematic aspect of the gasification with air technology.

Table 2 By-products obtained from plastic waste gasification with air

Syngas		**Tar and dust in syngas**	
Parameter	**Value(%)**	**Substance**	***Content ($g.m^{-3}$)**
- CO	8.5	Tar	18.0 (average)
- CO_2	10.8		28.9 (max.)
- H_2	4.8	Dust/soot	5.0 (average)
- N_2	63.6		11.0 (max.)
- CH_4	4.3		
- C_2H_6	0.4		
- C_2H_4	4.1		
- Other compounds (C_{3+})	3.6		
Gross calorific value (kcal Nm^{-3})	2 309.5		

4 Gasification with oxygen

The gasification and smelting process with oxygen makes it possible to transform waste plastic into (i) high-calorie fuel gas (a rich amount of H_2) without dioxin contamination and (ii) safe molten slag without heavy metal leaching.

Pilot scale tests of plastic waste gasification with oxygen were carried out in a testing unit installed at Sumitomo Metals, Corporate Research & Development Laboratories (Kashima, Japan) in March 2008. A general view and technological scheme of gasification unit is shown on Figure 2.

The furnace is a shaft type in which waste is gasified and smelted in one process using a top-blow lance together with side-blow oxygen lances: that is, it is a one-process furnace. The upper part of the furnace functions as a gasification reductor and the lower part functions as a smelting combustor in an oxygen-rich environment.

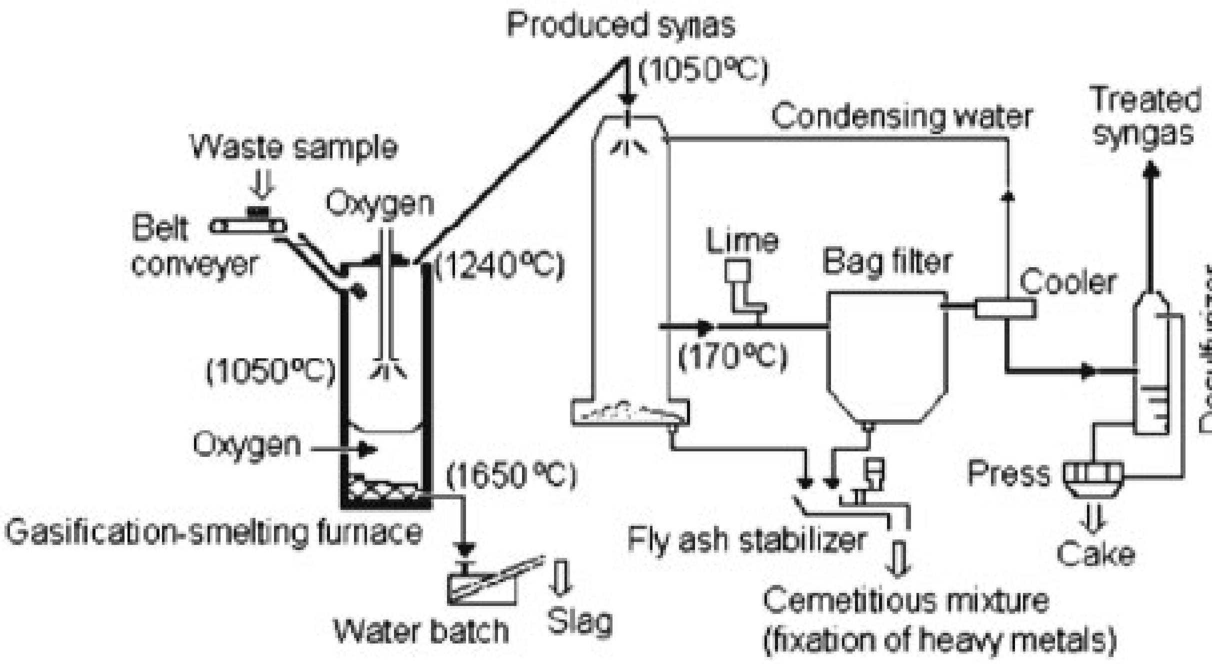

Figure 2 Scheme of the furnace incorporating a gasification unit with a smelting unit

When waste is fed into the furnace, it is burned and decomposed to a gas and a residue in an oxygen-rich environment. The residue melts at ~1 500 ºC and flows down to the lower part and is removed as slag through a tap into a water batch. The formed gas and some of the char rise upwards into the upper part, where they are gasified to fuel gas at ~1 000 ºC: thus, waste is thermally transformed to hydrocarbon gas with fuel value.

Multi-blowing oxygen has the following four effects: (i) top blowing prevents the mixing of coarse dust (above 0.1 mm) with fuel gas; (ii) good quality slag can be obtained by top blowing because the high-temperature zone is concentrated toward the center of the furnace; (iii) the multi-directional flow of gas is confined to a single direction by blowing oxygen through the top lance, resulting in a fuel gas of stable quality; and (iv) this unidirectional flow of gas presses dust against the inner surface of the furnace to form a coating layer of dust all over the inner surface.

The following measures are applied to reduce air emissions from the gasification process: (i) as stated above, top blowing prevents the mixing of coarse dust (fly ash containing metals) with fuel gas; (ii) the high-temperature fuel gas as well as fly ash contained in the gas are rapidly cooled from about 1 000 ºC to about 200 ºC in a quencher in order to prevent synthesis of PCDD/F; and (iii) a bag filter is applied to remove fly ash, chloride and other pollutants (e.g. H_2S). Before the cooled fuel gas and fly ash enter a bag filter, slaked lime powder is injected into the gas to treat air pollutants.

The production of fuel gas and slag was observed during the test operation. The formed slag was collected at a discharger of the water batch and its chemical composition was analyzed. The analytical results are shown in Table 3.

Table 3 Properties of syngas and slag produced from waste gasification-smelting test

Syngas		**Slag**			
Item	**Value**	**Item**	**Value**	**Item**	**Value**
Flow rate	117 $Nm^3\ h^{-1}$	Tapping rate	2.1 $kg\ h^{-1}$	Component:	($mg\ kg^{-1}$)
Component:	(%)	Component:	(%)	- Pb	< 50
- CO	39.0	- CaO	9.4	- Cd	< 50
- CO_2	30.3	- SiO_2	15.8	- Hg	< 0.005
- H_2	13.9	- Al_2O_3	23.2	- As	7.0
- N_2	16.8	- MgO	0.3	- Se	< 0.1
Calorific value	1610 $kcal\ m^{-3}$	- CuO	0.1	- Total Cl	460

5 Conclusion

Two different approaches of plastic waste gasification were studied: (i) gasification process with air (tests realized in May 2007 at University of Technology, Institute of Power Engineering, Brno / Czech Republic) and (ii) gasification-smelting process with oxygen (tests realized in March 2008, at Sumitomo Metals, Corporate Research &Development Laboratories, in Kashima / Japan). Obtained results showed that gasification is a technically feasible approach to utilizations of municipal plastic waste as alternative energy source.

References

Skála Z., Ochrana L., Lisý M., Baláša M., Kohout P., Skoblja S. ;	2007	Research into Biomass and Waste Gasification in Atmospheric Fluidized Bed, Report, Ateko, a.s., Hradec Králové.
EKO-KOM, a.s. ;	2008	Annual EKO-KOM Report, 2008, Prague.

Mechanical-thermal waste treatment (MTT) of residues from grain processing as an efficient way of their utilisation

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Abstract

This work is devoted to the solution of utilization problem of the imminent waste of grain processing on flour-and-cereals and feed mill factories. The possibility of this kind waste utilization by mechanical-biological treatment (MBT) with the purpose of the compost preparation is known. However, this method as applied to this kind of waste is rather difficult, long, expensive and, therefore, ineffective. The utilization of the technological waste from processing of grain, as the secondary raw materials, by the method of mechanical-thermal treatment (MTT) consisting in preparation from them fuel briquettes and, thus, use of this waste as fuel and energy resources is proposed in this work instead of MBT.

Keywords

waste to resources, processing grain waste, mechanical-biological treatment, mechanical-thermal treatment, alternative fuel, fuel briquettes.

1 Introduction

Now in the Republic of Belarus as well as all over the world there is a sharp problem of production waste utilization. One of the ways of this problem decision is the increase of the efficiency of the formed production waste utilization.

37.96 million tons of production waste was formed in 2007 on the territory of the Republic of Belarus. The volume of waste formation in comparison with previous year has increased on 13.4 %. Over 1500 kinds of production waste with a wide spectrum of morphological and chemical properties formed in Belarus. The level of the production waste use in 2007 has made 22.3 %. If we look up at a structure of production waste formation in 2007 without a waste of potash ores processing, we can see that in a whole mass of waste (10349 thousand tons) the great share of the vegetative and animal origin waste (30.8 %). The increase of the utilization degree of the production waste concerns to number of the priority aims for waste problems solution in the Republic of Belarus. In the Directive of the President of Belarus № 3 from June, 14th, 2007 “The Economy and thrift - primary factors of economic safety of the state” is noted sharp necessity of waste using and their more scale application for a national economy.

The inevitable waste formed at processing of grain in cereal-processing industry on flour-and-cereals plant and feed mill plant is a one of the kinds of a solid waste. Specific feature of grain processing technology of these manufactures is a formation of a significant amount of a technological waste. Reduction of such waste is impossible; its quantity is proportional to quantity of processed grain and will always be increased with increase in production.

The present work is devoted to the decision of utilization problem of this kind of waste, taking into account carrying out of technological processes at cereal-processing industry of the Republic of Belarus – using an example of Open joint-stock company “Molodechnensky feed mill and flour factory”. More than 800 tons of such waste was formed in 2007 in this plant. Over 15 thousand tons of the grain processing waste are formed annually in the given branch of industry totally in the country. Approximate structure of the waste in grain clearing process is following: the maintenance of grain is about 2 % of weights, organic impurity – seeds of weed plants – 20 %, culmiferous particles – 60 %, hull of grain (cellulose) – 12.5 %, aspiration dust – 5.5 %. Besides there are also toxic impurity of an ergot in waste from grain processing.

Now this kind of waste is not used as secondary raw material, it’s just taken out on dumps and is a source of a raised environmental contamination. Deficiencies of landfill method of such waste on dumps and ranges are obvious. It is a tearing away of the ground areas for landfilled of the waste and harmful influence subsequently of decaying waste on environment that in itself is an additional source of the raised environment contamination. The urgency of a problem of this waste utilization increases in connection with more rigorous ecological requirements, growth of payments for environmental contamination and placing of a waste, increase in expenses at transport services.

The existing situation demands working out of the necessary organizational-technical measures for reduction of the harmful influence of this branch enterprises on environment. Protection of environment against harmful influence of such enterprises can be realized in the next ways: by perfection of the realization mechanisms of nature protection activity, and also by working out of ways for utilization of a formed technological waste.

The possibility of this organic waste utilization by mechanical-biological treatment (MBT) with the purpose of the compost preparation is known. However, this method as applied to this kind of waste is rather difficult, long, expensive and, therefore, ineffective. Principal cause of it are the restrictions because of the process biological nature on which the factors and the requirements specific to biological activity spread. So, under the most optimum conditions of the composting (MBT) the restriction resulting action of one factors of an environment is rather essential, namely – the insufficient quantity of nitrogen. Thus process suppresses proportionally to degrees of insufficiency of this factor. The huge value has carbon-nitric balance (ratio C/N) for formation of the compost. The optimum limit of ratio C/N for composting can change from 20 or 25 up to 1. The more carbon-nitric balance differs from optimum, especially in the top limit, the process more slowly proceeds. Besides if carbon is present in the form, which highly resistant to bacterial influence, it is used by microbes in less quantity. The unique way of the process efficiency increaseis the increase of the nitrogen content. The addition of bacteria will aggravate a problem as there is no enough nitrogen even for an existing population. More perfect equipment will not give satisfactory result because the effective components of process, namely bacteria, do not have enough nitrogen for satisfaction of the metabolic needs.

The utilization of the technological waste from processing of grain, as the secondary raw materials, by the method of mechanical-thermal treatment (MTT) consisting in preparation from them fuel briquettes and, thus, use of this waste as fuel and energy resources is proposed in this work instead of MBT. We also carried out the comparative estimation of waste mechanical-biological (MBT) and mechanical-thermal treatment (MTT). We have established experimentally that MTT of waste from grain processing is more effective than MBT and allows to transfer completely this waste to useful resources.

2 Experimental

With the purpose of the possibility definition of the measure realization for utilization of the technological waste from grain processing on Open Society “Molodechnensky combine of bakeries” following experiments have been made: 1) the determination of the bulk waste density; 2) determination of the fraction waste sizes; 3) determination of the waste moisture; 4) determination of the ash waste value; 5) determination of the preparation possibility from this waste of fuel briquettes by pressing method.

The determination of bulk density was carried out with the purpose of determination of the waste consumption from grain processing at making from them fuel briquettes. The special attention has been turned on determination of the waste moisture – very important parameter influencing on hardness of briquettes. In case of the necessary parameter excess on moisture (more than 8 % of weight) briquettes can appear insufficiently strong because of the moisture excess go out in the form of the steam from the prepared product. The waste is necessary to drying up preliminary in this case. The determination of the ash waste from grain processing value also concerns to the important parameters for the solid fuel.

3 Results and discussion

The data received as a result of carried out experiments represented in Table 1.

Table 1. The parameters of the waste from grain processing

Bulk density, t / m^3	Sizes of waste fractions, мм	Moisture of waste, %	The ash waste value, %
0.13	Less than 7 мм (At a waste which was already exposed to preliminary clearing); at 5-10 % of weights. of waste – little more than 7 mm (14 mm maximum) - at processing of grain received directly at harvesting.	5	2.0-3.1

The proposed technology of fuel briquette preparation from this waste consists in the following. The production of briquettes is carried out by means of high-efficiency extruding machine, process of pressing providing continuity. As made experiments have shown, for preparation of briquettes with necessary hardness enough the pressure of 1000 кPa. Besides, the briquette formation is made without application of binding substance additives. The natural lignin, containing in plant cell, is used as the binding serves. The rise in temperature of the pressed material in process of the extrusion promotes of the surface briquette fusing which thanks to it get higher hardness. Received main parameters of fuel briquettes from waste formed at processing of grain in comparison with the most useable kinds of fuel represented in the Table 2.

As follows from data represented in table 2, briquettes from grain waste on the calorific capacity come nearer to coal. Such briquettes have plenty of advantages in comparison with traditional kinds of fuel. By ecological point of view they are more preferable than briquettes on the basis of coal or peat with filling compound from combustible waste of the various manufactures (sawdust, lignin, domestic waste, etc.). The prepared briquettes have a high competitiveness in comparison with other kinds of fuel thank to the qualities set forth above. Besides, the briquettes prices will not depend on jumps of the prices for natural kinds of fuel and growth of ecological payments.

Parameters of waste formed at processing of grain and productivity of extruding machine EB-350 by the given kind of a waste in comparison with of sawdust briquettes preparing represented in the Table 3.

The proposed technology of fuel briquettes preparation from this waste consists of the following. Production of briquettes is carried out by means of high-efficiency extruding machine, process of the pressing providing continuity. Besides, the briquettes formation is made without application of binding substance additives. The natural lignin, containing in plant cell, is used as the binding serves. The rise in temperature of the pressed material in process of extrusion promotes of the surface briquettes fusing which thanks to it get higher hardness.

Table 2 Main parameters of fuel briquettes from waste formed at processing of grain in comparison with the most useable kinds of fuel

Kind of fuel / Main parameters	**Density, kg / м³**	**Moisture, %**	**Ash value, %**	**Sulfur content, %**	**Calorific capacity, kJ / kg**
Sawdust briquetes	1000-1200	10	3.2	0.2	19250-20500
Briquettes from waste formed at processing of grain	900-1000	5	2.0-3.1	0.1	20900-21750
Air-dried wood	400-800	15-20	3.2	0.2	17800-20000
Peat	400-500	25-30	10	0.2	4500-5600
Coal	2000-2500	5-6	8.5	5-15	18400-22600
Fuel petroleum	980	1.5	1.5	1.0-1.5	40500
Methane	0.680	–	–	–	26900

Table 3. Comparative parameters of waste from grain processing with sawdust briquettes and productivity of extruding machine EB-350 (at pressure 1000 кPa)

Parameters / Type of waste	**Sawdust briquettes**	**Briquettes from waste formed at processing of grain**
Moisture , %	до 10, max.	до 8, max.
Treatment temperature , °C	320-350	250-290
Particle size, mm	до 4, max.	До 14, max.
Density, т / m³	0.29	0.13
Productivity of extruding machine, кg / h	350-500	300-350

4 Conclusions

Such briquettes have plenty of advantages in comparison with traditional kinds of fuel. By ecological point of view they are more preferable than briquettes on the basis of coal or peat with filling compound from a combustible waste of various manufactures (sawdust, lignin, domestic waste, etc.). Prepared briquettes have a high competitiveness in comparison with other kinds of fuel thank to the qualities set forth above. Besides, the briquettes prices will not depend on jumps of the prices for natural kinds of fuel and growth of ecological payments. It is also possible the making of the fuel pellets from this kind of technological waste.

The proposed way of technological waste utilization from grain processing (MTT), representing their respective processing and use as alternative fuel, provides the considerable ecological effect and also refer to perspective on economic and technological indicators.

5 References

RUF Bel RC “Ecology”, Minsk;	2007	Condition of the Environment of Belarus: the Ecological Report.
RUF Bel RC “Ecology”, Minsk;	2007	Information-statistic about the state of the condition of the environmental and ecological protection in the Republic of Belarus. Ministry of the environmental protection in the Republic of Belarus.
Editer by D.G. Wilson;	1985	Handbook of Solid Waste Management. Vol. 1, Strojisdat, Moscow.

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Composting products quality assessment and monitoring by hyperspectral imaging based logics

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Abstract

Main aim of the study was to investigate compost products characteristics analyzed through an innovative approach based on the collection and the analysis of the spectra associated to each pixel belonging to an image representative of the surface of a compost sample. Reflectance spectra of selected compost samples have been thus acquired in the visible-near infrared field (VIS-NIR): 400-1000 nm. Correlations have been established between physical-chemical characteristics of the different compost products and their detected reflectance spectral signature. The study demonstrated as a full control of the composting can be achieved adopting the proposed hyperspectral imaging (HSI) based approach. The procedure allows to follow the transformations occurring inside the raw organic waste materials to originate biologically stable, humic substances. Furthermore the developed investigative architecture allows to perform the detection of pollutants negatively affecting the utilisation of this product for specific use.

Keywords

Solid waste recycling, compost, hyperspectral imaging, sorting, quality control.

1 Introduction

Composting is an ancient technology, practiced today at every scale from the backyard compost pile to large commercial operations. Akkadians practiced composting in ancient Mesopotamia, a thousand years before Moses was born. There are references to composting in the Talmud, in the Old Testament, in ancient Chinese writings and in the Bagavad Vita, the ancient Hindu text written in Sanskrit. Ancient Greeks practiced composting, taking straw from animal stalls and burying it in cultivated fields. A retired Roman general, Marcus Porcius Cato, who lived from 234 BC to 149 BC, wrote a book titled "De Agri Cultura" (Concerning the Culture of the Fields) in which he described composting. Cato viewed compost as the fundamental soil enhancer, essential for maintaining fertile and productive agricultural land. He stated that all food and animal wastes should be composted before being added to the soil. Although Cato's descriptions of composting may seem simplistic to us now, for the time it was a revolutionary piece, and influenced farming operations in Europe for hundreds of years after, until the fall of the Roman Empire.

Composting consists on the aerobic decomposition of organic materials by micro-organisms under controlled conditions (TIQUIA ET AL., 2005). Micro-organisms break down the carbon bonds of organic materials in the presence of oxygen and moisture, giving off heat in the process. It is a dynamic process which will occur quickly or slowly, depending on the strategies utilised and the skill with which it is executed.

Composting requires three key activities; i) aeration, ii) moisture and iii) the proper carbon to nitrogen (C:N) ratio. Attention to these elements will raise the temperature to around 130-140 °C, and ensure rapid decomposition. The success with which the organic substances are composted depends on the organic material and the decomposer involved organisms (CASTALDI ET AL., 2005). Some organic materials are broken down more easily than others. Different decomposers thrive on different materials as well as at different temperature ranges. Some microbes require oxygen, and others do not; those that require oxygen are preferable for composting. A more diverse microbial community makes for a more efficient composting process. If the environment in the compost pile becomes inhospitable to a particular type of decomposer, it will die, become dormant, or move to a different part of the compost pile. The transforming conditions of the compost pile create a continually evolving ecosystem inside the pile. The decomposition occurring in the compost pile takes up all the available oxygen. Aeration is the replacement of oxygen to the centre of the compost pile where it is lacking. Efficient decomposition can only occur if sufficient oxygen is present (LASARIDI ET AL., 1998). This is called aerobic decomposition. It can happen naturally by wind, or when air warmed by the compost process rises through the pile and causes fresh air to be drawn in from the surroundings. Composting systems or structures should incorporate adequate ventilation. If the compost pile is not aerated, it may produce an odour symptomatic of anaerobic decomposition. Micro-organisms can only use organic molecules if they are dissolved in water, so the compost pile should have a moisture content of 40-60%. If the moisture content falls below 40% the microbial activity will slow down or become dormant. If the moisture content exceeds 60%, aeration is hindered, nutrients are leached out, decomposition slows, and the odour from anaerobic decomposition is emitted. The "squeeze test" is a good way to determine the moisture content of the composting materials. Squeezing a handful of material should have the moisture content of a well wrung sponge. A pile that is too wet can be turned or can be corrected by adding dry materials. Micro-organisms generate heat as they decompose organic material. A compost pile with temperatures between 32°C and 60°C is composting efficiently. Temperatures higher than 60°C inhibit the activity of many of the most important and active organisms in the pile. Given the high temperatures required for rapid composting, the process will inevitably slow during the winter months in cold climates. Compost piles often steam in cold weather. Some micro-organisms like cool temperatures and will continue the decomposition process, though at a slower pace. Important factors affecting the process of composting are thus nutrients (carbon and nitrogen), pH, time and physical characteristics of raw material (porosity, structure, texture and particle size). The quality, the entity and decomposition rate of compost depends on the selection and mixing of raw material, in respect of the recipe adopted to produce a marketable product.

In this paper an hyperspectral imaging based approach was applied. This technique, combining the advantage of spectroscopy and the classical imaging, could be particularly useful to assess compost maturity and to detect contaminants, in respect of a full quality control and certification of compost. The background was constituted by a large set of studies and experiments (BONIFAZI AND SERRANTI, 2006) (SERRANTI AND BONIFAZI, 2008), successfully carried out by the authors, to investigate the potentialities of the proposed approach in respect of innovative recognition-sorting strategies to apply online in waste recycling plants.

2 Compost characteristics and quality assessment

The great number of physical, chemical and biological methods used to study the properties of composts, have made it difficult to assess compost quality (BERNAI ET AL., 1998; ITAVAARA ET AL., 2002). Compost maturity has often been associated with the degree of compost humification (JOURAIPHY ET AL., 2005). Compost stability refers to the degree to which composts have been decomposed to more stable organic materials. Various global parameters have been currently used to assess both maturation process and quality of the final product, including physico-chemical properties, such as C:N ratio, humified organic and water soluble carbon, cation exchange capacity, Solvita tests (CANET AND POMARES, 1995; BERNAI ET AL., 1998; CHEN, 2003; GRIGATTI ET AL., 2004; CASTALDI ET AL., 2005; ZMORA-NAHUM ET AL., 2005), and biological properties, such as microbial respiration and enzyme activities (GARCIA ET AL., 1993; FANG ET AL., 1998; LASARIDI AND STENTIFORD, 1998; MONDINI ET AL., 2004; TIQUIA, 2005; ADANI ET AL., 2006).

Recent studies demonstrated as Near-Infrared Reflectance Spectroscopy (NIRS) can be successfully utilised to assess compost characteristics (ALBRECHT ET AL., 2008). NIRS measures the intensity of the absorption of near-infrared light for a sample and for each wavelength. Reflected light in the near infrared (800–2500 nm) and visible (400–700 nm) regions is energetic enough to excite overtones and combinations of molecular vibrations to higher energy levels. The resulting spectra give a unique signature with important biochemical information about the character and number of functional groups such as –CH, –OH, and –NH chemical bonds. NIRS is a highly reproducible technique able to draw a precise chemical fingerprint of an organic material (BEN-DOR ET AL., 1997). NIRS appears as a useful tool to predict soil organic carbon fractions (COZZOLINO AND MORON, 2006), and the organic C and total N content (GARCIA-CIUDAD ET AL., 1999; COZZOLINO AND MORON, 2006).

Compost can be used as a soil amendment in different market segments, including agriculture, landscaping, gardening, nurseries, top dressing, land reclamation and erosion control (DG ENVIRONMENT, 2004).

The potential use of compost in the listed markets is dependent on the characteristics of the compost, the limitations applicable to its use and pertinent laws and regulations. The quality of compost product is the most critical factor affecting its potential use. The quality depends on compost chemical, biological and physical characteristics, that are mainly determined by i) the source material utilized in the compost production and ii) the process used to remove contaminants. Important physical characteristics affecting the quality of compost product are colour, particles size-class distribution (the more the distribution is uniform the better is the compost), earthy odour, absence of contaminants (rocks, glass fragments, pieces of metal and plastics), adequate moisture, concentration of nutrients and amount of organic matter. Composting breaks down easily degradable plant and animal tissue but does not produce appreciable changes in *difficult-to-degrade* organics (wood, leather, polymers) or in inorganics (dirt, glass, ceramics and metals). Limitations on use of compost products are related to the potential effects on i) human and animal health and safety, ii) crop production and iii) quality of air, water and land resources, due to the possible presence of harmful substances (toxic compounds, pathogens, etc.). Compost should thus comply with specific characteristics to be competitive with other fertilizer and amendment products. With reference to EU legislation on compost products (DG ENVIRONMENT, 2004), different threshold values for undesirable materials (glass, plastic and metals < 0.5% dry matter) and for inert (soil and stones between $5x10^{-3}$ and 5 % as dry matter) are adopted.

3 Hyperspectral imaging

Hyperspectral cameras are able to deliver a wide range of information. Wavelength intervals are usually those ranging between 400-700 nm and 400-1000 nm and 1000-1700 nm. Several applications based on such a technology have been developed, both at research and industrial level, in several sectors as astronomy (HEGE ET AL., 2003), agriculture (MONTEIRO ET AL., 2007) (SMAIL ET AL., 2006), pharmaceuticals (RODINOVA ET AL., 2005) (ROGGO ET AL., 2005), medicine (FERRIS ET AL.,2001) (KELLICUT ET AL., 2004) and waste recycling (SERRANTI AND BONIFAZI, 2007), with particular reference to cullets (SERRANTI ET AL., 2006), fluff (BONIFAZI AND SERRANTI, 2006), plastics (BONIFAZI AND SERRANTI, 2008). The technology can be used on-line and is cheap and powerful.

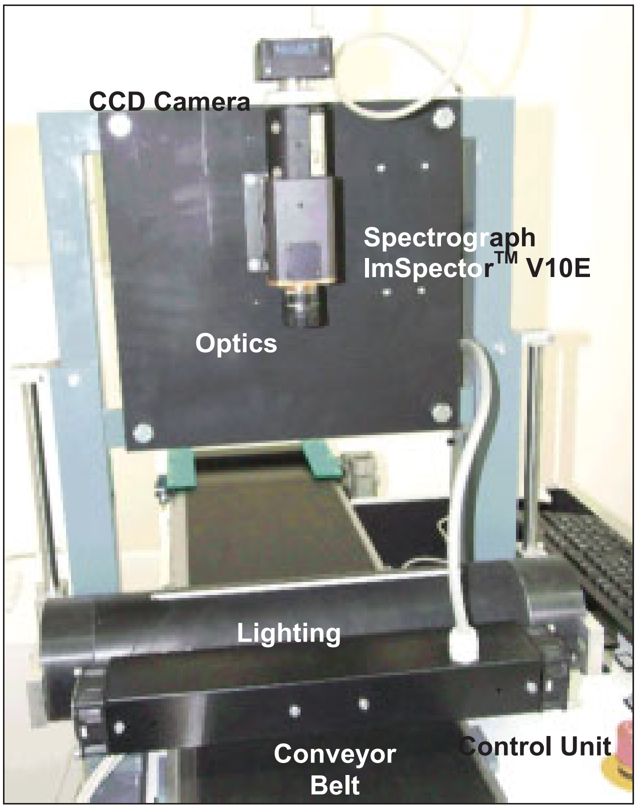


Figure 1 Spectral scanner architecture utilised to acquire compost samples spectra.

Spectra, with reference to this study, have been collected and analysed in order to identify possible correlations between: i) compost spectral signature and its maturity and ii) pollutants detection. The development beyond the state-of-the-art will be to interpret the possibilities of the proposed approach in determining the quality of composting process and resulting compost products.

4 Experimental

Tests have been carried out in order to verify the efficiency of the proposed approach in respect of: i) compost maturity and stability control, ii) compost particle characterisation, that is identification and classification of contaminants, iii) set up of innovative sorting able to fulfil the goals outlined in i) and ii). A specific hyperspectral detection based architecture was thus designed and realised at laboratory scale.

4.1 Laboratory set up, spectral acquisition and analysis

The spectral analyses have been carried out utilizing the detection architecture reported in Figure 1. The equipment assures a progressive and continuous horizontal translation of the sample and the "synchronized" acquisition (at a pre-established step) of the spectra. The sensing device being constituted by an ImSpector™ V10E working in the visible-near infrared spectral range (400-1000 nm), with a spectral resolution of 2.8 nm and a spatial resolution less than 9 µm (SSOM, 2008). The spectrograph is constituted by optics based on volume type holographic transmission grating. The grating is used in patented prism-grating-prism construction (PGP element) characterized by high diffraction efficiency, good spectral linearity and it is nearly free of geometrical aberrations due to the on-axis operation principle. A collimated light beam is dispersed at the PGP, the central wavelength passes symmetrically through the grating and prisms and the short and longer wavelengths are dispersed up and down compared to central wavelength.

Analyses have been carried out performing: i) a characterization of the “shape” of the entire detected spectra and/or identifying, at specific wavelengths, peaks or valley characterising compost detected firm and ii) to verify, adopting a Principal Component Analysis (PCA), the possible correlation existing among detected spectra, sample textural attributes, presence, characteristics and localisation of the different materials and/or contaminants. A PCA is an orthogonal linear transformation of the data to a new coordinate system where the greatest variance by any projection of the data comes to lie on the first coordinate (first principal component, PC1), the second greatest variance on the second coordinate (PC2), and so on. PCA can be used for dimensionally reduction in a data set while retaining those characteristics, that contribute most to its variance, by keeping lower-order principal components and ignoring higher-order ones.

4.2 Samples preparation

Compost products came from an Italian composting plant (AMEK Piccola Soc. Coop. s. r.l., Ferrara, Italy) and have been produced by an innovative process according to a patent pending process (AMEK & CTI, 2002). In this process natural enzymatic mixtures are added to the waste in order to speed up the bio-oxidation, reducing the number by which the treated heaps are turned, as well as the smelling emissions.

The source materials utilized in the compost production are:

- lignocellulosic matter,
- biodegradable fraction of municipal solid waste,
- vegetable waste from agro-industries and
- animal by-products.

At the beginning of the compost production process, selected enzyme blends (named VAP: Vegetable Active Principles) are mixed together with the selected wastes during the mixing and the homogenization of the different source materials. The resulting product is subjected to a composting process of 60-90 days at a controlled temperature that guarantees the total hygiene of the product and the elimination of infesting seeds. The final product is then sieved at 10 mm. After sieving compost is cured for months in static piles under controlled conditions in order to obtain a final product with no phytotoxicity and good also for use as substrate.

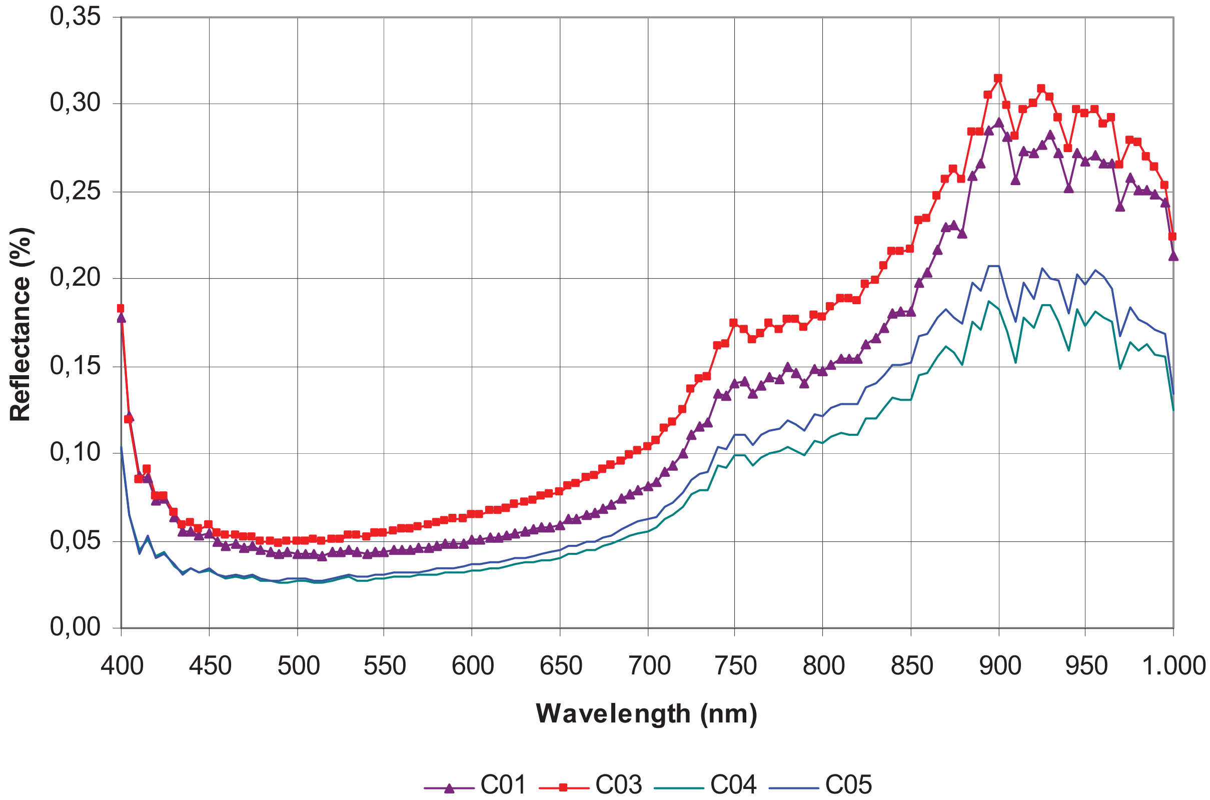


Figure 2 *Average reflectance spectra in the VIS-NIR field (400-1000 nm) of the different compost samples, as resulting by different processing (Sample C01: aged 120 days without enzyme blending. Sample C03: aged 300 days with enzyme blending. Sample C04: short curing with enzyme blending. Sample C05: short curing without enzyme blending).*

4.3 Samples manipulation

Tests have been carried out, at laboratory scale, on different compost samples collected in the core of the piles. The samples have undergone different processes: sample C01, aged 120 days without enzyme blending; sample C03, aged 300 days with enzyme blending; samples C04 and C05 short curing with and without enzyme blending, respectively. For each sample different Region of Interest (ROIs) have been investigated to assess compost quality, according to composting facility design, feedstock source and proportions used, composting procedure, length of maturation and pollutants.

5 Results

The acquired reflectance spectra for the different compost samples allow to perform a classification according to compost quality: ageing and/or mixing, performed or not, with the VAP. Spectral plots show as different materials present a different spectral signature (Figure 2). Increasing ageing, compost samples reflectance increases. The mixing with

VAP, enhancing compost stabilisation and ripening, produces an increase of the spectra reflectance according to the induced acceleration of the ageing process (Figure 2).

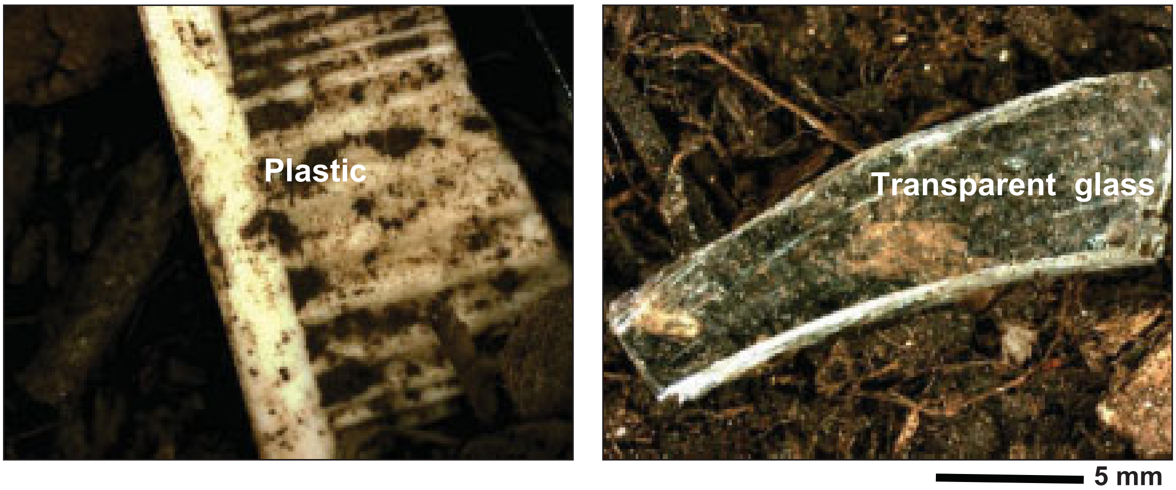


Figure 3 Examples of contaminants as detected in sample C03.

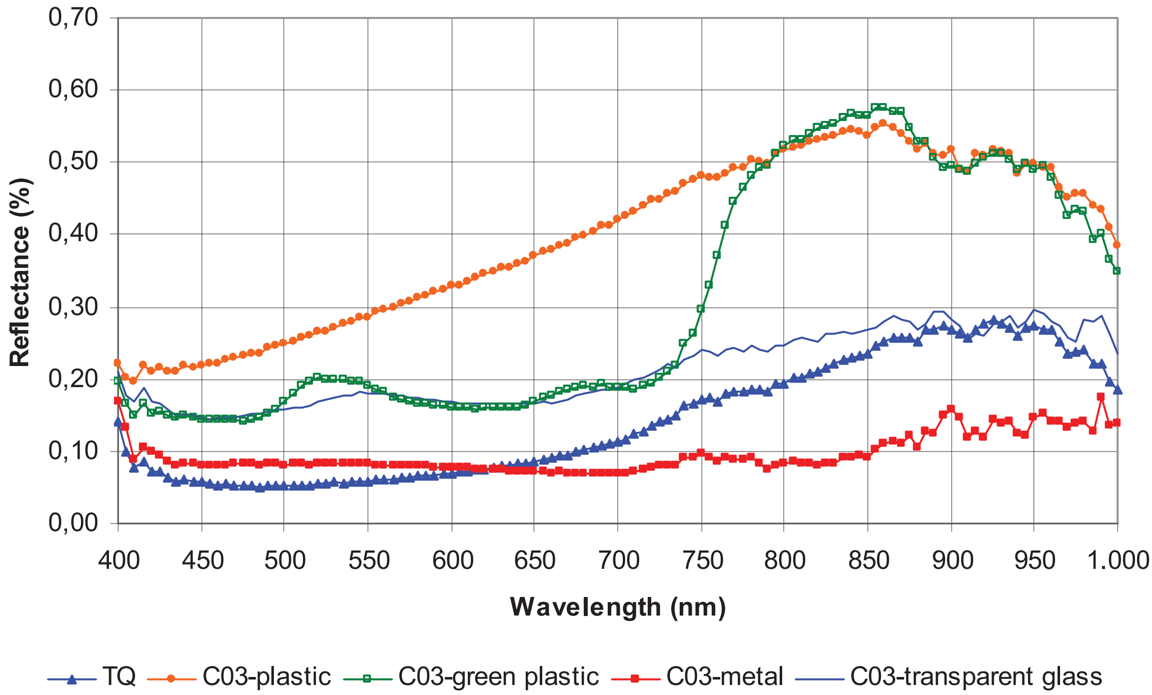


Figure 4 Average reflectance spectra in the VIS-NIR field (400-1000 nm) of different contaminants (plastics, glass and metal fractions,) as shown in Figure 3, and of the compost matrix, as detected in sample C03.

The spectrum of selected ROIs, located on particles contaminants was acquired, to make a comparison with the spectrum of each contaminant and the spectrum of the compost itself. Examples of contaminants identified inside the compost and the corresponding reflectance spectra for samples C03 and C=5 are shown in Figures 3 and 4 and Figures 5 and 6, respectively. 5.

The analysis of the spectra clearly outlines as the different polluting materials are characterised by different spectral signatures, due to their different physical-chemical attributes, like particle colour and composition.

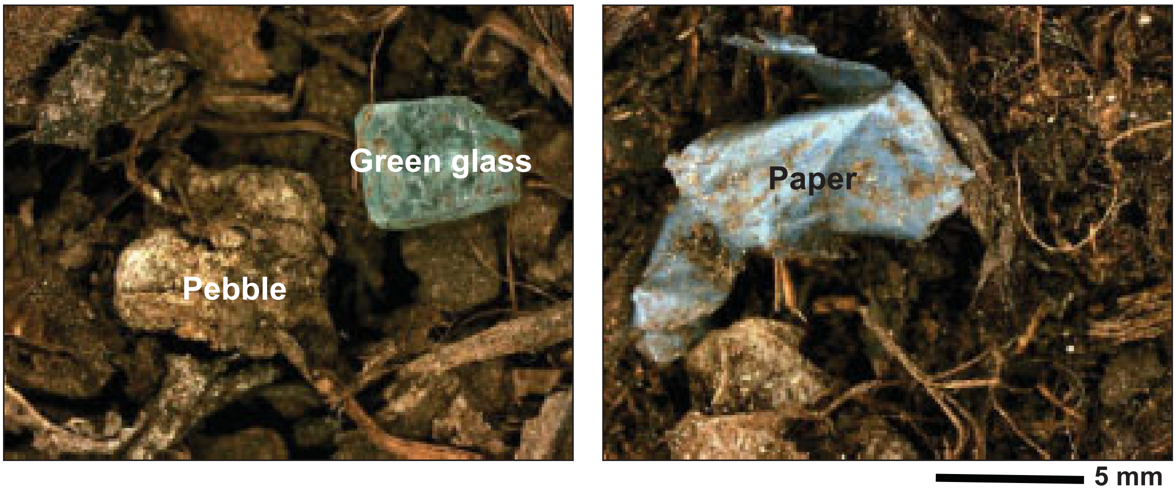


Figure 5 Examples of contaminants as detected in sample C05.

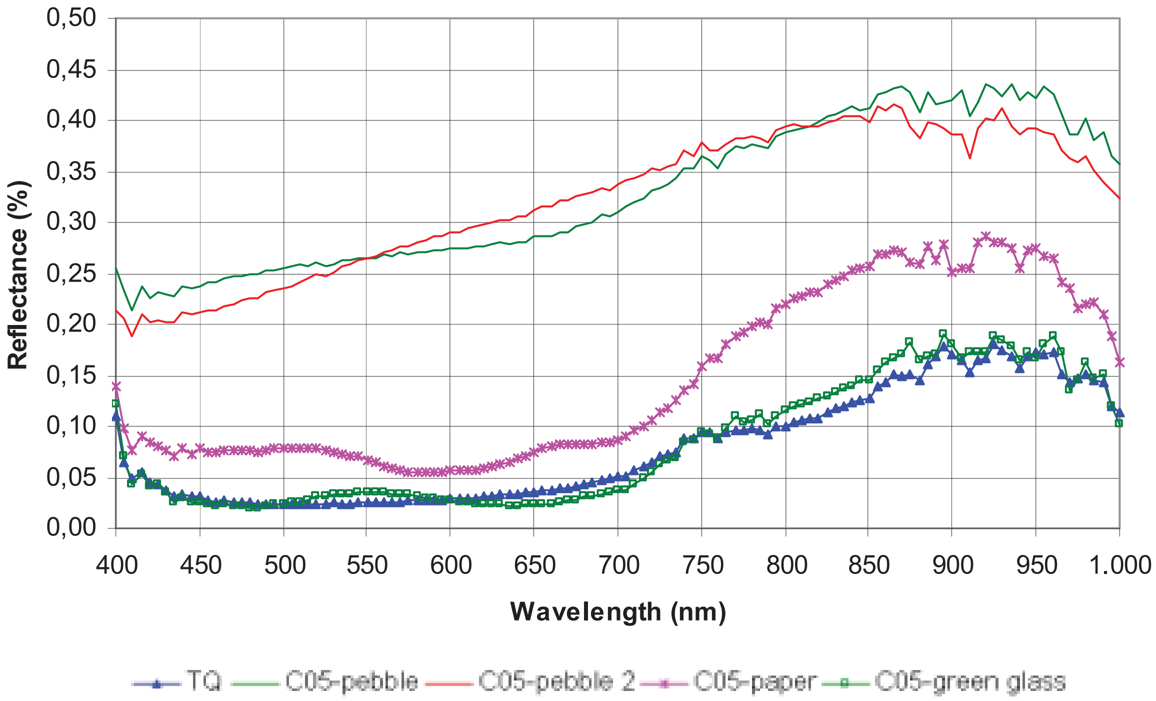
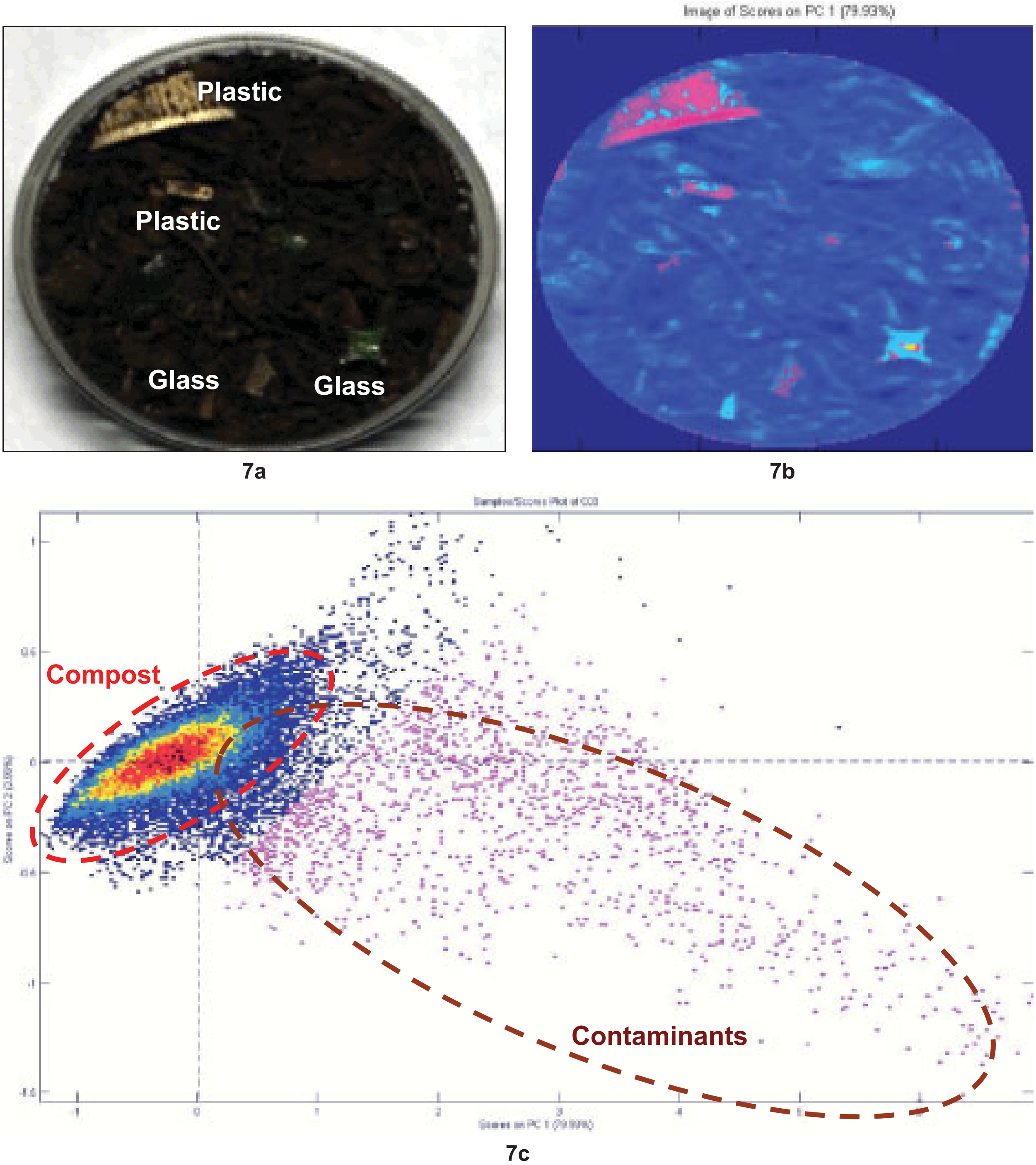


Figure 6 Average reflectance spectra in the VIS-NIR field (400-1000 nm) of different contaminants (pebbles, paper and metal fractions) as shown in Figure 5, and of the compost matrix, as detected in sample C05.

Different contaminants, on the base of the detected spectral signature, have been recognized: mainly plastic and glass fragments, subordinately metal fragments, paper and pebbles. Based on the analysis of the spectral firms, it is thus possible to identify presence and typology of the different contaminants. It is important to remark as compost spectral signature can be easily identified, from those characterizing the different contaminants, on the base of reflectance levels and on spectrum shape (Figures 4 and 6).

The application of PCA, adopting an **H***yperspectral* **P***rincipal* **C***omponent* **I***maging* **A***p-proach* (HPCIA) allows to perform a full identification of contaminants and their topologi cal assessment in the investigated hyperspectral image field (Figure 7).



7a 7b 7c

Figure 7 *Example of compost product (Sample C03) containing different contaminants. 7a: hyperspectral image as acquired, 7b: corresponding false colour image of the computed PC1 image as it results after the adoption of the Hyperspectral Principal Component Analysis (HPCIA), 7c: PC1-PC2 score plot.*

The procedure can be quite useful to design, set up and implement automatic quality control-sorting strategies addressed to certify compost characteristics and/or contaminants removal.

6 Conclusions

The possibility to apply an hyperspectral imaging based approach to determine the quality of compost products both in terms of quality and possible presence of contaminants was investigated. Tests carried out on different compost samples demonstrated as the proposed approach is quite efficient to qualify compost and to detects contaminants on the base of the spectral response. The achieved results introduce the possibility to utilize an hyperspectral sensor directly in the compost plant to control its maturity and stability. The great number of physical, chemical and biological methods utilised to study compost properties made its quality assessment difficult. Hyperspectral imaging can be considered as an efficient and low-cost technique that, combining imaging and reflectance spectroscopy, can be profitably utilized in compost characterization. Furthermore the proposed approach allow a full detection and control of contaminants.

7 Literature

Adani F., Ubbiali C., Generini P.	2006	The determination of biological stability of composts using the Dynamic Respiration Index: The results of experience after two years. Waste Manag. 26, 41-48.
AMEK & CTI	2002	A process of maturing and stabilizing biomasses under reduction of smelling emissions, EP02425717.2
Albrecht R., Joffre R., Gros R., Le Petit J., Terrom G., Périssol C.	2008	Efficiency of near-infrared reflectance spectroscopy to assess and predict the stage of transformation of organic matter in the composting process. Bioresource Technology, 99, 448–455.
Bernai M.P., Paredes C., Sanchez-Monedero M.A., Cegarra, J.	1998	Maturity and stability parameters of composts prepared with a wide range of organic wastes. Bioresource Technology, 63, 91–99.
Bonifazi G., Serranti S.	2006	Hyperspectral imaging based techniques in fluff sorting. The 21st Int. Conf. on Solid Waste Technology and Management: ICSWM 2006. 740-747. Philadelphia, PA, U.S.A.

Bonifazi G., Serranti S.	2007	Hyperspectral imaging based procedures applied to bottom ash characterization. Proc. of SPIE: Advanced Environmental, Chemical and Biological Sensing Technologies V, 6755, 0B-01-0B-10.
Bonifazi G., Serranti S.	2008	Compost quality control by hyperspectral imaging. Photonics Europe 2008. Proceedings of SPIE # 7003-81. Strasbourg, France.
Ben-Dor E., Inbar Y., Chen, Y.	1997	The reflectance spectra of organic matter in the visible near-infrared and short wave infrared region 400-2500 nm) during a controlled decomposition process. Remote Sensing Environment, 61, 1-15.
Canet R., Pomares F.	1995	Changes in physical, chemical and physicochemical-parameters during the composting of municipal solid wastes in two plants in Valencia. Bioresource Technology, 51, 259-264.
Cozzolino D., Moron A.	2006	Potential of near-infrared reflectance spectroscopy and chemometrics to predict soil organic carbon fractions. Soil Till. Res. 85, 78–85.
Castaldi P., Alberti G., Merella R., Melis P.	2005	Study of the organic matter evolution during municipal solid waste composting aimed at identifying suitable parameters for the evaluation of compost maturity. Waste Management, 25, 209–213.
Chen, Y.N.	2003	Nuclear magnetic resonance, IR and pyrolysis: Application of spectroscopic methodologies to maturity determination of composts. Compost Sci. Util. 11, 152-168.
DG Environment	2004	Biological treatment of biowaste.
El-Haggar S., Eggerth L.L., Diaz L.F., Chang M.T.F., Iseppi L.	2007	Marketing of composts, Compost Science and Technology, eds. L.F. Diaz et al. Elsevier: Amsterdam, 325-355. Handbook of Solid Waste Management.
Fang M., Wong J.W.C., Li G.X., Wong M.H.	1998	Changes in biological parameters during co-composting of sewage sludge and coal ash residues. Bioresource Technology, 64, 55–61.

Garcia C., Hernandez T., Costa C., Ceccanti B., Masciandaro G., Ciardi C.	1993	A study of biochemical parameters of composted and fresh municipal wastes. Bioresource Technology, 44, 17–23.
Ferris D., Lawhead R., Dickman E., Holtzapple N., Miller J., Grogan S.	2001	Multimodal hyperspectral imaging for the non invasive diagnosis of cervical neoplasia. Journal of Lower Genital Tract Disease, 5(2), 65-72.
Garcia-Ciudad A., Ruano A., Becerro F., Zabalgogeazcoa I., Vazquez de Aldana B.R., Garcia-Criado B.	1999	Assessment of the potential of near infrared spectroscopy for the estimation of nitrogen content in grasses from semiarid grasslands. Animal Feed Science Technology, 77, 91–98.
Grigatti M., Ciavatta C., Gessa, C.	2004	Evolution of organic matter from sewage sludge and garden trimming during composting. Bioresource Technology, 91, 163–169.
Hege E., O'Connell D., Johnson W., Basty S., Dereniak, E.	2003	Hyperspectral imaging for astronomy and space surveillance. Proc. of the SPIE, 5159, 380-391.
Itavaara, M., Karjomaa, S., Selin, J.-F.	2002	Biodegradation of polylactide in aerobic and anaerobic thermophilic conditions. Chemosphere, 46, 879–885.
Jouraiphy A., Amir S., El Gharous M., Revel J.C., Hafidi M.	2005	Chemical and spectroscopic analysis of organic matter transformation during composting of sewage sludge and green plant waste. Int. Biodeterioration Biodegradation 56, 101-108.
Kellicut D., Weiswasser J., Arora S., Freeman J., Lew, R., Shuman, C.	2004	Emerging technology: hyperspectral imaging. Perspectives in Vascular Surgery and Endovascular Therapy, 16(1), 53-57.
Lasaridi K.E., Stentiford E.I.	1998	A simple respirometric technique for assessing compost stability. Water Resource, 32, 3717-3723.
Mondini C., Fornasier F., Sinicco T.	2004	Enzymatic activity as a parameter for the characterization of the composting process. Soil Biol. Biochem. 36, 1587–1594.

Monteiro S., Minekawa Y., Kosugi Y., Akazawa T., Oda, K.	2007	Prediction of sweetness and amino acid content in soybean crops from hyperspectral imagery, ISPRS Journal of Photogrammetry and Remote Sensing, 62(1), 2-12.
Serranti S., Bonifazi G., Pohl R.	2006	Spectral cullets classification in the mid-infrared field for ceramic glass contaminants detection. International Journal of Waste Management Research. 24, 48-59.
Serranti S., Bonifazi G.	2007	Solid waste materials characterization and recognition by hyperspectral imaging based logics. The 2nd Int. Symposium MBT 2007: Mechanical Biological Treatment and Automatic Sorting of Municipal Solid Waste. 326-336. Hanover, Germany.
Serranti S., Bonifazi G.	2008	Hyperspectral imaging applied to plastic recycling. Global Waste Management Symposium. Copper Mountain Conference Center, CO, USA.
Smail V., Fritz A., Wetzel, D.	2006	Chemical imaging of intact seeds with NIR focal plane array assists plant breeding. Vibrational Spectroscopy, 42(2), 215-221.
Rodionova O., Houmøller L., Pomerantsev A., Geladi P., Burger J., Dorofeyev V.	2005	NIR spectrometry for counterfeit drug detection: a feasibility study. Analytica Chimica Acta, 549(1-2), 151-158.
Roggo Y., Edmond A., Chalus P., Ulmschneider M.	2005	Infrared hyperspectral imaging for qualitative analysis of pharmaceutical solid forms. Analytica Chimica Acta, 535(1-2), 79-87.
SSOM	2008	Spectral Scanner Operative Manual (Version 2.0). DV Optics S.r.l., Italy. http://www.dvoptic.com/index.html
Tiquia S.M.	2005	Microbiological parameters as indicators of compost maturity. J. Appl. Microbiol. 99, 816–828.
Zmora-Nahum S., Markovitch O., Tarchitzky, J. Chen, Y.	2005	Dissolved organic carbon (DOC) as a parameter of compost maturity. Soil Biol. Biochem. 37, 2109-2116.

Humification processes during the mechanical-biological pretreatment of residual waste materials

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Abstract

The research study on mechanical-biological pretreated wastes showed that the emission potential from a tunnel system of a large-scale treatment plant can be reduced by approximately 95% during aerobic treatment. Humification processes were detected whereby the humic substances produced during the aerobic processes were analysed in the organic matter and in the eluate. The humic substances were part of the analysed TOC in the organic matter and in the DOC in the eluate.

Summary

The analysis of mechanical-biological pretreated residual waste showed that during a rotting process in a tunnel system over a 9 week period, stabilisation of the organic fraction occured and that the emissions potential was reduced by approximately 95%. Moreover, through the biological degradation and transformation processes, the buildup of a humin matrix occured, which could be detected in the solid as well as in the eluate of the analysed material. A portion of the organic carbon content in the solid and in the eluate could be attributed to the humic substances.

Keywords

Humification processes, mechanical-biological pretreatment, residual waste

1 Introduction

The mechanical-biological pretreatment (MBP) of residual waste in Germany has been in operation on a large-scale since 1st June 2005. In the initial stages, MBA plants were still in the construction or start-up phase. Already at this stage, it was clear that the assignment values of the Waste Storage Ordinance (Annex 2) (Anonymus, 2001) could only be conditionally met. The dissolved organic carbon content (DOC) in the eluate was especially critical, since the assignment value of 250 mg/l could in many cases only be partially met. Since then, the assignment value has been increased to 300 mg/l and the limit value from 300 mg/l to 600 mg/l. The precise characteristics of the organic substance and the DOC in the eluate has been widely discussed. Since the question is regarding the sum parameter of the total organic carbon (TOC) content in the solid and the DOC in the eluate, the evaluation of the results give no detailed information regarding the ecological or toxilogical relevance (Dach et al, 2007).

In the context of a biological pretreatment, the formation of humic substances in the organic matrix can occur. Normally, these consist of 50% carbon and are therefore detected by TOC in the solids and the DOC in the eluate (Van den Bergh, 2001). A higher proportion of humic substances in the solid and the eluate could overestimate the parameters TOC and DOC since the humic substances are regarded as carbon sinks and are bound up in the long term. The following investigations aim to ascertain the extent to which biological pretreatment can stabilise residual waste, whether humic substances are formed and what fraction of these are carbon.

2 Materials and Methods

To evaluate the stability of mechanically-biologically pretreated waste, sample material from a large-scale plant for the pretreatment of residual waste was taken and analysed (at the laboratories of the Hamburg University of Technology at the Institute of Environmental Technology and Energy Economics, Bioconversion and Emissions Control Group)(Praagh et al, 2009). The analysed material consisted of the organic fraction of a residual waste (calorific fraction pre-separated) which had been aerobically treated for a period of up to 9 weeks in tunnels. In total, 4 materials which had been treated for periods of 0, 2, 6 and 9 weeks were analysed. For the analysis in the original substance and in the eluate, the materials were crushed to a diameter of d<10 mm using a cutting mill and frozen until the time of analysis. A portion of the sample material was dried at a temperature of T=105°C and then crushed to a diameter of 0.25 mm using a cutting and centrifugal mill.

The determination of the respiration activity AT_4, the gas potential GP_{21} and the elution were carried out according to the specifications of the Waste Storage Ordinance (Annex 2) (Anonymus, 2001). The respiration activity tests were undertaken in a Sapromat (Fa. Voith). The gas potential analysis was undertaken using the volumetric method in an eudiometer (Heerenklage, J. and Stegmann, R., 2006). For the elution test, the filtration was carried out using a cross-flow filtration at d<0.45 µm (0.1 m² ULTRAN Slice, Schleicher & Schuell, Dassel, Germany) at a maximum pressure of 6 bar via pressure filtration (Type ME25, Cellulose mixed ester, and Spartan 30/0.45 µm RC, 30mm, Whatmann plc, UK) (Anonymus, 2001). The dissolved organic carbon content in the eluate was determined according to DIN 38408 – H3 using the multi N/C analyser (Analytik Jena). The measurement of the chemical oxygen demand (COD) was carried out according to the DIN 38409 – H41 methods and the biological oxygen demand (BOD_5) according to the DIN 38409 – 51 dilution methods. The analysis of the cellulose and lignin fractions in the solids according to Van Soest (1963) were undertaken in the laboratories of Veolia Environnement (Limay, France). The determination of the fulvic acids and the humic acids were undertaken at the laboratories of the University of Natural Resources and Applied Life Sciences, Vienna, after the modified methods of Danneberg (Gerzabek et al., 1993). The analysis of the humic content in the eluate was undertaken by the TUHH using photometric determination at 530 nm of a NaOH/Na-oxalate mixture.

3 Results and Discussion

3.1 Reduction of the Emissions Potential during Rotting

The characteristic data of the 4 investigated materials from the mechanical-biological pretreatment are summarised in Table 1. The dry substance (DS) content varied between 54 wt% and 66 wt% in the wet mass (WM). The organic dry matter (oDM) had a content of 43 wt% at the beginning of the rotting process. After 9 weeks of treatment in the rotting process the organic dry matter content (oDM) reduced from approximately 40% to 26 wt% in the dry mass. The total organic carbon content (TOC) decreased during the aerobic treatment from 19 wt% to 12 wt% in the dry mass.

Table 1 Characteristics of the investigated sample material

Treatment duration	TS [wt% WM]	oTM [wt% DM]	TOC [wt% DM]-{}-	TOC [wt% oDM]	N-Total [wt% DM]	C/N [-]
0 Weeks	**54**	**43**	**19**	**44.2**	**0.99**	**19.2**
2 Weeks	**54**	**44**	**20**	**45.5**	**1.0**	**20.0**
6 Weeks	**67**	**28**	**13**	**46.4**	**0.84**	**15.5**
9 Weeks	**66**	**26**	**12**	**46.2**	**0.78**	**15.4**

The nitrogen content decreased from 0.99 wt% DM to 0.78 wt% by the end of the treatment. The C/N ratio decreased from 19.2 at the beginning of the rotting process to 15.4 after treatment as a result of C-mineralisation and N-immobilisation, and can be used as an initial indicator of humification (Pichler and Kögel-Knaber, 1999). The carbon content increased marginally in the organic substance from 44.2 wt% oDM to 46.2wt% oDM. According to Pichler and Kögel-Knaber (1999), this is due to the fact that components with low C content (carbohydrates) are preferably mineralised. The slightly elevated concentrations of the material after 2 weeks of rotting compared with the input material can be attributed to inhomogeneities.

The successful rotting process can be demonstrated using the stability criteria respiration activity RA_4 and gas potential GP_{21}. Figure 1 shows the progress of both parameters over the treatment period of 9 weeks. The respiration activity of 79.4 mg O_2/gDM in the rotter input material decreased by 95% to 4.1 mg O_2/gDM by the end of the process. The gas potential GP_{21} decreased by 97% from 246 l/kg DM to 6.5 l/kg DM. Both parameters adhere to the assignment values (5 mg O_2/gDM and 20 l/kg DM, respectively) of the Waste Storage Ordinance (Annex 2) (Anonymus, 2001).

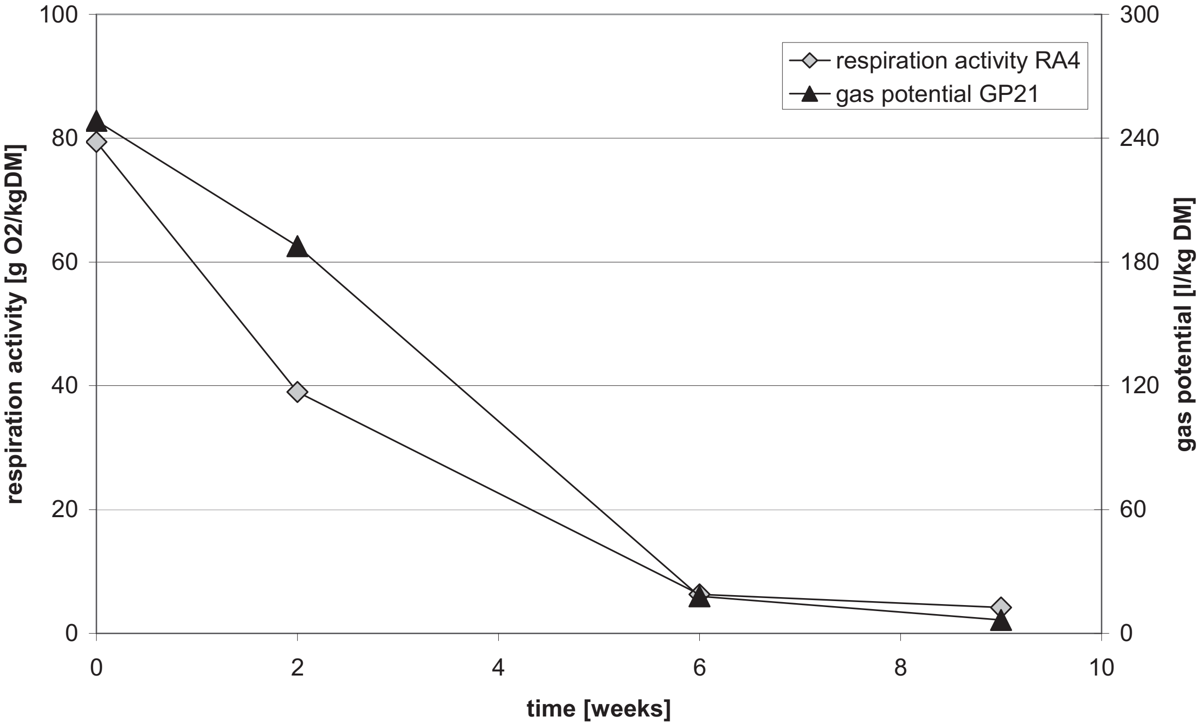

Figure 1 Progress of the respiration activity RA4 and the gas potential GP21 of the investigated materials over a 9 week rotting period.

The DOC in the eluate decreased from 3620 mg/l to 181 mg/l and likewise was beneath the assignment value of the Waste Storage Ordinance of 300 mg/l. In order to describe the stability characteristics of the eluate, the common wastewater treatment parameters Biological Oxygen Demand BOD_5 and Chemical Oxygen Demand COD were also analysed. Both parameters together with the DOC are presented over the treatment period of 9 weeks in Figure 2. The ratio BOD_5/COD decreased from 0.52 at the start to 0.08 by the end of the rotting process, thus indicating a biologically recalcitrant eluate. Accordingly, the BOD_5/DOC ratio decreased from 1.69 at the beginning of the rotting process to 0.27 after a 9 week treatment period.

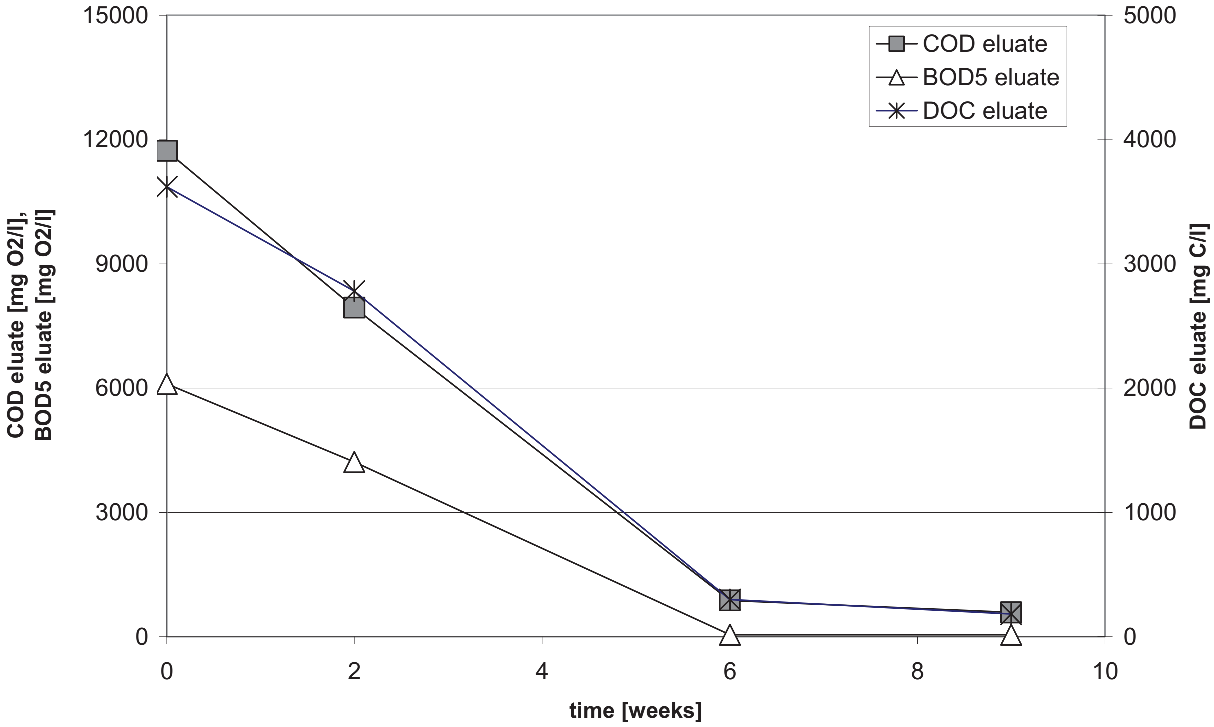

Figure 2 Progress of the DOC, COD and BOD5 content in the eluate of the investigated MBA materials

3.2 Characteristics of the Organic Substance

Humic substances form as a result of complex and still only partly explained physio-chemical and microbial processes from plant and animal residues. The main raw materials are cellulose and lignin, and to a certain extent peptides as well. Humic substances have no chemically defined structure, but consist of mostly inseparable mixtures of sometimes very complex macromolecules with varying molecular size distributions, structures and functions. Mixtures of humic substances can be roughly subdivided according to their solubility in an aqueous phase into acid-soluble fulvic acids, acid insoluble but alkaline-soluble humic acids, and practically insoluble humin. The carbon content of humic substances can be assumed to be roughly 50% wt% (Van den Bergh, 2001).

For the characterisation of the organic substance and the humification processes in the aerobically treated residual waste samples and the prepared eluate, the substance group analysis methods after Van Soest (1963) and the determination of the humic acid content were applied. In the gravimetric Van Soest analysis, the substance groups of the dissolved organic components, the hemicellulose, the cellulose and the lignins were measured. The microbiological degradation occurred at different rates. The starch and hemicellulose decomposed 15 times faster, cellulose about 3 times faster than lignin.

This shifts the composition of the organic matter in the direction of recalcitrant components. Through the microbial degradation and decomposition of the lignins, humic-like polymers are produced so that lignin is of particular importance during the formation of humic substances (Toll, 1981). To characterise the biological degradation, the change in the celluslose/lignin ratio is normally considered. According to Pichler and Kögel-Knabner (1999) instead of the term lignin, the term “refractory substances” is to be used, since other components in addition to lignin, such as humin, are included. In the examined MBA materials, the cellulose fraction decreased by about 60% after 9 weeks of treatment. In contrast, the lignin and refractory substances fraction increased in the organic dry matter by about 40 wt% by the end of the rotting period. The ratio of cellulose/lignin shifted from 1.68 at the beginning to 0.48 by the end. Scherer and Vollmer (1999) report similar cellulose/lignin fraction (C/L value) ratios, and specify a final C/L value of 0.4-0.8. During investigations by Hörig and Ehrig (1998), limit values of 0.5 for the C/L value were achieved during biodegradation of residual waste. In unsorted household waste from a landfill, C/L values of 0.55-0.7 were reported for old waste (Bookter and Ham, 1982; Suflita et al, 1992). Scherer and Vollmer (1999) note that, at the beginning of a rotting process, the C/L value lies between 1 and 3, and adjusts to about 0.4-0.7 by the end of the rotting period. The results of this investigation displayed in Figure 3 confirm this statement. The examined material had a C/L value of 0.48 after 9 weeks of treatment. Both the results of the RA_4=41 mg O_2/gDM and the GP_{21}=6.5 l/kg DM in the original substance (see Figure 1) as well as the BOD_5/COD ratio of 0.08 in the eluate of the investigated materials show a very low emission potential of the material.

The possible humic substance build-up during the aerobic treatment of the residual waste can be described with the concentration of the fulvic and humic acids and their ratios. During the investigation of the aerobically treated MBA materials, the concentration of the humic acids and the fulvic acids increased with treatment time. The concentration of the fulvic acids increased from a start concentration of 145 oD/gODM to 275 oD/gODM after 9 weeks of aerobic treatment. The concentration of the humic acids increased from 127 oD/gODM to 574 oD/gODM. The mass fraction of humic acids in the organic matter increased by a factor of 3.2 from 2.4% to 7.8% at the end of treatment (see Table 2). The ratio of humic acids / fulvic acids increased from 0.9 to 2.1 with increasing rotting time and is presented in Figure 3 together with the ratio of cellulose / lignin over the treatment duration. The increasing humic acids / fulvic acids ratio indicates that fulvic acids with a smaller molecular structure (800-9000 Da) decrease in proportion to increasing treatment duration. At the same time, larger humic acid structures (9000-500000 Da) form and can be regarded as a sink for refractory organic carbon in pretreated residual waste. By the end of treatment, the carbon content was approximately 450g per kilogram of organic dry matter. For an assumed carbon content of about 50% in the humic substances, the proportion of humic acids and fulvic acids amounts to approximately 13 wt% of the organic carbon content in the organic substance of the pretreated residual waste. It is possible that the actual content is higher since the lignin fraction could also be included. The pretreated waste material therefore shows a high level of humification before even being landfilled. In comparison, the composting of biowaste and subsequent spreading onto agricultural land and the ensuing degradation and conversion process of humic substances generates about 27 wt% humus.

Table 2 Humic acid content of the MBA samples given as optical density (oD) and as percent of the organic dry matter (oDM)

Treatment duration	Humic acids [oD / g oDM]	Fulvic acids [oD / g oDM]	Humic acids [% oDM]
0 Weeks	**127**	**145**	**2,4**
2 Weeks	**207**	**142**	**3,4**
6 Weeks	**442**	**247**	**6,2**
9 Weeks	**574**	**275**	**7,8**

The results of the investigation on the carbon content in the solids (TOC) and the dissolved organic carbon content (DOC) in the eluate show that the proportion of elutable carbon from solids (TOC) into the eluate (DOC) decreased during the 9 week rotting period from a start value of 20 wt% to about 1.6 wt% by the end of the period. Through aerobic treatment, the remaining organic carbon is fixed in the solid matrix and only small amounts can cross over as dissolved organic carbon into the liquid phase. Initial analysis of humic acids in the filtered eluate show a content of between 10 and 36 mg/l. According to Van den Bergh (2001), humic substances amount to 3.5 mg/l in rivers and more than 10 mg/l in moorland areas. The DOC in the eluate of the aerobically pretreated materials is partially a matrix which is biologically difficult to degrade and which will be subjected to conversion and degradation processes in the long term. After 6 weeks of rotting, about 9 wt% of the dissolved DOC (298 mg/l) appeared in the eluate as humic acids + fulvic acids (assumed C content of around 50%). This humic acid proportion lies in the same order of magnitude as that in the solid matrix. To verify the results, further investigations regarding the humic content in the eluate are to be undertaken.

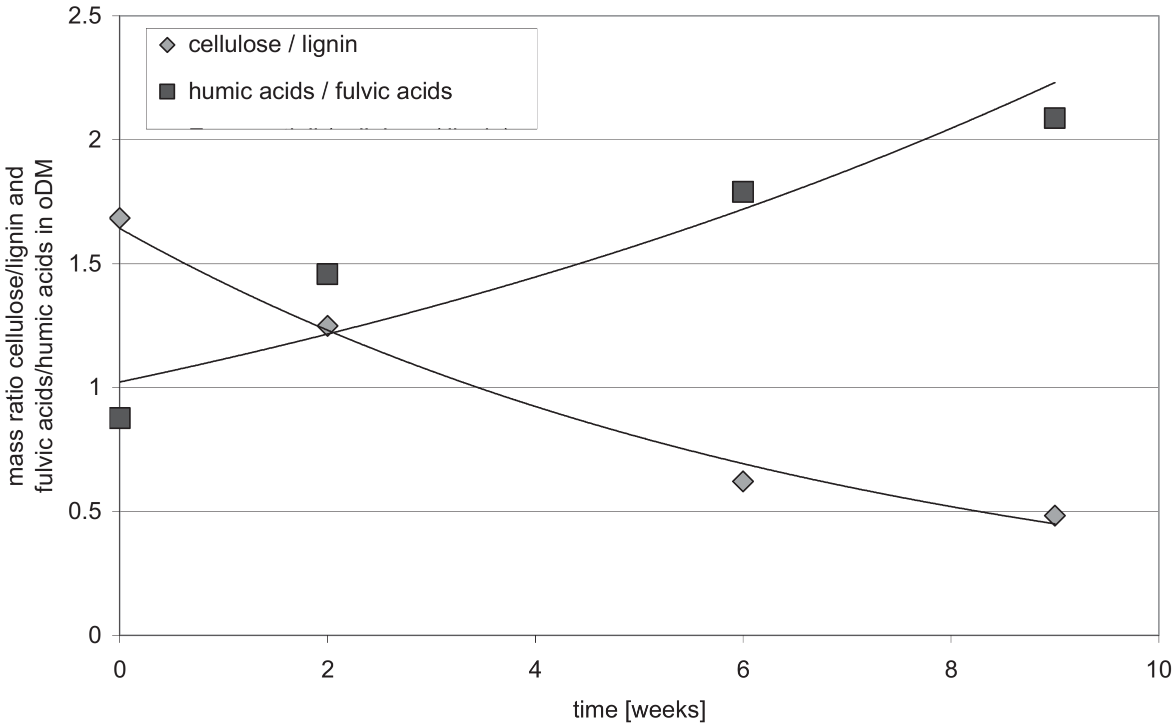

Figure 3 Change in the mass ratio of cellulose and lignin as well as fulvic acids and humic acids in the organic dry matter of residual waste during aerobic treatment

4 Summary

Within the scope of a mechanical-biological pretreatment of residual waste, the organic fraction was analysed over a 9 week aerobic treatment in tunnels. One material was analysed at the beginning and one at the end of the pretreatment as well as two other materials after a 2 and 6 week treatment period. During the rotting period, the biological activity in terms of the respiration activity RA_4 and the gas potential GP_{21} decreased by 95% and 97%, respectively. The dissolved organic carbon content in the eluate likewise decreased by 95%. Each of these parameters were within the respective assignment value of the Waste Storage Ordinance (Annex 2) (Anonymus, 2001). The 9 week aerobically pretreated material demonstrates a very low emissions potential and is biologically difficult to degrade. These also support the analyses of the BOD_5 and the COD in the eluate. The BOD_5/COD ratio was 0.08 after rotting. This shows that the material is biologically recalcitrant. In the solids, the carbon/nitrogen ratio decreased from about 20 to 15, meaning it can be regarded as stable.

Detailed investigations regarding the composition of the organic substance indicate that 60% of the cellulose would have been converted, and lignin or the refractory substances would have increased by 40% (relatively considered). The mass ratio of cellulose/lignin in the organic matter decreased from 1.68 initially to 0.48 and thus demonstrates a typical shift in the cellulose/lignin ratio during a mechanical-biological pretreatment. The ratio of humic acids/fulvic acids increased from 0.9 to 2.1 during aerobic treatment. Humic acids and fulvic acids are formed in the solids matrix and have an approximate 13 wt% share of the organic carbon content TOC. The material therefore already has a humus content that is achieved during composting of biowaste and is considered stable. Further biological decomposition and conversion processes in the organic matrix could take place in the long term.

Initial analysis of the humic acid fraction in the eluate of the pretreated materials show that the humic content with up to 36 mg/l is similar to samples taken from moors and can also be classified as very stable.

The humic content in the eluate is to be verified during further investigations.

5 Literature

Anonymus	2001	Verordnung über die umweltverträgliche Ablagerung von Siedlungsabfällen, Berlin 20.02.2001, Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, Deutschland
Anonymus	2004	Boden-, Ressourcen- und Klimaschutz durch Kompostierung in Deutschland, EPEA Internationale Umweltforschung GmbH
Heerenklage, J., Stegmann, R.	2006	Bestimmung der Stabilitätskriterien von MBA-Material in der Praxis, In: Deponietechnik 2006, Hamburger Berichte 29, S91-107, Verlag Abfall aktuell, ISBN 3-9810064-4-5
Scherer, Paul A.; Vollmer, G.-R.	1999	Entwicklung eines einfachen Hochleistungsvergärungsverfahrens zur Behandlung von Restmüll unter hyperthermophilern Bedingungen, das gleichzeitig pasteurisiert und eine Nachrotte erspart. In: Müll und Abfall 3/99, S. 150-158, ISSN 0027-2957
Soest van, P.J.	1963	Use of Detergents in the Analysis of Fibrous Feeds. II A Rapid Method fort he Determination of Fiber and Lignin, J.A.O.A.C. 50, 50-55
Amin, M., Lepom, P.	1995	Stoffgruppenanalyse zur Charakterisierung des biologisch abbaubaren Anteils der organischen Substanz in Müllproben, Müll und Abfall 4/95, S. 242-250
Bookter, T., Ham, R.	1982	Stabilisation of solid waste in landfills. J. Environ. Engin. 108: 1089-1100
Van den Bergh, J.	2001	Vor-Ort-Charakterisierung von aquatischen Huminstoffen und ihren Metallspezies. Dissertation an der Universität Dortmund
Dach, J., Warnstedt, A., Müller, G.	2007	Erfahrungen und Optimierungsansätze zur Einhaltung des TOC im Eluat.
Gerzabek, M.H.,	1993	Bestimmung des Humifizierungsgrades. In:

Danneberg, O., Kandeler, E.		Bodenbiologische Arbeitsmethode. Schinner F., Öhlinger R., Kandeler E., Margesin, R., Eds., Springer Verlag, 107-109
Höring, K.; Ehrig, H-J.	1998	Stabilisierungsgrad und Emissionsverhalten mechansich-biologisch vorbehandelten Restabfälle. Verbundvorhaben Mechanisch-biologische Behandlung von deponierenden Abfällen. Beiträge der Ergebnispräsentation 7.-8. September 1999, Potsdam
Van Praagh, M., Heerenklage, J., Smidt, E., Modin, H., Stegmann, R., Persson, K.M.	2009	Potential emissions from two mechanically–biologically pretreated (MBT) wastes In: Waste Management 29 (2009), 859-868, ISSN 0956-053X
Pichler, M., Kögel-Knabner, I.	1999	Humifizierungsprozesse und Huminstoffhaushalt während der Rotte und Deponierung von Restmüll. Verbundvorhaben Mechanisch-biologische Behandlung von deponierenden Abfällen. Beiträge der Ergebnispräsentation 7.-8. September 1999, Potsdam
Topp, W.	1981	Biologie der Bodenorganismen, UTB, Heidelberg, ISBN 3-494-02129-5
Modin, H.	2007	Impact of pre-treatment on the stability and leachability of three different wastes; Diplomarbeit an der Technischen Universität Hamburg-Harburg und an der Lund University (Schweden); In: Avdelning för Teknisk Vattenresurslära, ISRN LUTVDG/TVVR-07/5011+103p, ISSN-1101-9824

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Overall concept for the processing of alternative fuels (RDF)

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Overall concept for the processing of alternative fuels (RDF)

Keywords

Ersatzbrennstoff, Ersatzbrennstoffaufbereitung, Zerkleinerungstechnik, Einwellenzerkleinerer, Vorzerkleinerung, Nachzerkleinerung, Fördertechnik, Trenntechnik, Energieeinsparung

Alternative fuels, RDF production, shredding technology, single shaft shredder, primary shredding, secondary shredding, conveyor technology, separation technology, energy saving

1 Efficient RDF production

1.1 Introduction

In order to achieve an economical processing of alternative fuels it is necessary to employ adequate input material as well as efficient and powerful aggregates, e.g. shredding technology, separation technology and conveyor technology. The focus in this respect is high availability, easy maintenance and handling as well as low power demand.

1.2 RDF production with Lindner-Recyclingtech GmbH

Lindner-Recyclingtech GmbH has been offering innovative and successful solutions all-in-one for decades – research, development, construction, planning and production of modern shredding technology (single shaft primary and secondary shredding) for the processing of waste as well as comprehensive systems for RDF production using related control technology, separation and segregation technology and conveyor machinery in the modular construction system.

Having installed more than 100 RDF production plants worldwide, Lindner-Recyclingtech GmbH is one of the specialists in this field. The company offers efficient and compact RDF plants, which are produced in a special modular construction system with fully developed and tested single components. This special system allows maximal flexibility on smallest space as well as easy expandability subsequently. LINDNER's RDF production plant consists of primary shredding, conveyor and separation technology, secondary shredding as well as an innovative control and diagnostic system. By applying this modular system, input material, e.g. domestic waste, commercial waste and industry waste, can be turned into output granular of smaller than 25 mm with up to 25 tons throughput per hour.

1.3 Extract of Lindner-Recyclingtech GmbH references

Lindner-Recyclingtech GmbH has installed numerous RDF production lines, especially in the cement industry and in waste management companies. Renowned cement manufacturers, e.g. Lafarge, Holcim Group (Ecorec), Cemex, Heidelberg Cement, Wietersdorfer & Peggauer etc., as well as notable suppliers of RDF, e.g. Remondis, SITA, Veolia, Alba, ThermoTeam, Zuser, ASA, Saubermacher etc. can be counted among the numberless satisfied customers.

On the occasion of the excursion to MBA Südniedersachsen, Lindner-Recylingtech GmbH aggregates (primary shredder JUPITER 3200 and two secondary shredders POWER KOMET 2800) can be seen in operation. Originally, MBA Südniedersachsen used a tearing system for shredding – after immense problems this system has been replaced by the now installed Lindner-Recylingtech GmbH cutting system.

2 The single components of the Lindner-Recyclingtech GmbH RDF production plant

2.1 The primary shredding

The slow-running single shaft shredder JUPITER is equipped with a revolutionary cutting system, which turns the waste into a defined grain size. Thereby, the downstream plant components, e.g. Fe-, Ne- NIR-segregation, screening, air separation and secondary shredding, can work more efficient and failure-free and with fewer down times. Another feature is the sickle-shaped pusher system which allows to push even light material to the rotor without any problems and therefore leads to higher throughput capacities.

The cutting system enables very economical durability and the cutting of foreign parts, in spite of the abrasive input material. Even a massive foreign part in the cutting room does, due to the innovative safety clutch, no massive harm to the machine. The foreign part can be removed through the patented inwardly opening foreign part flap, which means that the hopper has not to be emptied. This operation does only take a few minutes, which allows a high availability of the shredder. Practical experience shows that the removal of the foreign part, with e.g. domestic waste, has to be executed at the maximum once or twice per shift. This easy removal has the effect that the contaminated material does not have to be disposed at high costs. The foreign part can rather be directly disposed.

JUPITER (on the market for 6 years) is predominantly used for primary shredding of untreated material with foreign parts (e.g. domestic waste, industry waste, commercial waste – throughput of up to 50 t/h).

Picture 1: Lindner-Recyclingtech GmbH slow-running primary shredder JUPITER

2.2 Conveyor and separation technology

The hinged conveyor, which is adjustable from 0 to 32 degrees and equipped with a self-cleaning system (both features developed by LINDNER) allows a direct placing of the shredder on the operating floor. This guarantees minimum maintenance and cleaning efforts for the discharge conveyor belt.

The „Heavy Fraction Separator HFS 1200“, which has been awarded with the Carinthian innovation and research award, is a modern and high performance aggregate with small power requirement in order to protect the secondary shredding. It separates foreign parts, e.g. stones, ceramics, from the waste and consequently protects the secondary shredder. Therewith the waste processing companies save expensive repairing costs and company stillstands. Because of its compact construction the aggregate can be integrated very simply as an inline-component in the existing main stream between primary and secondary shredder.

Picture 2: The awarded Lindner-Recyclingtech GmbH Heavy Fraction Separator HFS 1200

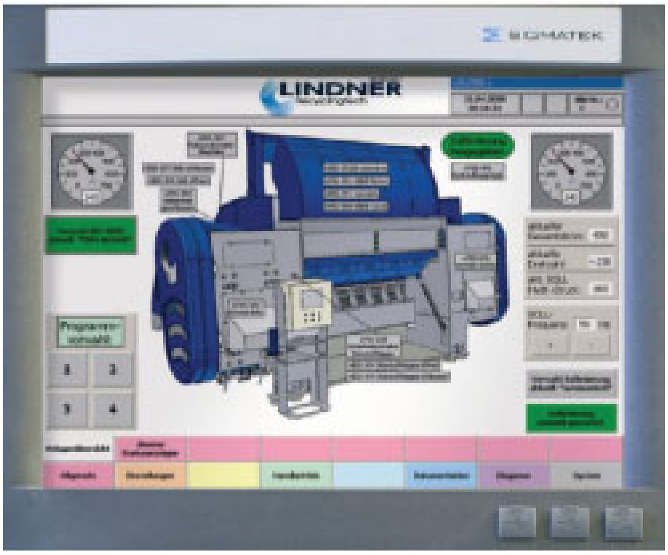
2.3 The secondary shredding

The newly developed secondary shredder POWER KOMET which was awarded with the 2nd place at the Carinthian innovation and research award has economic and ecological peak values. Comparable to JUPITER, POWER KOMET also captivates with the exceptional drive system with centrifugal mass. As independent experts confirm, an energy saving of at least 20-30% in comparison to common drive systems can be achieved by using this concept, which has been rather unusual in business so far. POWER KOMET has, due to this energy savings and further advantages, a relatively short payback period.

POWER KOMET is able to shred the pre-shredded input material free of foreign parts to a grain size of up to 15 mm. The innovative screen concept allows a fast exchange of the screens, which makes it possible to achieve grain sizes of 10-100 mm. POWER KOMET 2800 reaches throughput capacities of up to 12-15 t/h with an end-granulate of 25 mm.

2.4 The control concept

The new control concept via Industry PC and Touch Panel constitutes another innovative step, which offers diagnosis systems as well as online-support during maintenance. This fast service support via tele-maintenance enables an increase of availability. By using this system, important parameter for plant optimisation can be collected and analysed.

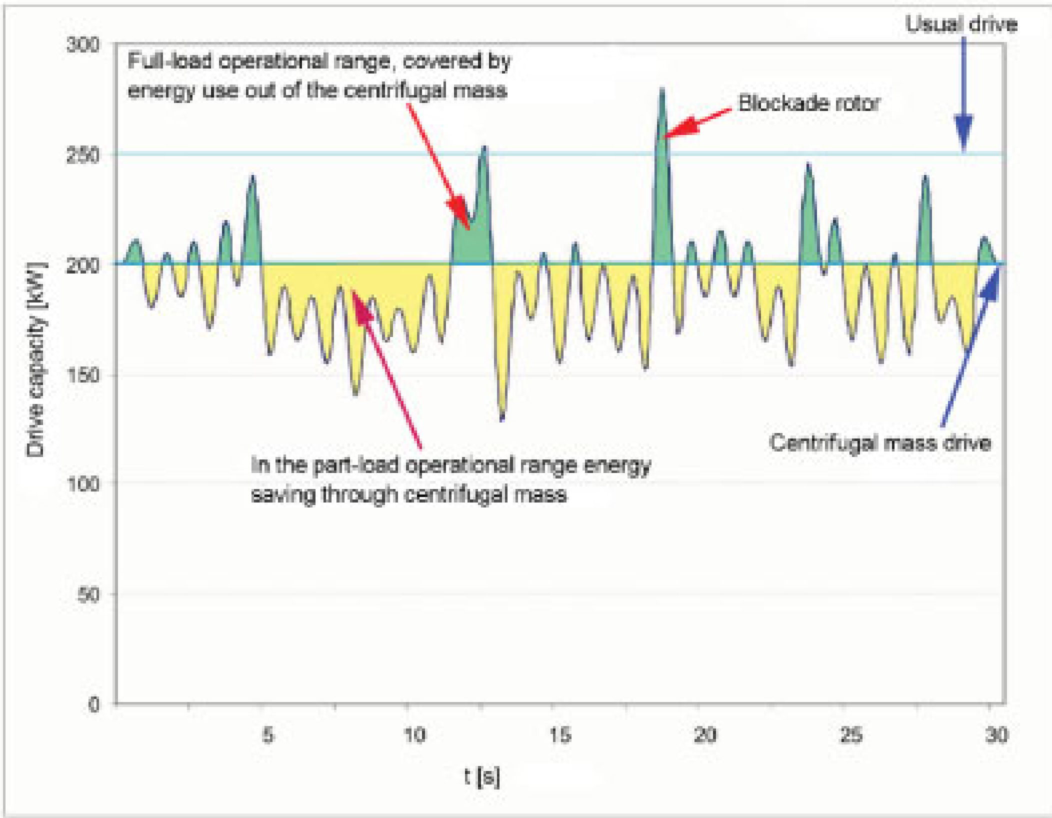


Picture 3: Lindner-Recyclingtech GmbH diagnosis systems and online-support

3 Market demands

It is the main priority of Lindner-Recyclingtech GmbH to supply its customers with efficient and high performance aggregates. The internal R&D department as well as in-house production makes it possible to react to customer wishes and market demands in a fast and efficient way. This is reflected in the high pioneer and innovation spirit within the company. In collaboration with renowned external institutions Lindner-Recyclingtech GmbH puts a lot of effort in research and development in order to be able to offer deciding advantages to the customer. The company is headed towards good service and easy handling as well as worldwide availability. Lindner-Recyclingtech GmbH puts special emphasis on stability, robustness and high availability of the aggregates, which allows running costs to remain low. The operation of shredding machines requires economical energy use and a minimisation of stillstands.

The innovative drive concept with centrifugal mass used by LINDNER is almost maintenance-free. The drive components are not burdened due to the elastic belt drive, which leads to long durability and high availability. The principle of drive systems with centrifugal mass in the drive has already been discovered by Leonardo da Vinci in the 15th century. LINDNER succeeded in making use of this old technology in a technologically trendsetting way in order to enable an efficient processing of waste. This drive concept offers the following advantages: In the part-load operational range energy is saved through centrifugal mass. Thus, this saved energy is available in the full-load operational range, which means that much higher full loads (up to five times of the full load) can be covered. Therefore, the drive capacity can be approximately 20 % lower compared to usual drives, e.g. instead of 250 kW only 200 kW are used.

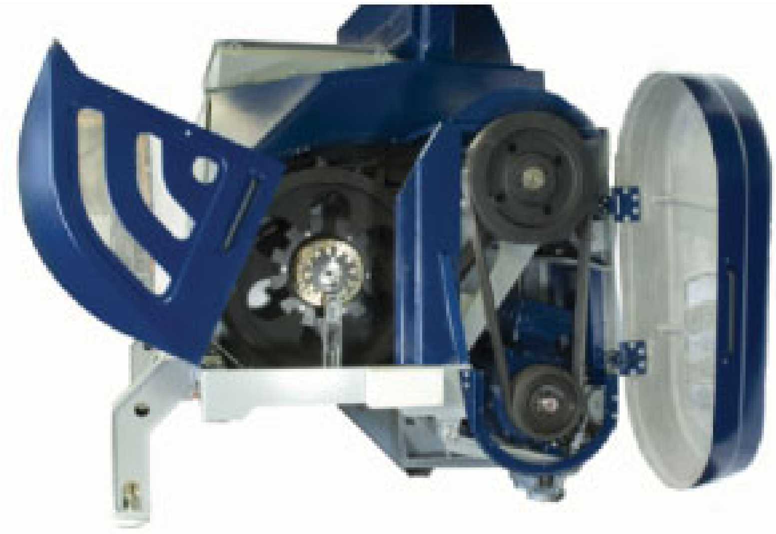


Picture 4: Shredder drive with high centrifugal mass

Picture 5: Innovative drive concept with centrifugal mass by Lindner-Recyclingtech GmbH

In order to facilitate and fasten maintenance works, an optimal accessibility to the cutting system has been developed. Thanks to the new clamping system the screens can be exchanged easily and quickly.

The drive guards of POWER KOMET made of glass fibre reinforced plastic are not only visually appealing but also contribute to a reduction of operation noises and facilitate the necessary maintenance works as the access to the drive unit is much easier.



Picture 6: Easy maintenance, easy access to the drive and fast service by the modern plastic protection of Lindner-Recyclingtech GmbH

The Lindner-Recyclingtech GmbH modular construction system offers, next to compact and flexible installation, also the possibility of a subsequent expansion. This system includes shredding machines, but also plants and plant components. Therewith, this comprehensive concept allows a reduced stock, easier maintenance as well as easy handling and training. Due to this modular system, which results in a similar basic structure of the aggregates, the training on one machine or the operation of one machine, is also valid for the other machines.

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