Matthias Kühle-Weidemeier (Hrsg.)

Waste-to-Resources 2009
3. Internationale Tagung MBA und Sortieranlagen

Mechanisch-biologische Abfallbehandlung und automatische Abfallsortierung

Tagungsband
(Originalsprachenausgabe)

12. - 14. / 15. Mai 2009

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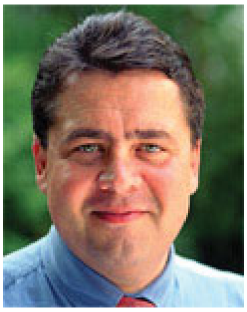


Grußwort von Bundesumweltminister Sigmar Gabriel

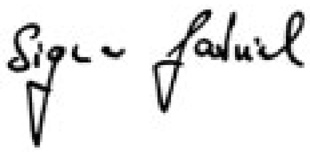
Eine moderne Abfallwirtschaft ist Ressourcen- und Klimaschutz gleichermaßen. Dies ist mittlerweile allgemein akzeptiert. Weltweit werden die Erfolge der Bundesrepublik Deutschland in diesen Bereichen anerkannt. Die abfallwirtschaftliche Neuausrichtung in Deutschland im Jahr 2005 hat dazu geführt, dass die jährlichen Emissionen von klimarelevanten Gasen aus Deponien um nahezu 46 Mio. Tonnen CO_2-Äquivalente reduziert werden konnten. Bis 2020 gibt es weiteres Potenzial von mehr als 5 Mio. Tonnen.

Die Ursache für diese positive Entwicklung sind zum einen die in Deutschland ergriffenen Maßnahmen zur Beendigung der Ablagerung biologisch abbaubarer Siedlungsabfälle. Um dieses Ziel erreichen zu können, wurden die Abfallbehandlungstechnologien weiterentwickelt und zahlreiche neue Abfallbehandlungsanlagen errichtet. Neben Müllverbrennungsanlagen tragen heute auch ca. 45 mechanisch - biologische Behandlungsanlagen zu einer ökologisch verträglichen Abfallbehandlung bei. Dabei werden die Abfälle nicht nur biologisch stabilisiert, sondern es werden verschiedene Abfallfraktionen abgetrennt, die energetisch oder stofflich verwertet werden können. Neue Techniken der mechanisch - biologischen Behandlung sowie die Verbesserung der MBA-Technologie und die Erweiterung und Optimierung der bestehenden Anlagen bilden einen Schwerpunkt der 3. Internationalen Tagung und Fachausstellung Waste-to-Resources.

Das Zeitalter billiger Rohstoffe und Materialien ist endgültig vorbei. Ressourcenschonung, Effizienzsteigerung und Kreislaufwirtschaft sind heute angesichts der knapper und teurer werdenden Rohstoffe und des weltweit stetig steigenden Bedarfs, insbesondere in den Entwicklungsländern, wichtiger denn je. Einen weiteren Schwerpunkt der Veranstaltung bilden folgerichtig verschiedene Technologien zur Sortierung von Abfallgemischen mit dem Ziel der weitestgehenden Gewinnung von Eisen- und Nichteisenmetallen, Ausgangsstoffen für die Kunststoff-, Papier- und Glasherstellung sowie mineralischen Rohstoffen. Diese können neben den bewährten Getrennterfassungssystemen bei den Haushalten und dem Gewerbe zu einer weiteren verstärkten Wertstoffgewinnung führen. So können die verschiedenen abfallwirtschaftlichen Maßnahmen neben der erheblichen Emissionsreduzierung klimarelevanter Gase auch zur Verbesserung der Abfallverwertung und zur Ressourcenschonung beitragen.

Ihre Grundlage haben erfolgreiche abfallwirtschaftliche Maßnahmen neben den rechtlichen Regelungen in leistungsfähigen Technologien zur Abfallbehandlung und -entsorgung. Viele sind in den letzten zwei Jahrzehnten in Deutschland entwickelt und zur Anwendung gebracht worden. Ein solcher technologischer Vorsprung, den sich Deutschland erarbeitet hat, kann angesichts der rasanten Entwicklungen am Weltmarkt allerdings auch rasch verloren gehen. Konsequenz ist, dass wir auch künftig bei der Weiterentwicklung von Abfallentsorgungstechnologien und -verwertungsverfahren nicht nachlassen dürfen, um die Nase weiter vorne zu haben und unsere erreichte Position zu halten.

Es kommt es darauf an, das bereits Erreichte weiter auszubauen. Wichtig ist es aber auch, die Potenziale auf europäischer Ebene und darüber hinaus im internationalen Umfeld zu nutzen. Hier können wir unsere Erfahrungen weitergeben und unser technisches und technologisches know how anbieten. Ich bin überzeugt davon, dass auch die 3. Internationale Fachtagung MBA und Sortieranlagen (Waste-to-Resources), über die ich gerne die Schirmherrschaft übernommen habe, für das nationale und internationale Fachpublikum, Aussteller und Auftraggeber erneut ein gutes Forum sein wird, diese Fragen zu diskutieren und Zusammenarbeiten zu vereinbaren. Ich wünsche der Veranstaltung einen guten Erfolg!



Sigmar Gabriel

Bundesumweltminister

Mechanical Biological Treatment and its role in Europe

Wolfgang Müller

Poyry Environment GmbH, department IGW, Witzenhausen

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.

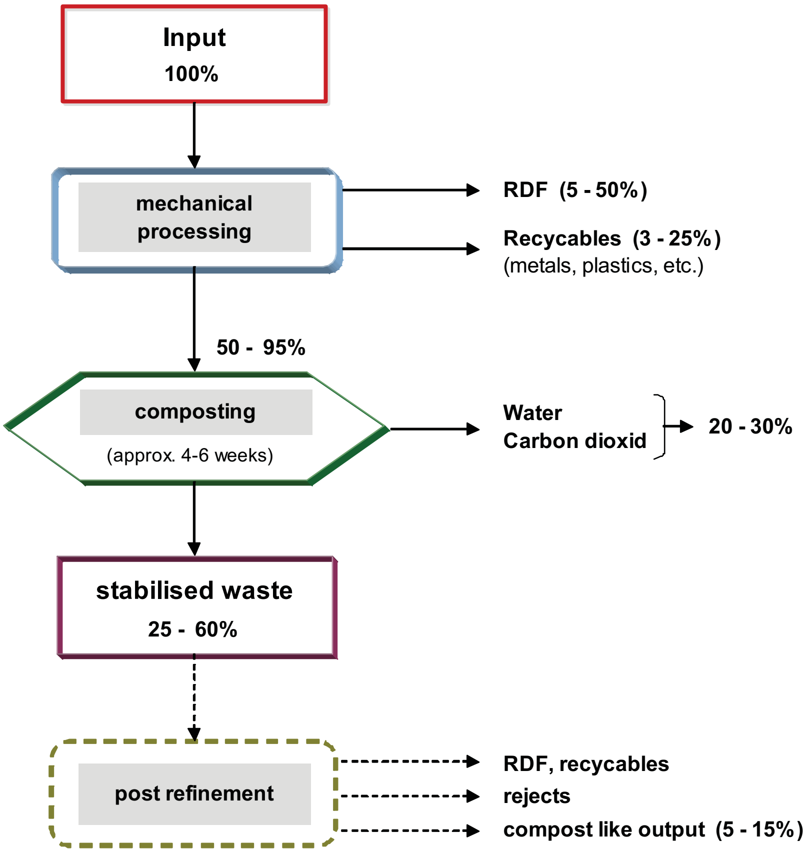


Figure 1: MBT for stabilisation

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.

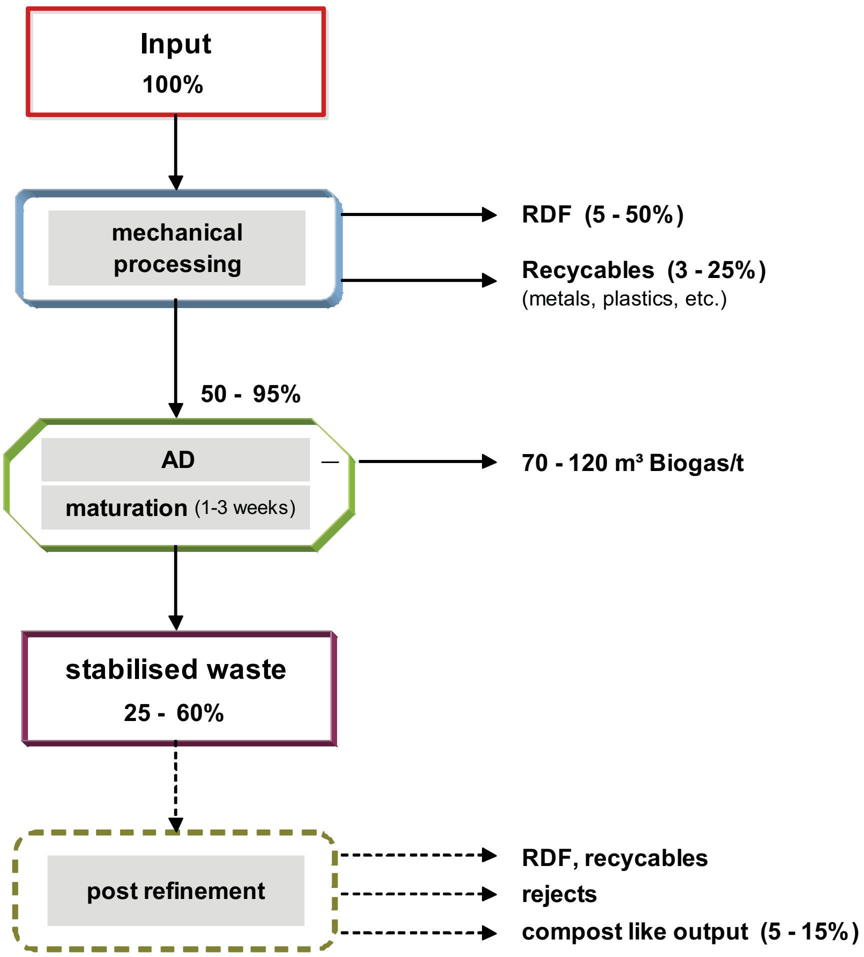


Figure 2: MBT with Anaerobic Digestion

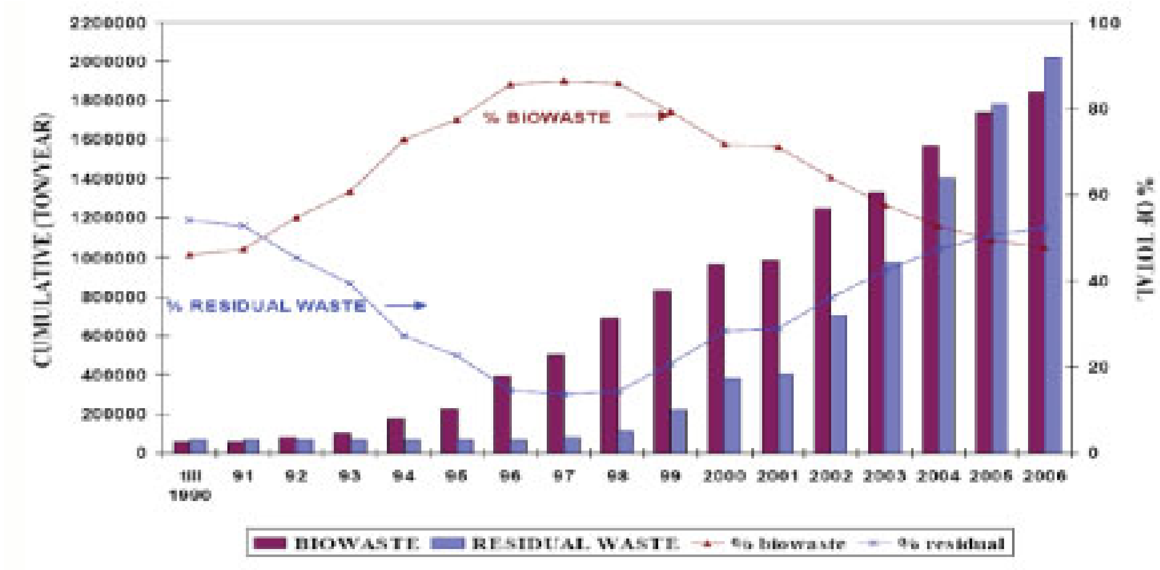


Figure 3: Development of MBT plants in Europe (deBare, 2007)

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.

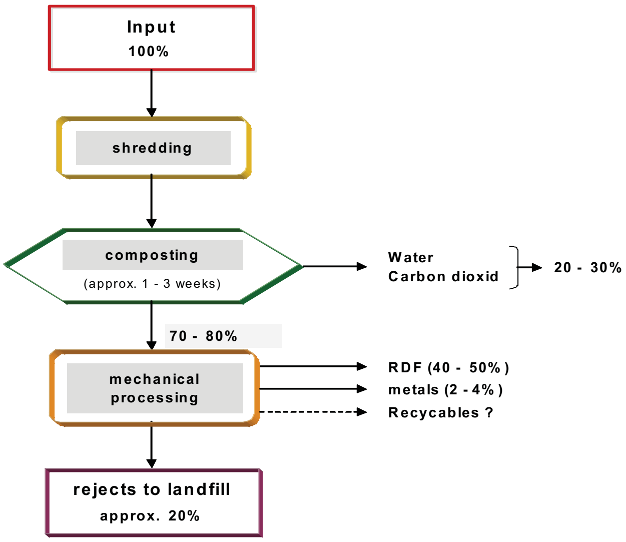


Figure 4: MBT – biological drying

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

Nguyen Thi Diem Trang[1], Nguyen Binh[2], Nguyen Gia Long[2]
[1]Hanoi University of Science, [2]Hydraulic-Machine Co.,LTD, Vietnam

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.

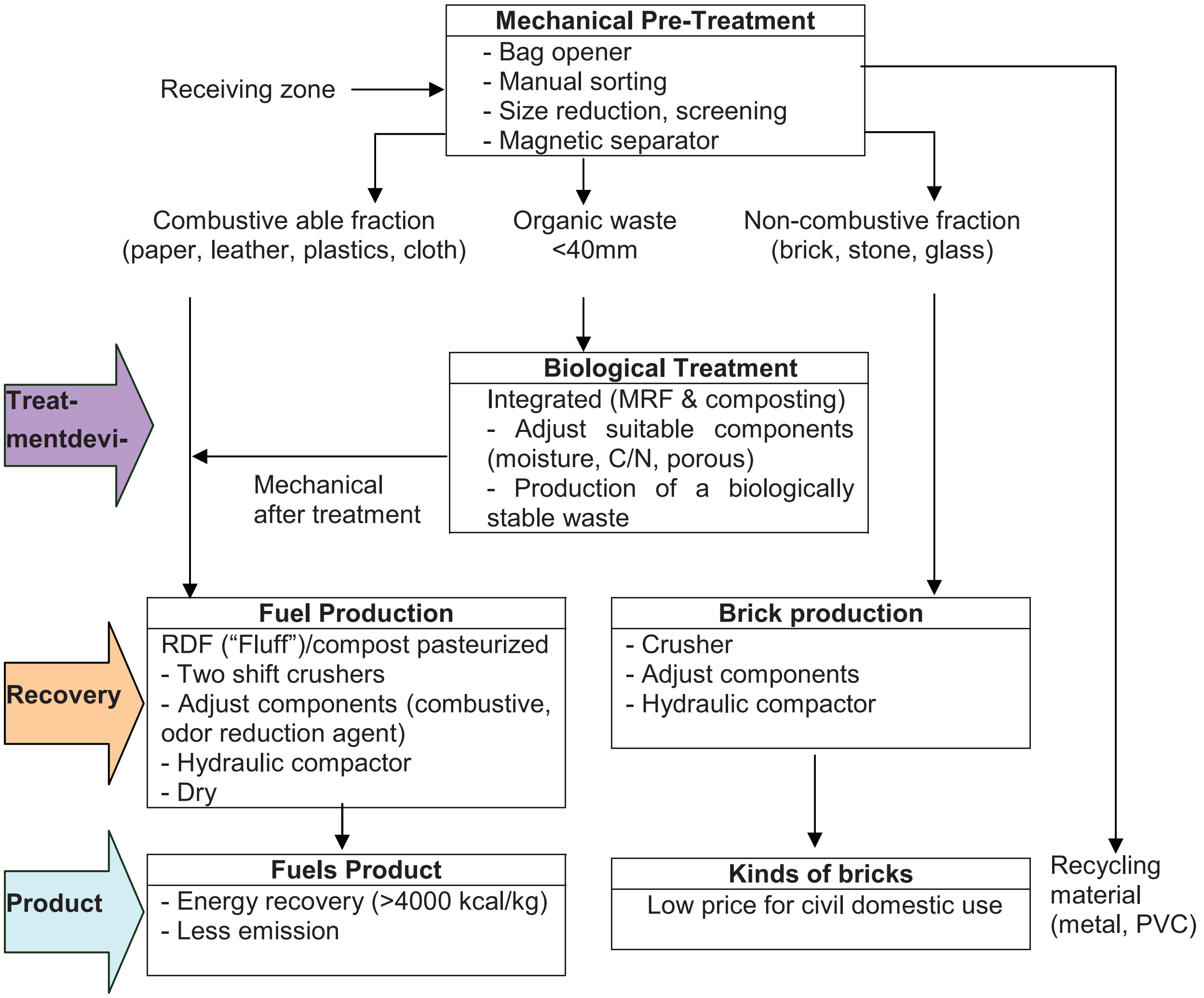
The project organized daily door-to door organic waste collection. Once organic waste was collected it was then transferred to a community plant built by the project capable of treating 2 to 3 tons per day.

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

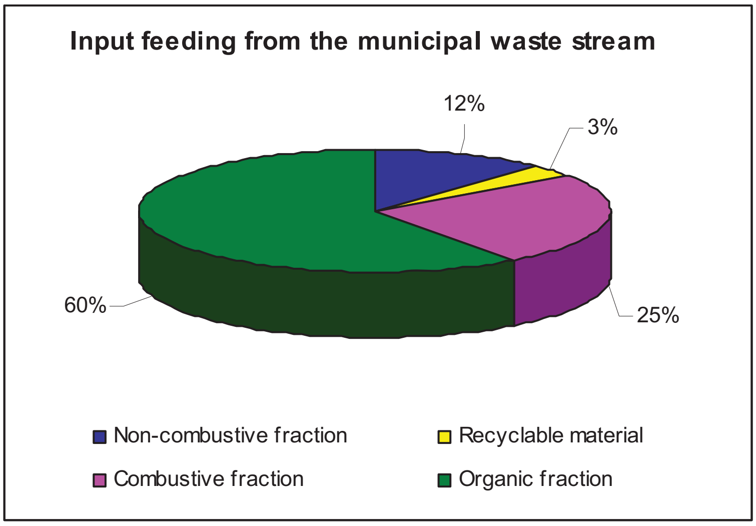
Schematic diagram of the MBT-CD.08 is as follows:



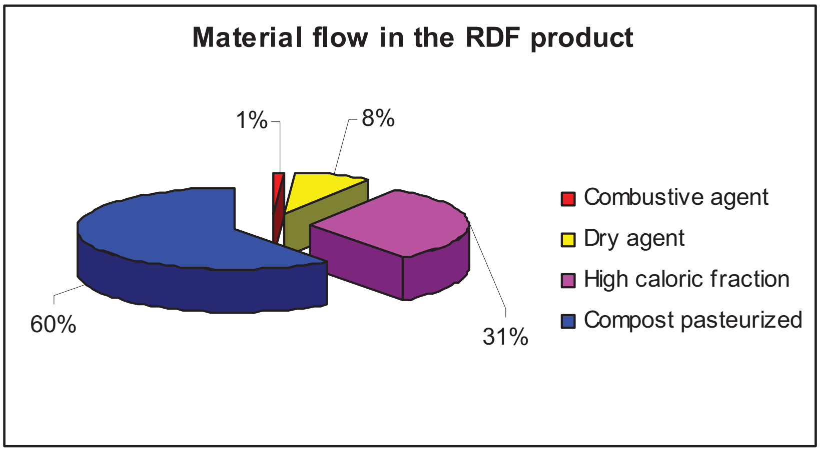
The MBT-CD.08 is used for a capacity of 15 tons/day, which has been tested successfully in Duy Tien district, Ha Nam province since June 2006; it is therefore suitable for small town or district. However the system is constructed with module, the capacity can reach to 100 tons/day if more modules are 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

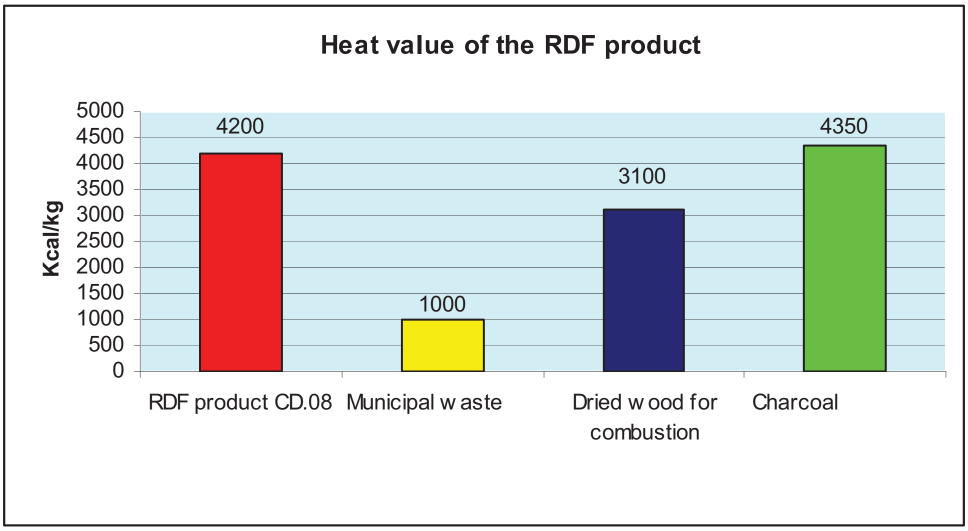
Input feeding from the municipal waste stream of Duy Tien district:



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

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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.

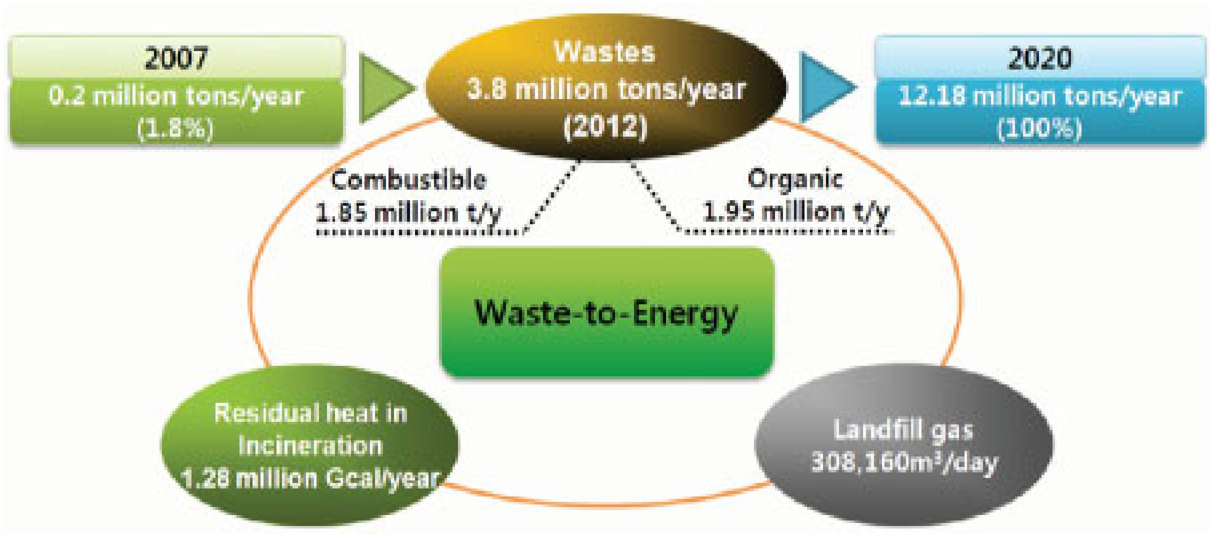

Figure 1 Promotion Goals

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 Environ-ment Energy Town	Combustible Waste MBT, RDF power plant, etc	Organic Waste Biogasifica-tion, 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.

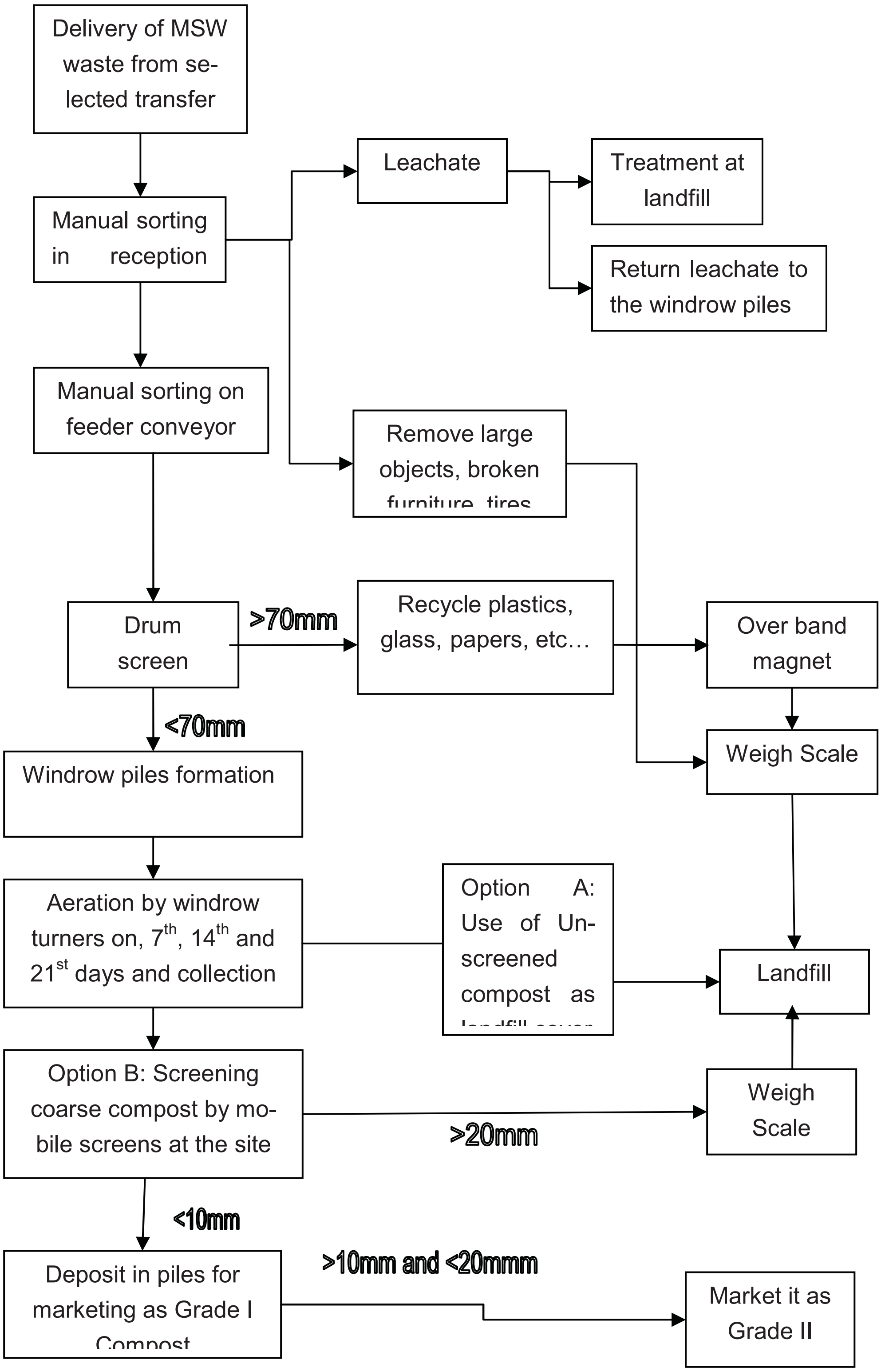

Figure 1 Process Flow sheet for the 4000 tpd Windrow Compost Plant

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, re-agents 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.

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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.

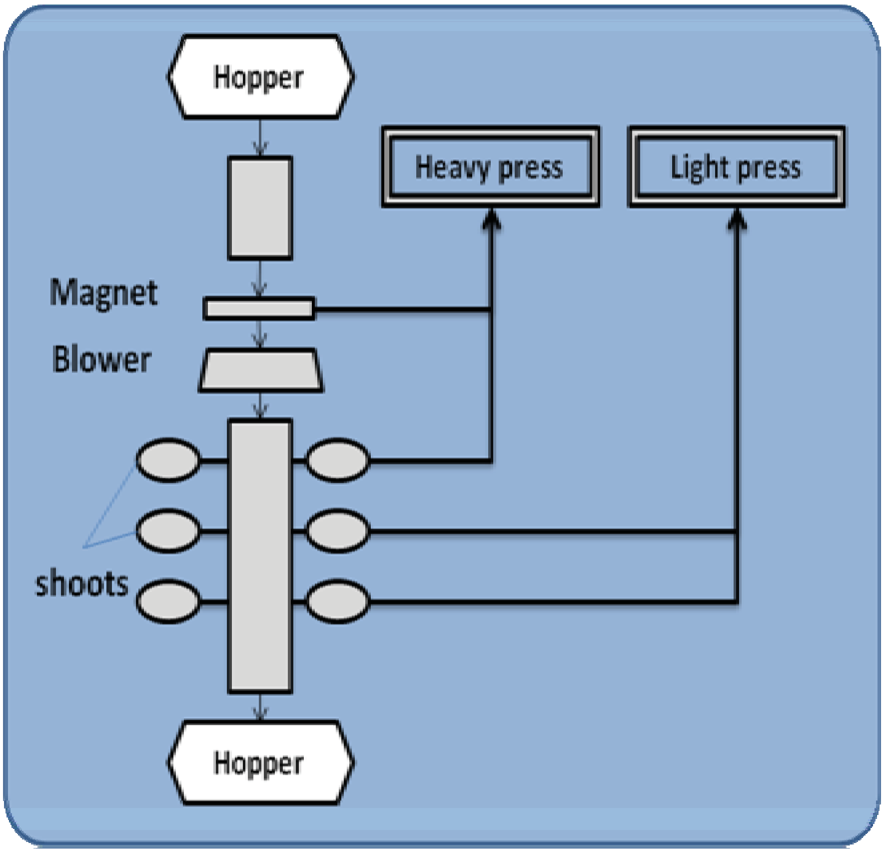

Figure 4: Sorting line

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.

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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.

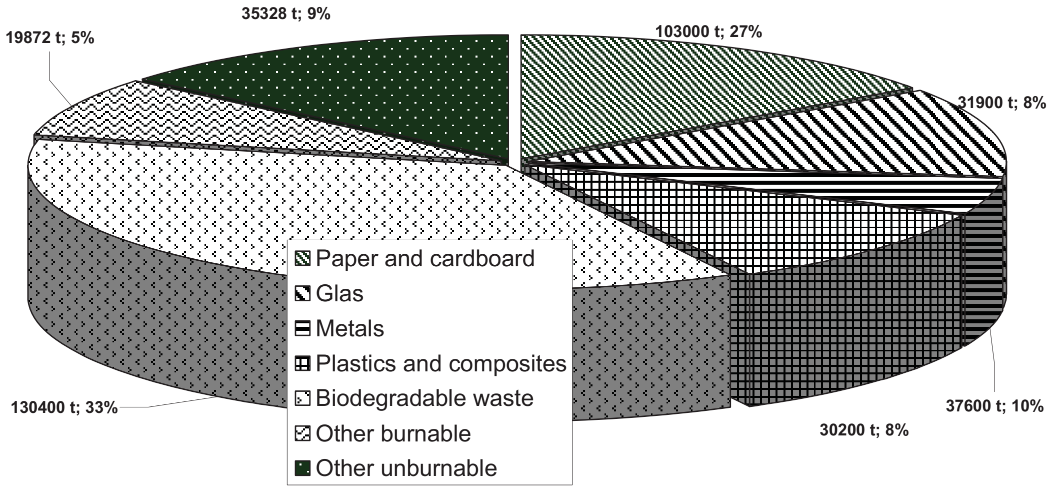

Figure 2 Municipal solid waste generation forecast (2013; Šiauliai, Panevežys, Telšiai and Tauragė waste management regions; Lithuania)

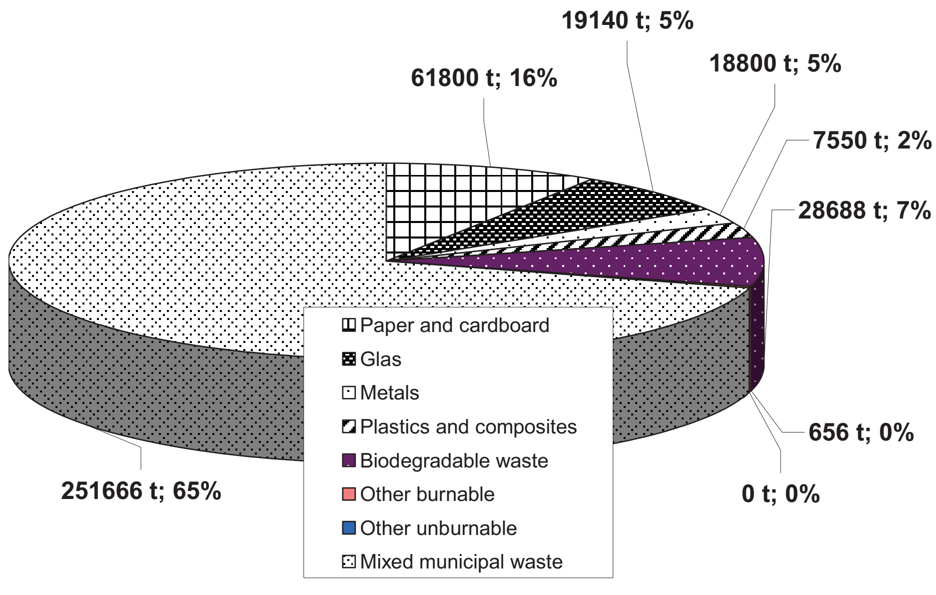

Figure 3 Municipal waste collection forecast (2013; Šiauliai, Panevežys, Telšiai and Tauragė waste management regions; Lithuania)

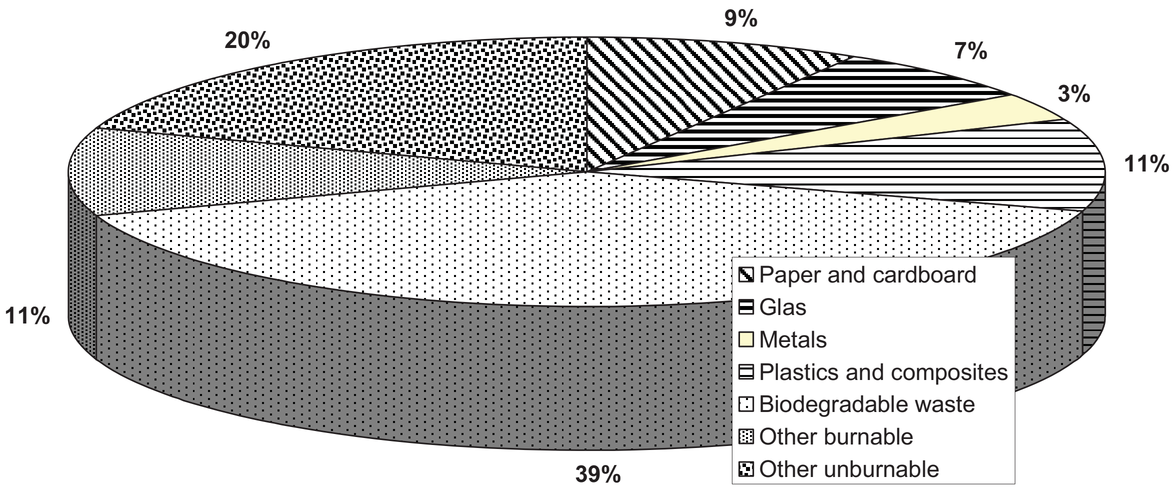

Figure 4 Mixed municipal solid waste content forecast (2013; Šiauliai, Panevežys, Telšiai and Tauragė waste management regions; Lithuania)

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.

<u>3 alternative</u>: ***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.

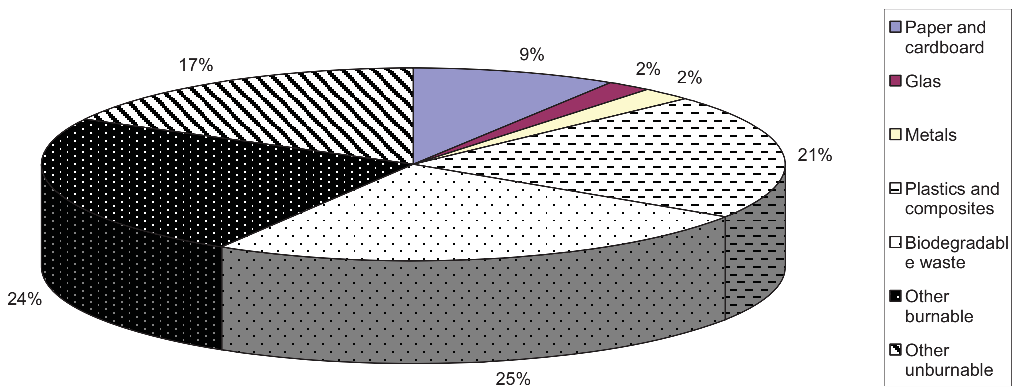

Figure 5 HCF content forecast (2013; Šiauliai, Panevežys, Telšiai and Tauragė waste management regions; Lithuania)

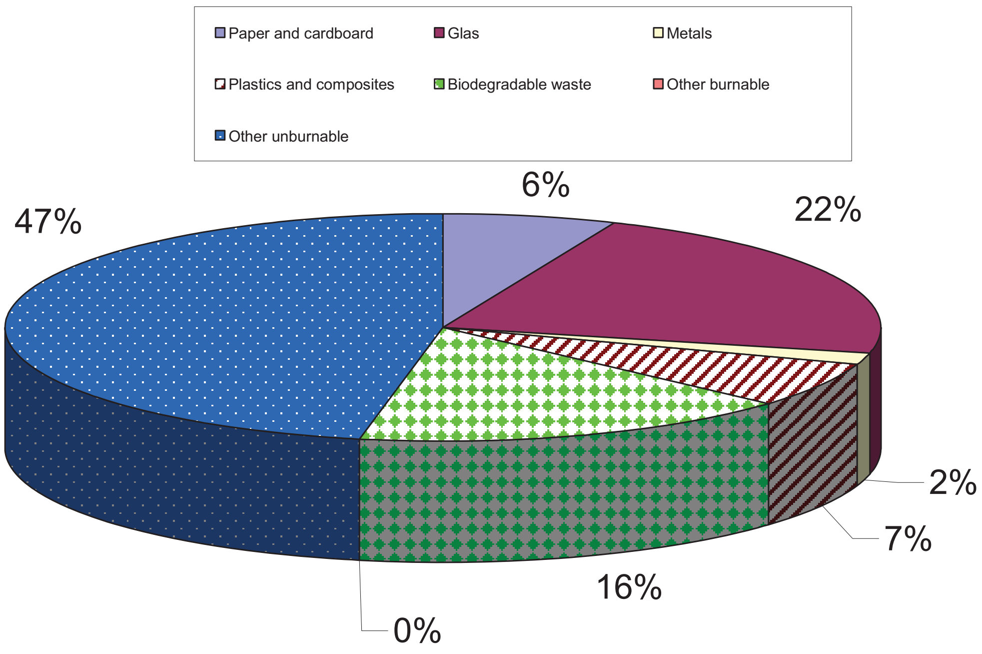

Figure 6 Dry stabilized LCF content forecast (2013; Šiauliai, Panevežys, Telšiai and Tauragė waste management regions; Lithuania)

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.

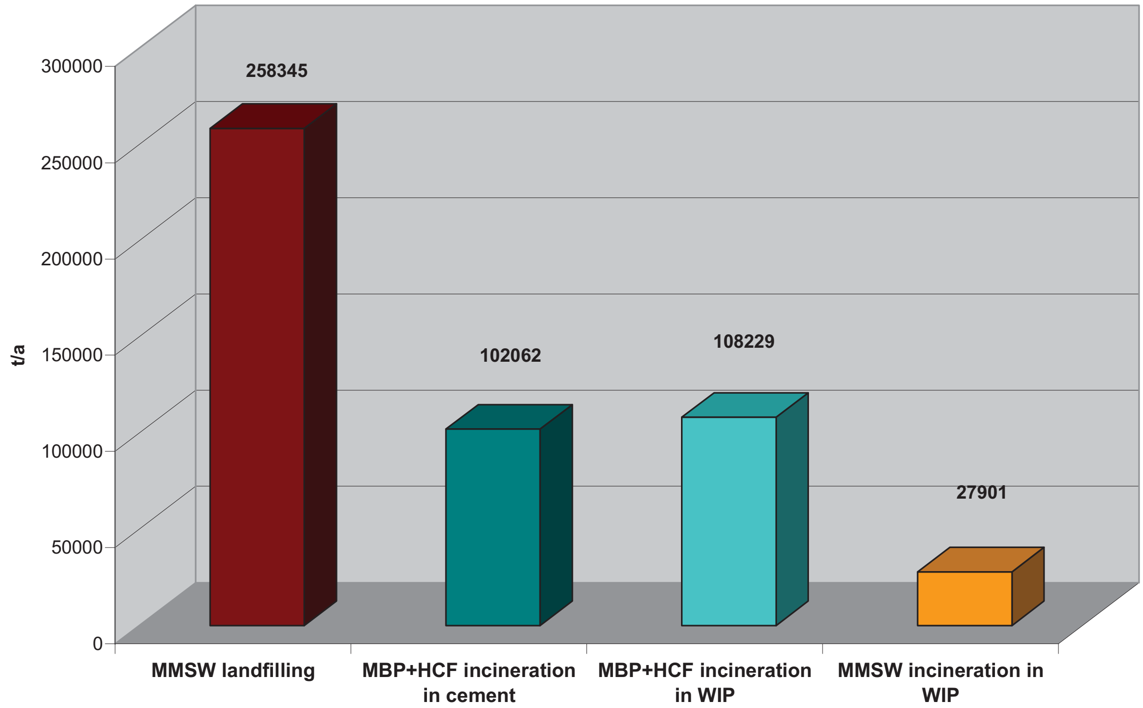

Figure 7 *Waste or waste treatment residues flows to the landfill for MMSW treatment alternatives (2013; Šiauliai, Panevežys, Telšiai and Tauragė waste management regions; Lithuania)*

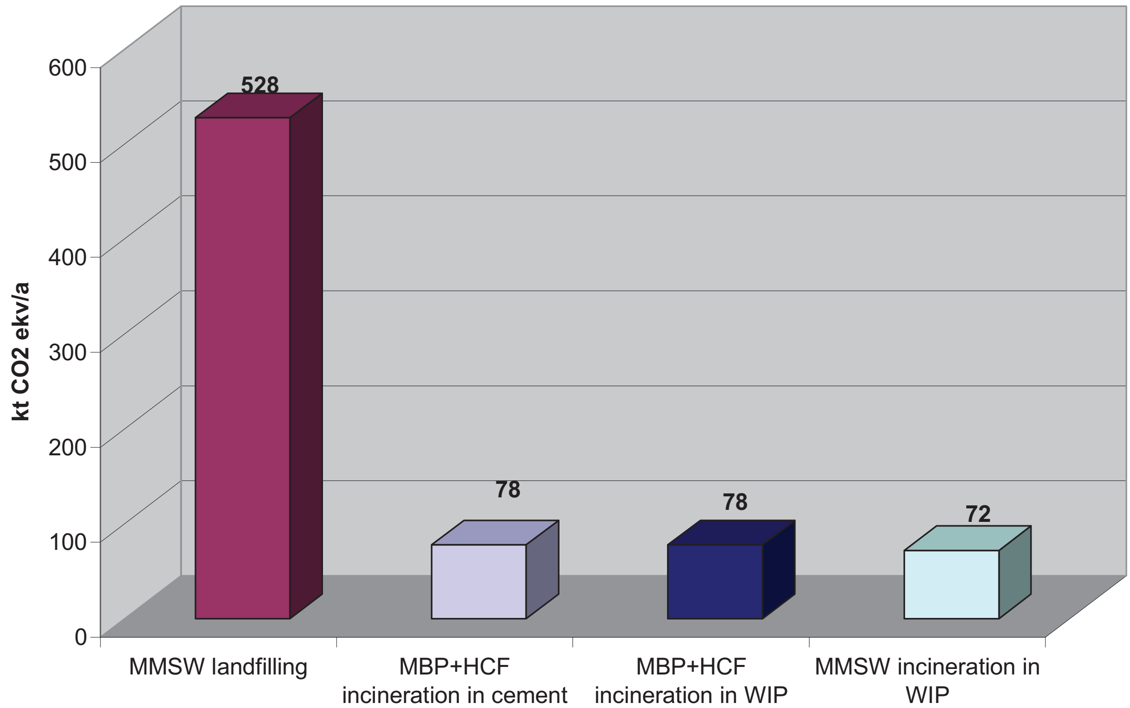

Figure 8 *Greenhouse gas emissions for MMSW treatment alternatives (2013; Šiauliai, Panevežys, Telšiai and Tauragė waste management regions; Lithuania)*

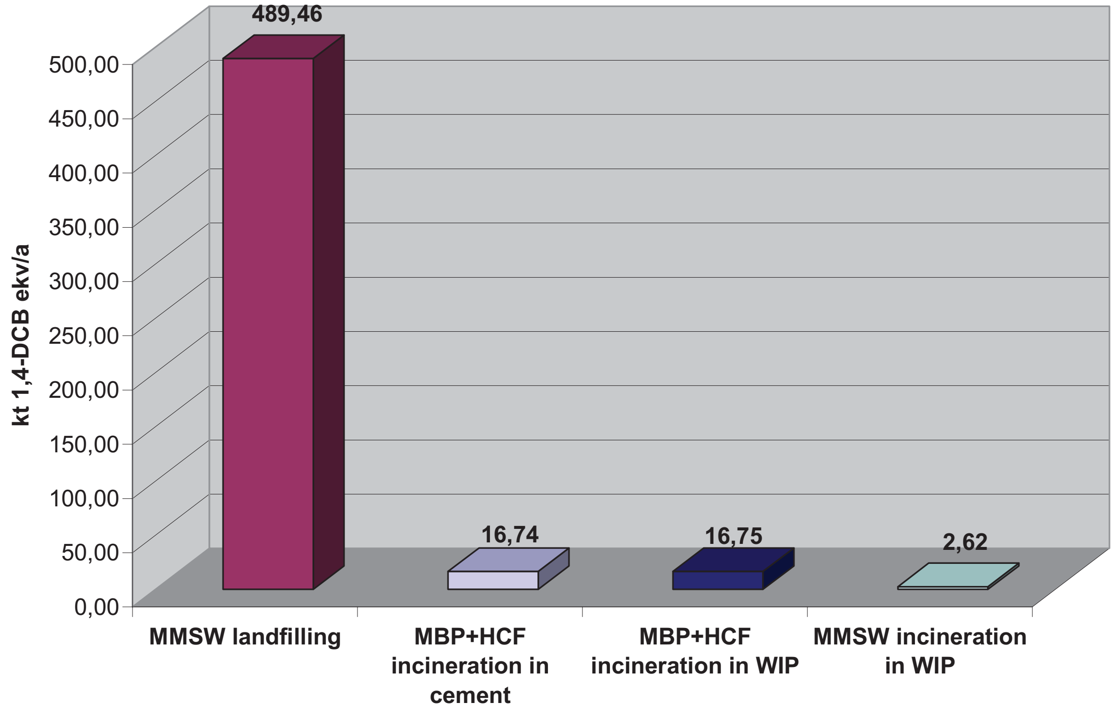

Figure 9 *Human toxicity for MMSW treatment alternatives (2013; Šiauliai, Panevežys, Telšiai and Tauragė waste management regions; Lithuania)*

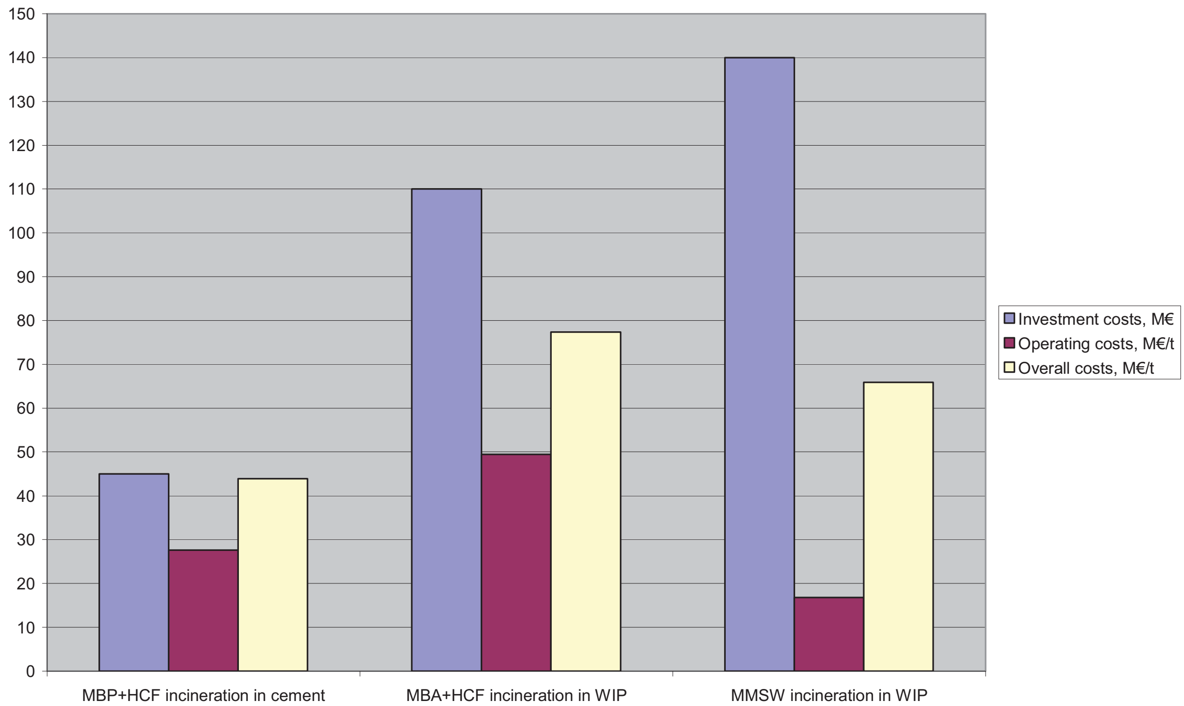

Figure 10 *Possible investment, operating and overall costs for MMSW treatment alternatives (2013; Šiauliai, Panevežys, Telšiai and Tauragė waste management regions; Lithuania)*

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.

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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

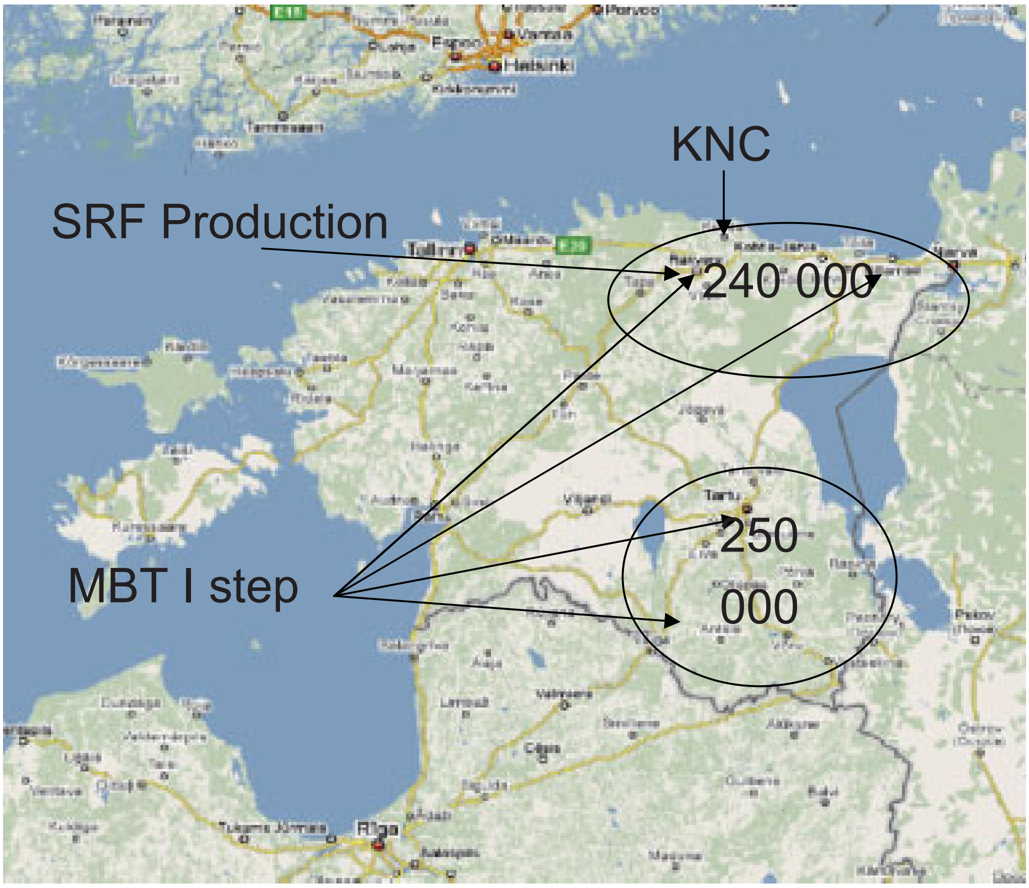
European Union law promotes separate collecting and composting of biowastes and considers the mixed solid wastes MBT technology and its products as low potential matters. The chain of collecting biodegradable wastes by categories is economically more expensive and less effective as it brings about the 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

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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.

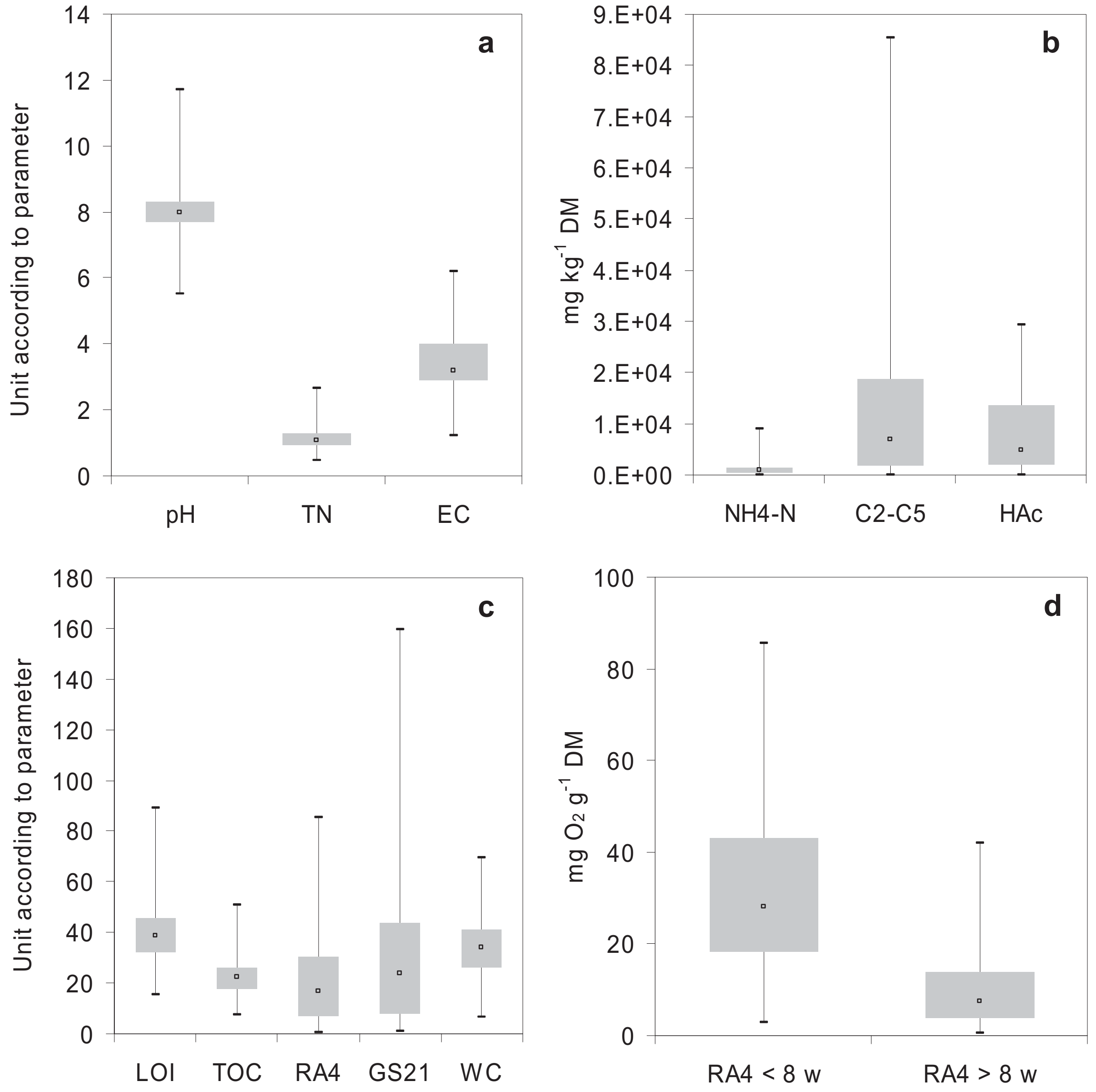

Figure 1 Box plots indicating the minimum, the maximum, the median and the 25 % and 75 % quantile of the measured parameters

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.

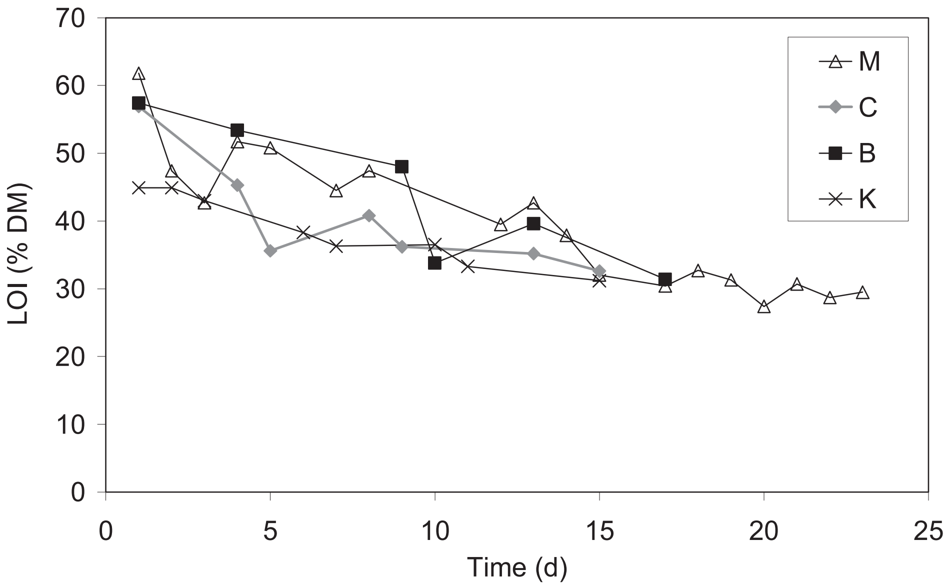

Figure 2 Development of the loss on ignition (LOI) in several selected MBT-plants

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.

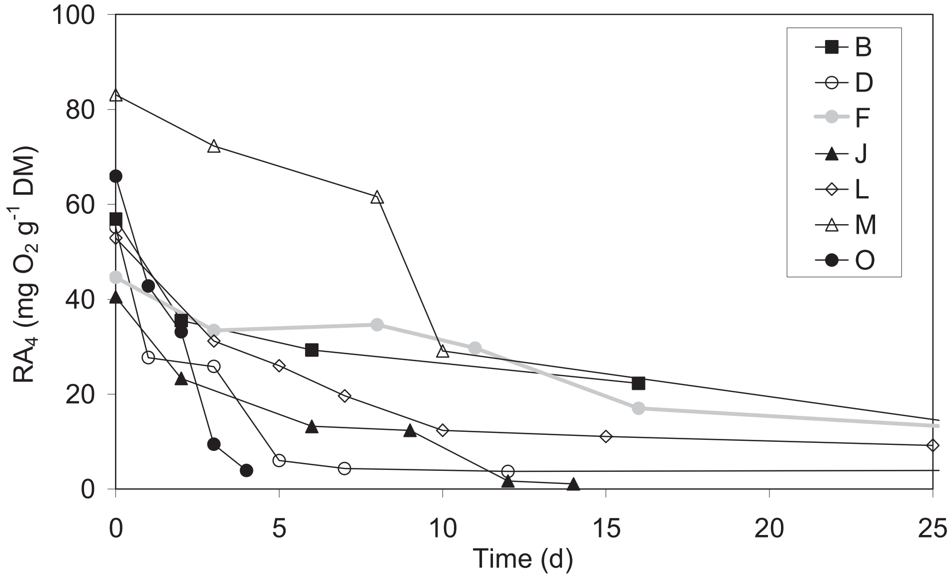

Figure 3 Development of respiration activities in several selected MBT-plants

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.

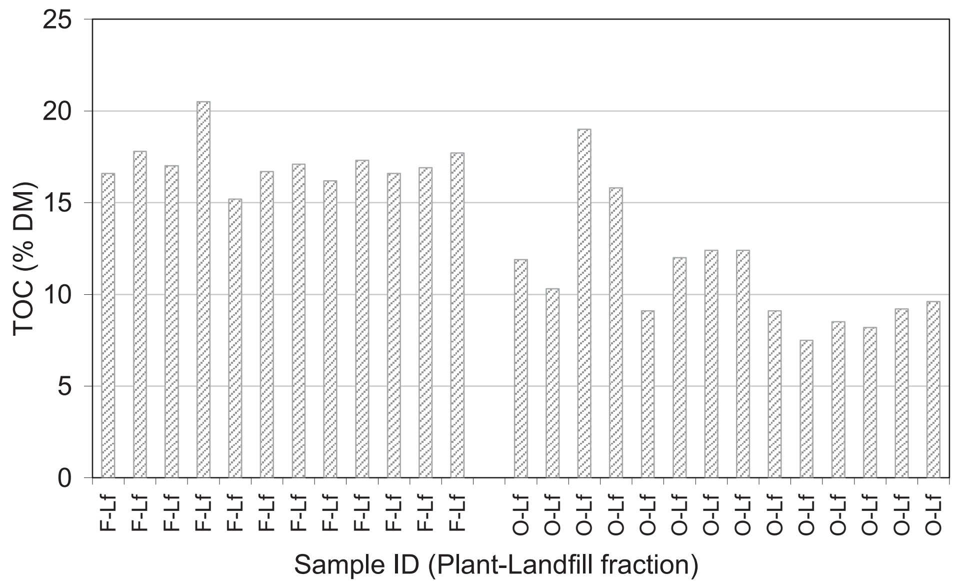

Figure 4 Variability of TOC in „landfill fractions" from two MBT-plants (F-Lf and O-Lf)

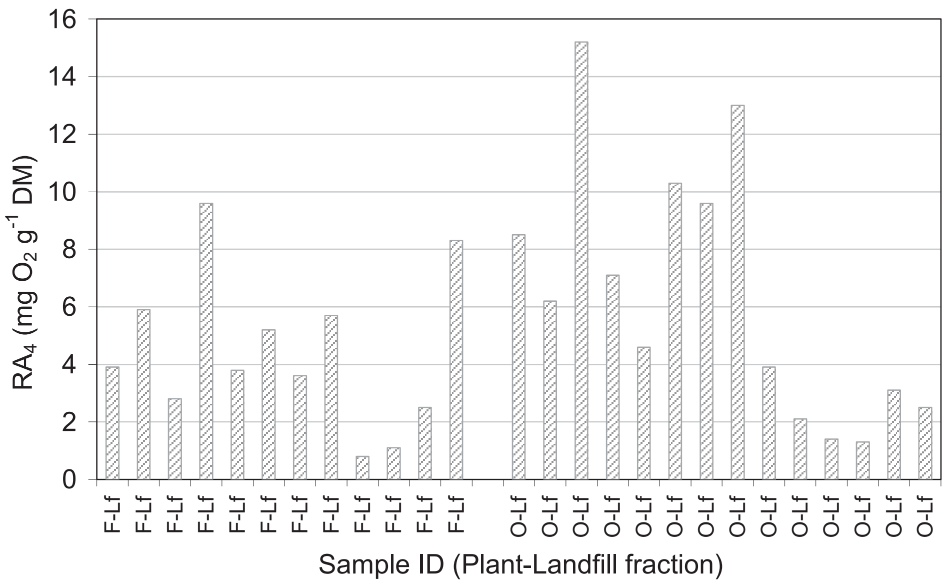

Figure 5 Variability of respiration activity (RA_4) in „landfill fractions“ from two MBT-plants (F-Lf and O-Lf)

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.

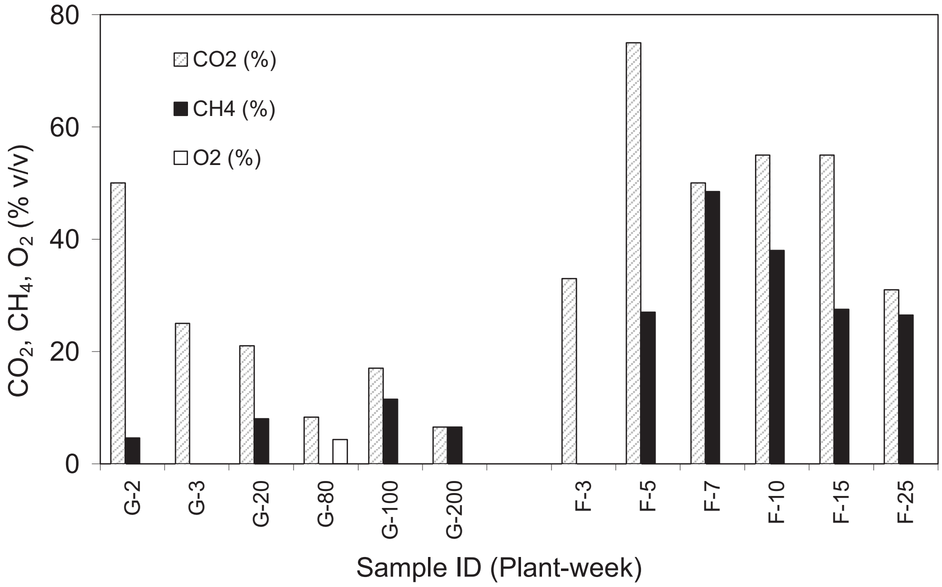

Figure 6 Measurement of gas composition in the heap at different stages of the biological treatment (MBT-plants “F” and “G”)l

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.

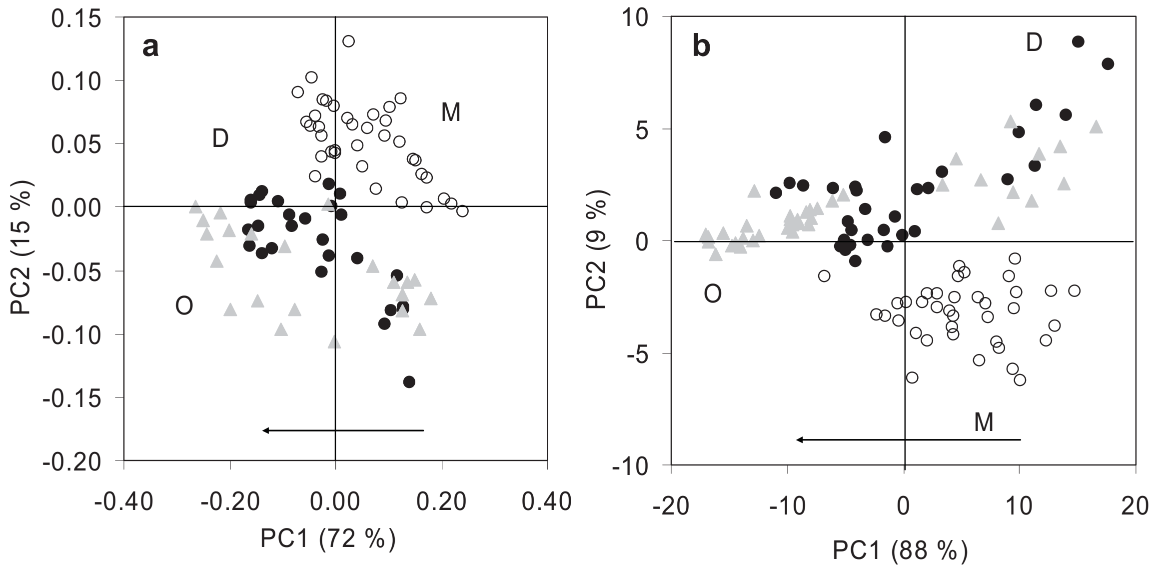

Figure 7 PCA based on (a) spectral and (b) thermal data of three MBT-plants (D, M, O)

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.

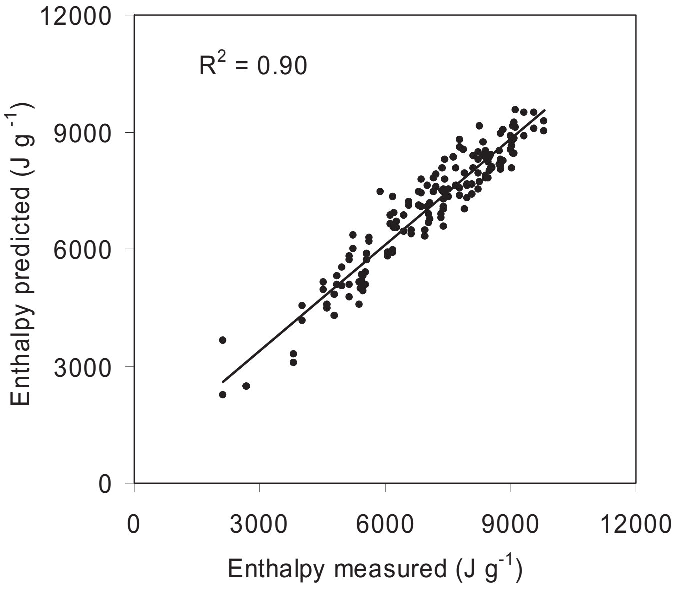

Figure 8 *Correlation between the calorific value determined by the bomb calorimeter and by the heat flow profile*

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.

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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.

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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.

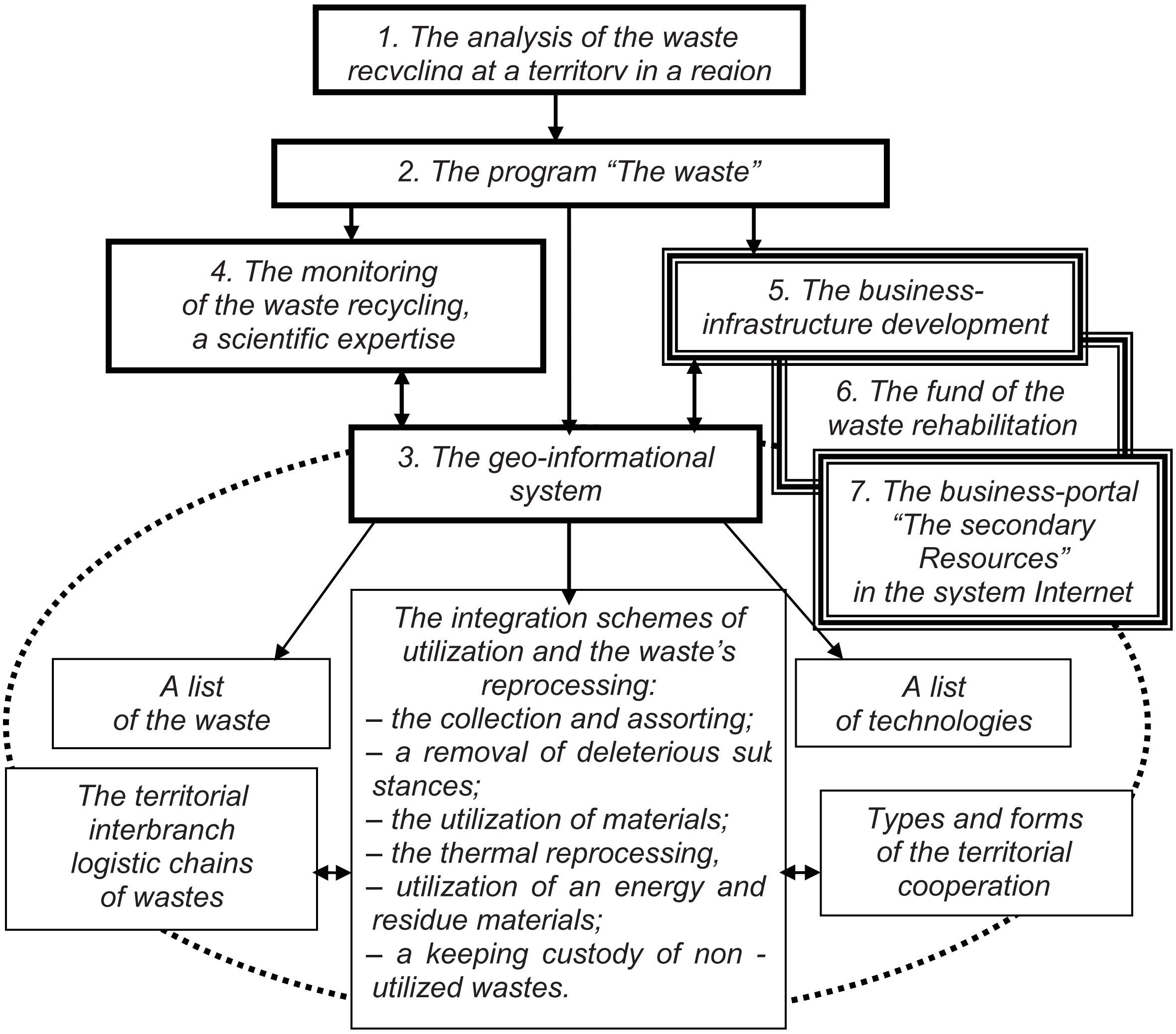

Figure 1 The algorithm of the industrial waste capitalization and consumption in a region

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.

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Von der Abfall- zur Ressourcenwirtschaft – die Abfallwirtschaft der Zukunft. Brauchen wir noch die Müllverbrennung?

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Wasteconsult International

From waste to resource management – The future of waste management

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.

Inhaltsangabe

In Hinblick auf die durch Bevölkerungswachstum und Erschöpfung der Lagerstätten bedingte Verknappung und Verteuerung von Rohstoffen ist es sinnvoll, zukunftsfähige Modelle der Restabfallbehandlung zu erarbeiten, um eine ressourcenschonende, umweltgerechte Abfallwirtschaft zu gewährleisten.

Der folgende Beitrag gibt einen Überblick über die Verfügbarkeit und den Verbrauch verschiedener Rohstoffe (Energierohstoffe und metallische bzw. nichtmetallische Rohstoffe) weltweit. Zudem zeigt er, wie durch das Recycling von Materialien, CO_2-Emissionen eingespart werden können und so neben der Ressourcenschonung auch positive Effekte für das Klima zu erzielen sind.

Die heutigen Methoden der Restabfallbehandlung (thermisch und mechanisch-biologisch) werden bezüglich ihrer Eignung für eine zukünftige Abfallwirtschaft unter nachhaltigen Gesichtspunkten bewertet. Der Beitrag schließt mit Handlungsempfehlungen für den künftigen Umgang mit Restabfällen.

Keywords

Ressourcenwirtschaft, Abfallwirtschaft, Ressourcenverbrauch, Rohstoffe, Recycling,

waste management, resources, raw materials, waste treatment.

1 Einleitung

Angesichts der baldigen Erschöpfung vieler Rohstoffvorkommen und gleichzeitig steigendem Verbrauch aufgrund von Bevölkerungswachstum und steigendem Wohlstand gewinnt die Rückgewinnung von Rohstoffen aus Abfällen stark an Bedeutung. In welchem Maß und in welcher Qualität Rohstoffe aus Restabfällen zurückgewonnen werden können, hängt wesentlich von der Art der Restabfallbehandlung ab. Hierbei stehen sich vor allem mechanische / mechanisch-biologische Abfallbehandlung (MBA) und thermische Behandlung, also Müllverbrennung (MVA) gegenüber.

2 Bevölkerungswachstum, steigender Wohlstand und zur Neige gehende Rohstoffvorräte als Einflussfaktoren auf die Abfallwirtschaft

2.1 Bevölkerungsentwicklung und Rohstoffverbrauch unterschiedlicher Staaten

Die Weltbevölkerung wird bis zum Jahr 2050 um 2,5 Milliarden, von 6,7 (Stand 2007) auf ca. 9,1 Milliarden wachsen (mittleres Szenario). Jährlich ist dies ein Zuwachs von durchschnittlich 56 Millionen Menschen (UN, 2009).

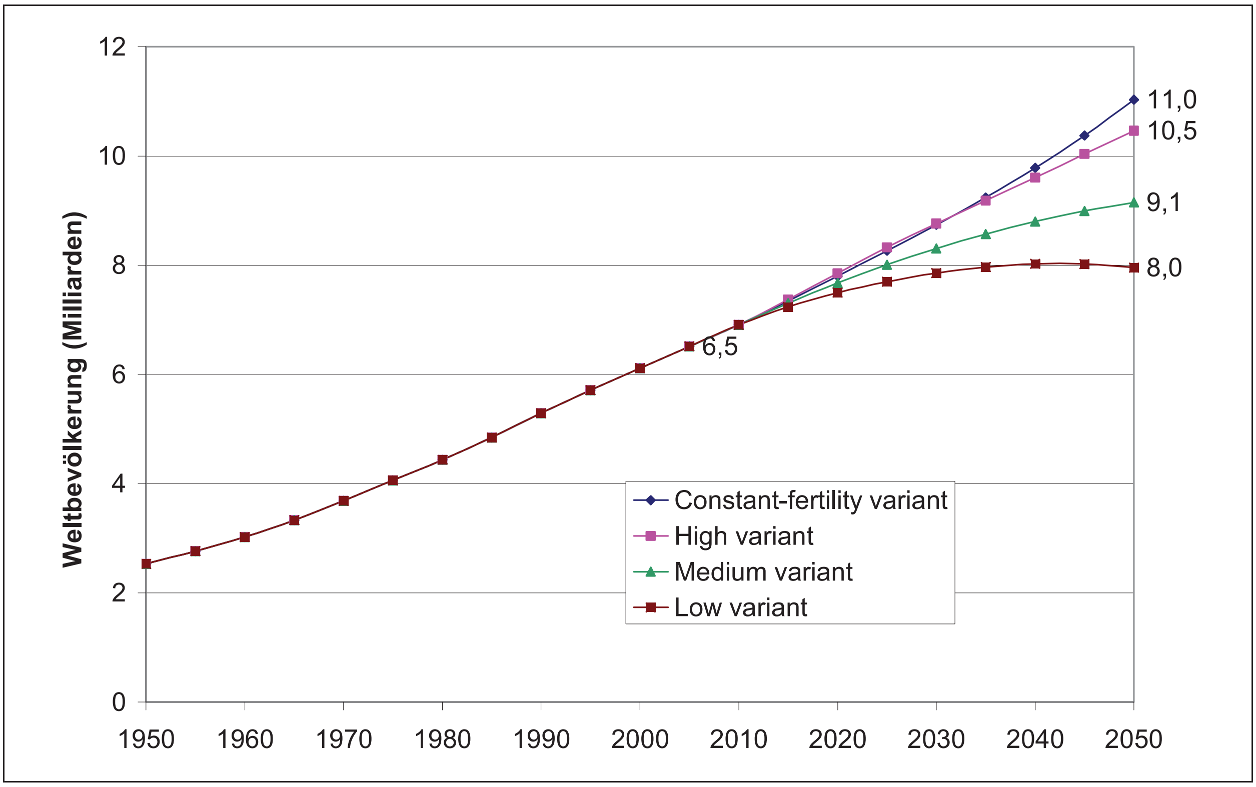

Abbildung 1: Weltbevölkerungsentwicklung (Datenquelle: UN, 2009)

Die Deutsche Stiftung Weltbevölkerung gibt auf Ihrer Internetseite für den aktuellen Zeitpunkt (April 2009) einen jährlichen Bevölkerungszuwachs von 81 Millionen Menschen an, das entspricht fast der Bevölkerung Deutschlands.

Vor allem in Entwicklungs- und Schwellenländern ist der Bevölkerungszuwachs meist sehr hoch. Für den Rohstoffverbrauch sind dabei Indien und China von besonderer Bedeutung, da sie eine außerordentlich große Einwohnerzahl und ein hohes Wirtschaftswachstum haben.

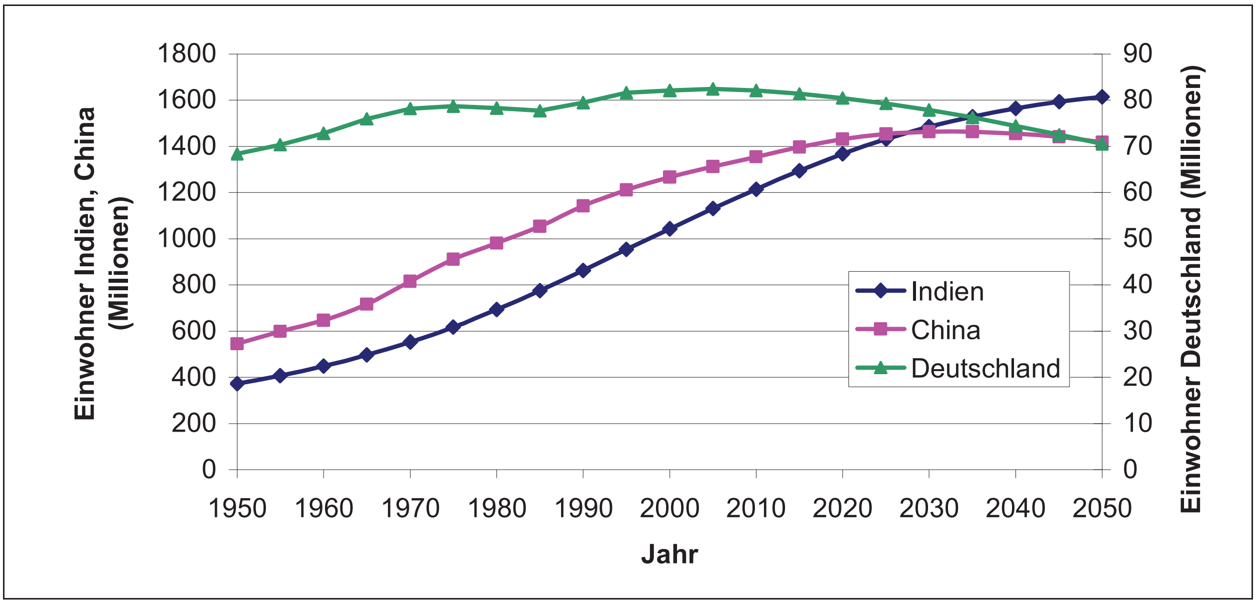

Abbildung 2: Bevölkerungsentwicklung in Indien, China und Deutschland (Daten: UN, 2009)

In Abb. 3 ist der pro Kopf-Verbrauch verschiedener Ressourcen in ausgewählten Ländern dargestellt. Zusätzlich ist der pro Kopf-Verbrauch aller Rohstoffe dargestellt. Dazu zählen: Biomasse (Wald, Nahrungs- und Futtermittel, tierische Biomasse), fossile Energieträger und Mineralien. Vor allem beim Verbrauch der fossilen Energieträger nähert sich China bereits an das Niveau Europas an.

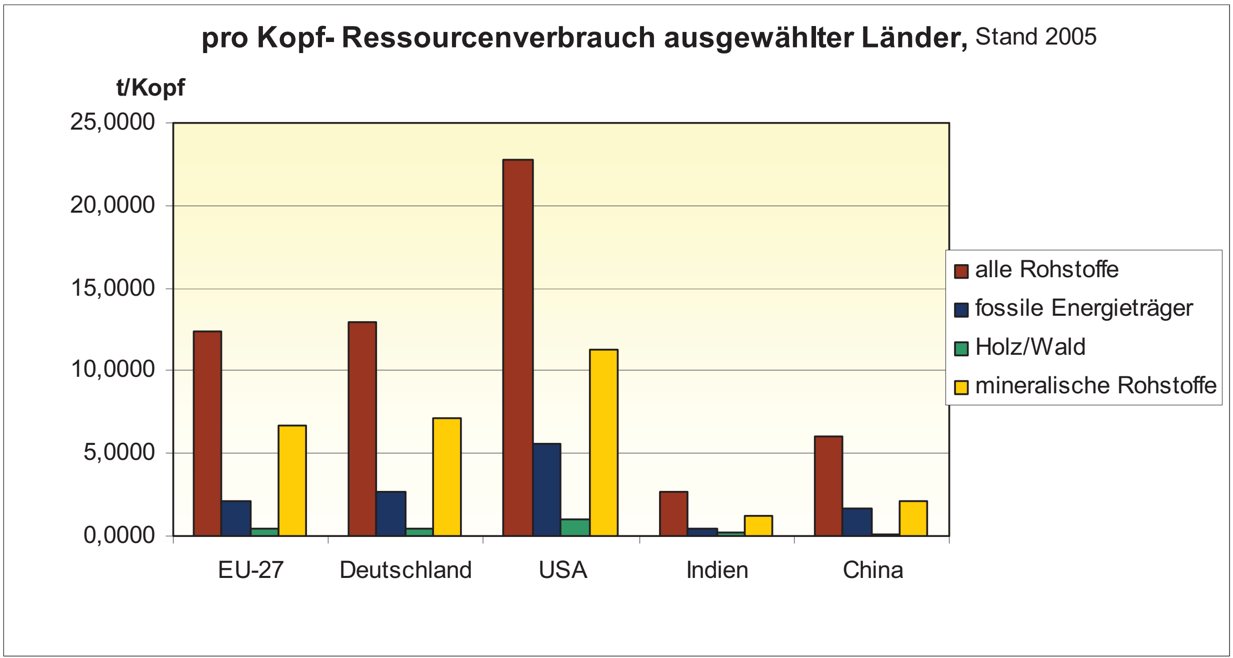

Abbildung 3: pro Kopf-Verbrauch verschiedener Ressourcen ausgewählter Länder (DATENQUELLE: SERI, 2009)

2.2 Reichweite von Energierohstoffen

Unter Energierohstoffen werden hier die fossilen Energieträger Erdöl, Erdgas, Stein- und Braunkohle sowie Uran verstanden. Die Reichweitenangaben für die Rohstoffe beziehen sich auf ihre statische Reichweite, d.h., die Reichweite der heute sicheren und wahrscheinlichen Vorräte bei einer konstanten Produktion (auf heutigem Niveau). Eine Erhöhung der Nachfrage und der Produktionsmengen ergäbe folglich eine Verkürzung der Reichweite (BARDT, 2008).

Bei den Lagerstätten unterscheidet man zwischen Reserven und Ressourcen. Reserven sind die bei heutigen Preisen und Fördertechniken wirtschaftlich gewinnbaren Mengen. Ressourcen sind nachgewiesene, aber derzeit technisch und/oder wirtschaftlich nicht gewinnbare Rohstoffe. Ressourcen können also durch Preissteigerungen oder neue Fördertechnologien zu Reserven werden (BGR, 2007).

Die statischen Reichweiten dieser Energieträger sind sehr unterschiedlich. Die größte Reserve ist noch bei der Kohle, vor allem bei der Braunkohle vorhanden. Welche Unterschiede sich durch die differenzierte Betrachtung der Reserven oder Ressourcen ergeben können, zeigt sich am Beispiel Uran. Die Reichweite der Reserven ist auf 46 Jahre beziffert, zusammen mit den Ressourcen auf 348 Jahre. Erdöl hat die kürzeste Reichweite mit etwa 42 Jahren; zieht man noch die Ressourcen in die Betrachtung mit ein, so erhöht sich die Reichweite auf 63 Jahre (BGR 2007). In Hinblick auf das Thema

Recycling ist Erdöl vor allem als Grundlage für die Herstellung von Kunststoffen relevant.

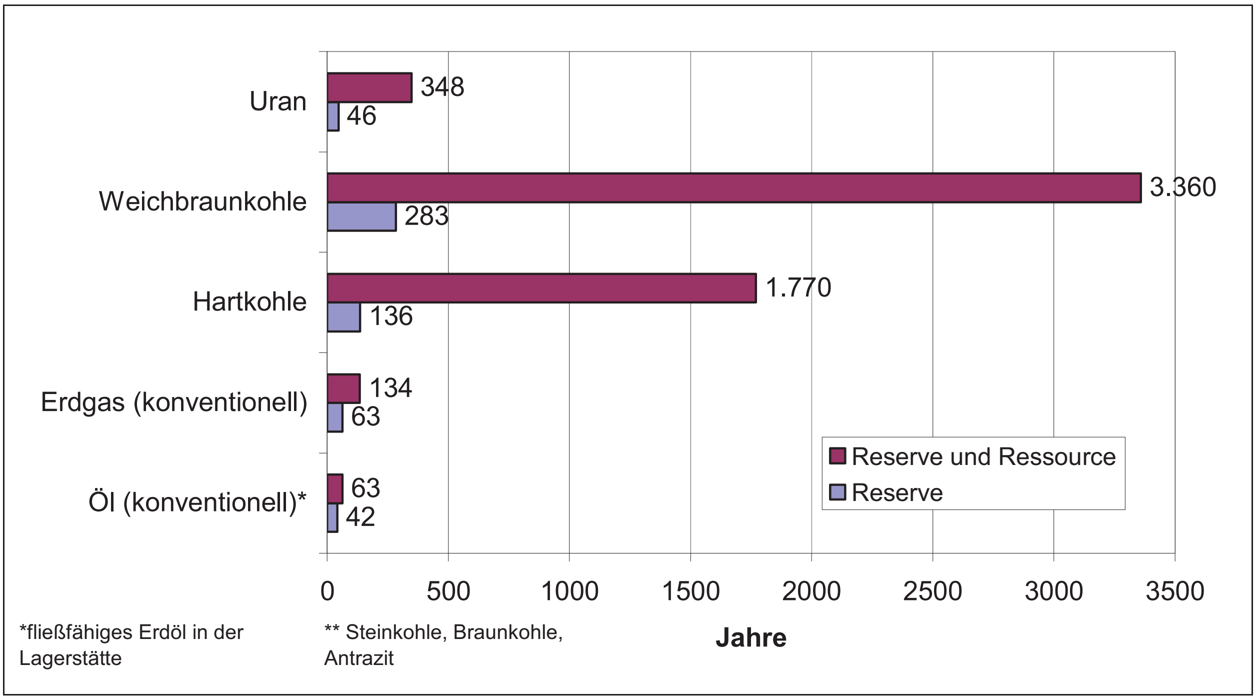

Abbildung 4: Statische Reichweite verschiedener Energieträger (DATENQUELLE: BGR 2007)

2.3 Reichweite von metallischen und mineralischen Rohstoffen

Metallische und mineralische Rohstoffe sind in der öffentlichen Diskussion um Rohstoffknappheit noch nicht so präsent wie die Energierohstoffe, obwohl bei wichtigen und kaum ersetzbaren Metallen die Reserven noch deutlich eher erschöpft sein werden. Auch das für die industrielle Landwirtschaft unentbehrliche Mineral Phosphat wird in 122 Jahren erschöpft sein. (BARDT 2008).

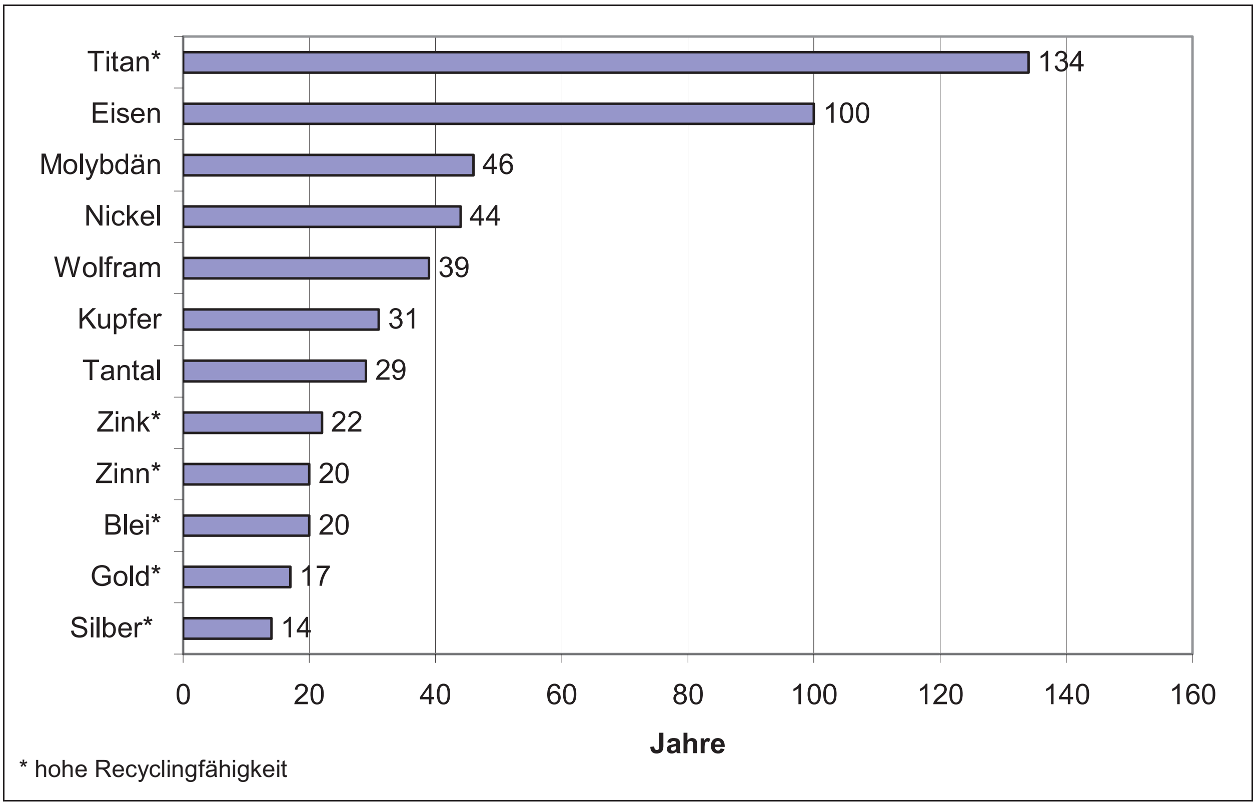

Abbildung 5: Reichweite der Reserven metallischer Rohstoffe (DATENQUELLE: BARDT 2008)

Vom Institut für Wirtschaft in Köln (IW Köln) wurde eine Rohstoffversorgungs-Risiko-Rating-Liste mit kritischen Rohstoffen erstellt, deren Reichweite unter 30 Jahren liegt und deren Vorkommen / Abbau auf bestimmte Länder bzw. Unternehmen beschränkt ist. Gold, Silber und Zink tauchen nicht in dieser Liste auf, da sie eine hohe Recyclingfähigkeit besitzen. Aus dem selben Grund werden Blei, Titan und Zinn als weniger kritisch eingestuft. Als sehr kritisch wird die Versorgung mit Chrom, Molybdän, Niob und den Metallen der Platingruppe klassifiziert, da die Versorgung überwiegend von drei Ländern und drei Unternehmen abhängt (IW KÖLN, 2005).

Die zunehmende Unsicherheit bei der metallischen Rohstoffversorgung spiegelt sich auch in der Entwicklung der Rohstoffpreise wider, die von 2005 bis 2008 um durchschnittlich 235% anstiegen, die Preise für Eisenerz und Stahlschrott sogar um 385% (BARDT 2008). Der derzeitige Preiseinbruch dürfte eine vorübergehende Erscheinung sein.

2.4 Preisentwicklung von Sekundärrohstoffen

Auch die Preise von Kunststoffregranulaten sind in den letzten Jahren stark angestiegen. Mit einsetzender Wirtschaftskrise im zweiten Halbjahr 2008 kam es aber auch hier zu einem massiven Preiseinbruch, der Recyclingbetriebe in ihrer Existenz bedroht.

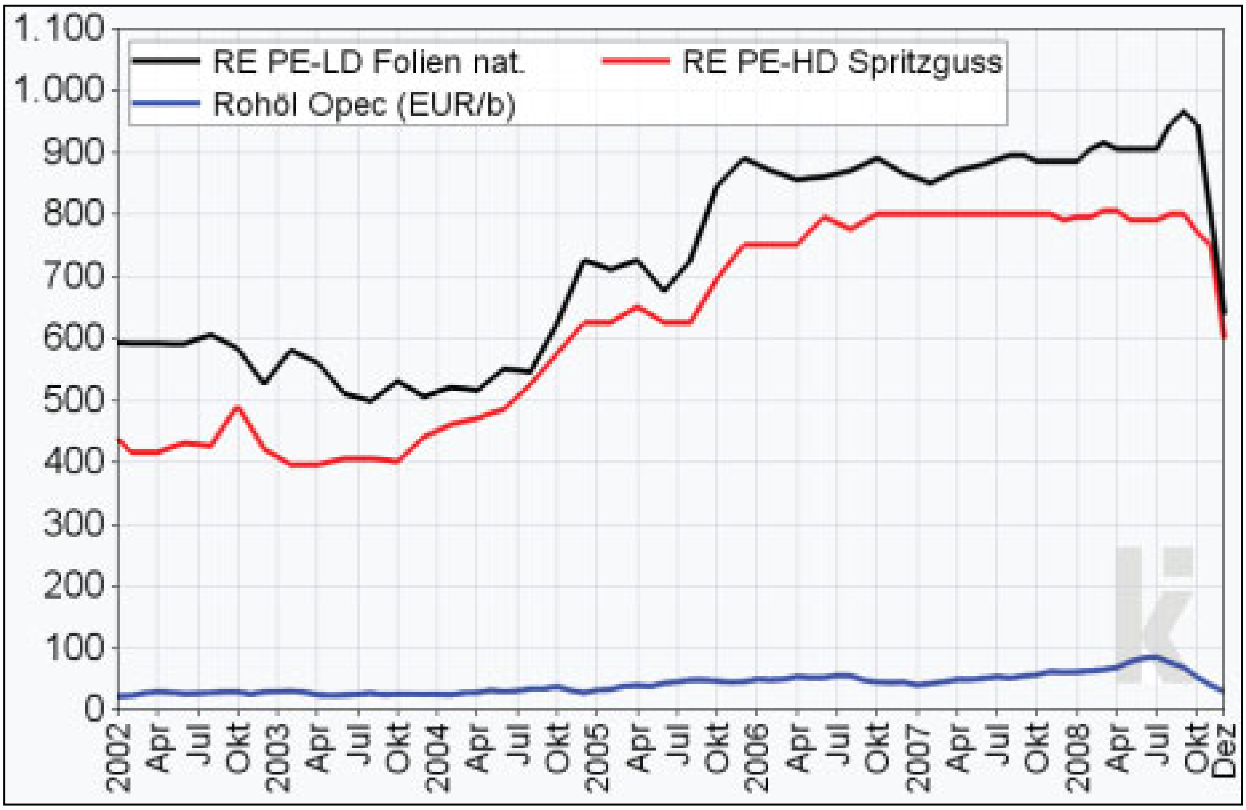

Abbildung 6: Preisentwicklung für Kunststoffregranulate im Vergleich zur Entwicklung des Rohölpreises (Quelle: kiweb, 2009)

Ähnlich sieht es bei den Händlerpreisen für Altpapier aus:

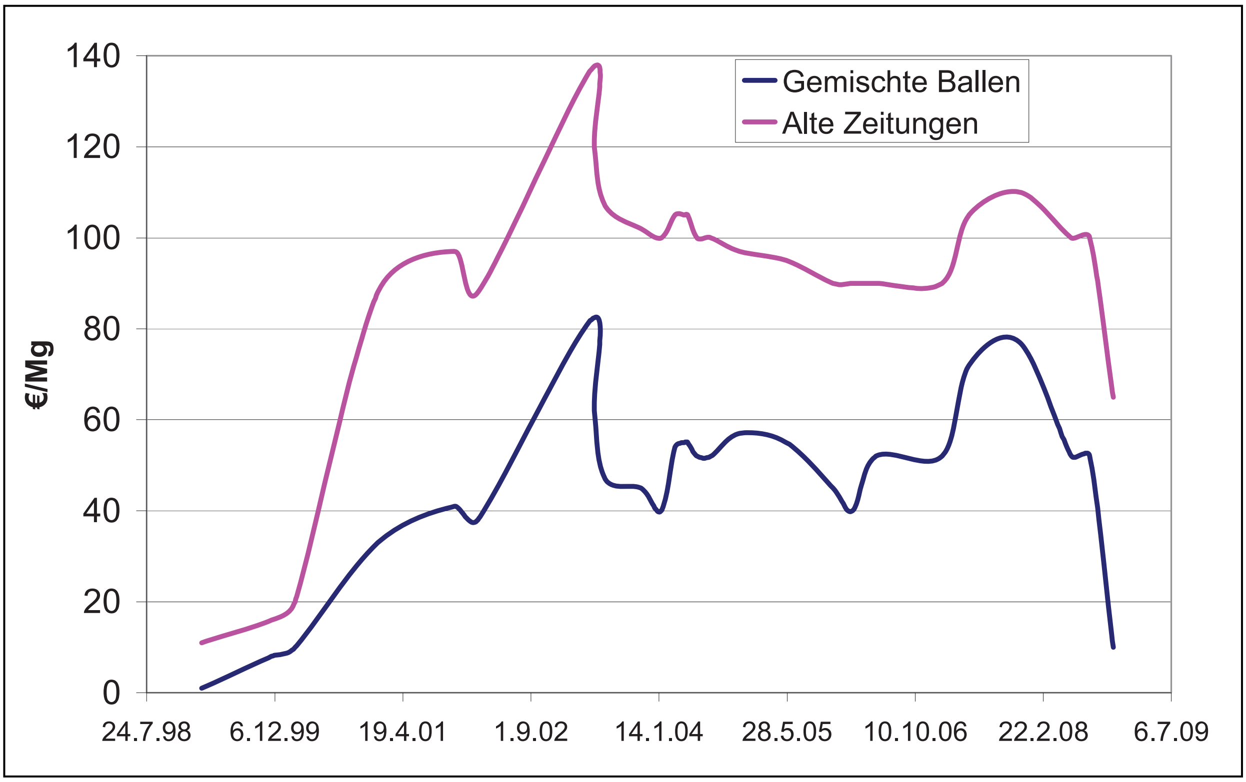

Abbildung 7: Händlerpreisentwicklung von Altpapier (Datenquelle: EUWID)

2.5 Reduktion von Energieverbrauch und CO_2- Emissionen durch Recycling

Recycling ist nicht nur aus Sicht der Versorgungssicherheit oder des Ressourcenschutzes interessant, sondern auch in Bezug auf den Klimaschutz. Das Fraunhofer-Institut UMSICHT untersuchte 2008 im Auftrag von INTERSEROH die CO_2-Emissionen bei der Erzeugung von Primär- und Sekundärprodukten aus Polyethylen (PE), Polyethylenterephthalat (PET), Kupfer, Aluminium, Stahl, Holz und Papier, Pappe, Karton (PPK).

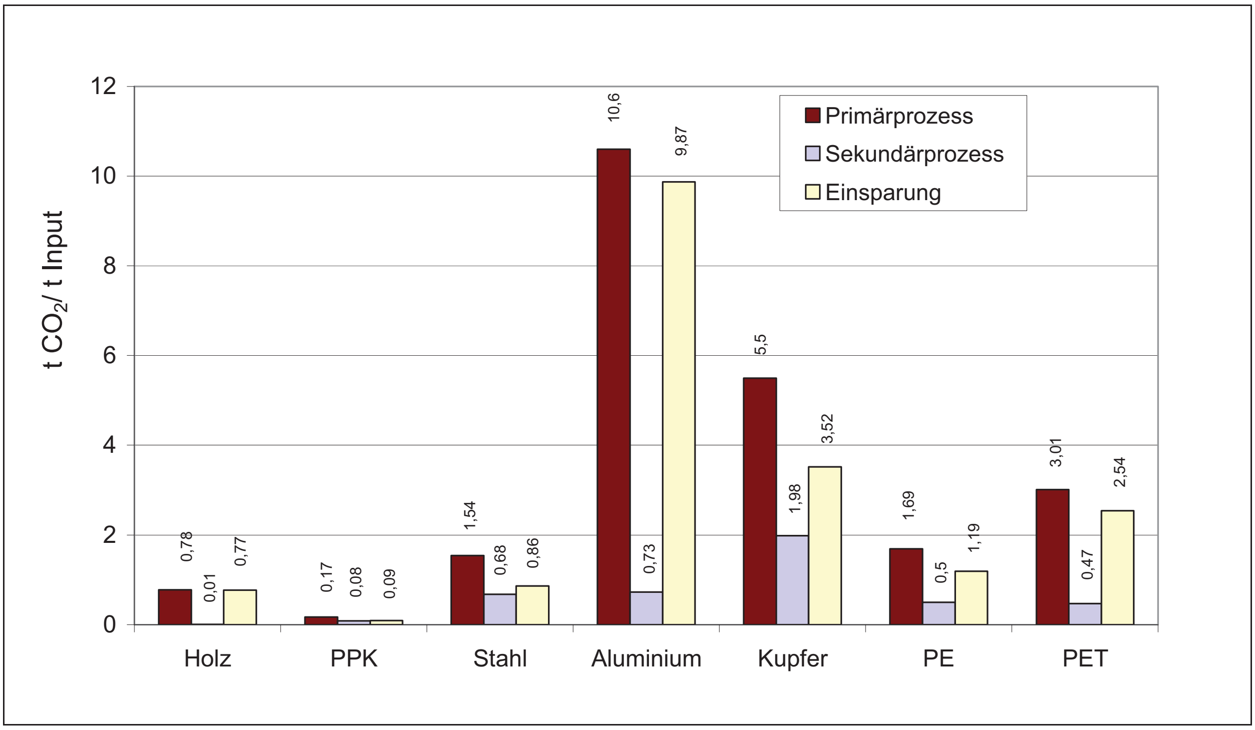

Abbildung 8: CO_2-Emissionen bei der Produktion von Primär- und Sekundärrohstoffen (Datenquelle: Interseroh, Umsicht, 2008)

Bei allen untersuchten Materialien sind die Einsparungen massiv. INTERSEROH, UMSICHT (2008) beschreiben die stoffspezifische Situation wie folgt:

Zur Zeit werden in Deutschland 40% Rohstahl aus Stahlschrott hergestellt. Im Primärprozess, d.h. von der Eisenerz-Gewinnung bis zur Produktion des Stahls im Hochofen fallen 1,54 t CO_2 pro t Rohstahl an. Im Gegensatz dazu sind es im Sekundärprozess, der aus Erfassung, Aufbereitung und Verarbeitung von Stahlschrott besteht, etwa 0,68 t CO_2 pro t Rohstahl. Dies entspricht folglich einer Einsparung von rund 56%. Durch die teilweise lange Nutzungsdauer von Stahlprodukten fällt folglich auch wenig Stahlschrott an und der Bedarf übersteigt die Kapazitäten von wiederverwertbarem Material.

Aluminium wird in Deutschland schon überwiegend durch Recycling von Aluminiumschrott hergestellt. Die Einsparung an CO_2 beträgt dabei fast 95%, evtl. auch mehr je nach Schmelzwerk. Aluminiumschrott kann fast verlustfrei mit 5% der Herstellungsenergie des Primärprozesses aufbereitet werden.

Der Recyclinganteil von Kupfer liegt in Deutschland bei 45%. Beim Einschmelzen kommt es kaum zu Qualitätsverlusten. Die CO_2-Einsparung beträgt dabei etwa 36%.

Bei der Papierherstellung im engeren Sinn werden vergleichsweise wenig CO_2-Emissionen verursacht. Im Sekundärprozess sind die Emissionen relevant, die beim Transport anfallen. Aber auch wenn diese berücksichtigt werden, ergibt sich beim Papierrecycling noch eine Einsparung der Emissionen um 0,09t CO_2 pro hergestellter t Papier. Zudem wird durch die Verwendung von Altpapier auch der Wald geschont, was sich positiv auf seine Bedeutung als CO_2-Speicher auswirkt und übermäßigem Einschlag entgegenwirkt. Dies fand aber in der Untersuchung keine Berücksichtigung. Eine Papierfaser lässt sich allerdings nur 5-7-mal recyceln.

Ähnlich sieht es bei der Verwendung von Holz zur Herstellung von Spanplatten aus. Hier wurde ebenfalls nicht der Schonungseffekt des Waldes berücksichtigt. Aber auch ohne Einbeziehung des CO_2-Speicher-Effektes kommt man bei der Verwertung von Holz im Sekundärprozess auf eine CO_2-Einsparung von 0,77t/t Material.

Polyethylen (PE) und Polyethylenterephtalat (PET) lassen sich auch nicht unendlich wiederverwenden, da eine Abnahme der Molekülketten erfolgt. Doch auch hier liegen die CO_2-Emissionen im Recyclingverfahren deutlich unter denen im Primärprozess und zwar bei PE um 70% und bei PET um 85%. Diese Einsparung ergibt sich auch unter der Berücksichtigung der langen Transportwege nach Südostasien, wo die meisten Materialien recycelt werden.

3 Eignung von Restabfallbehandlungsverfahren für die Anforderungen einer nachhaltigen Abfallwirtschaft

3.1 Abfallbehandlungsverfahren in Deutschland

Für nicht inerte Siedlungsabfälle besteht in Deutschland de facto eine Behandlungspflicht. Restabfälle werden entweder thermisch oder mechanisch-biologisch behandelt. Die Müllverbrennung ist dabei derzeit noch das dominierende Behandlungsverfahren. Gut 80 Gew.-% des Restabfalls werden thermisch und knapp 20 Gew.-% mechanisch-biologisch behandelt (KÜHLE-WEIDEMEIER, 2005).

3.2 Mechanisch-biologische Abfallbehandlung (MBA)

3.2.1 Stand heute

Abbildung 7 zeigt die Stoffstrombilanz der deutschen MBAs (KÜHLE-WEIDEMEIER ET AL., 2007). Die Ausbeute an Materialien, die einer stofflichen Wiederverwertung zugeführt werden, ist nicht sehr hoch. Aus etwa 4,9 Mio. Mg/a Input werden ca. 10 Mio. Mg NE-Metalle und ca. 127 Mg Fe-Metalle ausgeschleust. Der größte Teil des Anlagenoutputs sind heizwertreiche Fraktionen, die einer energetischen Verwertung (Verbrennung) zugeführt werden. Die nächst größere Teilmenge wird deponiert (ca. 1.060.000 Mio. Mg).

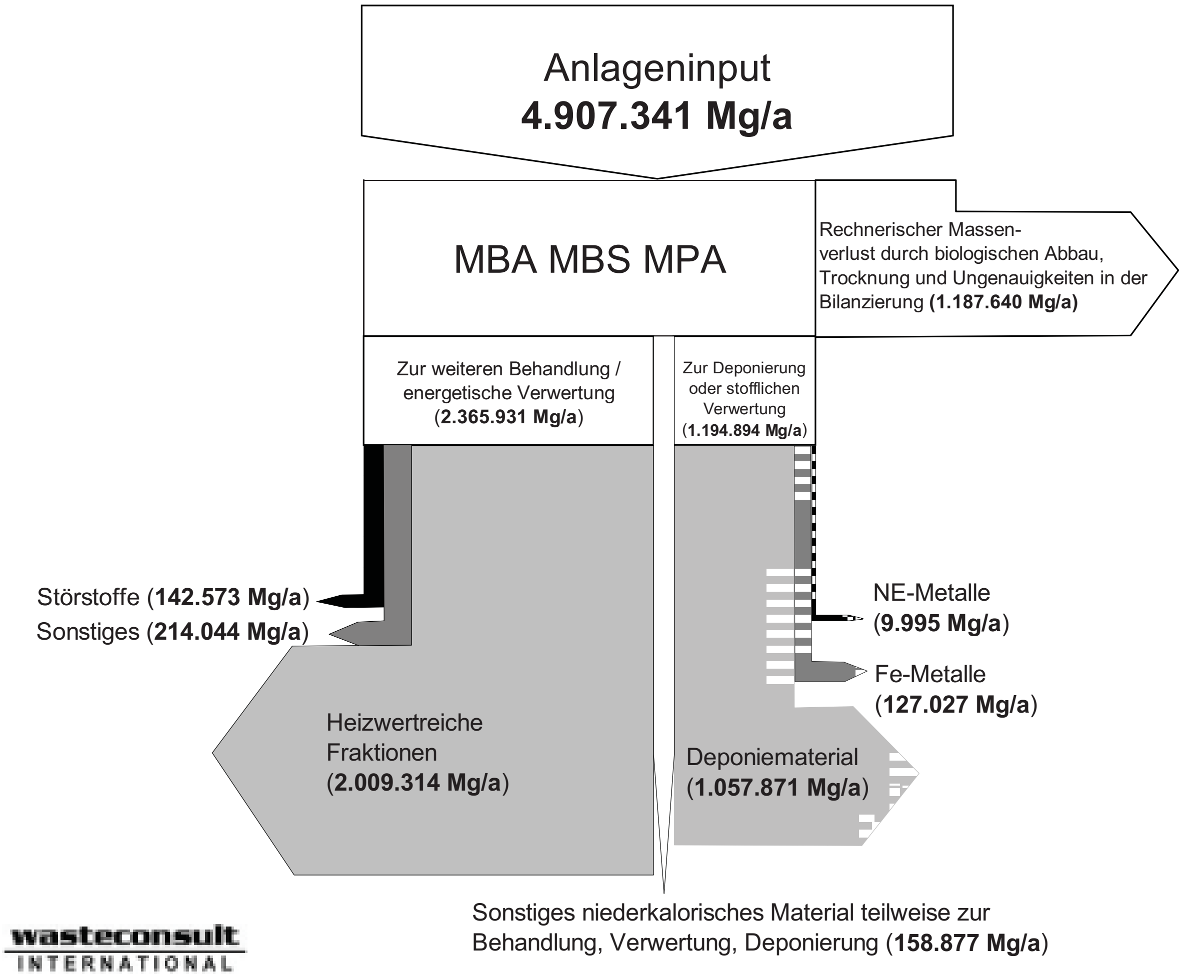

Abbildung 9: Stoffstrombilanz der deutschen MBAs (Kühle-Weidemeier et al., 2007)

3.2.2 Bewertung

Die mechanisch-biologische Abfallbehandlung vor der Deponierung verschwendet zur Zeit noch Energie und Rohstoffe. Eine autarke Energieversorgung oder Energiegewinnung kann nur durch Anlagen erreicht werden, die durch anaerobe Behandlung Biogas produzieren. Die Fraktion, die für eine Deponierung vorgesehen ist, enthält wertvolle Stoffe, die für eine Rückgewinnung in Frage kämen. Auch unter heutigen Voraussetzungen war dies vor dem Preiseinbruch schon wirtschaftlich möglich (z.B. bei Papier und Holz). In der heizwertreichen Fraktion ist ebenfalls ein hoher Anteil an stofflich verwertbaren Bestandteilen vorhanden, wie z.B. Kunststoffe, Papier, Pappe, Karton und Holz.

3.2.3 Verbesserungspotenzial und künftige Bedeutung

Große Fortschritte in der sensorgestützten Sortiertechnik ermöglichen es, künftig aus der MBA einen wesentlich größeren Anteil von stofflich verwertbaren Abfallbestandteilen auszuschleusen. Dies gilt sowohl für die Grob- als auch für die Feinfraktion. Besonders günstige Voraussetzungen für die Abtrennung von Sekundärrohstoffen bieten Anlagen mit nassmechanischer Aufbereitung oder Trockenstabilisierung. Sortiertechniken, die bisher weitgehend nur in Sortieranlagen für Verpackungsabfälle eingesetzt wurden, können auch Einzug in die MBA halten.

Diese Entwicklung wird augenblicklich aber durch mehrere Faktoren gefährdet: In Deutschland besteht trotz Übernahme von Abfallkontingenten aus Italien eine Überkapazität für die Behandlung von Siedlungsabfällen. Dies führt dazu, dass Verbrennungsanlagen zu Niedrigstpreisen Abfälle akquirieren. Verbrennungsanlagen gehören meist großen Energiekonzernen wie z.B. E.ON, die genügend Kapital haben, um solche Situationen durchzustehen und ggf. auch kommunale oder mittelständische private Anlagen durch Preisdruck und Mengenentzug in den Ruin zu treiben. Entlastend wirkt sich allerdings aus, dass MBAs nun auch die heizwertreichen Fraktionen zu deutlich günstigeren Konditionen (geringeren Zuzahlungen) abgeben können.

Der gegenwärtige Preisverfall auf dem Sekundärrohstoffmarkt ist so drastisch, dass die Gewinnung von Sekundärrohstoffen sich häufig nicht mehr lohnt. Insbesondere reine Abfallsortieranlagen (die nicht zu den MBAs gezählt werden) sind in ihrer Existenz stark bedroht. Der Preisverfall ist sicher nur vorübergehender Natur, aber es ist die Frage, ob das Durchhaltevermögen der Anlagenbetreiber oder die Dauer des Preiseinbruchs länger ist. Hier drohen große Nachhaltigkeitspotenziale verloren zu gehen.

Die Konzeption der MBAs als stoffspezifische Abfallbehandlungsanlagen bietet beste Voraussetzungen für die Integration zusätzlicher Trenneinrichtungen zur Gewinnung weiterer stofflich verwertbarer Fraktionen. Neben der Separation von materiell kostbaren Bestandteilen kommt technisch auch die Abtrennung mineralischer Schwerfraktionen in Frage, die dann nicht mehr teuer deponiert werden müssten. Nassmechanische Aufbereitungen ermöglichen auch die Abtrennung einer nativen Organikfraktion.

Die MBA ist somit ein Behandlungskonzept, das die Anforderungen an eine ressourceneffiziente, nachhaltige Kreislaufwirtschaft erfüllt, wenn konsequent an seiner Weiterentwicklung gearbeitet wird. Der Anteil der zu deponierenden Reste wird deutlich zurückgehen.

3.3 Thermische Abfallbehandlung

3.3.1 Klassische Hausmüllverbrennung (MVA)

Die „klassischen" Müllverbrennungsanlagen für unbehandelte Restabfälle sind ein bewährtes, sehr zuverlässiges (Rostfeuerung, ggf. auch Wirbelschicht) und mit geeigneter Rauchgasreinigung auch umweltverträglich einsetzbares Abfallbehandlungsverfahren. Gut 80% des deutschen Restabfalls werden so behandelt.

Die entstehenden Schlacken werden je nach Qualität (Elutionsverhalten) als Baustoff verwertet oder deponiert. Das Langzeitverhalten der Schlacken ist umstritten und die Verwertung von Schlacken im Straßenbau wird je nach Standpunkt auch als Liniendeponie bezeichnet. Ein Teil der Rückstände aus der Rauchgasreinigung ist hoch giftig und wird unter Tage deponiert. Als weitere stofflich verwertbare Fraktion werden in der MVA Eisenmetalle ausgeschleust. Diese liegen dann in stark oxidiertem Zustand vor.

Bei der Müllverbrennung wird als weiteres Produkt auch Energie freigesetzt. Müllverbrennungsanlagen werden daher auch als Waste to Energy Anlagen bezeichnet, was gefälliger klingt als der aus der Vergangenheit belastete Ausdruck Müllverbrennung. Da der Brennstoff der MVA aber zu einem erheblichen Anteil aus Wasser, Sand und Materialien mit geringem Heizwert besteht, ist der Energieertrag eher gering. Zudem verfügen nicht alle Anlagen über eine Wärmenutzung, da nicht überall ein geeigneter Abnehmer für die Abwärme vorhanden ist. Insbesondere in Entwicklungsländern ist der Heizwert des Restabfalls oft so gering, dass keine selbstgängige Verbrennung möglich ist und Öl zugefeuert werden muss. Aus Waste to Energy wird dann Energy to Waste.

3.3.2 Ersatzbrennstoffkraftwerke

Ersatzbrennstoffkraftwerke, die mit aufbereitetem, heizwertreichem Abfall betrieben werden, sind „echte" Kraftwerke, die dem Slogan „Waste to Energy" wirklich gerecht werden. Zudem sind sie meist an Industrieanlagen angegliedert, so dass durch Kraft-Wärme-Kopplung eine optimale Nutzung der Verbrennungsenergie möglich ist.

3.3.3 Bewertung und künftige Bedeutung

In Hinblick auf Ressourcenschonung sind thermische Abfallbehandlungsanlagen Energie und Rohstoffvernichtungsanlagen. Tabelle 1 zeigt am Beispiel von Kunststoffen nochmals die große Differenz zwischen Heizwert und Energieäquivalent, die für die in der thermischen Abfallbehandlung verlorene bzw. ungenutzte Energie steht.

Tabelle 1: Heizwert im Vergleich zum Energieäquivalent als Summe von Energieaufwand zur Herstellung + Heizwert (Reimann 1988)

Stoffart	Heizwert-Bereiche Hu	Energie-Äquivalent*
	kJ/kg	kJ/kg
Polyethylen (PE)	43.000	70.000
Polypropylen (PP)	44.000	73.000
Polystyrol (PS)	40.000	80.000
PVC hart	18.000	53.000

Nichteisenmetalle sind aus der Verbrennungsschlacke praktisch nicht rückgewinnbar und Eisenmetalle erfahren eine Qualitätsminderung.

Im Sinne einer nachhaltigen Ressourcenwirtschaft sind Müllverbrennungsanlagen daher nur für Abfälle geeignet, deren stoffliche Verwertung nicht möglich oder nicht sinnvoll ist. Das traf bisher für einen sehr großen Anteil der Restabfälle zu, so dass die MVA in Deutschland zu Recht eine weite Verbreitung als teure, aber zuverlässige Behandlungstechnik gefunden hat.

Durch viele Innovationen in der Aufbereitungs- und Sortiertechnik hat sich diese Situation aber geändert. Eine Ausschleusung erheblicher Mengen stofflich verwertbarer Abfallbestandteile aus dem bisher in die Verbrennung gehenden Stoffstrom ist technisch möglich, ökologisch sinnvoll und häufig sogar wirtschaftlich profitabel. Nach Überwindung der derzeitigen Absatzkrise für Sekundärrohstoffe wird daher schon aus wirtschaftlichen Gründen ein wachsender Anteil der Abfälle nicht mehr verbrannt, sondern aussortiert und stofflich verwertet werden, sofern dies nicht durch unter den Kosten liegende Dumpingpreise der Verbrennungsanlagenbetreiber verhindert wird.

4 Rückgewinnung von Rohstoffen aus Deponien

Schon lange wird über den Rückbau von Deponien zur Rohstoffgewinnung spekuliert. Ein großes Rückbauprojekt, das aber nicht mit der Zielsetzung der Rohstoffgewinnung erfolgte, ist in der Dissertation von BRAMMER (1997) beschrieben. Einen Deponierückbau mit Aussortierung von Wertstoffen beschreiben VISVANATHAN ET AL., 2007.

Aufgrund bisher mangelnder Wirtschaftlichkeit ist die Rückholung von Rohstoffen aus Deponien abgesehen von Pilotprojekten nicht auf der Tagesordnung. Mittelfristig kann sich dies jedoch ändern, da hier beachtliche Ressourcen lagern:

Tabelle 2: Rohstoffpotenzial in deponierten Abfällen (Daten aus 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 Zusammenfassung und Handlungsempfehlungen

Zur Neige gehende Rohstoffvorkommen, rasante Zunahme der Weltbevölkerung und steigender Wohlstand in vielen Entwicklungsländern erfordern ein konsequent ressourcenorientiertes Handeln auch in der Abfallwirtschaft. Darunter ist eine massive Steigerung des Anteils der ausgeschleusten, stofflich verwertbaren Abfallbestandteile zu verstehen. Dieses dient gleichzeitig auch dem Klimaschutz, da für die Erzeugung von Sekundärrohstoffen wesentlich weniger Energie eingesetzt werden muss als für die Gewinnung von Primärmaterialien und entsprechend weniger CO_2 emittiert wird.

Weiterentwickelte MBAs und sensorgestützte Sortieranlagen sind die Kernbausteine einer nachhaltigen, stoffstromspezifischen Abfallbehandlung, die beim Restabfall erst durch die technischen Fortschritte der letzten Jahre in der mechanischen Aufbereitung und der sensorgestützten Sortierung möglich wird. Die jetzigen MBAs sind der Anfang eines vielversprechenden Weges, der zu echten Stofftrennanlagen führen wird, die nur noch geringe Mengen Deponiegut hinterlassen.

Thermische Abfallbehandlungsanlagen werden dem Anspruch einer ressourcenorientierten Abfallwirtschaft nicht gerecht, da sie Rohstoffe und die für deren Erzeugung aufgewandte Energie vernichten. Mit zunehmenden Möglichkeiten zur Ausschleusung von

Sekundärrohstoffen wird die thermische Behandlung daher an Bedeutung verlieren. Staaten, die erst beginnen, ihr Abfallbehandlungssystem aufzubauen, sollten diese Entwicklung einplanen um teure Überkapazitäten zu vermeiden.

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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.

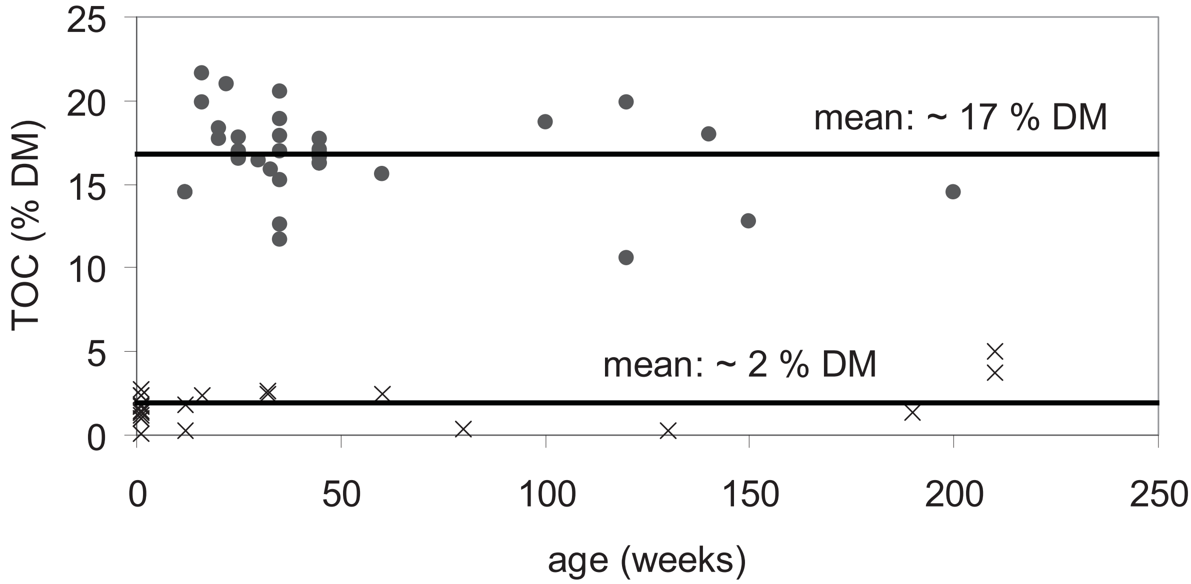

Figure 1: The TOC values of material from landfilled MBT material (●) and slag from MSWI bottom ash (×)

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.

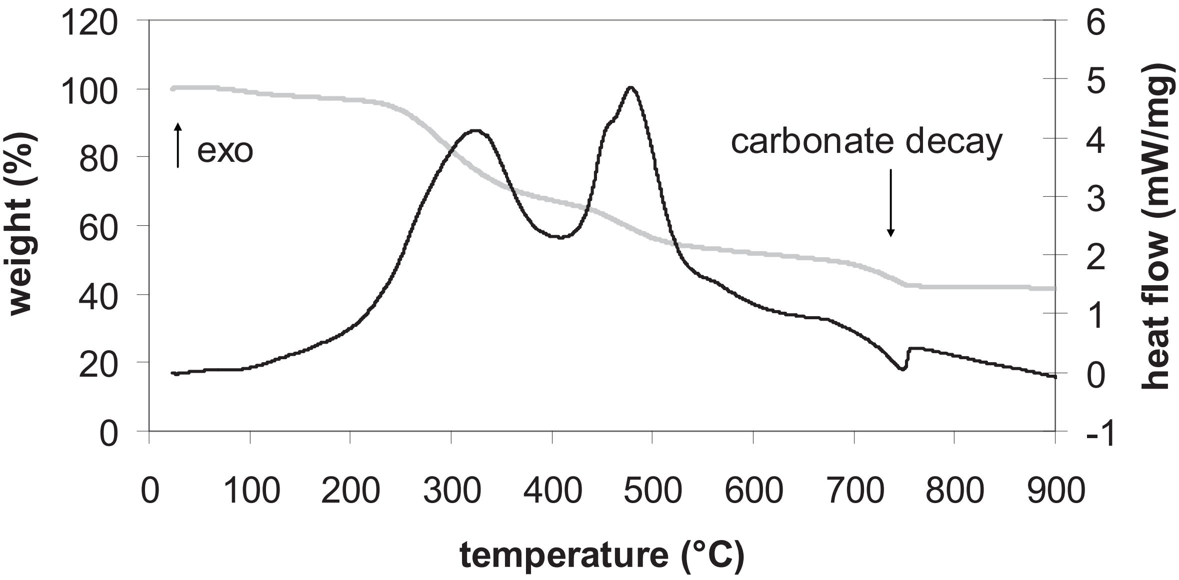

Figure 2: Weight loss and heat flow curve of MSW indicating the decay of carbonates by the weight loss and the endothermic reaction

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.

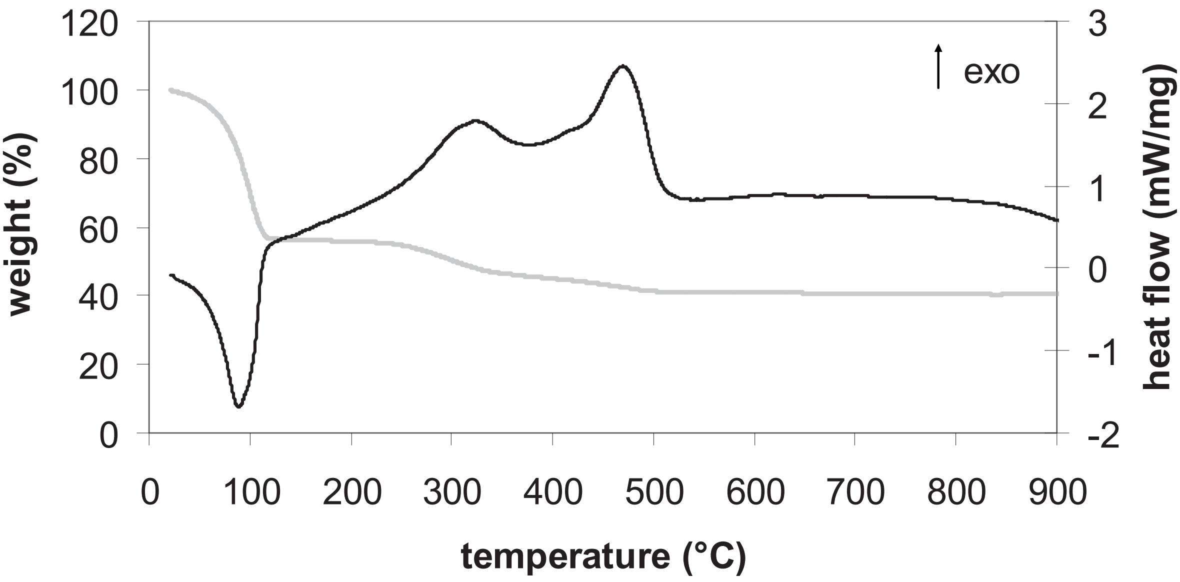

Figure 3: The mass loss and the heat flow (enthalpy) of biogenic waste with an original water content

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

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Bewertung der Systemkosten für den Einsatz von Kunststoffen unter Einbeziehung der Kosten für Entsorgung

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

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.

Inhaltsangabe

Der Beitrag bewertet die realen Systemkosten der Kunststoffproduktion und Entsorgung. Die Entsorgungskosten für Kunststoffe fließen bislang jedoch nur teilweise in die Konsumentenpreise ein, so dass ein erheblicher Wettbewerbsnachteil für nachwachsende Rohstoffe entsteht, obwohl diese erheblich geringere Produktionsenergie verbrauchen und geringere Entsorgungskosten verursachen. Kunststoffabfall ist kein Wertstoff und sollte als Abfall zur Beseitigung betrachtet werden.

Keywords

Kunststoffe, Verwertung, Entsorgung, Systemkosten, Antimon, Plastics, Recycling, Disposal, System costs, Antimony

1 Einleitung

Kunststoffe sind zunehmend Teil unserer Alltagswelt. Jeder, der sich in irgendeiner Form mit Abfall beschäftigt, begegnet ihnen allerdings noch ein zweites Mal - am Ende ihrer Nutzungsdauer als Bestandteil des Abfalls. Anlass für den vorliegenden Beitrag waren mehrere Beobachtungen über Kunststoffe, die wir im Rahmen unserer Tätigkeit machen konnten.

Die Firma EcoEnergy betreibt seit 2005 die Demonstrationsanlage für das SCHUBIO®-Verfahren zur nassmechanischen Trennung von Abfällen. Im Verfahren werden biogene, nativ organische Bestandteile von den organischen Bestandteilen aus fossilem Kohlenstoff, den Kunststoffen, getrennt. Die Analysenergebnisse dieser Fraktionen zeigen in allen Versuchen eine Schadstoffabreicherung in den nativ organischen Fraktionen gegenüber einer Schadstoffanreicherung in den kunststoffhaltigen Fraktionen.

Ein zweiter Hinweis aus der Praxis für eine Schadstoffbelastung von Kunststoffen zeigte sich bei einer Analyse der für eine Mitverbrennung bis 25 % der Feuerungswärmeleistung in einem Kohlekraftwerk vorgesehenen Ersatzbrennstoffe. Bei der Aufstellung der Kriterien für die Mitverbrennung wurden neben den Emissionen auch die Qualitäten von REA-Gips und Flugasche berücksichtigt. Im Ergebnis konnten nur Stoffgemische, die kaum Kunststoffe enthielten, die Kriterien einhalten.

Diese Ergebnisse gaben den Anstoß für eine genauere Betrachtung der Systemkosten für den Einsatz von Kunststoffen unter Berücksichtigung der Kosten für die Entsorgung.

2 Herstellung von Kunststoff

Rohstoff für die Kunststoffproduktion ist Rohbenzin (Naphtha). Naphtha entsteht als Nebenprodukt bei der Rohöldestillation.

Noch bis in die 50er Jahre wurde das Rohbenzin direkt als Kraftstoff verwendet. Mit der erhöhten Kompression der Verbrennungsmotoren wurde die Entwicklung klopffesterer Kraftstoffe mit höherer Oktanzahl notwendig. Naphtha wurde so zu einem Nebenprodukt der Kraftstoffherstellung.

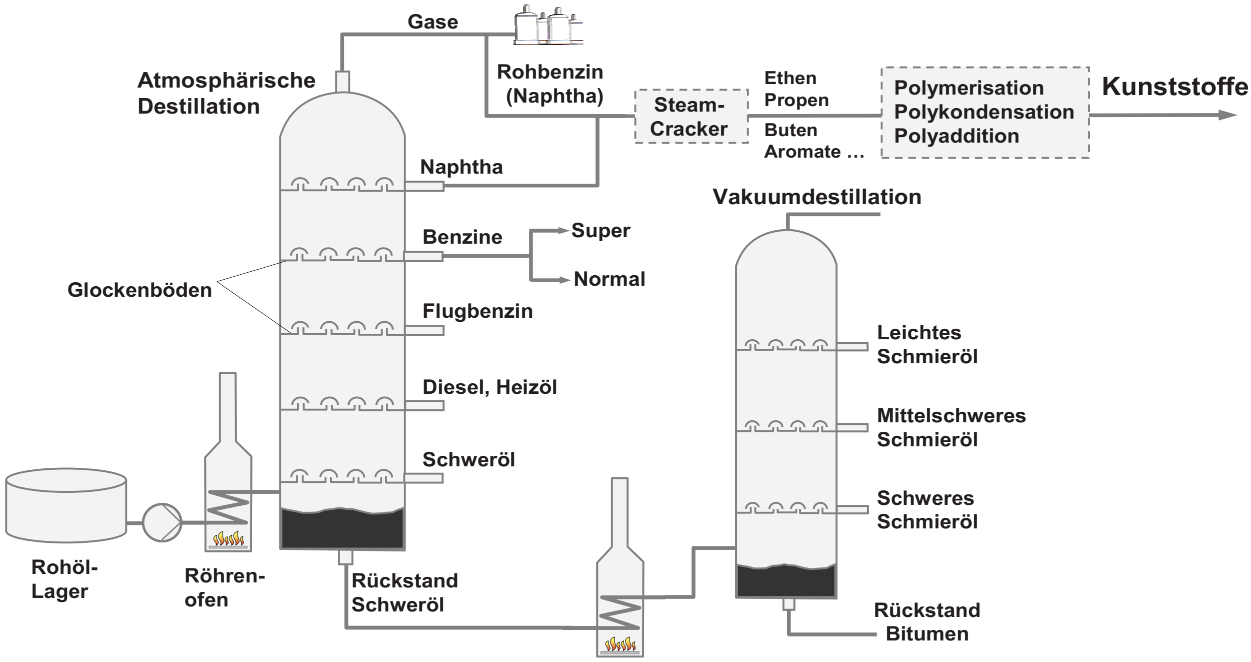

Abbildung 1: Destillation von Rohöl und Produktion von Kunststoff

In modernen Raffinerien fällt etwa 9 % Naphtha bei der Erdölraffination an. Wird jedoch mehr Benzin und Diesel und weniger Schweröl produziert, entstehen ca. 12 % Naphtha. In Deutschland werden ca. 120 Mio. t Rohöl verbraucht und 20 Mio. t Kunststoffe produziert. Zusätzlich benötigtes Naphtha wird aus Rotterdam über eine Produktpipeline nach Deutschland importiert. Aus dem Naphtha werden über einen Steamcracker die Zielprodukte zur Kunststoffherstellung, vor allem Ethen, gewonnen (siehe Abbildung 2).

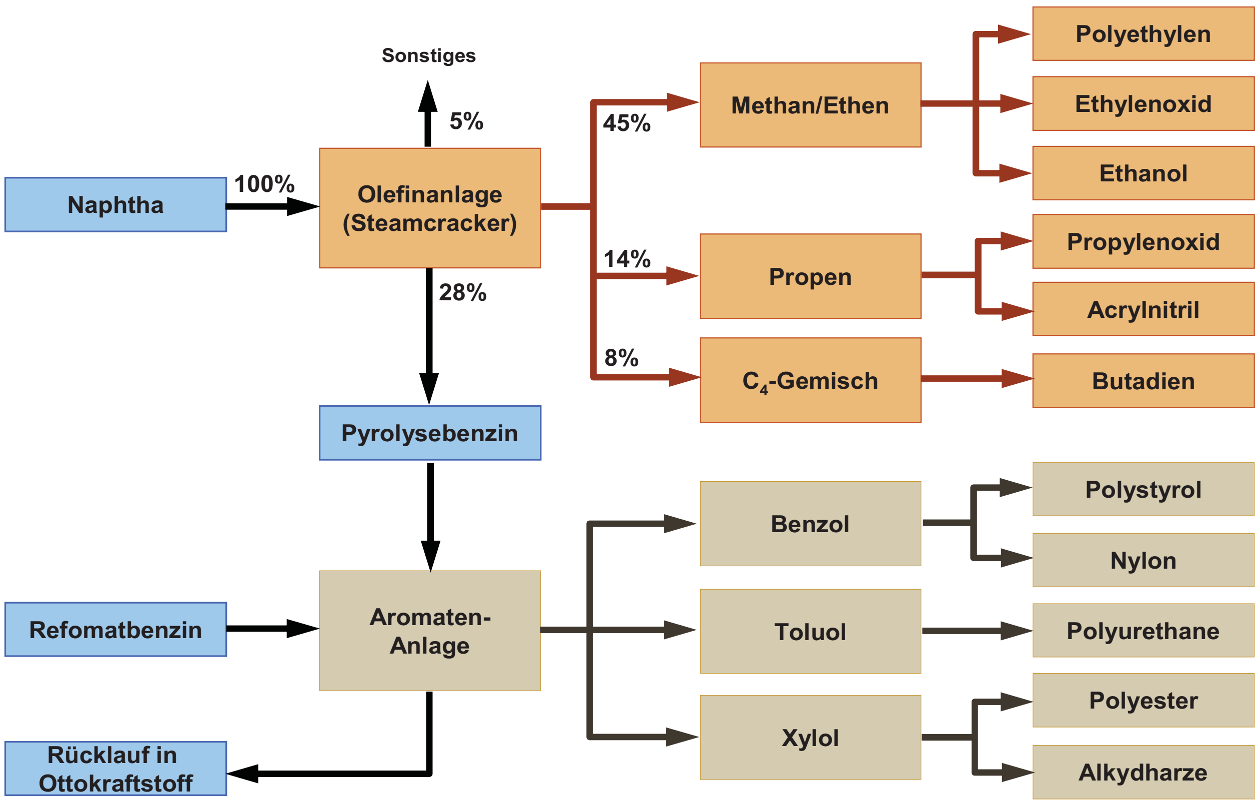

Abbildung 2: Produkte eines Naphtha-Steamcrackers

Die Verteilung der einzelnen Fraktionen ist abhängig von den Eigenschaften des Rohöls. Die Ausgangsstoffe für die Kunststoffproduktion werden also nicht in Abhängigkeit vom Kunststoffbedarf (Consumer-Markt), sondern in Abhängigkeit von der Rohölqualität und den technischen Möglichkeiten der Raffination erzeugt.

Der Betrieb der Raffinerie ist dementsprechend nur möglich, wenn auch das entstehende Naphtha zu Kunststoffen weiterverarbeitet wird. Aktuell, im März 2009, wurde aufgrund mangelnder Nachfrage nach Kunststoffen der Steamcracker der BASF in Ludwigshafen abgestellt. In den USA sind zwar die Lager für Rohöl gefüllt, für Benzin gehen die gelagerten Mengen jedoch zurück, da die Abnahme der Kunststoffe eingebrochen ist. Die Nachfrage nach Kunststoffen ist je nach Sorte zwischen 20 % und 70 % zurückgegangen. Entscheidend für den Betrieb einer Raffinerie ist die Logistik der entstehenden Nebenprodukte, die wie z. B. Naphtha in erheblichem Umfang anfallen. Für das Produkt Benzol zum Beispiel können schon aufgrund der Bestimmungen der Störfallverordnung nicht kurzfristig Lagerkapazitäten geschaffen werden. Mangelnde Nachfrage führt dann zum Abschalten der Raffinerie. Die Produktion von Polystyrol, dessen Rohstoff Benzol ist, kann daher nicht unterbrochen werden. Um die Abnahme zu sichern, werden die Preise für Kunststoffe so angepasst, dass sie billiger sind als die entsprechenden natürlichen Rohstoffe.

Ein weiteres Beispiel ist das in der Abfallwirtschaft viel diskutierte PVC. PVC besteht zu 57 % aus Chlor, zur Produktion wird HCl eingesetzt. In der chemischen Industrie be-stand früher aus der Kochsalzelektrolyse ein Überschuss an HCl, da NaOH in der Produktion gebraucht wurde. Mit der Produktion von PVC wurden sowohl HCl als auch Naphtha beseitigt, sie bot daher einen Ausweg aus einem Entsorgungsproblem. Aufgrund der angekurbelten Nachfrage und Akzeptanz für PVC hat sich heute diese Situation umgekehrt.

3 Kosten der Rohkunststoffproduktion

In vielen Raffinerien wird Naphtha immer noch abgefackelt. Zur Kunststoffproduktion wird Naphtha über einen Steamcracker in diverse kurzkettige Kohlenwasserstoffe aufgespaltet.

Wegen seiner heterogenen Zusammensetzung ist Naphtha nicht einfach zu verbrennen. Gasturbinen zur energetischen Verwertung von Naphtha müssen über externe Brennkammern verfügen sowie speziell explosionsgeschützt ausgeführt sein. Zudem haben sie geringe Standzeiten und müssen nach 3 bis 5 Jahren erneuert werden. Wegen der leichten Entzündlichkeit stellt der Transport auch zudem eine logistische Herausforderung dar, daher sind Kunststoffproduktion und Raffinerien häufig in räumlicher Nähe installiert.

Tabelle 1: Aktuelle Brennstoffkosten im Vergleich zu Naphtha

Brennstoff	Bezugskosten übliche Einheit	Energieinhalt	energiebezogene Bezugskosten
Naphtha	332,00 €/t	43,50 MJ/kg	27,48 €/MWh
Rohöl	49,60 US$/bbl	42,80 MJ/kg	22,26 €/MWh
Heizöl S Kraftwerke	167,00 €/t SKE	41,80 MJ/kg	20,50 €/MWh
Heizöl L Industrie	303,00 €/t SKE	41,80 MJ/kg	37,20 €/MWh
Erdgas Industrie	22,33 €/MWh	-	22,33 €/MWh
Erdgas Kraftwerke	21,84 €/MWh	-	21,84 €/MWh
Steinkohle	112,50 €/t	29,32 MJ/kg	13,81 €/MWh
Braunkohlenstaub	112,00 €/t SKE	21,00 MJ/kg	13,75 €/MWh
Altholz	-1,00 €/t	15,00 MJ/kg	-0,24 €/MWh
Holz, trocken, gehäckselt	30,00 €/fm	15,00 MJ/kg	11,08 €/MWh
Stroh, trocken	60,00 €/t	17,00 MJ/kg	14,95 €/MWh
Getreideganzpflanze	90,00 €/t	17,00 MJ/kg	22,42 €/MWh
Getreide	120,00 €/t	17,00 MJ/kg	29,90 €/MWh
Pflanzenöl	500 €/m³	37,00 MJ/kg	52,88 €/MWh
Biogas aus Maissilage (Bezug: Biogasausbeute)	22,00 €/t	-	23,20 €/MWh

Eine Verarbeitung von Naphtha zu Kunststoffen ist gegenüber der energetischen Nutzung daher lukrativer. Die Preise für Naphtha lagen in den letzten Jahren zwischen 150 €/t und 400 €/t. Die Tabelle 2 zeigt zum Vergleich die Kosten verschiedener Brennstoffe.

Der Brennstoff Naphtha rangiert im Vergleich zu Benzin, Diesel und Heizöl L auf einem niedrigeren Preisniveau. Die Verarbeitung von Naphtha zu den Grundstoffen für die Kunststoffproduktion erfordert nochmals ca. die gleiche Energie wie der Energiegehalt des Naphthas selbst.

Tabelle 2: Produktionsenergie als kumulierter Energieaufwand (KEA) im Vergleich zu Beschaffungs- und Entsorgungskosten von Kunststoffen und anderen Materialien

Material	**KEA MJ/kg**	**Beschaffungskosten**		**Heizwert MJ/kg**
		€/t	**€/MWh KEA**	
Naphtha (Rohbenzin)	55	332	21,7	43,5
LDPE Folie	91,8	800	31,4	46
HDPE Folie	99,8	800	28,9	46
PP Spritzguss	118,8	850	25,7	44
PVC Folie	66,3	820	44,6	20
PS (high impact)	91,8	860	33,7	46
PET Flasche	101,4	1060	37,6	46
PET Folie	109,2	1020	33,6	46
Stahl	35,8	247	24,8	0
Aluminium	193,3	1450	27,0	0
Weißglas	12,7	140	39,6	0
Wellpappe, Karton	19,8	160	29,1	15
Papier (grafische etc.)	44,8	500	40,2	17
Holzspäne f. Pressplatten	17,0	55	11,6	16
Stammholz, frisch	14,0	150	38,6	10
Stammholz, getrocknet	19,0	220	41,7	15

In Deutschland werden jährlich ca. 20 Mio. t Kunststoffe produziert. Würden diese 20 Mio. t nicht produziert, ergäbe sich bei einer durchschnittlichen Produktionsenergie von 90 MJ/kg Kunststoff eine Gesamtbrennstoffleistung von ca. 62 Gigawatt. Übersetzt in elektrische Grundleistung bei 50 % el. Wirkungsgrad, entspräche dies einem Grundlastkraftwerk mit 30 Gigawatt elektrischer Leistung. Die installierte Leistung aller Kernkraftwerke in Deutschland beträgt heute 21,5 Gigawatt. Die gesamte durchschnittliche Jahresleistung in Deutschland beträgt 80 Gigawatt. Würden diese Kunststoffe in MVA verbrannt, ergäbe dies nur eine Feuerungswärmeleistung mit der Grundlast 29,5 GW und einer elektrischen Leistung bei 24 % el. Wirkungsgrad von 7 GW. Die energetische Verwertung von Kunststoffen kann nur ein Viertel der zur Kunststoffherstellung eingesetzten Energie (KEA) als Stromäquivalent zurückgewinnen.

4 Verdrängung von nachwachsenden Rohstoffen durch Kunststoff

Bei der Raffination von Rohöl fallen die Fraktionen Naphtha, Benzin, Diesel/Heizöl, Schweröl, Bitumen und Petrolkoks in einem gewissen Verhältnis an, zu dem auch der Absatz der Produkte erfolgen muss. Das folgende Beispiel zeigt, wie hier auch die Politik massiv eingreift, um den Absatz zu gewährleisten. Unter anderem wegen der hohen Mineralölsteuern gibt es in Deutschland seit längerer Zeit den Trend von der Ölheizung hin zur Gasheizung, sowohl in Privathaushalten als auch in der Industrie. Dies führte zu einem Überangebot von Diesel auf dem Markt. Über eine entsprechende Steuerpolitik wurde der Diesel verbilligt. Heute ist Deutschland eines der Länder mit dem höchsten anteiligen Dieselabsatz.

Seit den 50er Jahren des vorigen Jahrhunderts werden auf Kunststoffe keine Mineralölsteuern oder andere Abgaben erhoben. Auch Kunststoffe, die zur energetischen Verwertung in Kohle- oder Zementwerken, zur Reduktion in Stahlwerken oder zur Methanolproduktion in der Schwarzen Pumpe eingesetzt werden oder wurden, unterliegen nicht der Mineralölsteuer. Auf alle anderen Mineralölprodukte, die zur Produktion von Energie verwendet werden, wird Mineralölsteuer erhoben.

Der stoffliche Einsatz nachwachsender Rohstoffe, wie zum Beispiel Baumwolle, wird in keiner Weise gefördert. Es bilden sich daher bereits Initiativen von Textilanbietern wie IKEA, Otto, C&A und H&M, um Baumwollbauern in Afrika zu unterstützen, da deren Existenz durch die Konkurrenz billiger synthetischer Textilien, die unter anderem aus PET-Recyclingmaterial hergestellt werden, massiv bedroht ist.

Auch das EEG, das die energetische Nutzung von Frischholz als nachwachsenden Rohstoff zur energetischen Nutzung fördert, trägt dadurch zu steigenden Holzpreisen bei. Eine Förderung von stofflich genutztem Holz erfolgte nicht, so dass auch hier die Kunststoffindustrie gute Möglichkeiten hat, den Werkstoff Holz in vielen Applikationen zu ersetzen. So gibt es zum Beispiel Produkte aus dickwandigem Kunststoff wie Gartenpalisaden, Gartenbänke oder Terrassenbohlen, die Holz ersetzen.

Natürliche Faserdämmstoffe verbrauchen bei gleicher Dämmleistung nur ca. ein Zehntel der Produktionsenergie von kunststoffbasierten Dämmstoffen. Dennoch können sich diese Dämmstoffe preislich nicht gegenüber Dämm-Materialien aus PUR und Polystyrol durchsetzen. Dämmung wird heute unabhängig von der Produktionsenergie des eingesetzten Dämmstoffs staatlich gefördert.

Aufgrund der hohen Produktionsenergie, gekoppelt mit hohen Entsorgungskosten, ist die Dämmung mit Kunststoffen unter ökologischen und volkswirtschaftlichen Gesichtspunkten kritisch zu betrachten. Hier ist die Politik zum Handeln aufgefordert.

5 Entsorgung von Kunststoffabfällen

Der Kunststoffanteil in den Abfällen wird heute meist als Wertstoff angesehen. Dennoch werden heute ca. 50 % der Kunststoffe thermisch beseitigt. Selbst die Verwertung von gemischten Gewerbeabfällen ist zweifelhaft. Die separate Sammlung von Kunststoffen aus Haushaltungen zur Verwertung steht weiter in der allgemeinen Kritik.

5.1 Energetische Verwertung von Kunststoffabfällen

Reine Produktionsabfälle aus Polyethylen und Polypropylen mit geringen Schadstoffgehalten können bei entsprechender Qualitätskontrolle in Kohlekraftwerken und Zementwerken energetisch verwertet werden. Kritische Inhaltstoffe von Kunststoffen allgemein sind Chlor, Brom und vor allem die Schwermetalle Quecksilber, Blei, Cadmium und Antimon. Neben dem Emissionsschutz sind auch die erhöhten Belastungen der Produkte Zement oder der zu verwertenden Reststoffe aus dem Kohlekraftwerk zu beachten.

5.1.1 Cadmiumbelastung

Cadmium ist ein bei der Zinkverhüttung anfallendes Abfallprodukt und wurde früher als Farbpigment in Kunststoffen allgemein und vor allem als Stabilisator in PVC eingesetzt. Nach unserer Betrachtung der Schadstoffverteilung eines Steinkohlekraftwerkes bei einer Mitverbrennungsrate von Abfällen von 25 % der Feuerungswärmeleistung müssen Cadmiumkonzentrationen von < 0,4 mg/kg eingehalten werden, um die Grenzwerte der REA-Gips Verwertung einhalten zu können. Biogene Abfälle ohne Kunststoffe können diese Grenzwerte einhalten. Der Grenzwert der Bundesgütegemeinschaft Sekundärbrennstoffe e.V. für Cadmium von 4 mg/kg ist auf geringere Mitverbrennungsraten berechnet. Kunststoffhaltige Abfälle können die neuen schärferen Grenzwerte kaum einhalten.

Nach der EU-Richtlinie 76/769/EWG gilt für Kunststoffe ein Grenzwert für Cadmium von 100 mg/kg. Über die Hälfte des Kunststoffbedarfs in Deutschland wird importiert, obwohl wir, bezogen auf die Import-Exportbilanz, insgesamt ein Kunststoffexporteur sind. Eine Überwachung der Cadmiumbelastung der importierten Kunststoffe ist fast unmöglich. Die Cadmiumkonzentration kann bei einigen Kunststoffen bei über 200 mg/kg liegen.

5.1.2 Antimonbelastung

Antimon ist als Korrosionskatalysator bei der energetischen Verwertung bisher unbekannt und wurde bisher auch nicht untersucht. Die Antimonkonzentrationen in Kunstoffen sind um den Faktor 1.000 bis 2.000 höher als in der Kohle. In Naturprodukten ist

Antimon in einer Konzentration von < 0,01 mg/kg vorhanden, in PET sind 300 mg/kg und in Polyester 150 mg/kg produktionsbedingt enthalten. Antimonhaltige Flammschutzmittel werden aufgrund gestiegenen Brandschutzes bei Kunststoffen im Elektroniksektor, Automobilbau und in der Bauindustrie allgemein eingesetzt. In der Rückwand eines Fernsehers wurden Antimongehalte von 4.400 mg/kg gemessen.

Seit 2006 ist die Migration von giftigem Antimon in das Getränk bei PET-Flaschen nachgewiesen worden. Auch warnen Ärzte vor der Verwendung von PET-Textilien, die u. a. aus PET-Recyclat produziert werden, da durch den Schweiß Antimon in die Haut übergehen kann und zu Hautreizungen und Neurodermitis führen kann. In Japan wurde versucht, Antimon bei der PET-Herstellung durch teures Titan und Phosphat zu ersetzen. Aufgrund der Gelbfärbung bei diesem Prozess wurde wieder auf Antimonverbindungen zurückgegriffen. Zurzeit gibt es dafür keinen Lösungsansatz.

Der Antimongrenzwert für die energetische Verwertung von Abfällen in der Zementindustrie beträgt in der Schweiz 5 mg/kg. Die Grenzwerte für „Kunststoffabfälle" zur energetischen Verwertung in der Zementindustrie wurden auf 300 mg/kg und speziell für PET-Abfälle auf 800 mg/kg heraufgesetzt. In Deutschland wurde aufgrund der erhöhten Antimonkonzentration in den Kunststoffabfällen der Antimongrenzwert auf 50 mg/kg von der Bundesgütegemeinschaft Sekundärbrennstoffe e.V., Deutschland, für Abfälle heraufgesetzt. Eine Langzeitbetrachtung bzgl. der Herauslösung von Antimon im Altbeton bei der Verwendung von antimonbelastetem Zement ist bisher nicht erfolgt. Verbindliche Erklärungen bzgl. einer Einschränkung des Antimoneinsatzes in Kunststoffen stehen noch aus. Ein Ersatz für die Funktion von Antimon sowohl als Stabilisator bei PET und Polyester oder Synergist bei bromierten Kunststoffen ist technisch noch nicht gefunden.

5.1.3 Bleibelastung

Blei wird als Stabilisator bei der PVC-Produktion und als Farbstoff verwendet. PVC, das heute in den Abfall gelangt, enthält ca. 2.000 mg/kg Blei, der Grenzwert für die Mitverbrennung liegt bei 70 mg/kg. Laut einer Selbstverpflichtungserklärung der PVC-Hersteller (Vinyl 2010) soll ab 2015 der Bleieinsatz im PVC beschränkt werden.

5.1.4 Quecksilberbelastung

Für die PVC-Herstellung wird Salzsäure verwendet. Noch heute wird zwei Drittel der Salzsäure mit Chloralkali-Elektrolyse mit dem Amalgamverfahren hergestellt. Bei diesem Verfahren ist es unvermeidbar, dass die Salzsäure mit Quecksilber in Kontakt kommt und das Quecksilber in das PVC eingebunden wird. 1973 wurden 58 mg Quecksilber pro kg Chlor verbraucht. PVC-Produkte haben eine Nutzungsdauer von 2 bis 50 Jahren. Die Grenzwerte für die Mitverbrennung liegen bei 0,6 mg/kg.

5.1.5 Chlorbelastung

Die Chlorfracht im kunststoffbelasteten Abfall stammt mittlerweile zu 60 % bis 95 % aus Kunststoffen. Bekanntestes Beispiel ist Roh-PVC mit 57 % Chloranteil, in den Produkten sind nur zwischen 30 % und 80 % Roh-PVC, teilweise als Verbundwerkstoffe, so dass nur 12 % bis 30 % Chloranteil in den PVC-basierten Kunststoffen enthalten ist. Dies erschwert die Aufreinigung durch automatische Sortiersysteme sehr, zudem ist der Ausschuss weder als PVC verwertbar noch ist die Akzeptanz der MVA-Betreiber gegeben, diese PVC-Gemische mit > 10 % Chloranteilen zu verbrennen. Chlor wird neben PVC auch in vielen anderen Kunststoffen als Flammhemmer eingesetzt.

Die energetische Verwertung von kunststoffbelastetem Abfall in entsprechend ausgelegten Abfallverbrennungsanlagen (EBS-Kraftwerke) mit Kraft-Wärme-Kopplung ist für fast alle Kunststoffabfälle möglich. Grundsätzlich ist jedoch die thermische Behandlung in MVA eine Beseitigung. Die Abgrenzung der Verwertung und Beseitigung in MVA ist durch das KrW-/AbfG festgelegt. Chlor trägt im Zusammenspiel mit den Chloridbildnern Schwermetalle und Alkalien maßgeblich zur Hochtemperaturkorrosion im Kessel bei. Viele EBS-Kraftwerke wurden für einen maximalen Chlorgehalt von ca. 1 % genehmigt. Nicht alle Abgasreinigungstechniken der heute betriebenen MVA oder EBS-Kraftwerke erlauben einen Chlorgehalt > 2,5 %. Neben den durch Kesselkorrosion verursachten Kosten, wie z.B. erhöhter Wartungsaufwand, geringere Verfügbarkeit und Reisezeit der Entsorgungsanlage, werden durch Chlor auch ein erhöhter Betriebsmittelverbrauch zur Chloreinbindung und erhöhte Kosten für die Entsorgung der Reaktionsprodukte aus der Chlorabscheidung verursacht.

Insgesamt entstehen allein durch die Chlorfracht ca. 400 bis 700 €/t PVC Mehrkosten, die Grundkosten der Abfallverbrennung sind noch nicht eingerechnet. Diese Mehrkosten sind in Preisgleitformeln der Ersatzbrennstoffanlagenbetreiber für die Annahme von Ersatzbrennstoffen hinterlegt. Es ist ersichtlich, dass das Vorhandensein von PVC in einem Abfallgemenge zur energetischen Verwertung nicht den Rückschluss zulässt, dass PVC energetisch in diesen Anlagen verwertet werden kann.

5.2 Rohstoffliche Verwertung

Die rohstoffliche Verwertung spielt in Deutschland keine Rolle mehr, nachdem 1999 die Kohleölanlage in Bottrop geschlossen wurde, die Vergasungsanlage zur Methanolsynthese SVZ 2005 den Betrieb eingestellt hat und die Stahlwerke die Annahme von DSD-Kunststoffen 2005 aufgegeben haben. Bei der Stahlproduktion spielt der Antimongehalt ebenfalls eine wesentliche Rolle. Antimon hat die Tendenz zur Korngrenzensegregation und - in wesentlich stärkerem Maß - zur Oberflächensegregation in Stählen und Eisenbasislegierungen. Dies führt zur Versprödung des Stahls und erhöhter Korrosionsneigung. In kommerziellen Stählen sind ca. 10 mg/kg Antimon enthalten. Wegen der zunehmenden Verwendung von Schrott minderer Qualität aus z. B. Automobilrecycling, Elektronikschrott und Eisenschrott von MVA-Schlacken ist damit zu rechnen, dass der Antimongehalt von Stählen in der Zukunft weiter ansteigen wird. Mit einer Renaissance der Kunststoffverwertung in der Stahlindustrie ist nicht zu rechnen.

5.3 Werkstoffliche Verwertung

Die werkstoffliche Verwertung von kunststoffhaltigen Abfällen wird hier genauer betrachtet. Ein Recycling von Kunststoffen impliziert, dass das gleiche Produkt wieder aus den Regranulaten produziert werden kann. Das ist leider bis heute so nicht möglich.
Betrachtet man allein die Verdampfungsrate von Weichmachern bei Kunststoffen unterschiedlichen Alters oder auch die unterschiedliche Additivzugabe je nach Anwendungsbereich des Kunststoffes, wird dieser Zusammenhang deutlich. Post-Consumer Kunststoffe sind daher auch nach einer sortenreinen Trennung nicht recyclingfähig, sondern nur zum Downcycling geeignet.

Auch der Begriff „Bottle-to-Bottle“ beim PET-Flaschenrecycling bedeutet nur, dass ca. 15 % des Recycling-PET dem Roh-PET zur Produktion neuer Flaschen zugemischt werden kann. Die Zumischung von Regranulaten aus Produktionsabfällen zu Neuware ist der heute höchste Grad der werkstofflichen Verwertung. Aus Post-Consumer-Abfällen ist dies mit vertretbarem Aufwand und Zumischraten > 10 % zu Werkstoffen mit gehobenen Qualitätsansprüchen nicht möglich.

Werkstoffliche Verwertung bedeutet in der Regel die Produktion von dickwandigen Produkten, die dann spätestens nach dieser Nutzung endgültig thermisch beseitigt werden müssen. Diese Form der Verschiebung des Zeitpunktes der thermischen Beseitigung steht ökologisch und ökonomisch natürlich über einer Deponierung. Es bestehen heute auch in Deutschland nicht die MVA-Kapazitäten, um alle anfallenden Kunststoffe zu entsorgen. In Deutschland wurden 2007 ca. 15 Mio. t Kunststoffe verbraucht. Normiert auf die mittleren Heizwerte in MVA entspricht dies 60 Mio. t/a MVA-Kapazität. Wir haben aber heute nur < 20 Mio. t/a MVA-Kapazität. Die MVA-Kapazitäten können nicht in dem Maß erweitert werden, wie dies nach den Kunststoffproduktionszahlen der letzten Jahre und der mittleren Nutzungsdauer dieser Kunststoffe erforderlich wäre.

5.4 Gesellschaftsdeponie

Werden schadstoffbelastete Kunststoffe z.B. als Gartenpalisaden, Gartenbänke oder schwere Fahrradständer in der Gesellschaft vor der endgültigen Beseitigung zwischengelagert, bezeichnen wir dies als Gesellschaffdeponierung. Die Gesellschaftsdeponie sichert den Kunststoffabfall für eine spätere geregelte Entsorgung.

5.5 Thermische Beseitigung in MVA

Der anerkannte Königsweg für die Entsorgung von kunststoffbelasteten Abfällen ist die MVA. Kunststoffe tragen mit 50 % bis 80 % zu den Kosten der MVA bei. Zwar sind die Kunststoffe nur zu 15 % bis 40 % im Abfall enthalten, aufgrund des hohen Heizwertes tragen diese Abfälle aber zu 50 % bis 90 % zur Feuerungswärmeleistung der Abfallverbrennung bei. Die Kosten der Abfallverbrennung sind im Wesentlichen von dem Volumen der angelieferten Abfälle, das die Logistik und die Kosten für Bunkerung und Beschickung der Verbrennung bestimmt, von der Feuerungswärmeleitung und von dem Schadstoffinventar abhängig. Die Massendurchsatzleistung spielt bei den Kosten der Abfallverbrennung eine untergeordnete Rolle. Eine Tonne kunststoffhaltiger Gewerbeabfall mit 16.000 kJ/kg verdrängt zwei Tonnen Hausmüll mit 8.000 kJ/kg. Der Betreiber der MVA hat bei Einsatz dieses kunststoffhaltigen Gewerbeabfalls nur die Hälfte der Einnahmen gegenüber der Hausmüllverbrennung. In Deutschland betrugen die mittleren Kosten der Abfallverbrennung in den letzten 3 Jahren ca. 150 €/t bezogen auf einen mittleren Heizwert von 10.000 kJ/kg. Kunststoffe mit ca. 40.000 kJ/kg verdrängen 4 t Abfall mit 10.000 kJ/kg. Kunststoffe müssten theoretisch 600 €/t kosten, wenn diese als Monoabfälle verbrennbar wären, abzüglich der geringeren Kosten für die Schlackeverwertung. Heute gibt es jedoch noch keine MVA, die dauerhaft Heizwerte von 16 MJ/kg zulässt, Ausnahme ist z. B. die zirkulierende Wirbelschicht-Verbrennung (ZWS).

5.6 Deponierung

Kunststoffabfälle aus der Altautoaufbereitung und Restkunststoffe aus deponiertem MBA-Rottematerial werden auch in Deutschland noch offiziell deponiert. Im Ausland, mit Ausnahme weniger Staaten, ist die Kunststoffdeponierung immer noch der Hauptentsorgungsweg.

5.7 Export zur Scheinverwertung

Kunststoffabfälle werden offiziell zum größten Teil im Ausland werkstofflich verwertet. Erstmals wurde 2008 vom Bundeskriminalamt ein Bericht „Abfallwirtschaftskriminalität im Zusammenhang mit der EU-Osterweiterung“ veröffentlicht. Zitat: „Auf dem europäischen Entsorgungsmarkt ist von einem großen Dunkelfeld illegaler Verbringungspraktiken, insbesondere von so genannten „Scheinverwertungen" auszugehen. Das Umweltgutachten 2002 des Sachverständigenrates kommt zu dem Schluss, dass die Scheinverwertung gängige Praxis ist und bezeichnet die abfallwirtschaftliche Entwicklung als eine Perversion der Abfallwirtschaft. Der Wegfall des Anschluss- und Benutzungszwanges bei Verwertungsmaßnahmen führte ferner zu einer erheblichen Steigerung des überregionalen und grenzüberschreitenden Transportaufkommens …".

Kunststoffabfälle stellen nach unserer Ansicht einen gefährlichen Abfall dar. Eine Gefährdung der Umwelt durch Kunststoffabfälle besteht langfristig und ist daher nicht unmittelbar wahrzunehmen. Es geht dabei nicht um eine akute toxische Wirkung, sondern um die Persistenz der Kunststoffe in der Umwelt.

Zwischen Kalifornien und Hawaii wurden 2004 mehrere Mio. Tonnen Kunststoffmüll auf dem Meer treibend entdeckt. Diese Kunststoffe werden nach und nach mechanisch zerkleinert und der Kunststoffanteil im Meeresplankton steigt messbar. Der Abbau und damit die Freisetzung der toxischen Inhaltsstoffe verlaufen über einen geschätzten Zeitraum von mehr als 500 Jahren.

Verschmutzungen von Luft und Wasser können innerhalb weniger Jahre behoben werden. Die Luftbelastung im Ruhrgebiet beispielsweise konnte durch Filteranlagen schnell wieder verringert werden. Die Verschmutzung der Umwelt durch Kunststoffe kann dagegen über 1000 Jahre andauern.

Das vordergründig bedeutendste Problem der Nutzung von Erdöl sind die CO_2-Emissionen. Dieses Problem macht 90% der Ölnutzung aus und ist durch Nutzung nachwachsender Rohstoffe innerhalb von 50 bis 100 Jahren zumindest theoretisch lösbar. Die Kunststoffnutzung macht 10% des Rohölverbrauchs aus. Die Folgen eines nicht verantwortungsvollen Umgangs mit Kunststoffabfällen sind innerhalb der nächsten 1000 Jahre nicht umkehrbar.

6 Fazit

Kunststoffabfall ist kein Wertstoff. Die realen Systemkosten der Kunststoffproduktion und nachhaltigen Entsorgung sind grundsätzlich höher als die Verwendung von Grundstoffen wie Glas, Papier, Holz, Naturfasern, Stein, Metall usw.

Die Systemkosten fossiler Kunststoffe werden sich mit der zunehmenden Knappheit der Ressource Erdöl weiter erhöhen. Der Kunststoffverbrauch wird sinken, damit schränken sich auch die werkstofflichen Recyclingmöglichkeiten weiter ein.

Der Druck zur Scheinverwertung von Kunststoffabfällen kann nur gestoppt werden durch eine schnellstmögliche Entscheidung für einen Anschluss- und Benutzungszwang für kunststoffhaltige Abfälle zur Beseitigung.

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Alternative Fuels from Waste

Pathways of interest & key challenges

Jorge Hau

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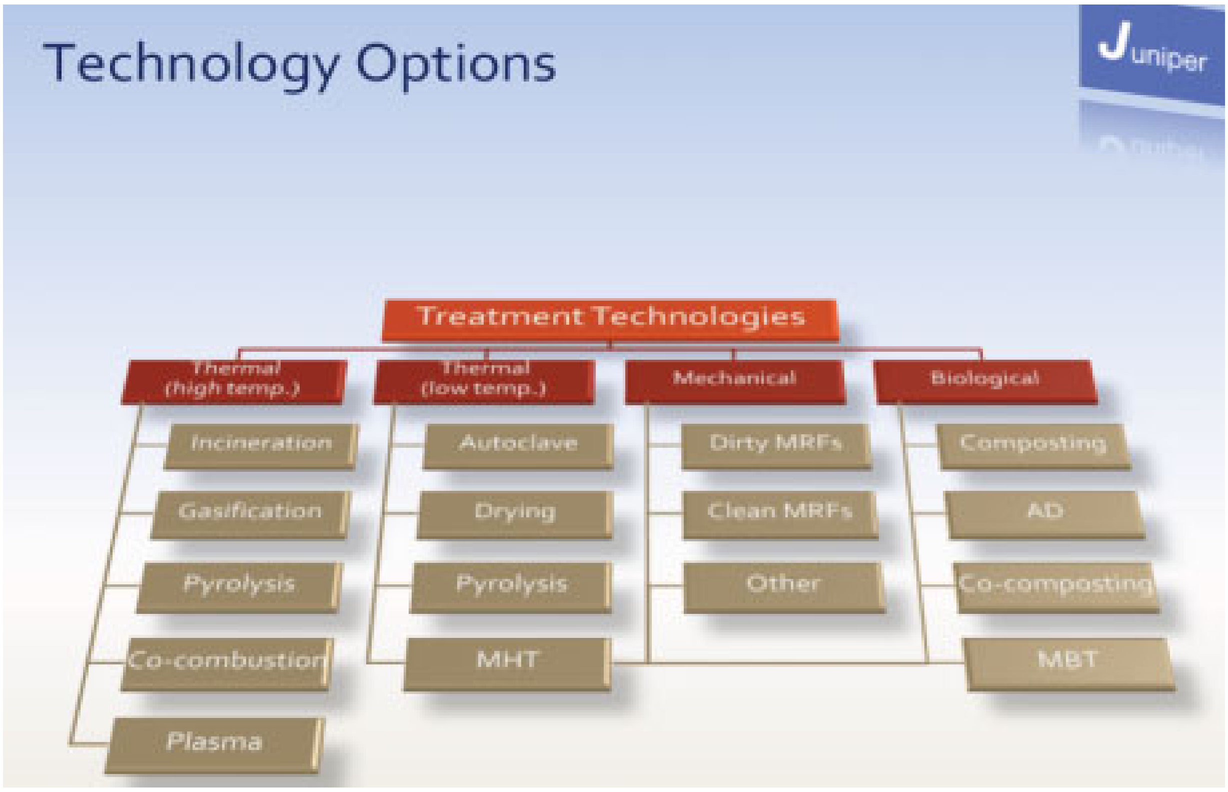
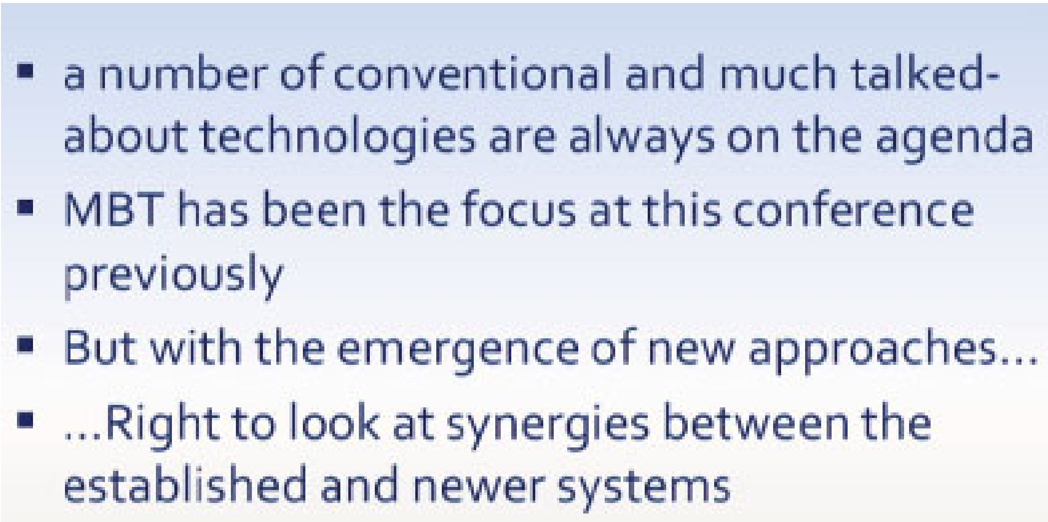
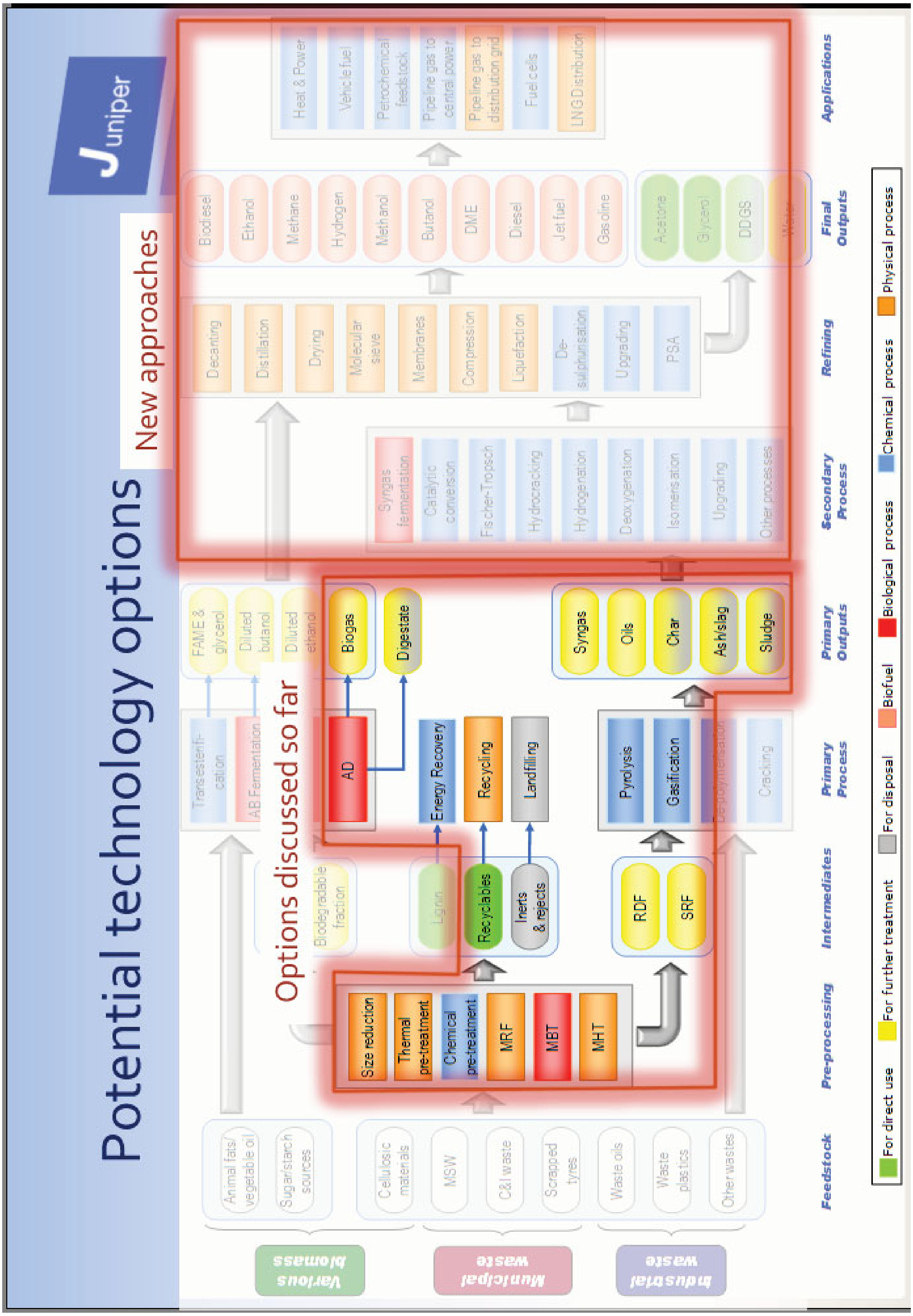
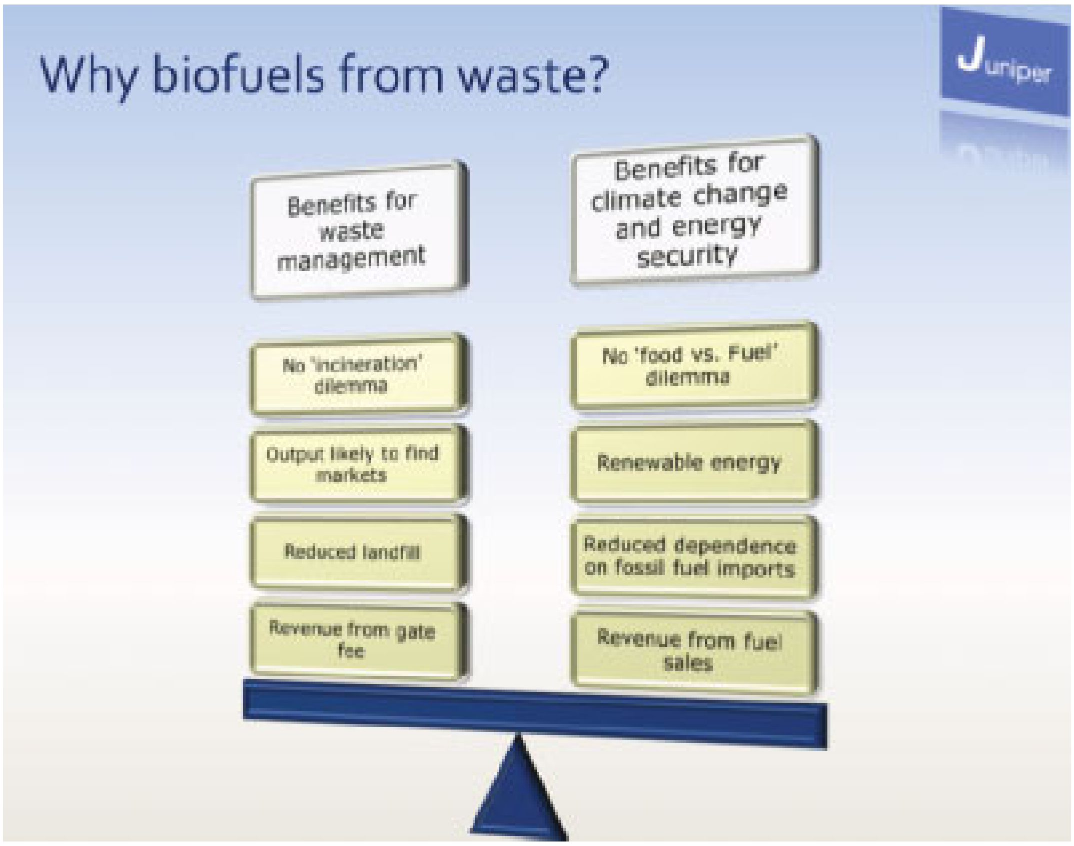
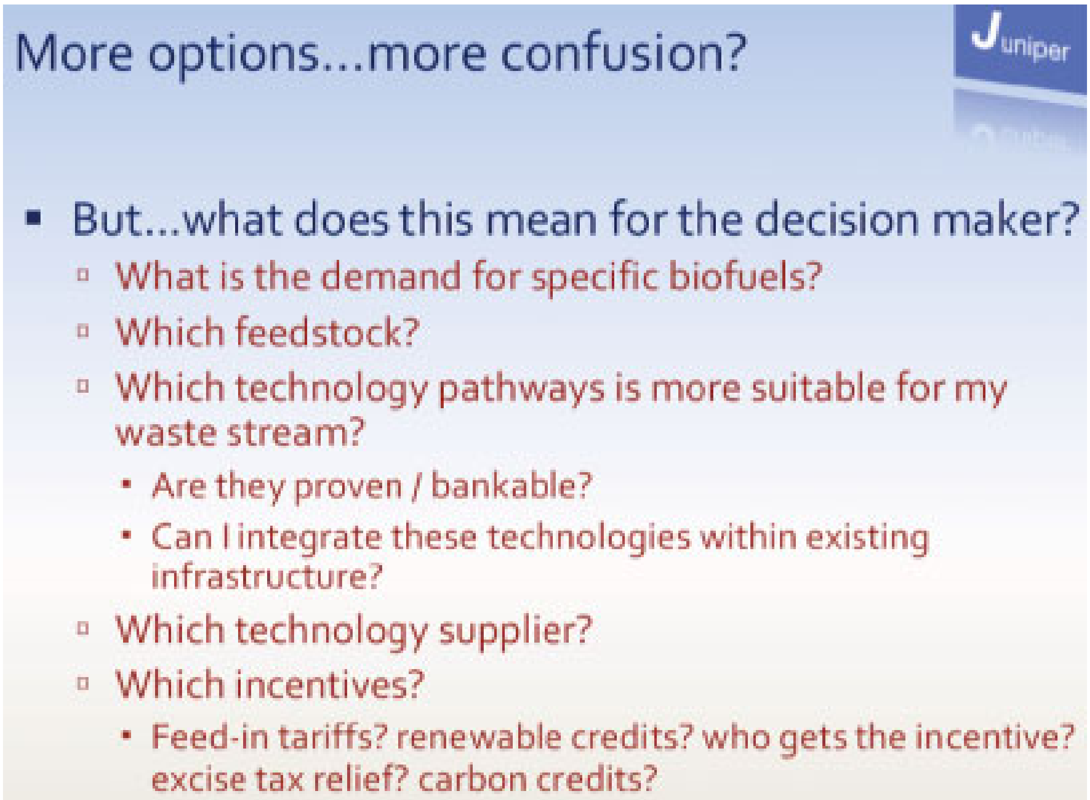


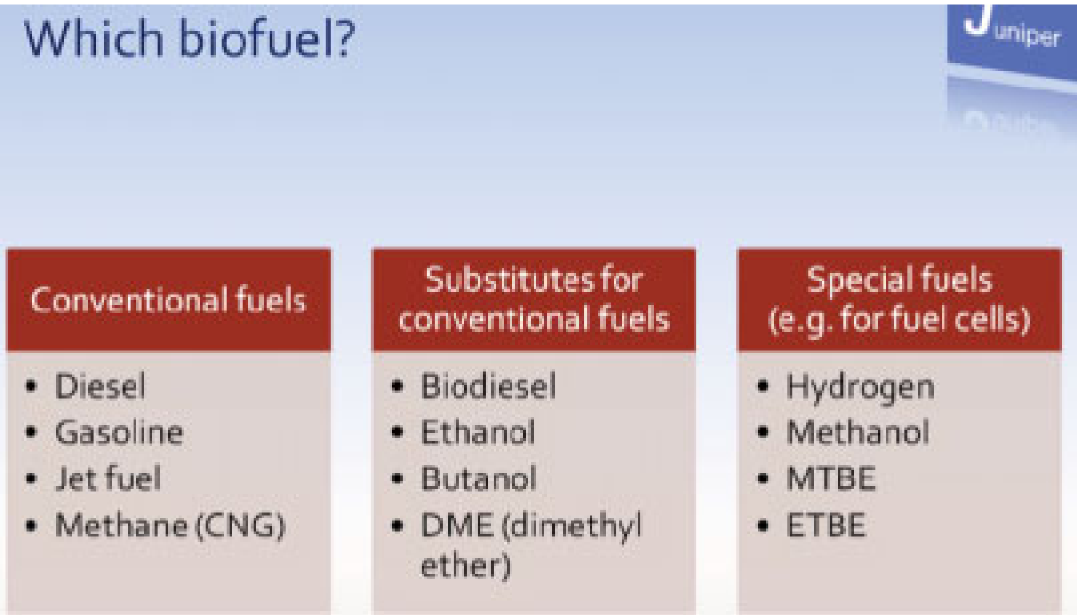

Whenever we talk about waste...
Juniper
a number of conventional and much talked-about technologies are always on the agenda
MBT has been the focus at this conference previously
Discussing issues like
adequately stabilising the input waste for landfilling
finding sustainable markets for MBT outputs: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

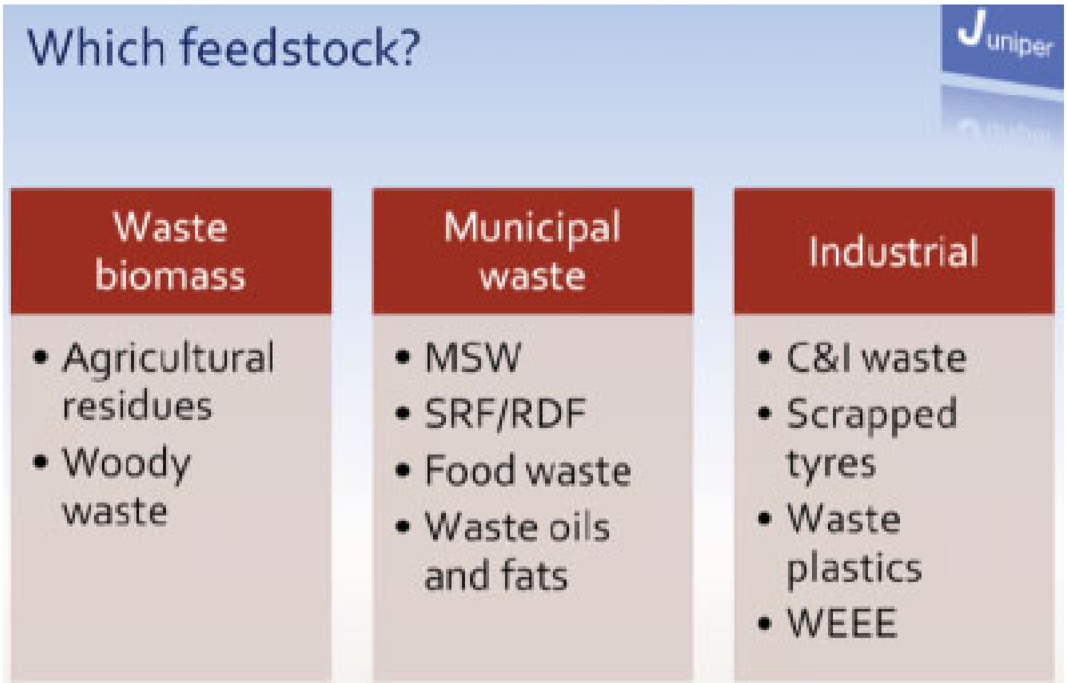

a number of conventional and much talked-about technologies are always on the agenda
MBT has been the focus at this conference previously
But with the emergence of new approaches...
...Right to look at synergies between the established and newer systems


Potential technology options
Juniper
New approaches
Options discussed so far
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?
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?
▪ 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?
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?
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?

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- 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

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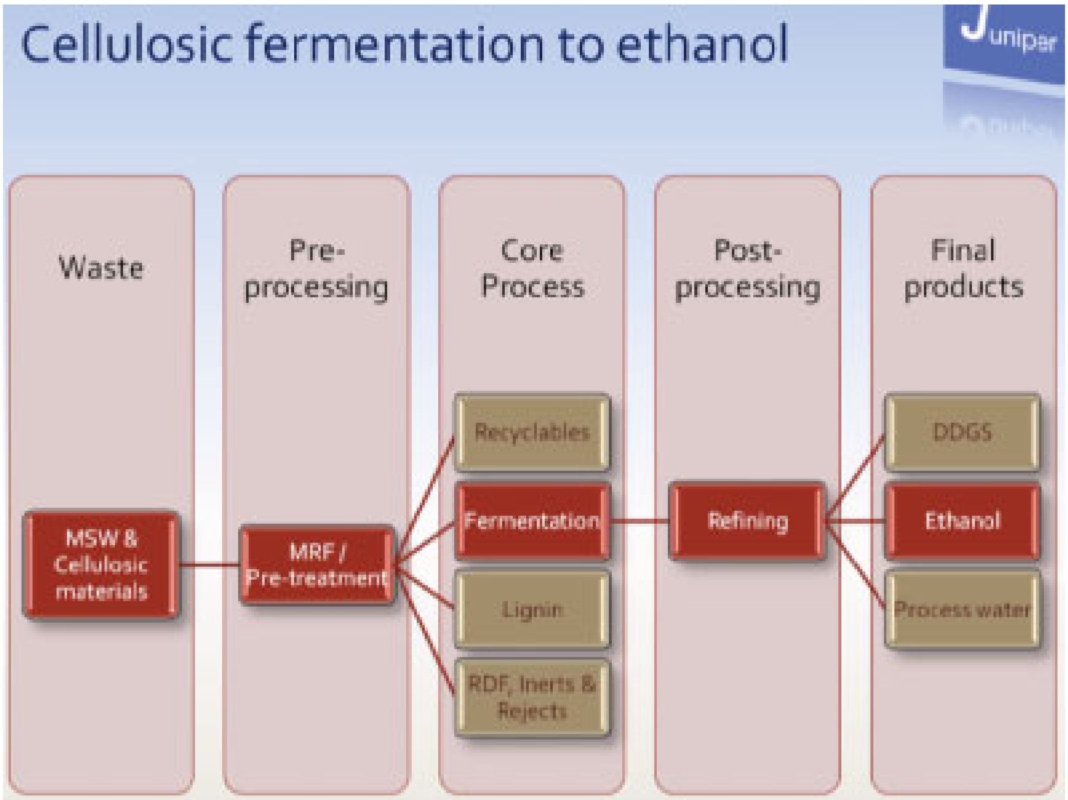
- Cellulosic Fermentation to *Ethanol*
- Gasification + Catalytic Conversion to *Alcohols & DME*
- Gasification + Syngas 'Fermentation' to *Ethanol*
- Gasification + Fischer-Tropsch to *Diesel, Jet Fuel & Gasoline*
- Depolymerisation to *Diesel*
- AD + Biogas Upgrading to *Biomethane*
- Fast Pyrolysis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



Cellulosic fermentation to ethanol

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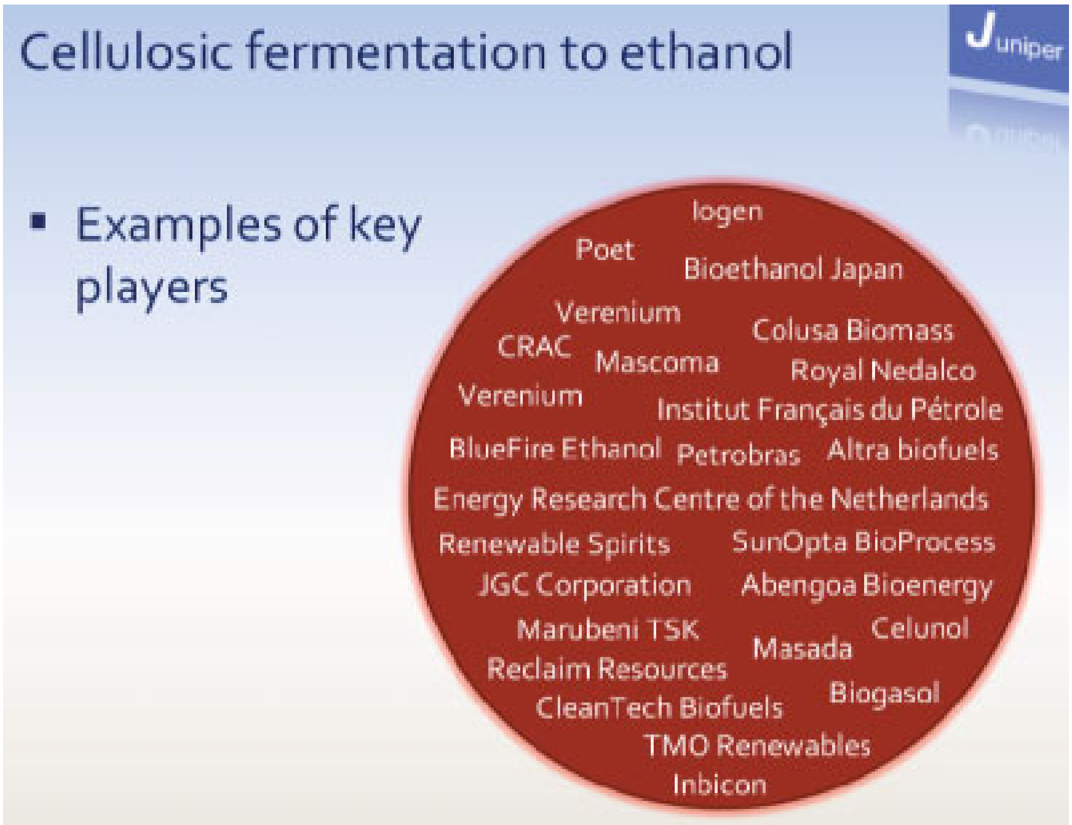
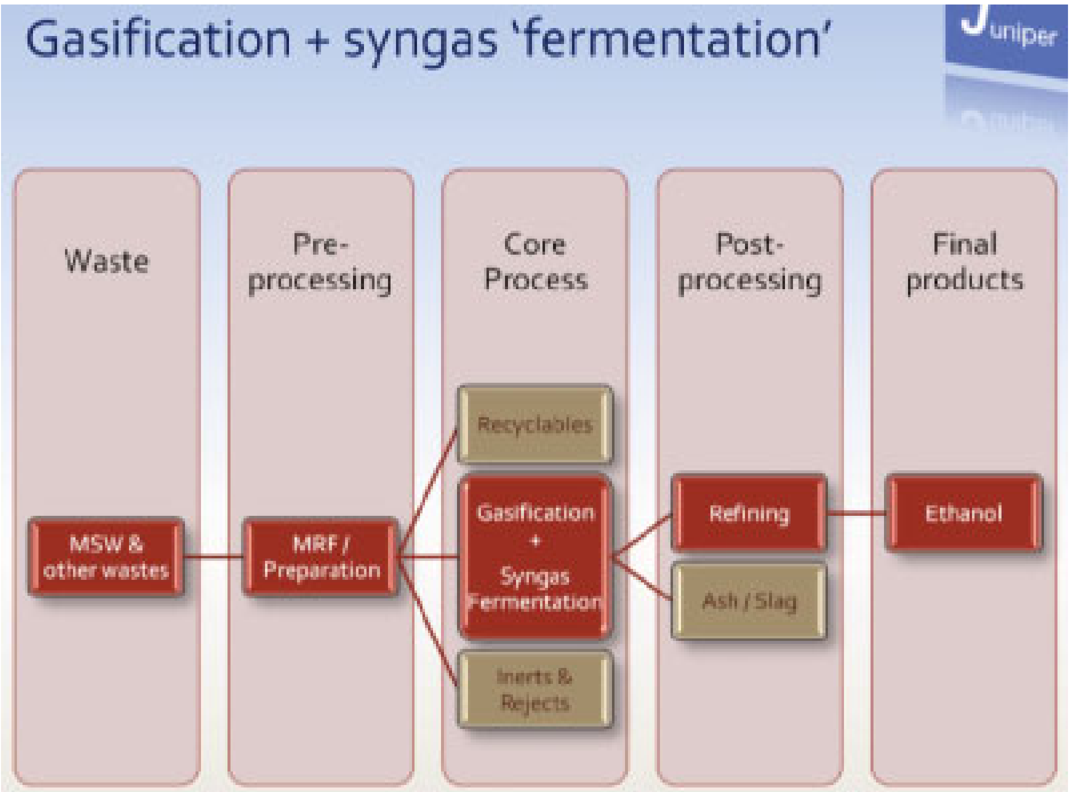
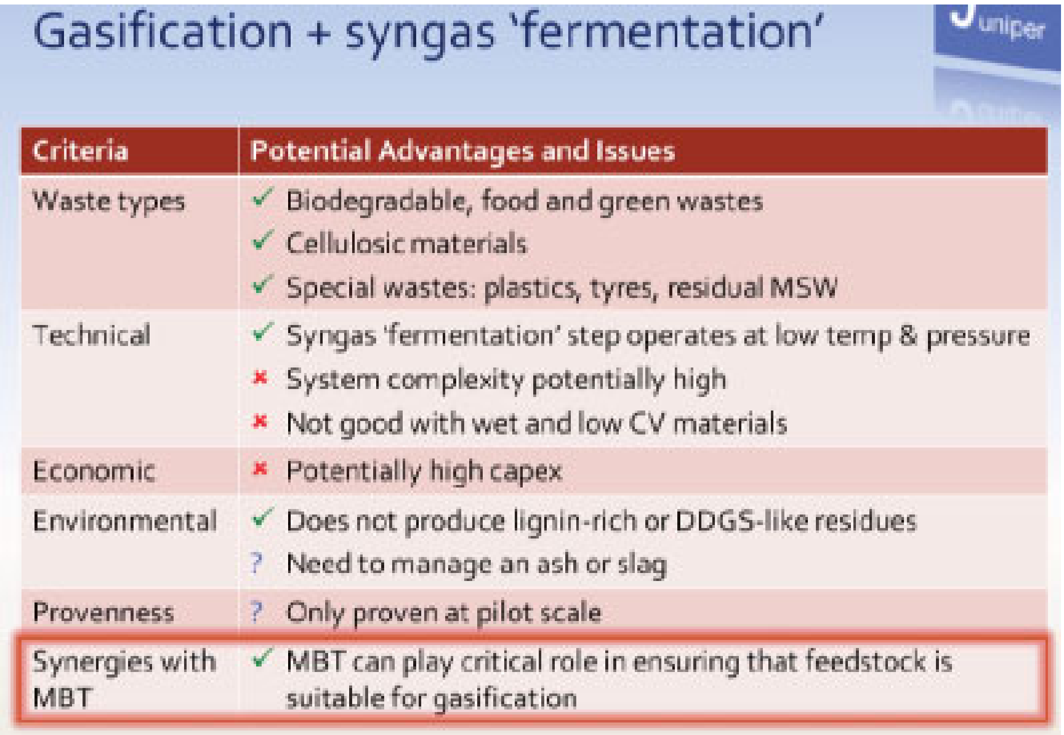
Criteria	Potential Advantages and Issues
Waste types	✓ Biodegradable, food and green wastes ✓ Cellulosic materials (e.g. waste wood, crop residues)
Technical	✓ Can handle wet and low CV materials ✗ Pre-treatment of cellulosic materials still being developed
Economic	✗ Opex may be high (enzymes, pre-treatment 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

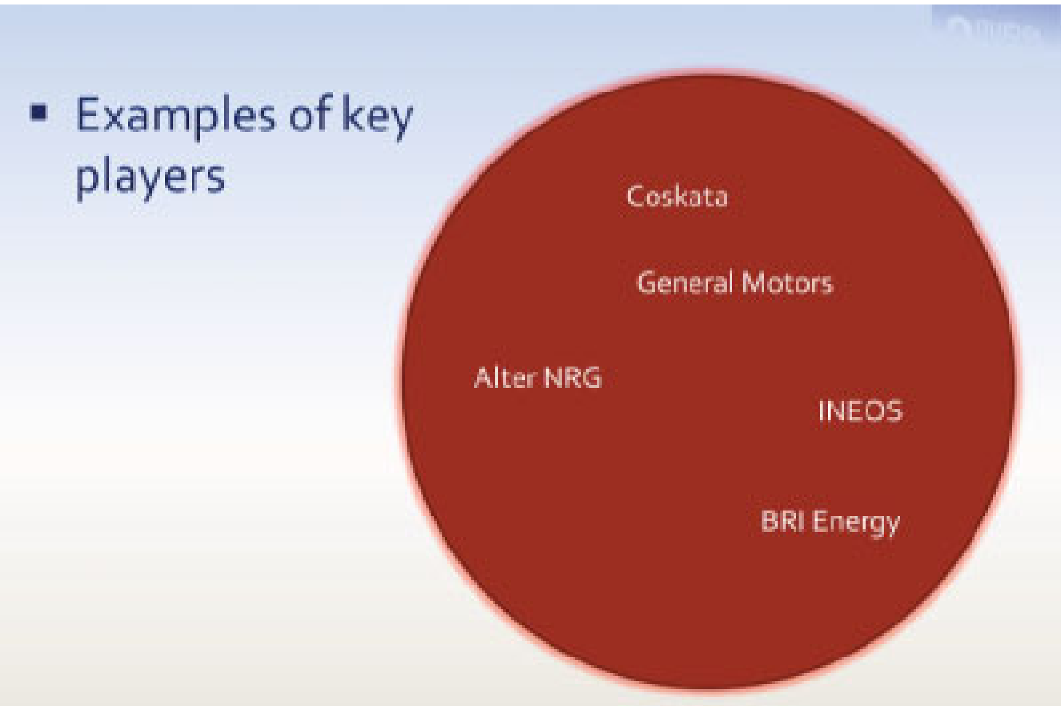

Cellulosic fermentation to ethanol
Juniper
Examples of key players
Iogen
Poet
Bioethanol Japan
Verenium
Colusa Biomass
CRAC
Mascoma
Royal Nedalco
Verenium
Institut Français du Pétrole
BlueFire Ethanol
Petrobras
Altra biofuels
Energy Research Centre of the Netherlands
Renewable Spirits
SunOpta BioProcess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

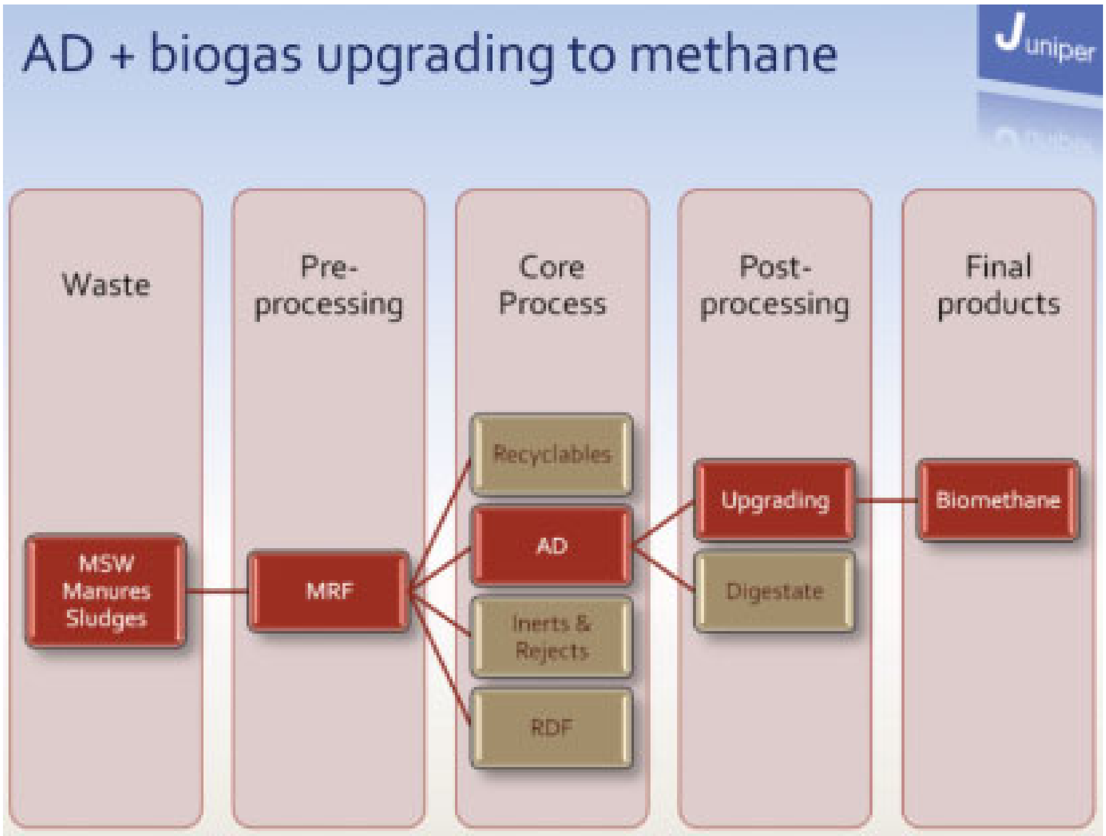

Gasification + syngas 'fermentation'
Juniper
Waste
Pre-processing
Core Process
Post-processing
Final products
Recyclables
MSW & other wastes
MRF / Preparation
Gasification + Syngas Fermentation
Refining
Ethanol
Ash / Slag
Inerts & Rejects



Gasification + syngas 'fermentation'

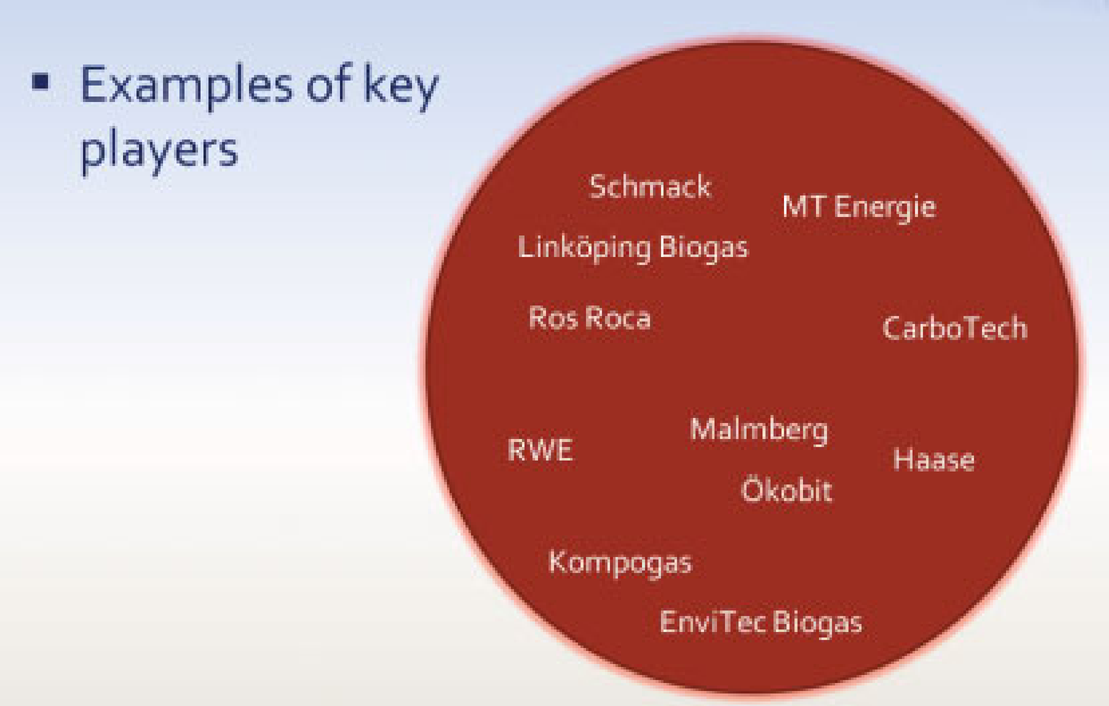
Criteria	Potential Advantages and Issues
Waste types	✓ Biodegradable, food and green wastes ✓ Cellulosic materials ✓ Special wastes: plastics, tyres, residual MSW
Technical	✓ Syngas 'fermentation' step operates at low temp & pressure ✗ System complexity potentially high ✗ Not good with wet and low CV 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



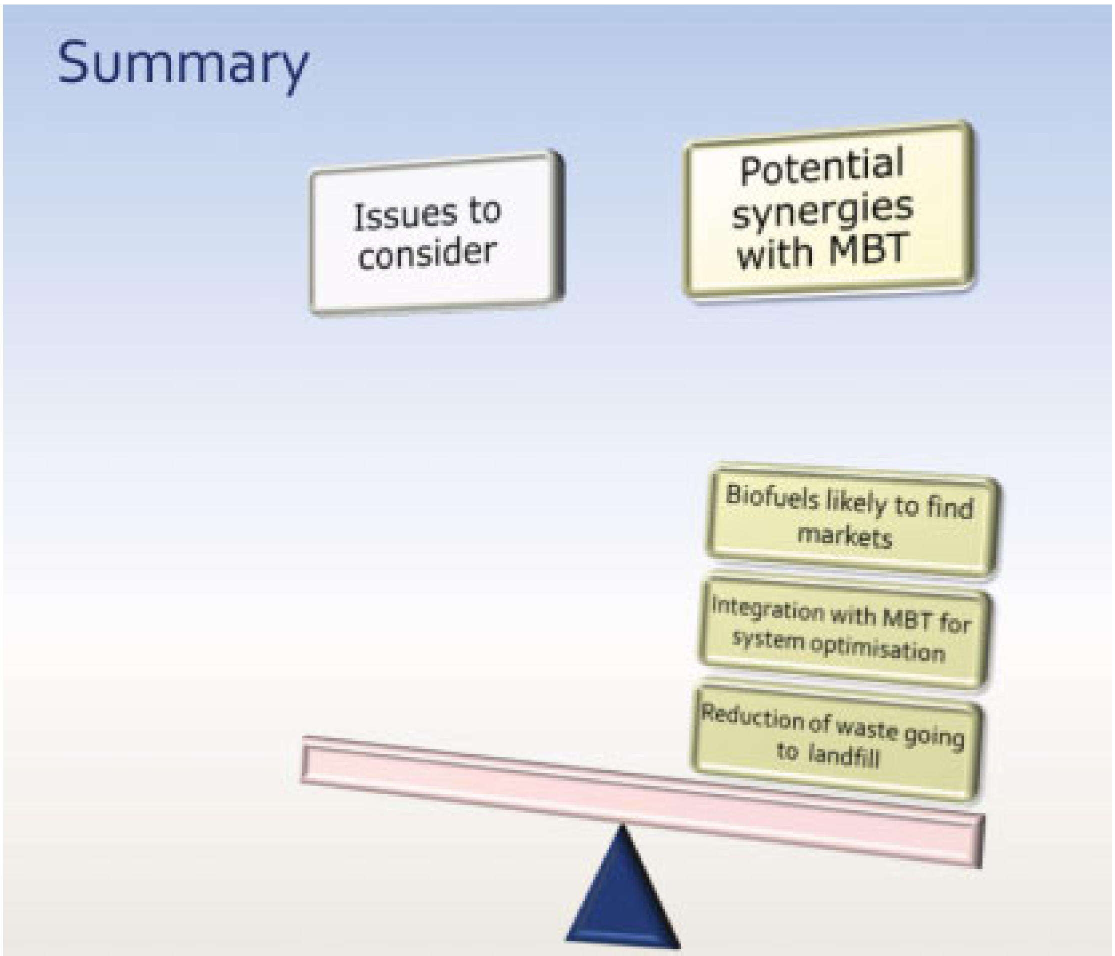


AD + biogas upgrading to methane

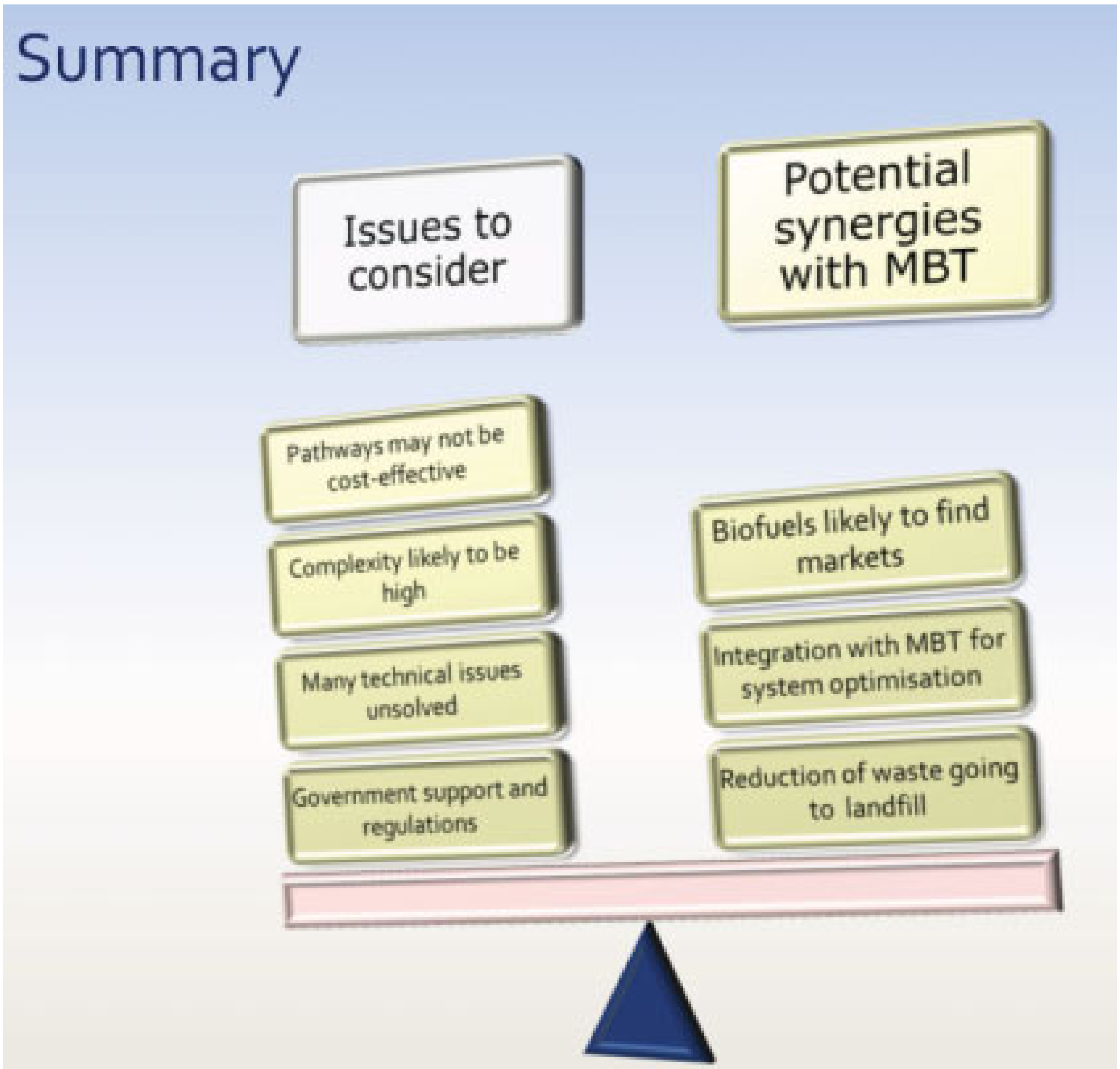
Criteria	Potential Advantages and Issues
Waste types	✓ Biodegradable, food and green wastes
Technical	✓ Can handle wet and low CV materials
Economic	– Very case specific
Environmental	✓ Can avoid incineration as desirable in some countries ✗ ...but need to treat off-gases from process and manage CO_2-rich 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

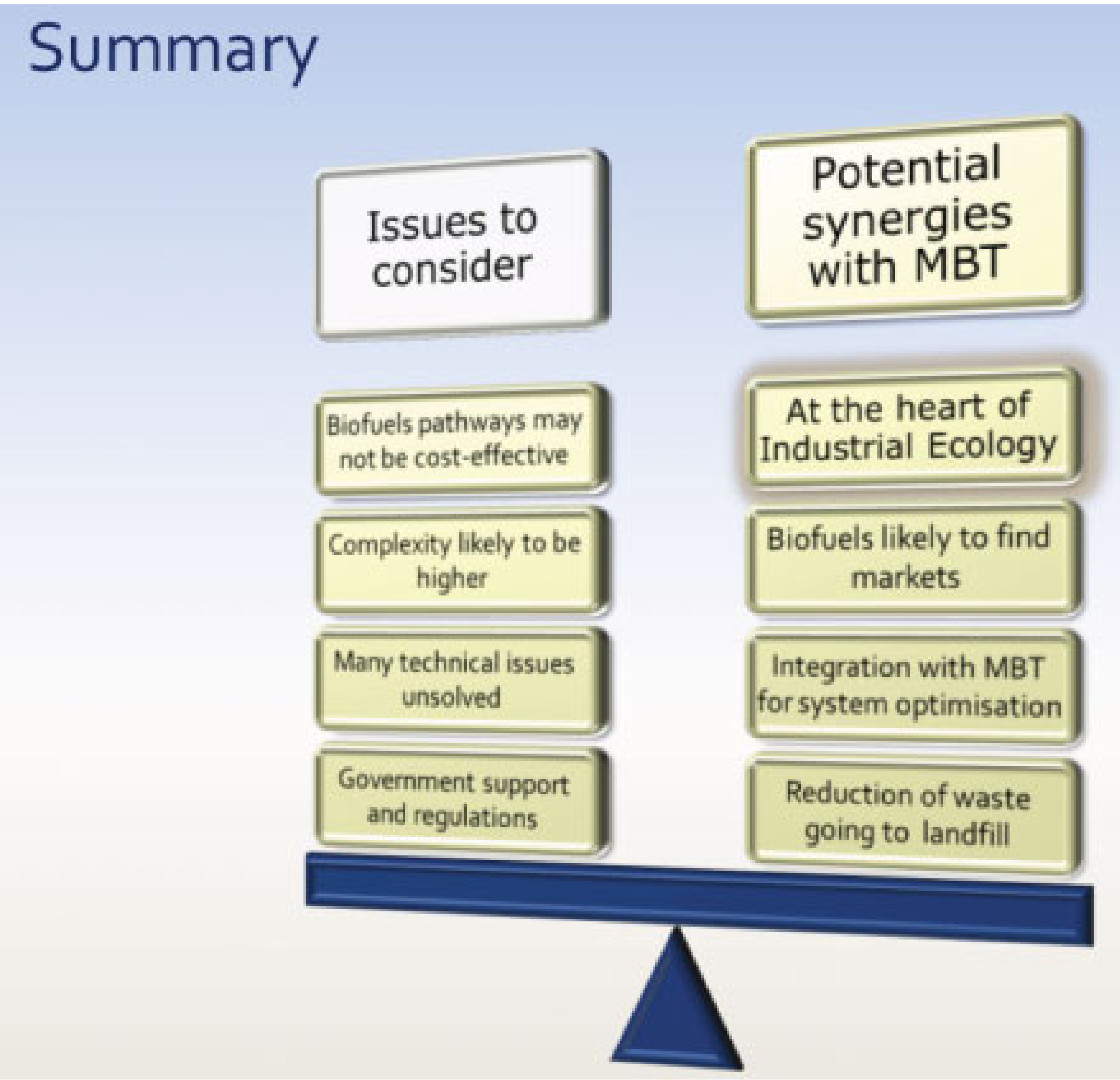


Examples of key players
Schmack
MT Energie
Linköping Biogas
Ros Roca
CarboTech
Malmberg
RWE
Haase
Ökobit
Kompogas
EnviTec Biogas



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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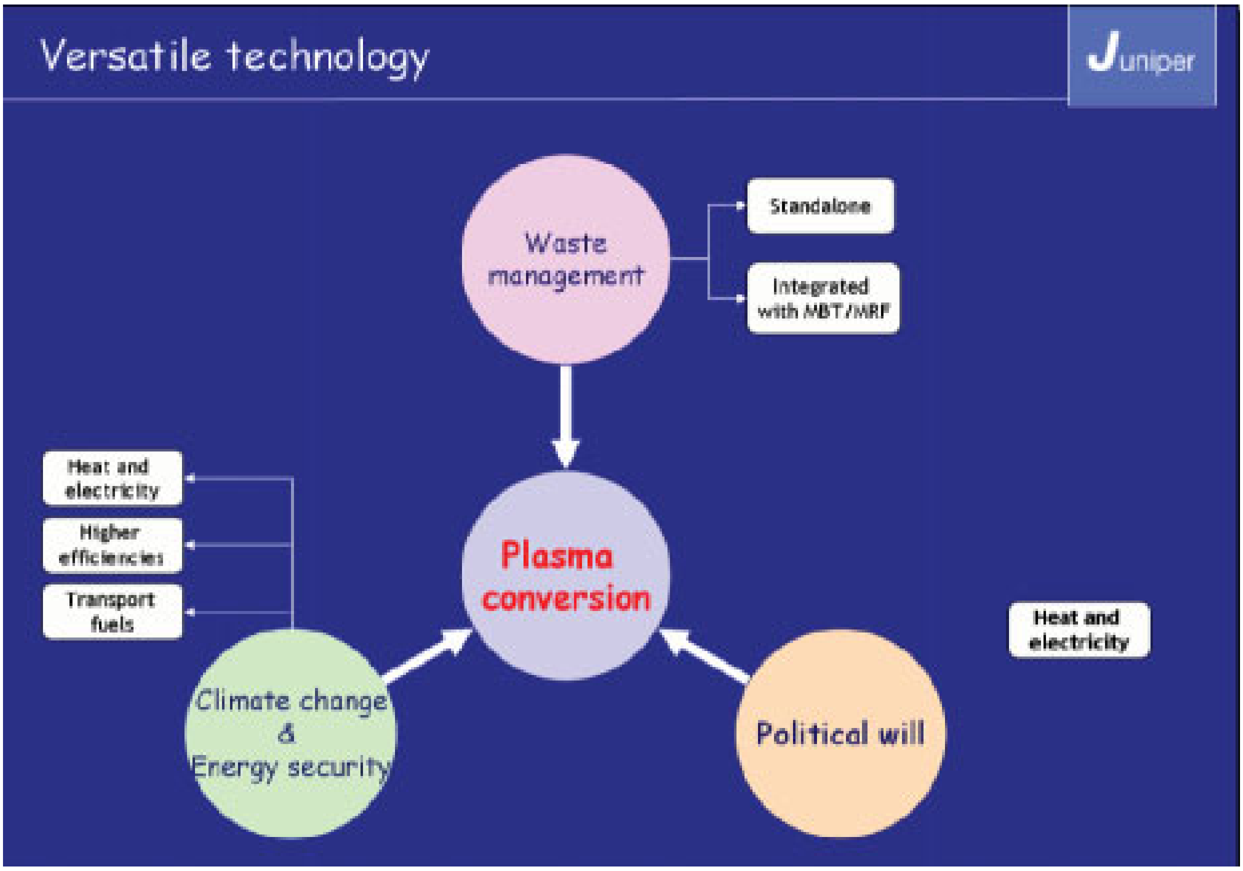
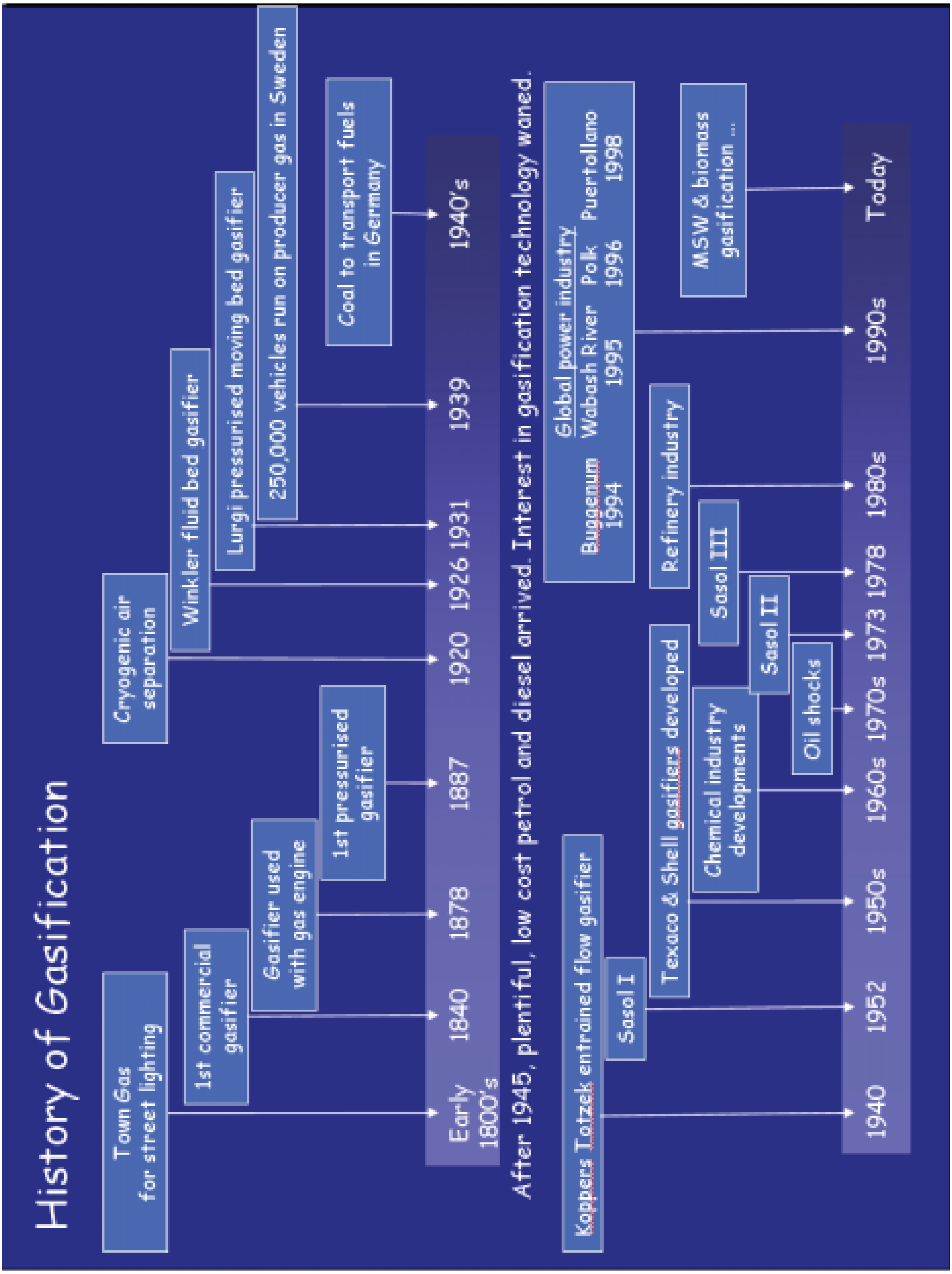
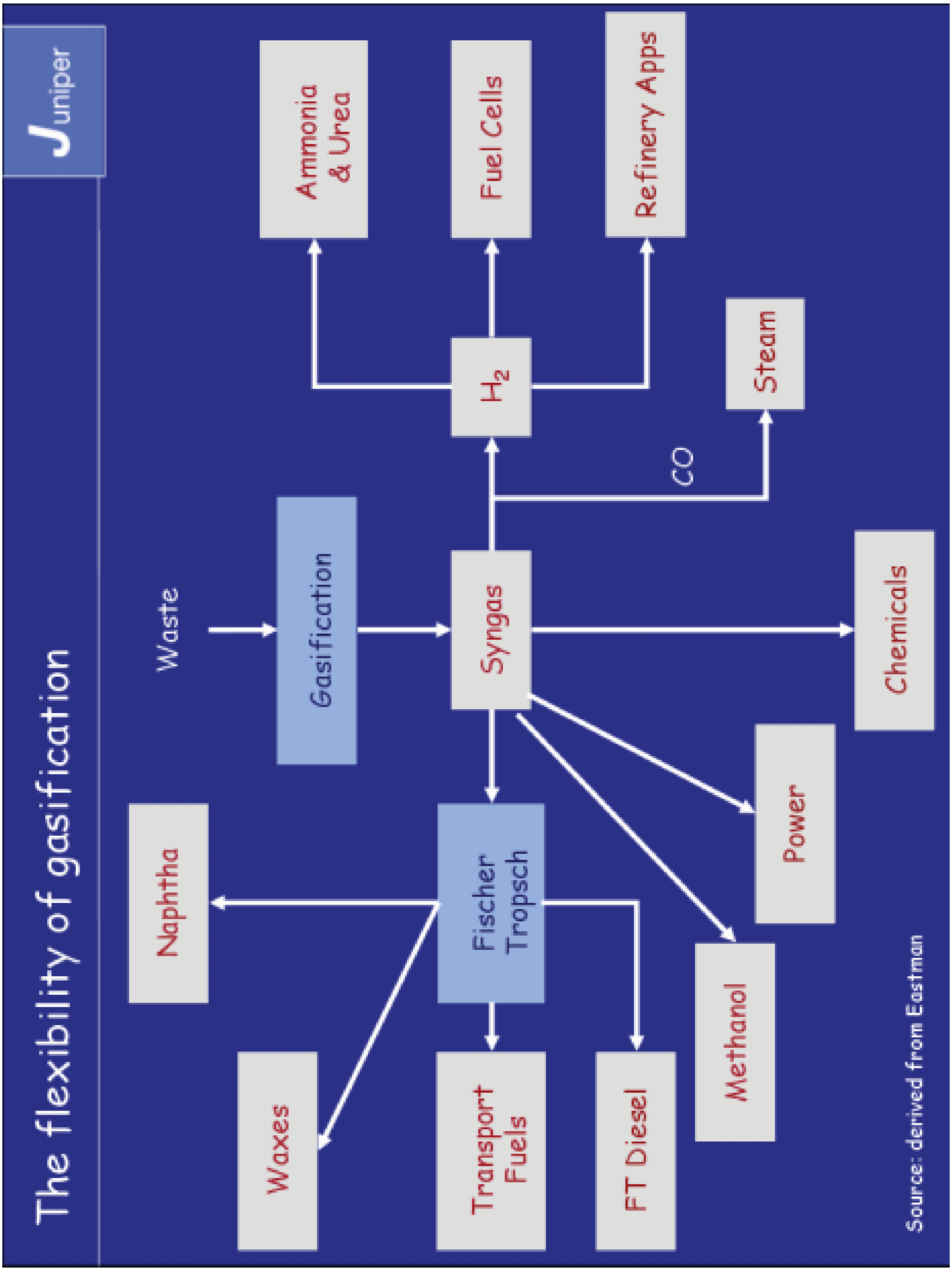
Plasma conversion of waste and biomass - a new solution?

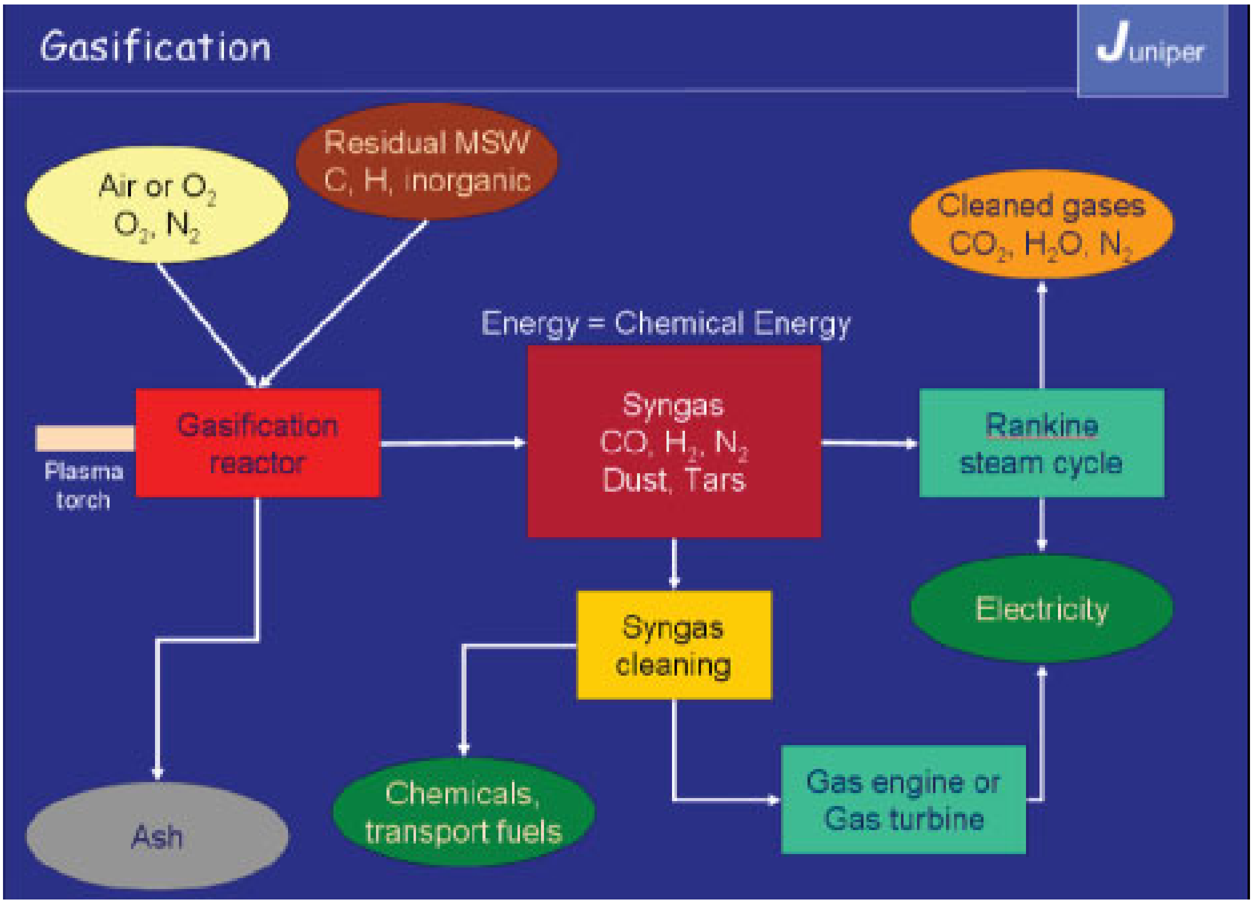
Dr. Egan Archer

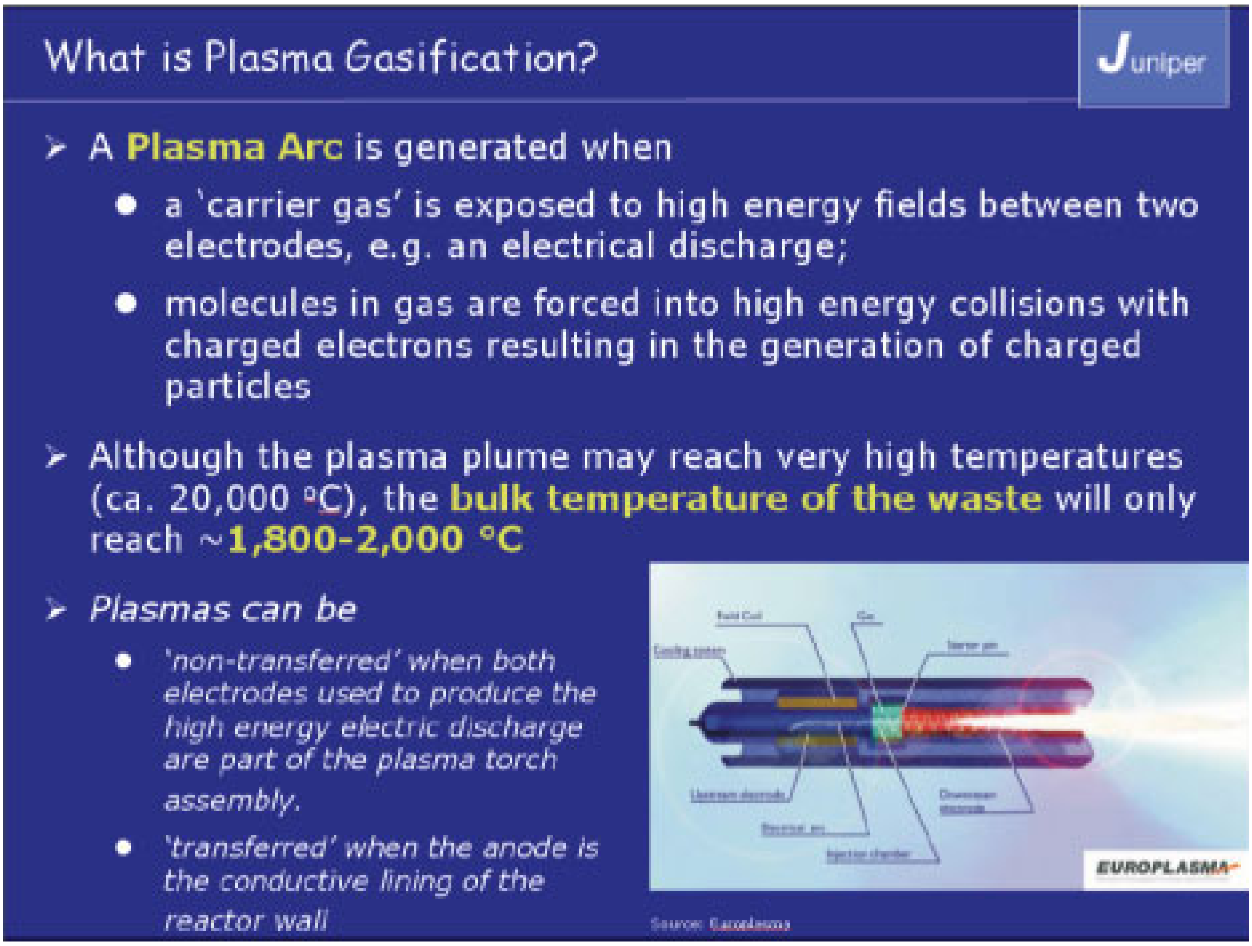
Director, Juniper Consultancy Services Ltd.

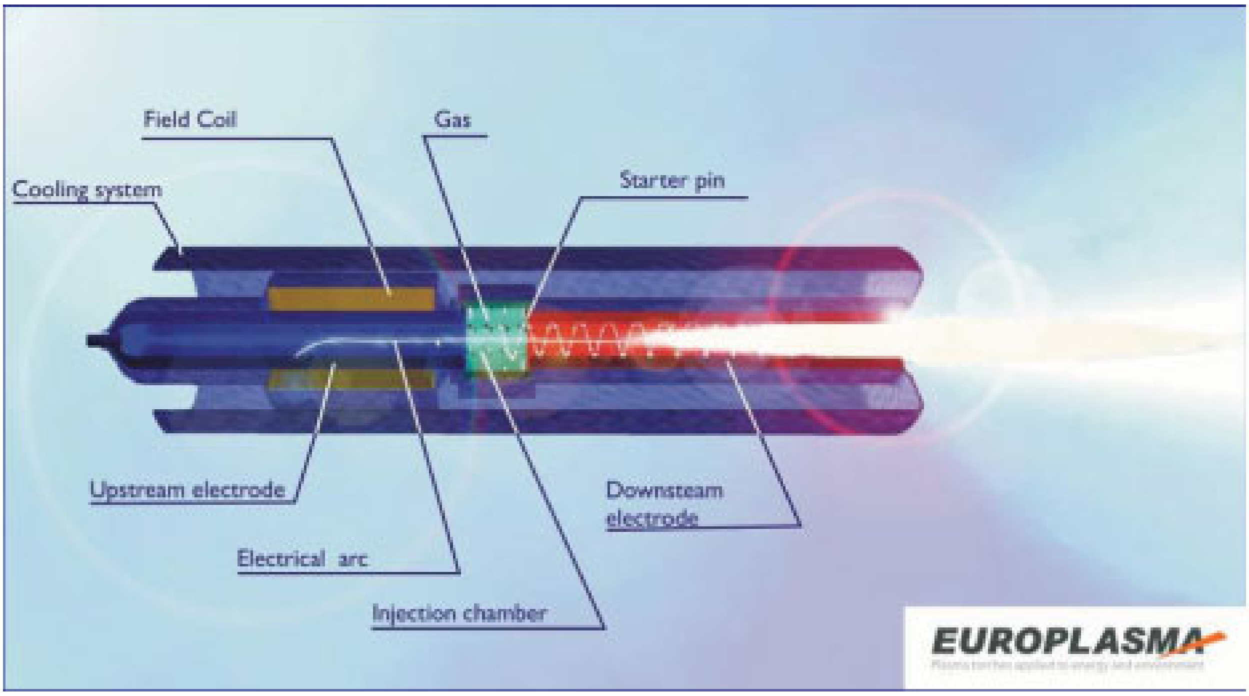



History of Gasification
Town Gas for street lighting
1st commercial gasifier
Gasifier used with gas engine
1st pressurised gasifier
Cryogenic air separation
Winkler fluid bed gasifier
Lurgi pressurised moving bed gasifier
250,000 vehicles run on producer gas in Sweden
Coal to transport fuels in Germany
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

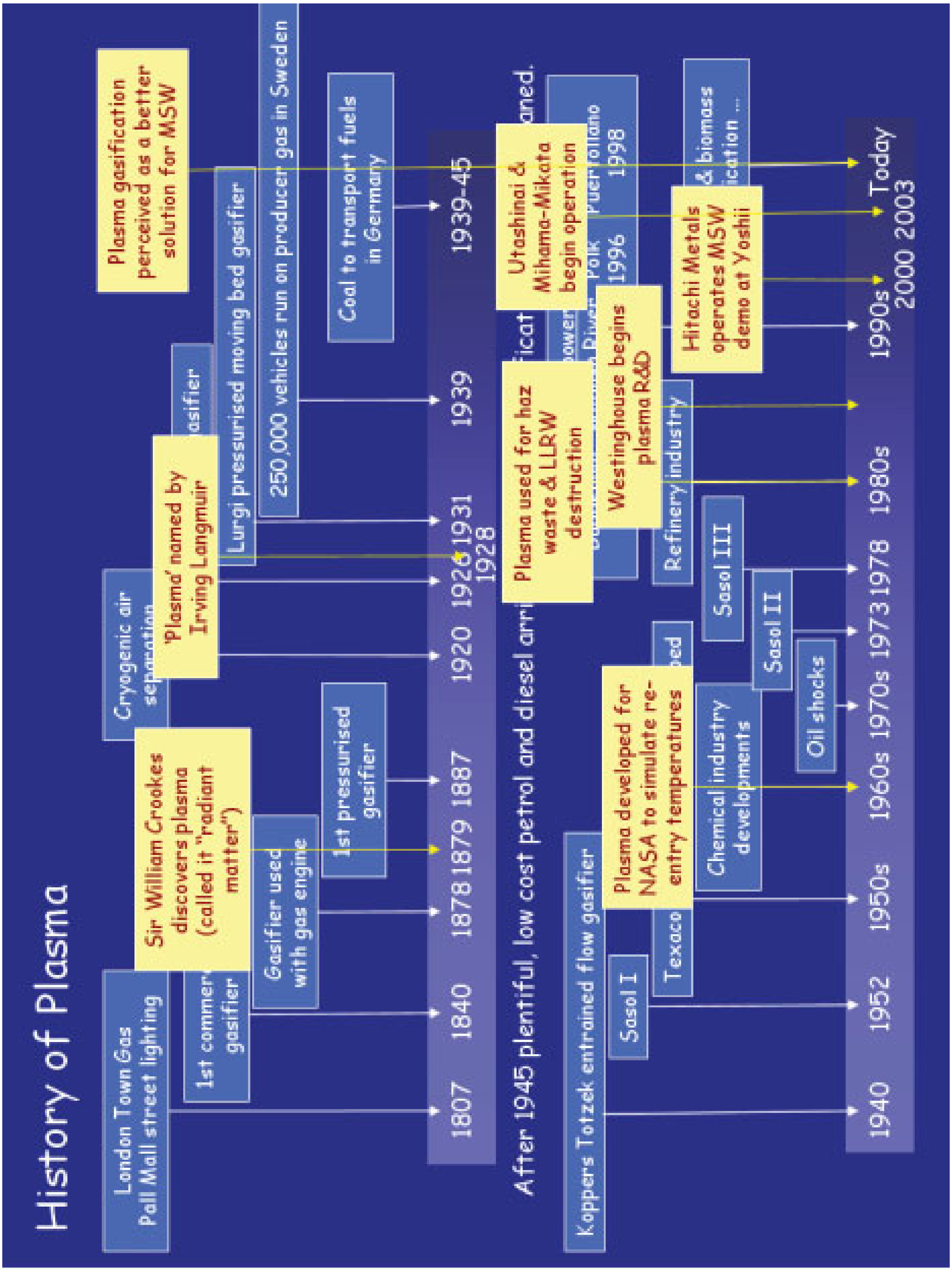

The flexibility of gasification
Juniper
Waste
Gasification
Syngas
H_2
CO
Ammonia & Urea
Fuel Cells
Refinery Apps
Steam
Chemicals
Power
Methanol
Fischer Tropsch
Naphtha
Waxes
Transport Fuels
FT Diesel
Source: derived from Eastman


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





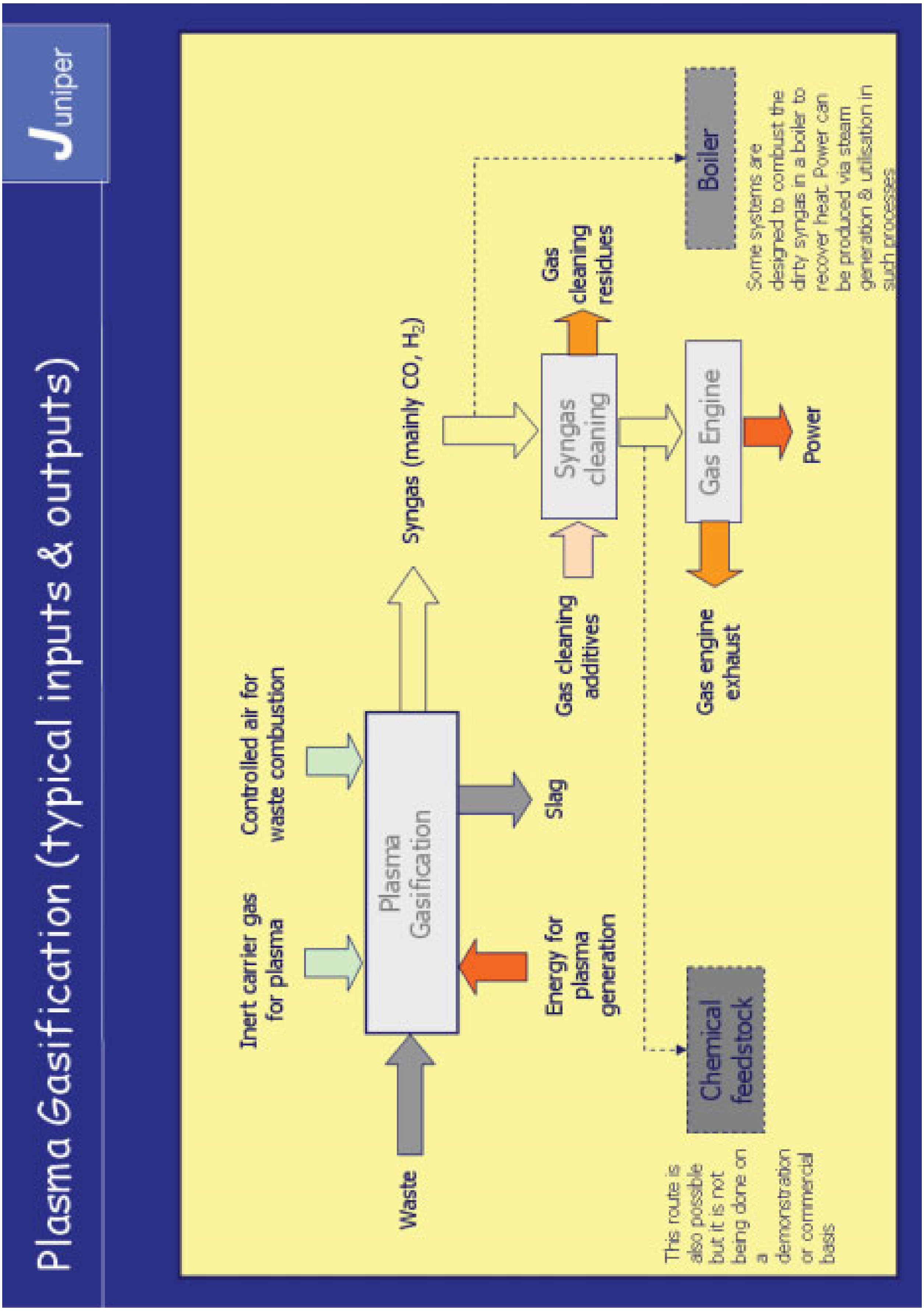
Source Europlasma

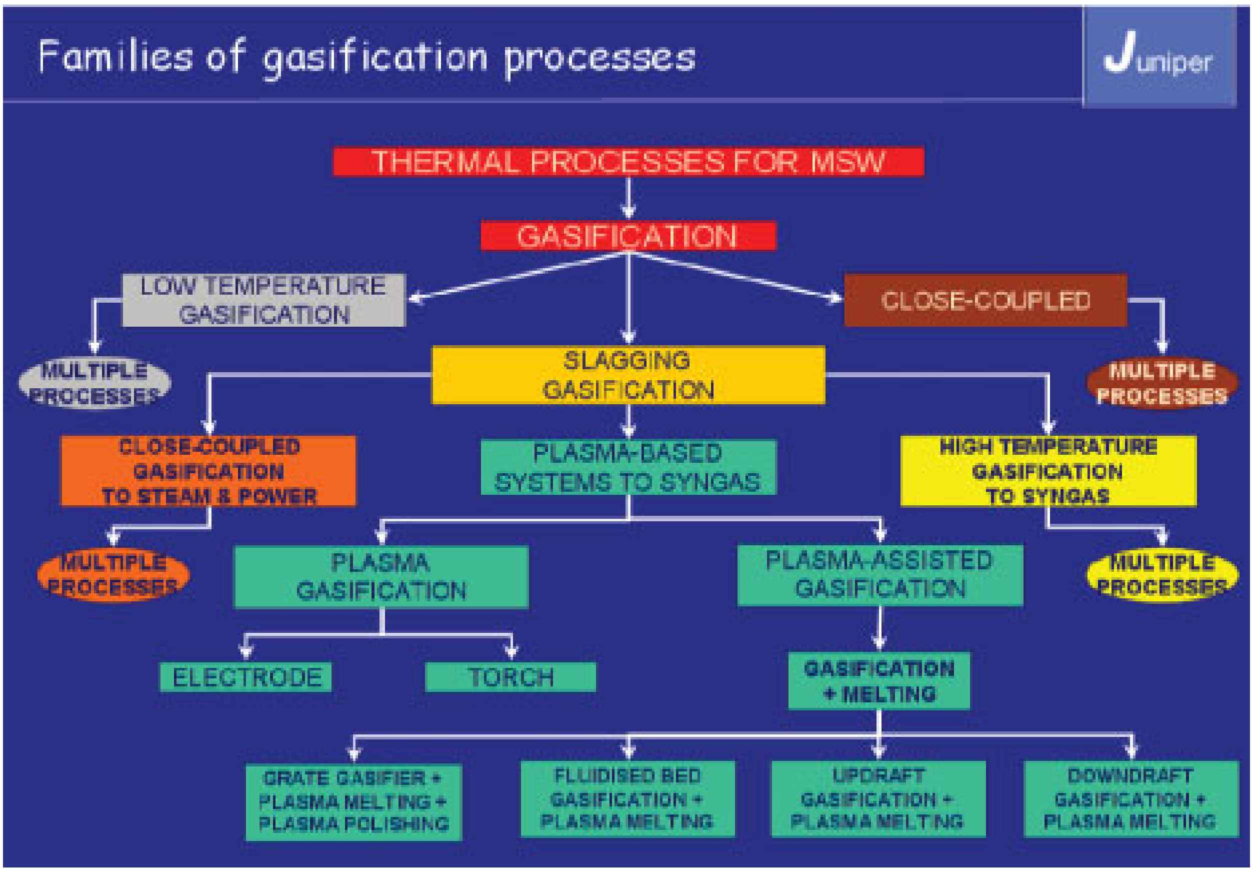

History of Plasma
London Town Gas Pall Mall street lighting
Sir William Crookes discovers plasma (called it "radiant matter")
Gasifier used with gas engine
1st pressurised gasifier
Cryogenic air
'Plasma' named by Irving Langmuir
Lurgi pressurised moving bed gasifier
250,000 vehicles run on producer gas in Sweden
Coal to transport fuels in Germany
Plasma gasification perceived as a better solution for MSW
1807 1840 1878 1879 1887 1920 1926 1928 1931 1939 1939-45
After 1945 plentiful, low cost petrol and diesel arri
Koppers Totzek entrained flow gasifier
Sasol I
Texaco
Plasma developed for NASA to simulate re-entry temperatures
Chemical industry developments
Oil shocks
Sasol II
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)
Juniper
Waste
Inert carrier gas for plasma
Controlled air for waste combustion
Plasma Gasification
Energy for plasma generation
Slag
Syngas (mainly CO, H2)
Gas cleaning additives
Syngas cleaning
Gas cleaning residues
Gas Engine
Power
Gas engine exhaust
Boiler
Chemical feedstock
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
This route is also possible but it is not being done on a demonstration or commercial basis



Leading plasma processes targeting MSW

Company	Process Status	
	Hazwaste	MSW/RDF
Advanced Plasma Power (GasPlasma)	N/A	Pilot
Alterning (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

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- **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

Source: Alter NRG

WPC Plasma torch being test fired

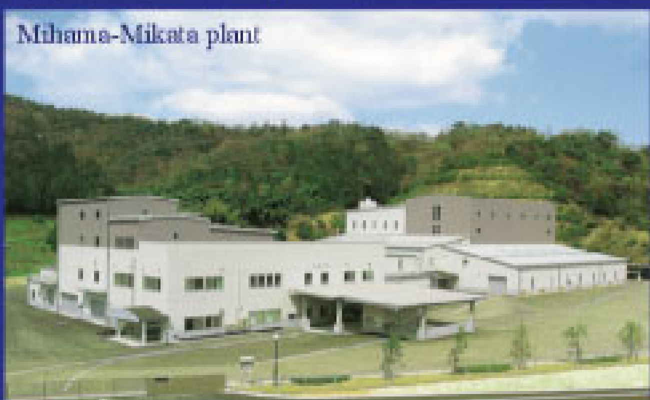
Source: Alter NRG

Westinghouse plasma gasification plants

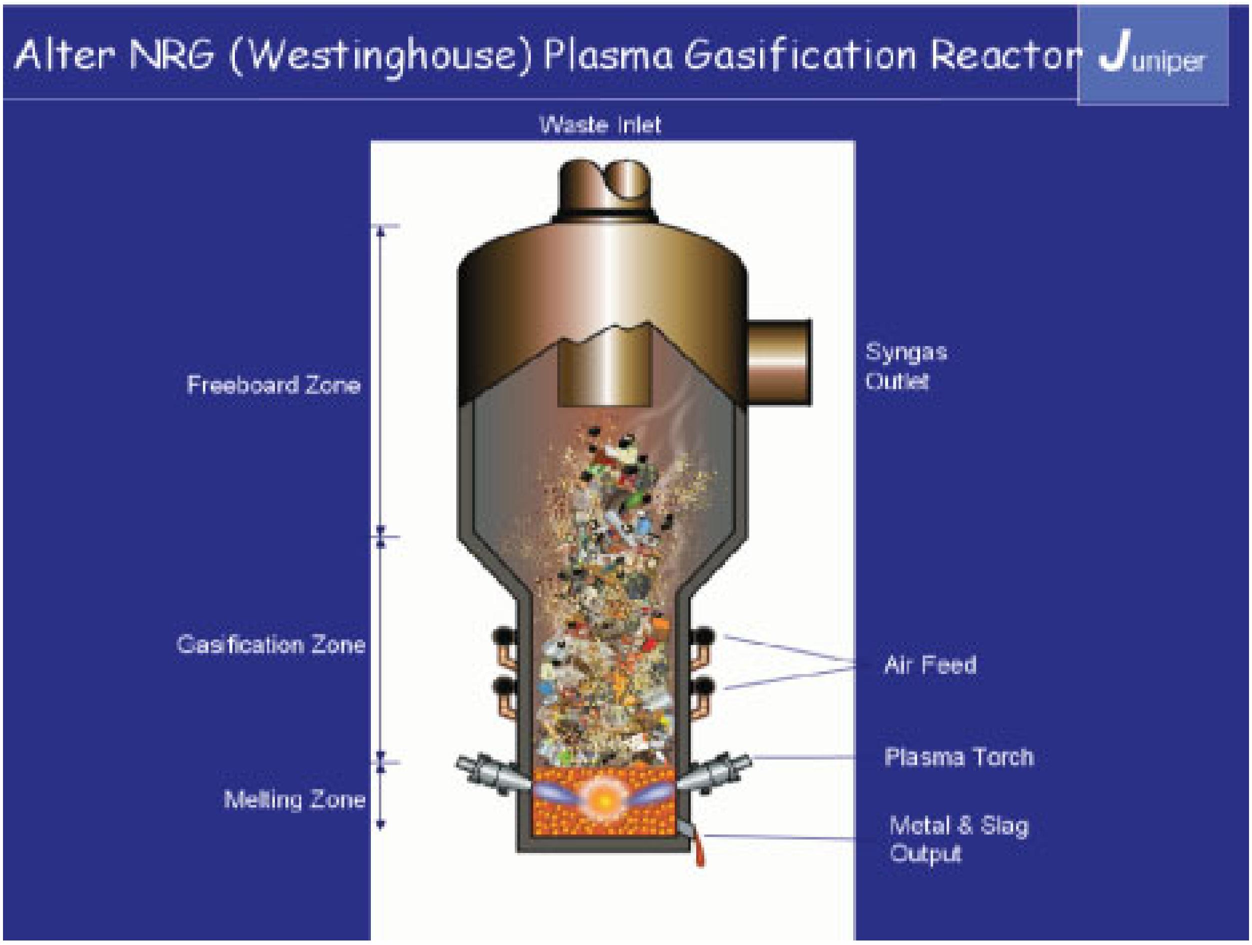
Juniper

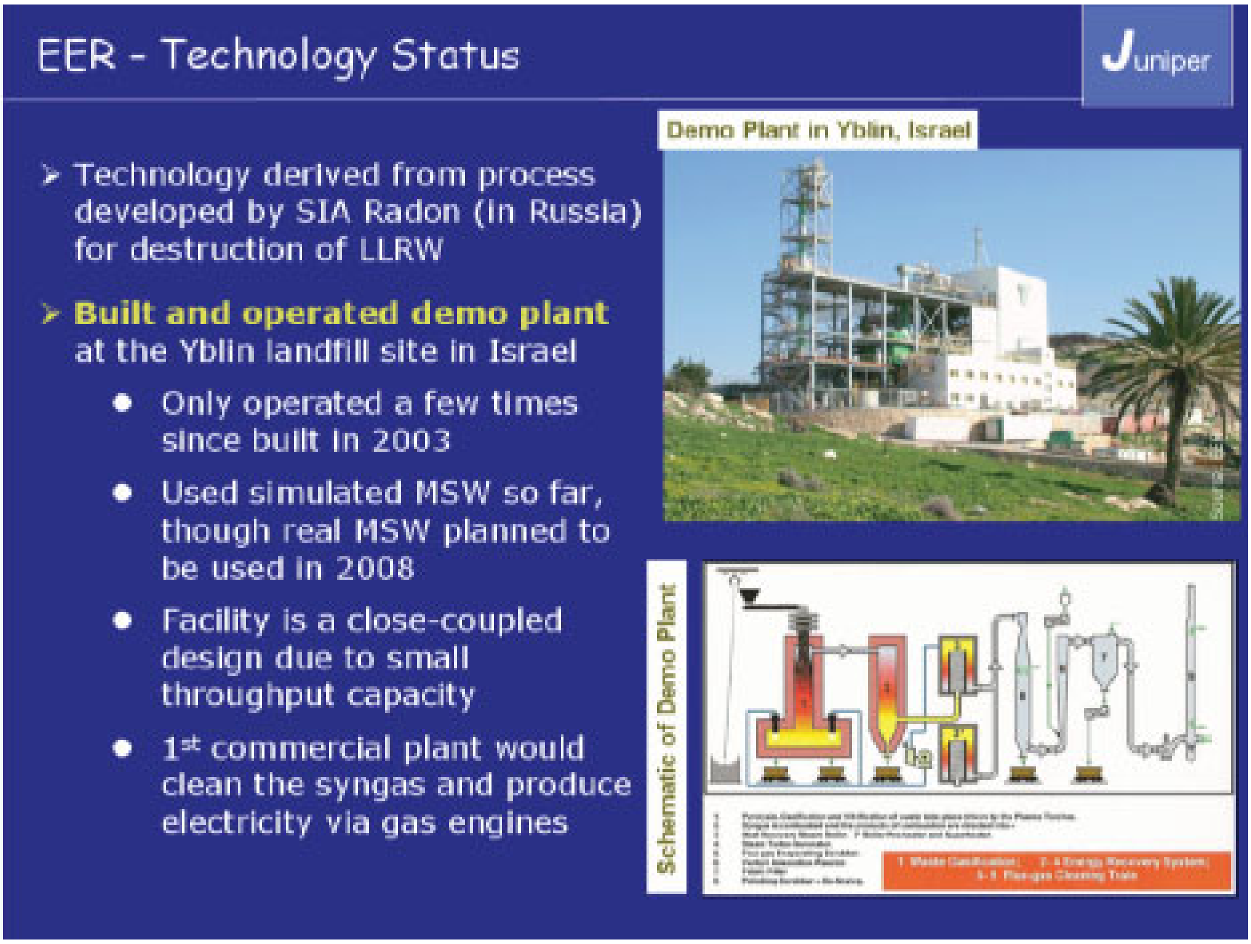
Yoshii plant

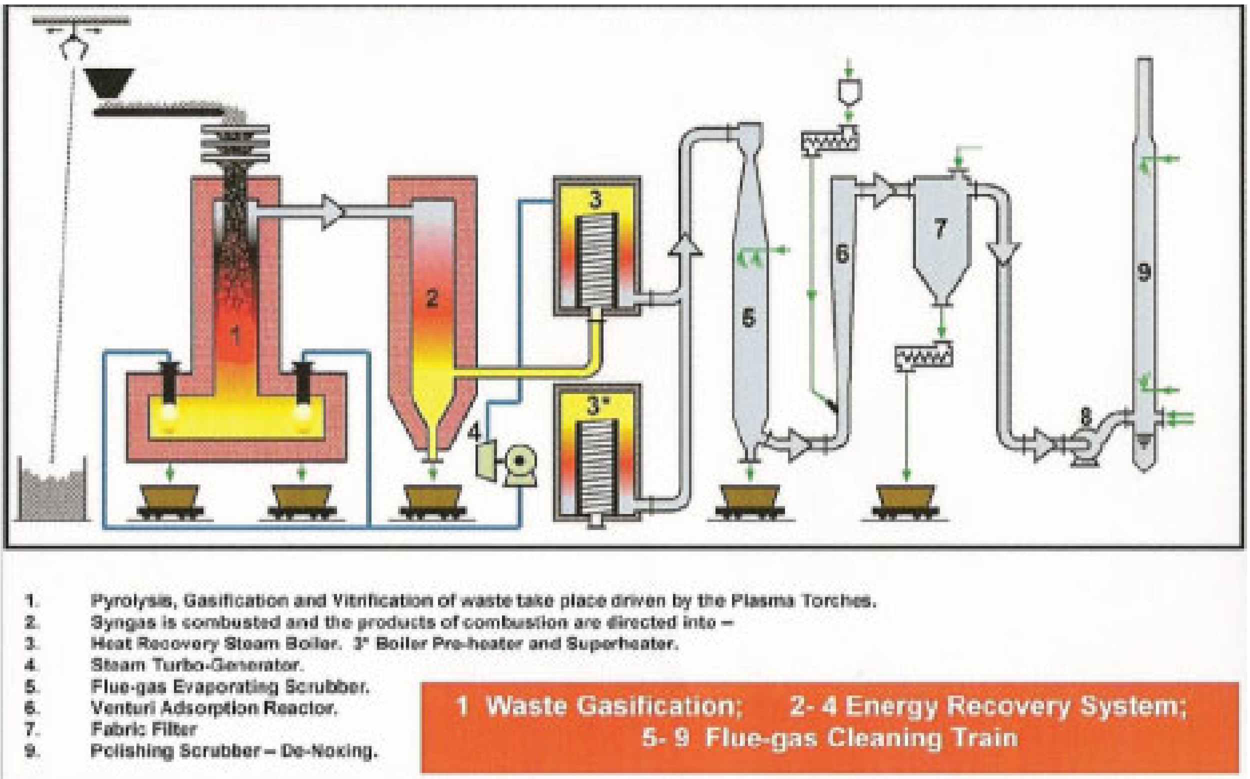
Utashinai plant

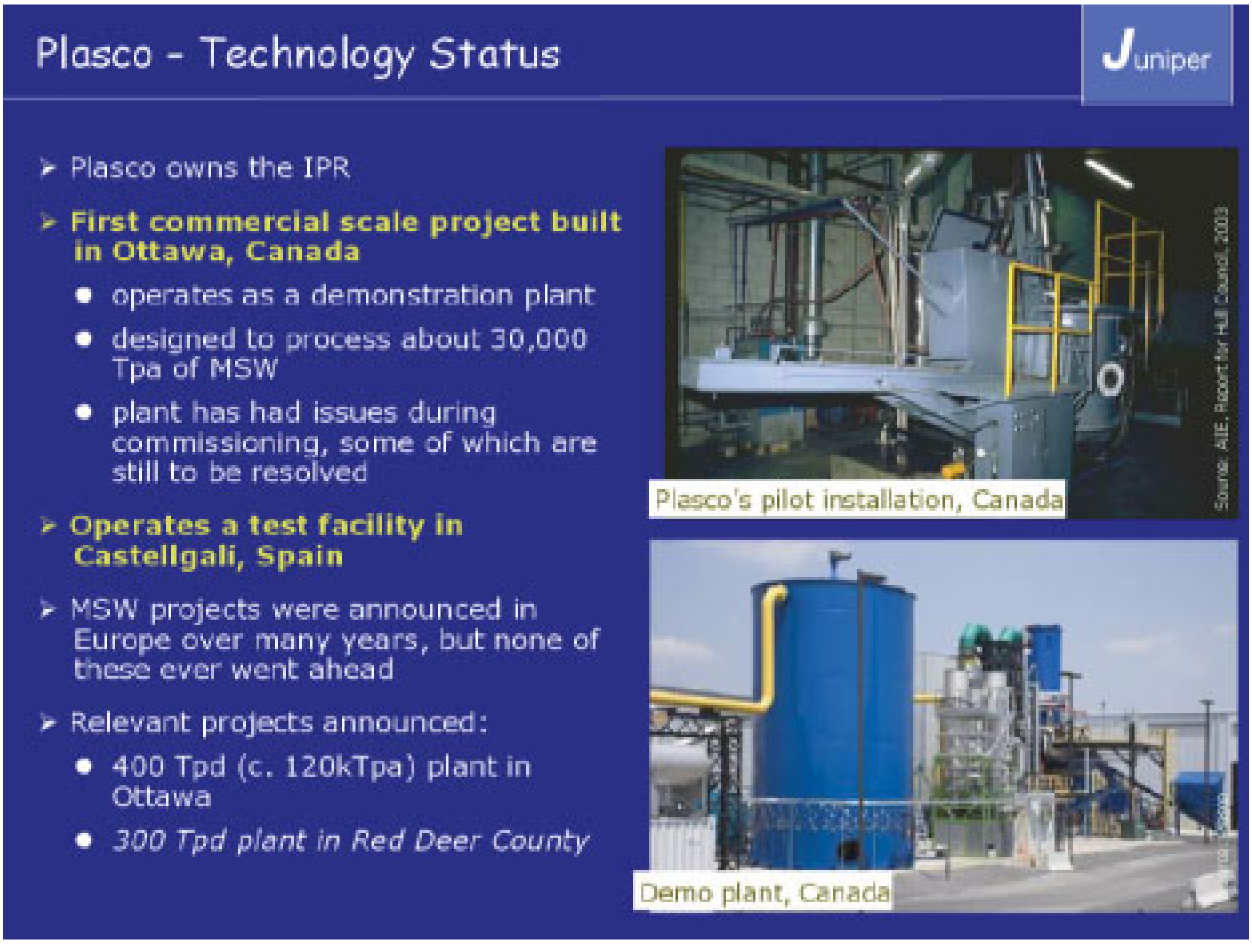


Mihama-Mikata plant


Alter NRG (Westinghouse) Plasma Gasification Reactor
Juniper
Waste Inlet
Freeboard Zone
Syngas
Outlet
Gasification Zone
Air Feed
Plasma Torch
Melting Zone
Metal & Slag
Output


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

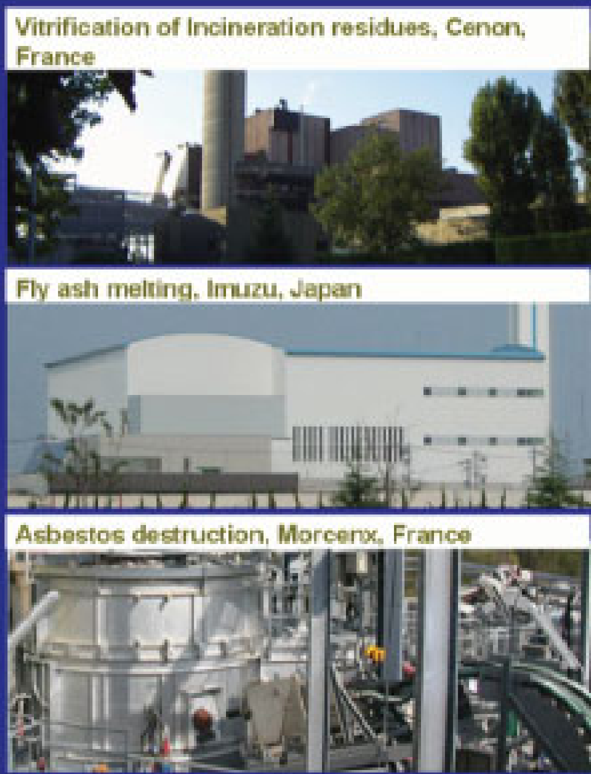

1. Pyrolysis, Gasification and Vitrification of waste take place driven by the Plasma Torches.
2. Syngas is combusted and the products of combustion are directed into –
3. Heat Recovery Steam Boiler. 3* Boiler Pre-heater and Superheater.
4. Steam Turbo-Generator.
5. Flue-gas Evaporating Scrubber.
6. 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
Source: AIE, Report for Hull Council, 2003
Demo plant, Canada

Europlasma - Technology Status

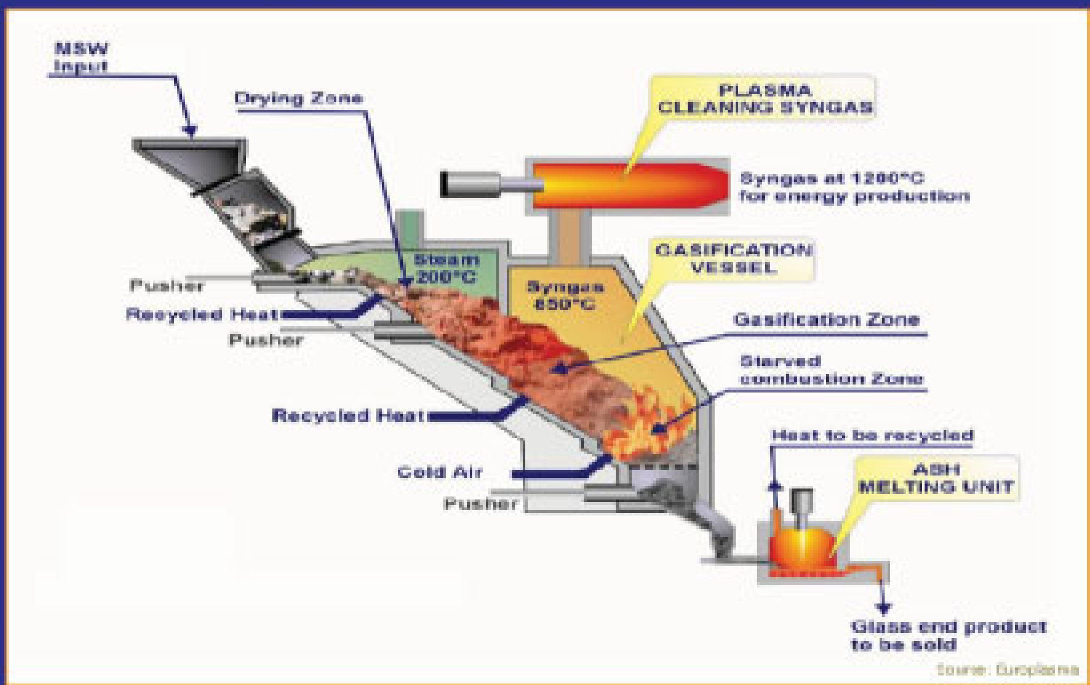
Juniper

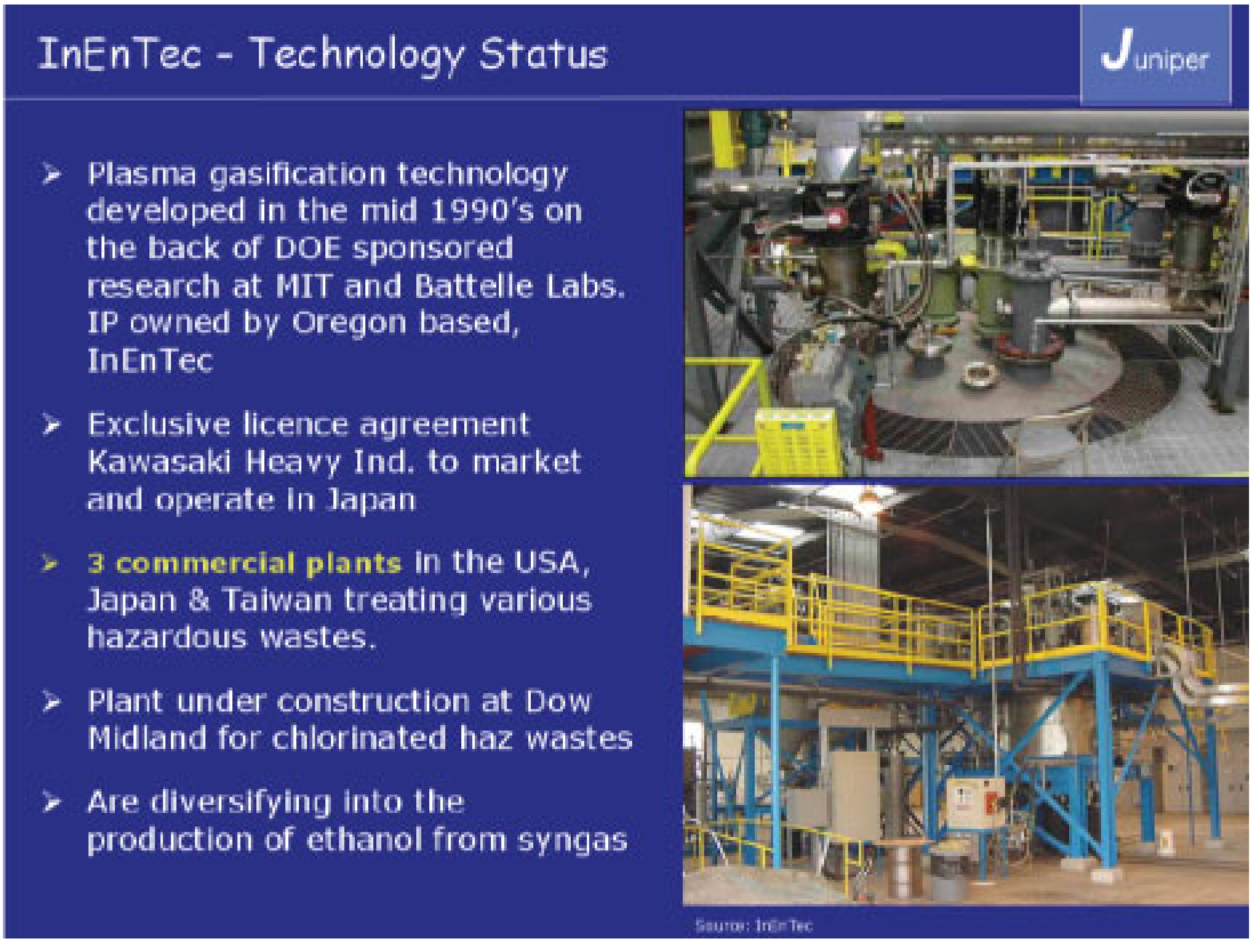
- Europlasma specialises in the use of plasma technology for industrial applications, most notable for haz. waste destruction (vitrification)
- **32 Europlasma torches delivered** for various applications in metal industry and hazardous waste destruction
- Currently expanding its business to
  - CHO-Power: 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

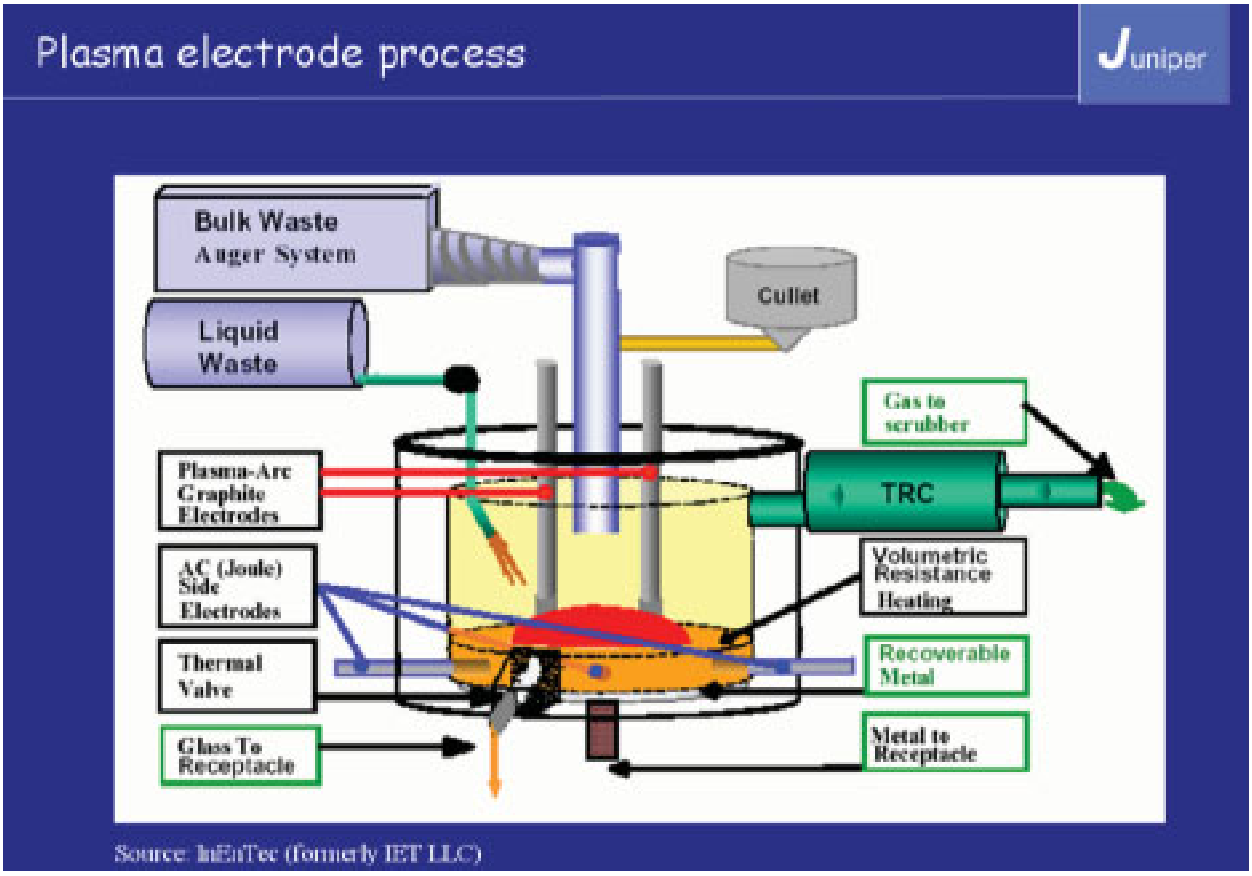


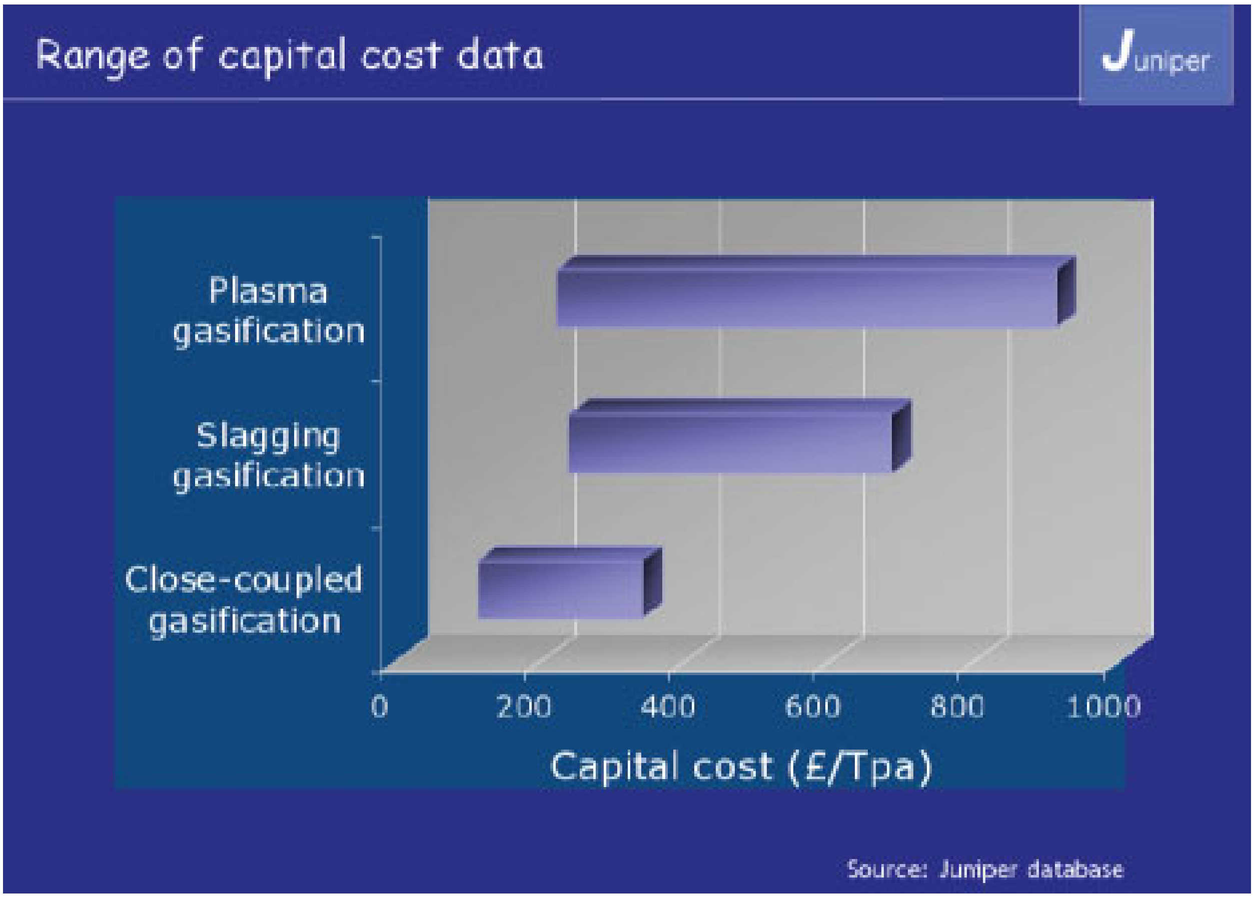
Europlasma - CHO-Power Process

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
Bulk Waste
Auger System
Liquid Waste
Cullet
Gas to scrubber
TRC
Plasma-Arc Graphite Electrodes
AC (Joule) Side Electrodes
Volumetric Resistance Heating
Thermal Valve
Recoverable Metal
Glass To Receptacle
Metal to Receptacle
Source: InEnTec (formerly IET LLC)



Newer roles for plasma technology

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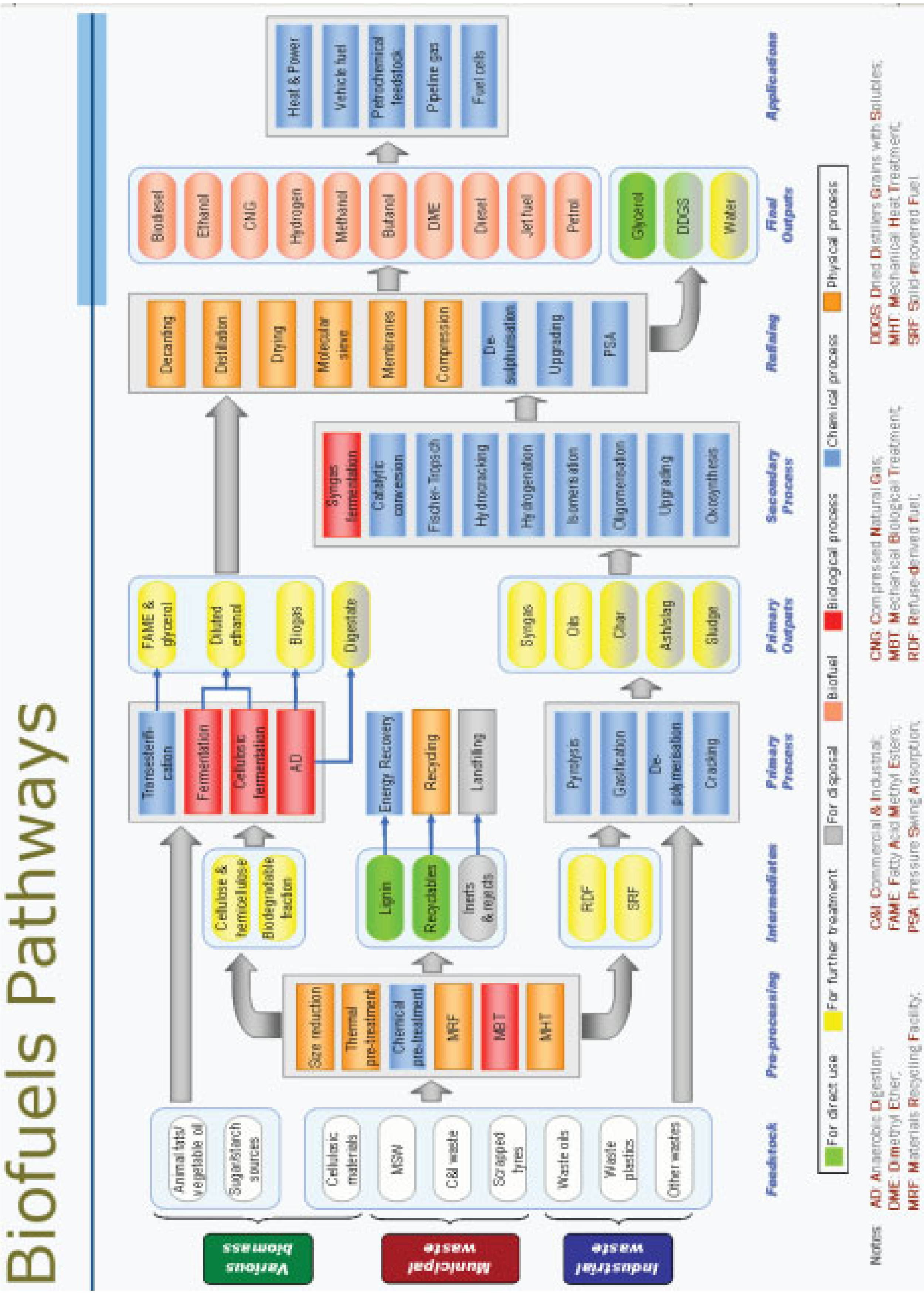
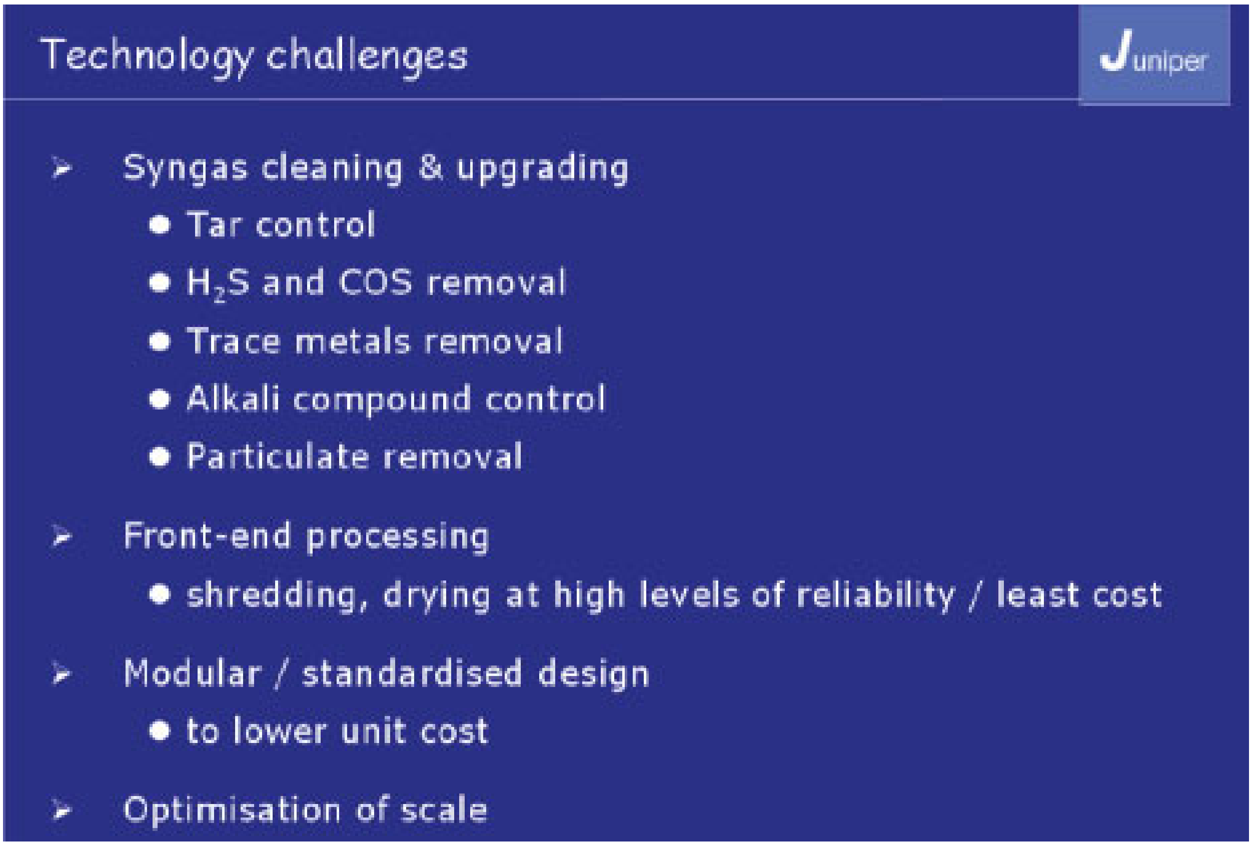
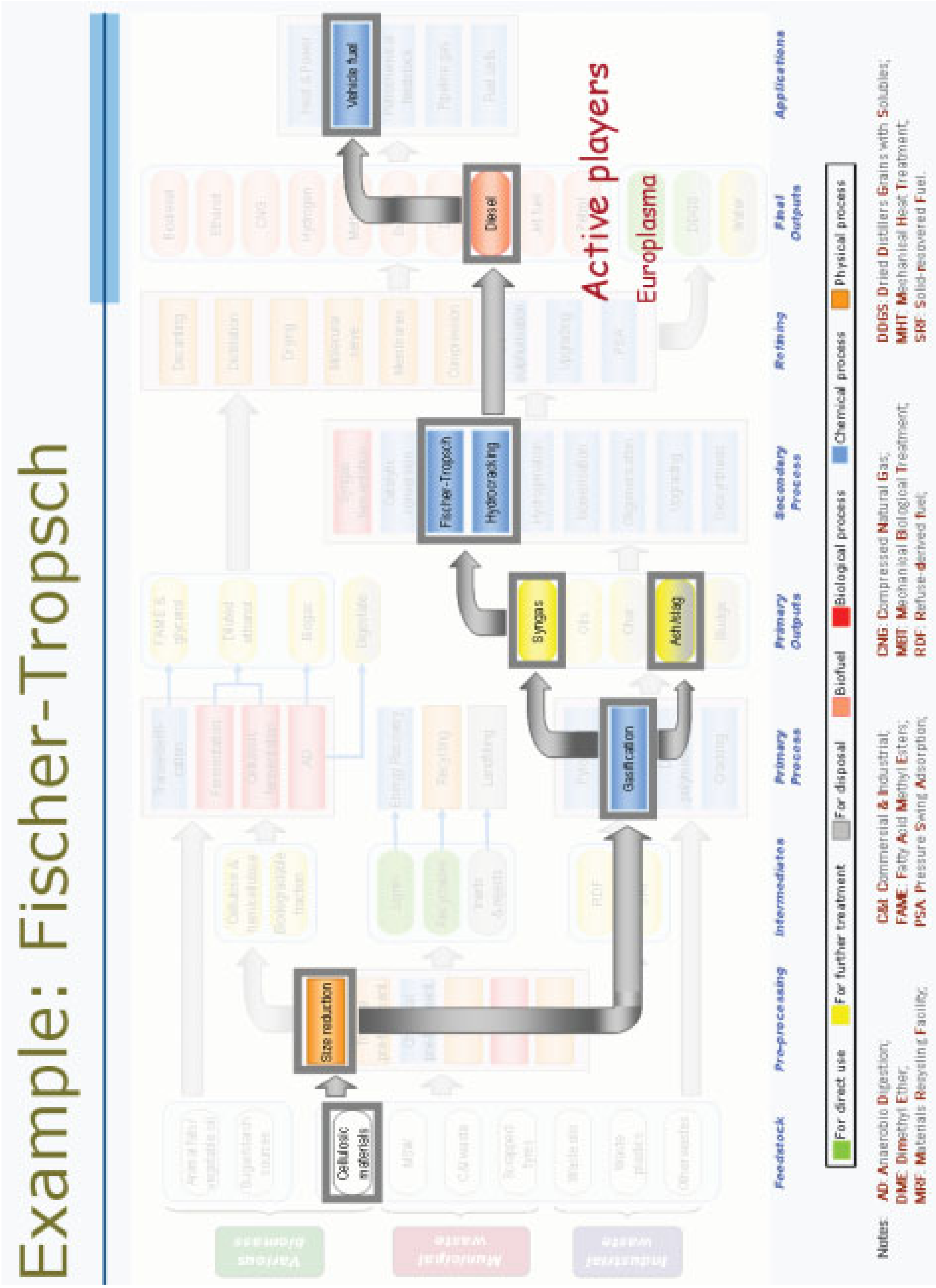
- sustainability objectives include the reduction of CO_2 emissions by:
  - displacement of fossil fuels
  - increase in thermal efficiency
  - conservation of exergy
- biomass utilisation:
  - forestry residue
  - agri-wastes
  - food wastes
  - energy crops
- waste utilisation as a resource (fuel):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


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


Technology challenges
Juniper
Syngas cleaning & upgrading
Tar control
H_2S 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;
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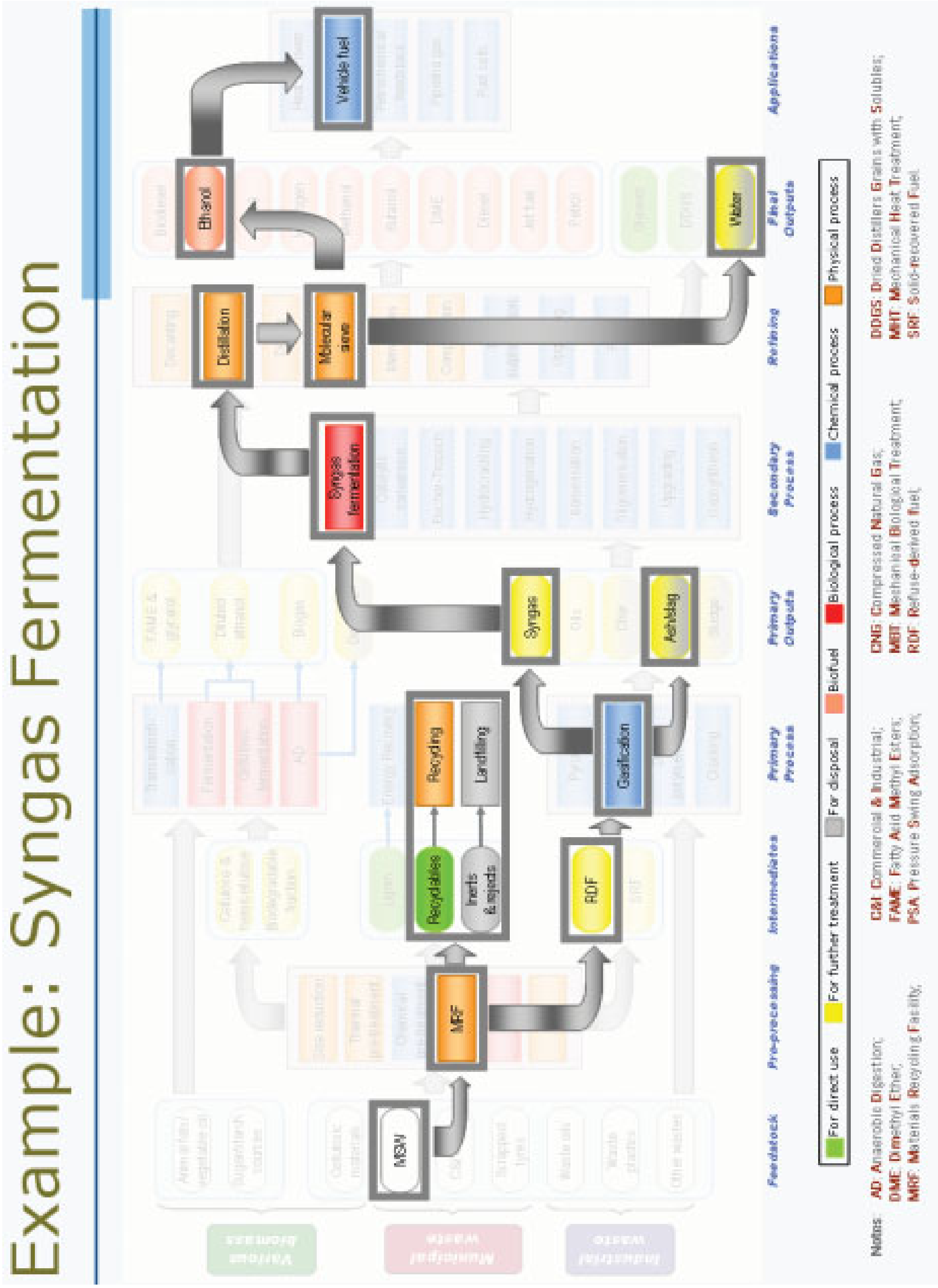
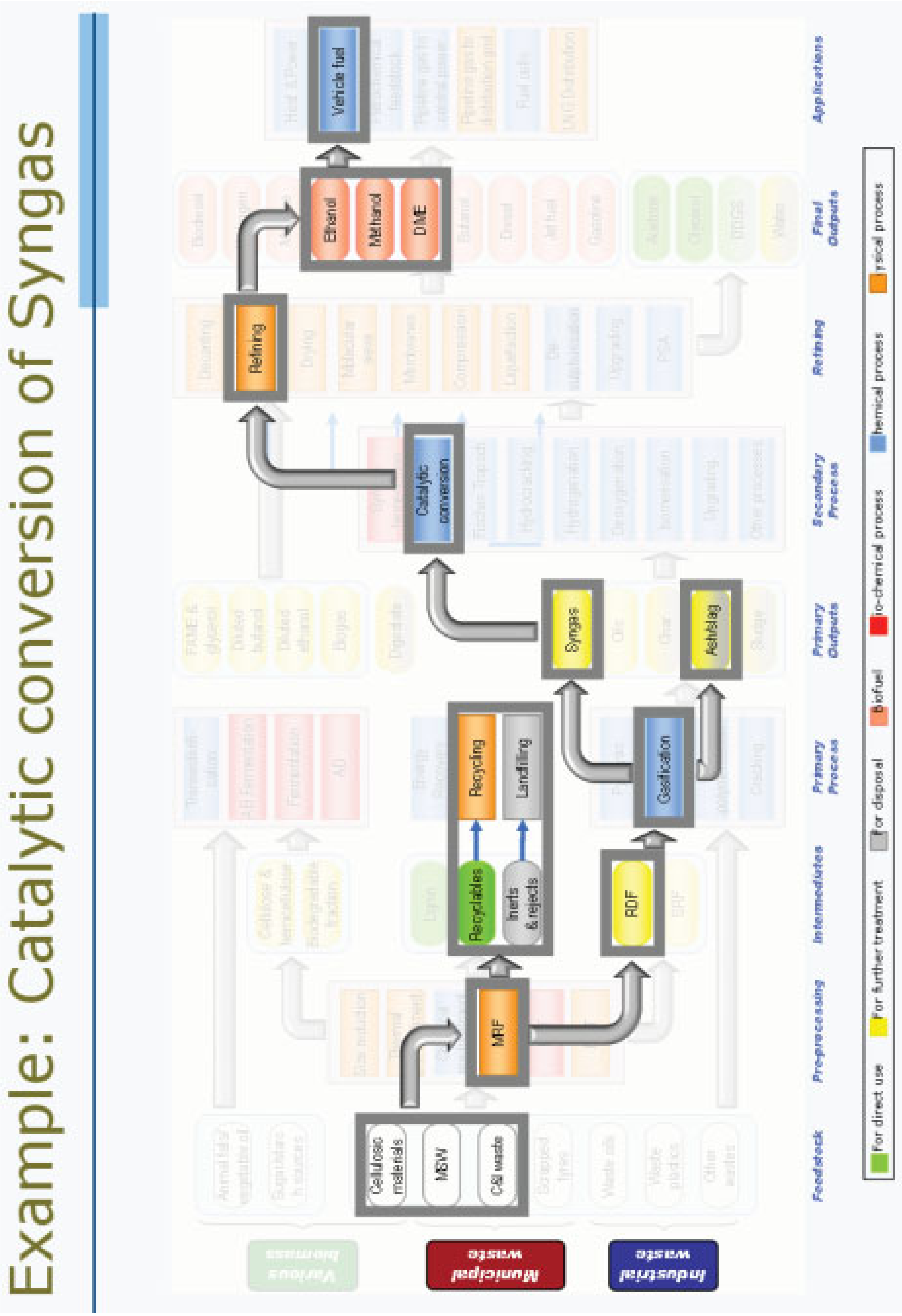

Example: Syngas Fermentation
Feedstock
Pre-processing
Intermediates
Primary Process
Primary Outputs
Secondary Process
Refining
Final Outputs
Applications
MSW
MRF
Recyclables
Inerts & rejects
Recycling
Landfilling
RDF
Gasification
Syngas
Ash/slag
Syngas fermentation
Distillation
Molecular sieve
Ethanol
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; 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: Catalytic conversion of Syngas
Vehicle fuel
Ethanol
Methanol
DME
Refining
Catalytic conversion
Syngas
Ash/slag
Gasification
Recycling
Landfilling
Recyclables
Inerts & rejects
RDF
MRF
Cellulosic materials
MSW
C&I waste
Municipal waste
Industrial waste
Feedstock
Pre-processing
Intermediates
Primary Process
Primary Outputs
Secondary Process
Refining
Final Outputs
Applications

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

Dave Purchase

Environment Agency, Bristol, UK

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

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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

Emmanuel Adler*, Nicolas Fruteau, Jean-Marie Rebillat*****

*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)

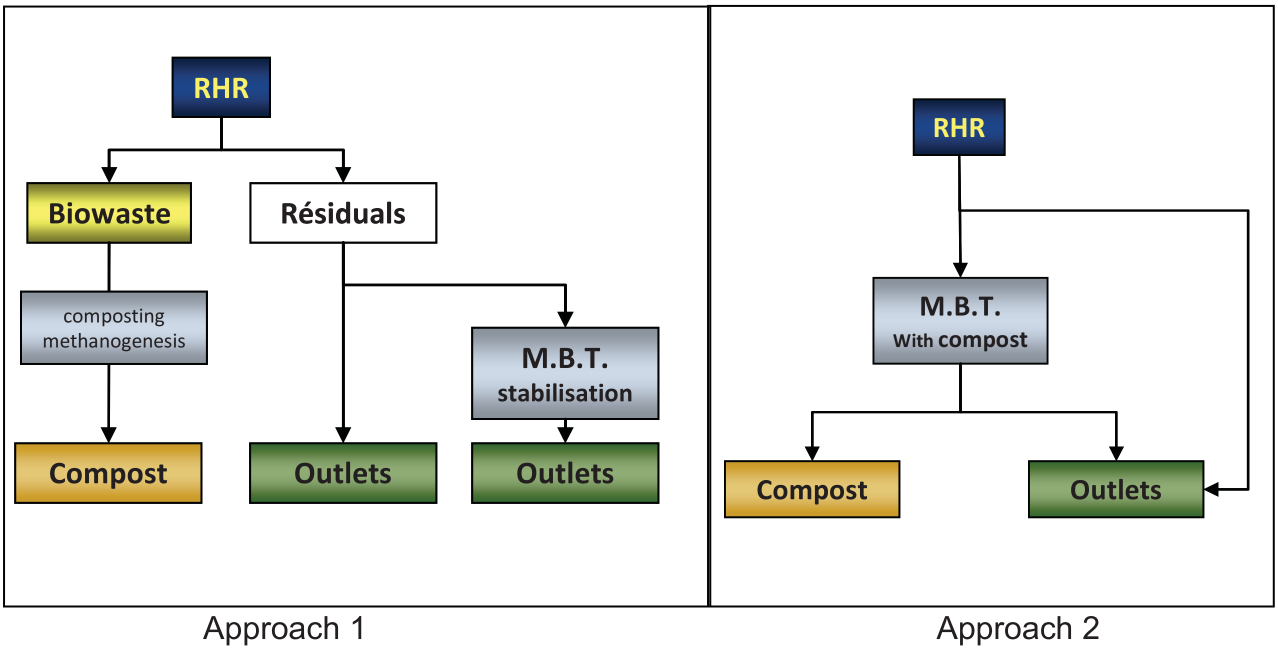

Figure 1: Typology of managing pathways of the organic matter of RHR

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.

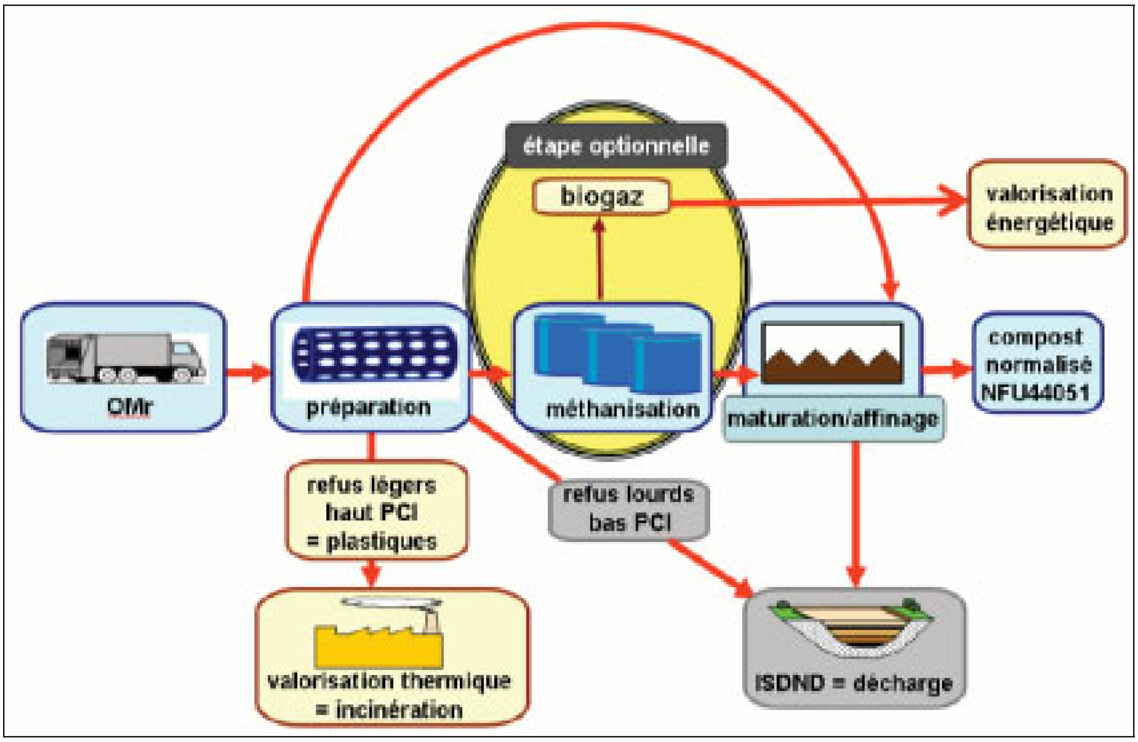

Figure 2: Schematic diagram of the MBT process applied to RHR (with optional methanogenesis)

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-

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[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):

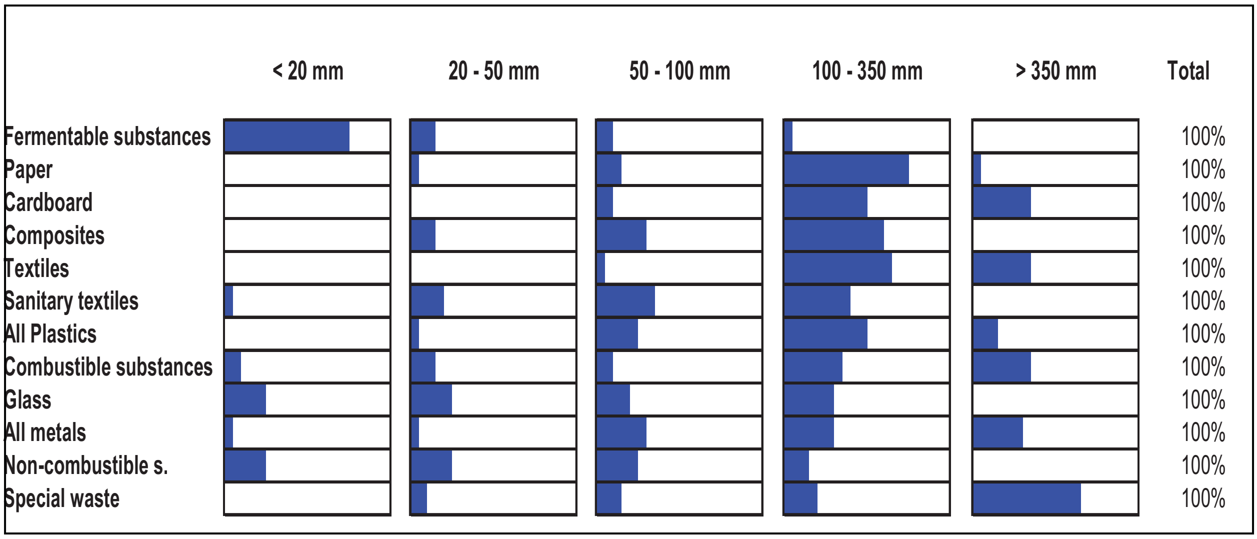

Figure 2: Granulometric distribution of the 12 categories of typical RHR

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

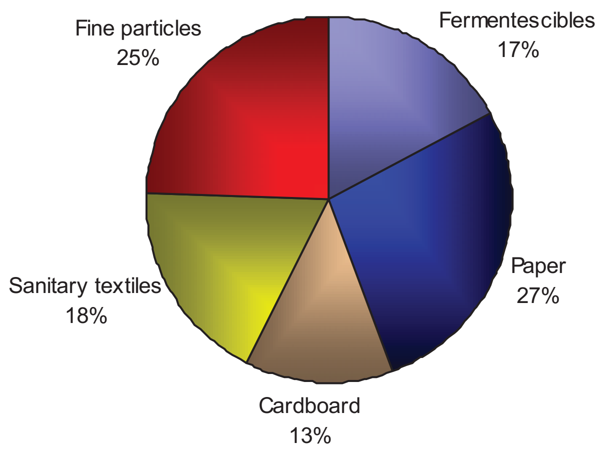

Figure 3 : Distribution of the biodegradable organic matter (as % of the gross) in a typical batch of RHR

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.

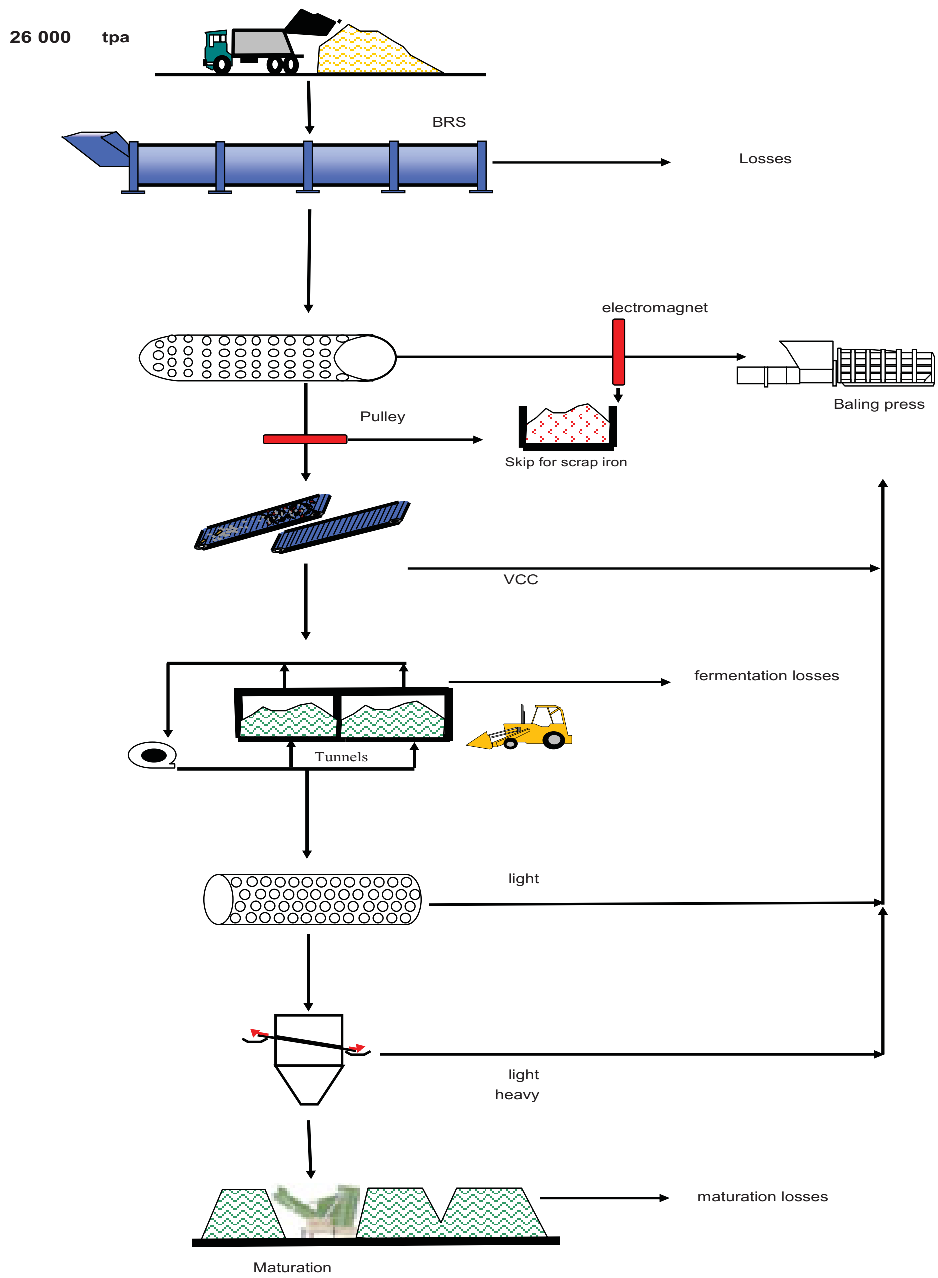

Figure 3: Schematic diagram of the MBT project (26,000 tonnes per annum)

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.

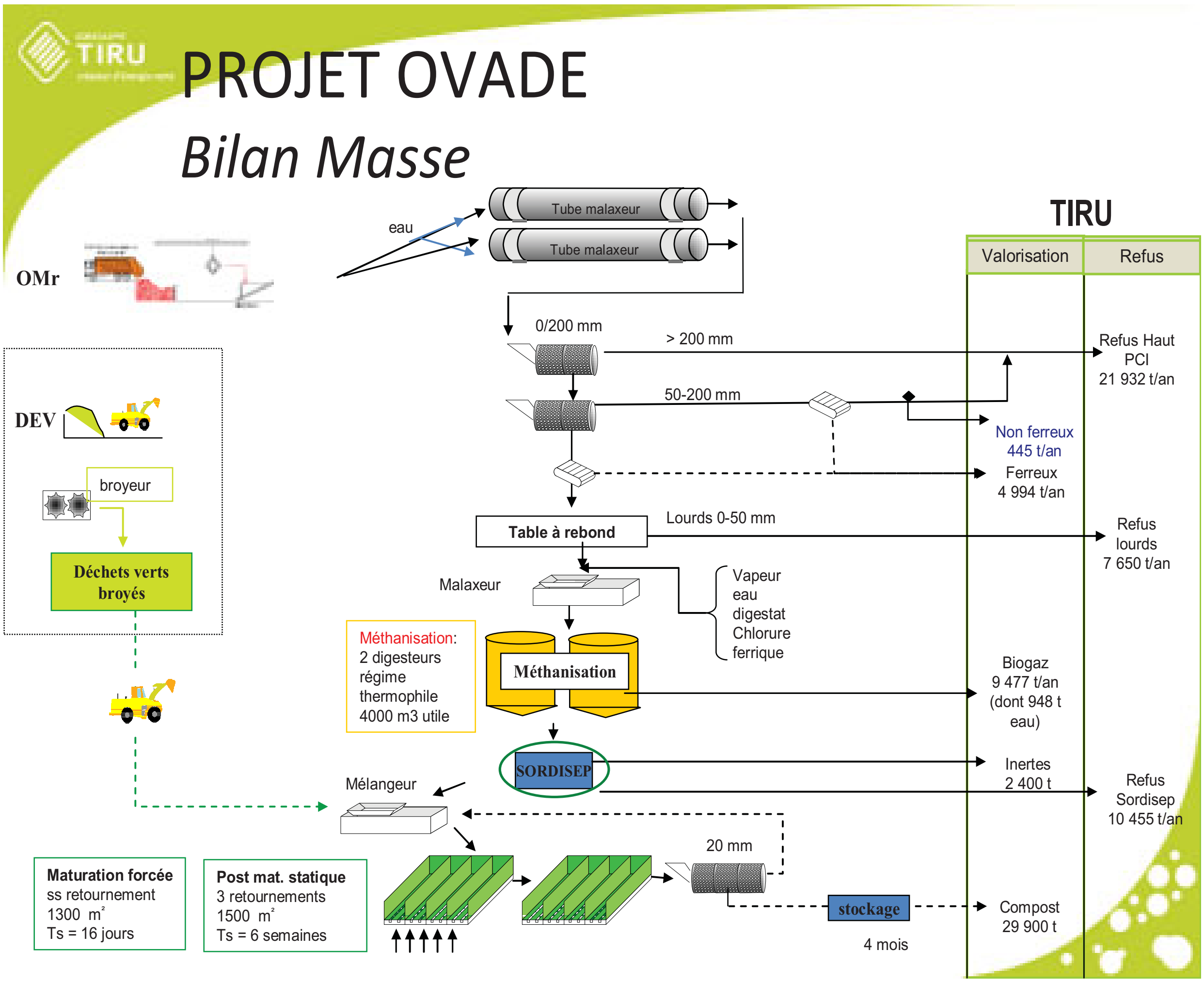

Figure 5: Schematic diagram of the MBT project at Bourg en Bresse

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:

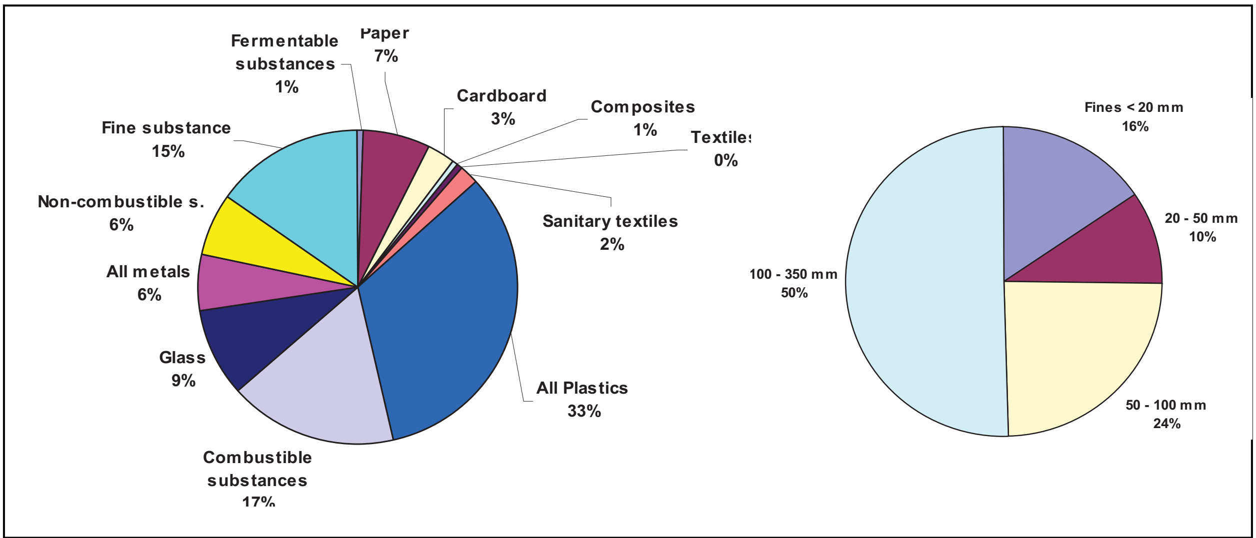

Figure 6: Breakdown of the 9 metals in RHR

[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.

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Erweiterung von MBAs um eine anaerobe Stufe am Beispiel Rostock

Michael Nelles, Joachim Westphal und Gert Morscheck

1 Einleitung

Seit dem 1. Juni 2005 müssen Siedlungsabfälle vor der Deponierung behandelt werden. Ziel dieser Vorbehandlung ist die Inertisierung des Abfalls, dadurch sollen Reaktionen des Abfalls in der Deponie verhindert werden. Zur Vorbehandlung haben sich in Deutschland zwei Verfahren etabliert, die thermische Behandlung der Abfälle in Müllverbrennungsanlagen (MVA) und die mechanisch-biologische Abfallbehandlung (MBA).

Eine Vielzahl von MVA und MBA stehen in Deutschland für die Vorbehandlung der Siedlungsabfälle bereit. 46 MBA behandeln etwa 25% der Rest-Siedlungsabfälle [DOEDENS u.a., 2007]

MVA zerstören die organische Substanz und andere brennbare Bestandteile der Abfälle und nutzen deren Energiegehalt.

MBA trennen die Abfälle i.d.R. in verbrennbare Fraktionen, hauptsächlich Kunststoffe, die dann in speziellen Anlagen thermisch verwertet werden, und eine Fraktion, die sehr viele nativ organische Anteile enthält, und meist aerob behandelt wird.

Die Verfahren der mechanisch(-biologisch)en Abfallbehandlung haben ihre prinzipielle Funktionsfähigkeit nachgewiesen. Die technischen Schwierigkeiten, die während des Betriebs der Anlagen aufgetreten waren, konnten zwischenzeitlich zu erheblichen Teilen gelöst werden. Bei einzelnen Anlagen sowie in verschiedenen Teilbereichen der MBA-Technik besteht dagegen noch Optimierungsbedarf (THOMÉ-KOZMIENSKY und THIEL, 2008).

Bereits zu Beginn der 90er Jahre begann Rostock sich Gedanken über die zukünftige Abfallbewirtschaftung zu machen. 1993 hatte die TASi den entsorgungspflichtigen Körperschaften vorgeschrieben bis zum 31. Mai 2005 Vorbehandlungsanlagen zu errichten. Im Mai 1994 erfolgte die Gründung der EVG (Entsorgungs- und Verwertungsgesellschaft mbH Rostock).

Unter Führung der EVG arbeitet ein Beratergremium, welches sehr breit zusammengesetzt war (Wirtschaft, Verbände, Verwaltung, Umweltverbände und Universität Rostock) und Lösungen intensiv diskutierte. Dabei ging es hauptsächlich um die Entscheidung eine MVA oder eine MBA zu errichten.

Im Mai 1996 erfolgte die Ausschreibung eines europaweiten Technikanbieterwettbewerbes für die Restabfallbehandlung der Stadt Rostock und der angrenzenden Landkreise.

Im Juni 1997 kam es zum Bürgerschaftsbeschluss zum Bau einer Restabfallbehandlungsanlage bestehend aus mechanisch-biologischer Aufbereitung und thermischer Behandlung am Standort Seehafen Rostock.

Im September 1998 erfolgte der Abschluss Entsorgungsvertrag zwischen der EVG mbH Rostock und der Hansestadt Rostock.

Im Dezember 1998 begann das Genehmigungsverfahren und im September 2000 wurde der Genehmigungsbescheid nach BImSchG für die Errichtung und den Betrieb der RABA Rostock erteilt.

Im Januar 2004 fällt die Bürgerschaft der Hansestadt einen weitreichenden Beschluss zur Konzeptänderung, jetzt wird der Bau einer MBA geplant, eine Verbrennungsstufe in der Verantwortung der EVG wird nicht errichtet. Zurzeit errichtet die Vattenfall Europe New Energy GmbH ein Sekundärbrennstoff-Heizkraftwerk direkt neben der MBA.

Am 27.05.2004 erfolgt die Grundsteinlegung für die MBA Rostock, die dann am 01.06.2005 in Betrieb genommen wurde.

Im Juli 2008 wurde eine Vergärungsanlage als Ergänzung der MBA in Betrieb genommen.

2 Anlagentechnik

Die mechanisch-biologische Abfallbehandlungsanlage (MBA) Rostock wird seit dem 1. Juni 2005 von der EVG betrieben. Es wird der Hausmüll der Hansestadt Rostock sowie der Landkreise Bad Doberan, Güstrow und Nordvorpommern behandelt. Etwa 120.000 Mg Abfall wurden pro Jahr angeliefert und behandelt.

Der Hausmüll wird in der MBA zuerst einer mechanischen Behandlung (Siebung, Sichtung, FE- und NE-Ausschleusung, Kunststofftrennung) unterzogen. Dabei werden Wertstoffe abgetrennt und die aufbereitete, organikhaltige Feinfraktion der biologischen Behandlung zugeführt.

Bislang wurden aus den Abfallmengen zwei verschiedene Endprodukte gewonnen: Zum einen Sekundärbrennstoff (etwa 40 % der Gesamtmenge) und zum anderen wird nach der Rotte ein ablagerungsfähiges Deponiegut (etwa 50 %) erzeugt. Der Ersatzbrennstoff wird in unterschiedlichen Stückgrößen produziert und als Kohleersatz in Zement- und Kraftwerken eingesetzt. Abnehmer ist auch das Nehlsen Heizkraftwerk in Stavenhagen, das mit dem hochwertigen Ersatzbrennstoff Energie für das angrenzende Pfanni-Werk produziert. Ab dem 2. Quartal 2009 werden alle Sekundärbrennstoffe an das Vattenfall SBS-Heizkraftwerk geliefert, das direkt neben der MBA errichtet wird.

Der organische Abfallanteil wird in einer Kombination von Intensiv- und Nachrottebehandlung innerhalb von 10 Wochen stabilisiert und anschließend auf Deponien abgelagert werden. Der Rotteprozess erfordert eine ständige Belüftung des Rottematerials in den Rottereaktoren. Zur Temperaturregelung während des Rottevorgangs wird eine Kühlung benötigt. Zudem muss die Abluft, die in die Umwelt abgegeben wird, durch eine Nachoxydation gereinigt werden. Alle drei Komponenten sind sehr energie- und damit kostenintensiv. Hinzu kommt, dass die organische Fraktion auch nach der aeroben Behandlung noch bislang nicht genutzte Energie enthält.

Die hohen Energiekosten und die bisher ungenutzte Energie des biogenen Materials haben nach Neubewertung der Abfallströme zu einer zukunftsorientierten und umweltschonenden weiteren Stufe der Abfallbehandlung geführt; der Energiegewinnung durch Vergärung.

Die neue, ergänzte Vergärungsanlage mit KOMPOGAS-Technologie erhöht die Inputkapazität von 120.000 auf nun genehmigte 135.000 Tonnen Abfall pro Jahr. Dies wurde möglich, da durch den Vergärungsprozess bereits vor der Intensivrotte ein biologischer Abbau erfolgt, der zu einer Reduzierung der Belastung in der bisherigen Schwachstelle RTO (Regenerativ Thermische Oxidation zur Abluftreinigung) führte. Nach umfangreichen Tests wurde die Anlage im ersten Quartal 2008 in Betrieb genommen.

Eine Voraussetzung für die Bestückung der Vergärungsanlage ist die Änderung des Materialflusses im Trennungsprozess der MBA. Ziel ist es, die Hälfte der Biomasse, die bislang aus den Trennungsverfahren in die Intensivrottereaktoren geleitet wurde, der Vergärung zuzuführen. Dies geschieht, indem die organischen Stoffe nach der Hartstoffabscheidung in einen Zwischenbunker eingebracht werden. Die sedimentierenden Stoffe dagegen werden nach Abscheidung der nicht eisenhaltigen Metalle direkt in den Rottetunnel gebracht.

Das organikreiche Material aus dem Zwischenbunker wird über Förderbänder mittels automatischer Steuerung - zyklisch gleichmäßig verteilt - in die drei liegenden Vergärungs-Fermenter eingebracht. Ein automatisches Rührwerk durchmischt das Material in den Fermentern mit jeweils 1.200 m³ Fassungsvermögen. Bei einem mittleren Wassergehalt von 75 % und einer relativ konstanten Temperatur von 53,5°C werden unter Sauerstoffabschluss optimale Bedingungen für Erzeugung von Biogas geschaffen. Die Verweilzeit im Fermenter beträgt 10 bis 12 Tage.

Nach der Entschwefelung wird das Biogas über zwei gasmotorisch betriebene Blockheizkraftwerke (2 x 625 kW elektrisch) zu Strom und Wärme. Auf diese Weise werden durch die EVG über 12.000 MWh/a Elektroenergie in das öffentliche Netz eingespeist.

Die Abwärme der Blockheizkraftwerke wird zur Beheizung der Fermenter und der anliegenden Gebäudeteile genutzt. Die vollständige Wärmenutzung sowohl der BHKW´s als auch der Abgaswärme erfolgt mit Inbetriebnahme des Vattenfall-Heizkraftwerkes durch Einspeisung in den Dampfkreislauf.

Die Gärreste werden über einen kombinierten Trocken-/Nassaustrag der gemeinsamen Verrottung mit den anderen organischen Bestandteilen zugeführt. Dieses Verfahren dient der Optimierung des anschließenden Rottevorgangs.

Neben der Verarbeitung des biologischen Anteils des Hausmülls ist zusätzlich die Zuführung von Speiseresten und überlagerten Lebensmitteln möglich. Der Input von Speiseabfällen beträgt jährlich 4.000 Tonnen.

Komplettiert wird das Gesamtkonzept der Anlage im Überseehafen durch das Sekundärbrennstoff-Heizkraftwerk, dessen Inbetriebnahme voraussichtlich im 1. Quartal 2009 durch die Firma Vattenfall Europe New Energy Ecopower GmbH als Betreiber erfolgt. Dorthin wird die EVG dann zukünftig Sekundärbrennstoffe und die Abluft der MBA liefern, die bislang selbst aufwendig gereinigt und verbrannt werden musste (RTO). Damit erfolgt auch eine energetische Nutzung des in der Abluft der Aerobstufe befindlichen Methans (ca. 0,1 %).

Damit ist die EVG über Mecklenburg-Vorpommern hinaus Vorreiter, indem sie die Abfälle nutzt, um umweltschonend Energie zu gewinnen und Ersatzbrennstoffe ohne umweltbelastende Transporte nach dem neusten Stand der Technik energetisch zu verwerten. MBA, Vergärung und Heizwerk ermöglichen eine vollständige Energierückgewinnung und bilden gemeinsam einen der modernsten Abfallwirtschaftsstandorte in Deutschland.

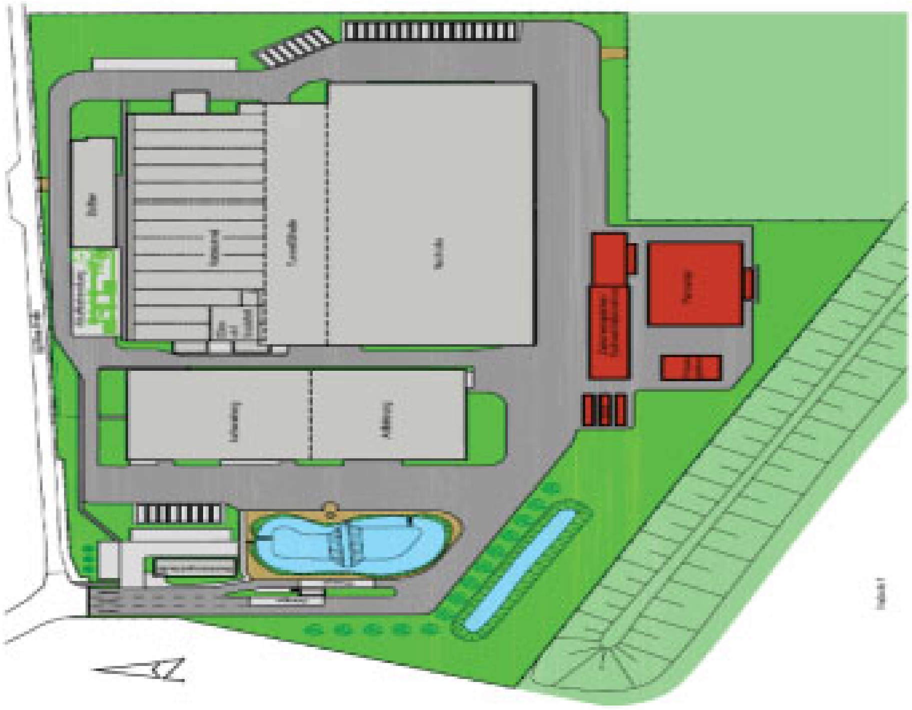

Abbildung 1: Lageplan der MBA mit aerober und anaerober Behandlung

Das verfahrenstechnische Konzept der MBA ist nachfolgend durch ein Grundfließbild dargestellt (Abbildung 2).

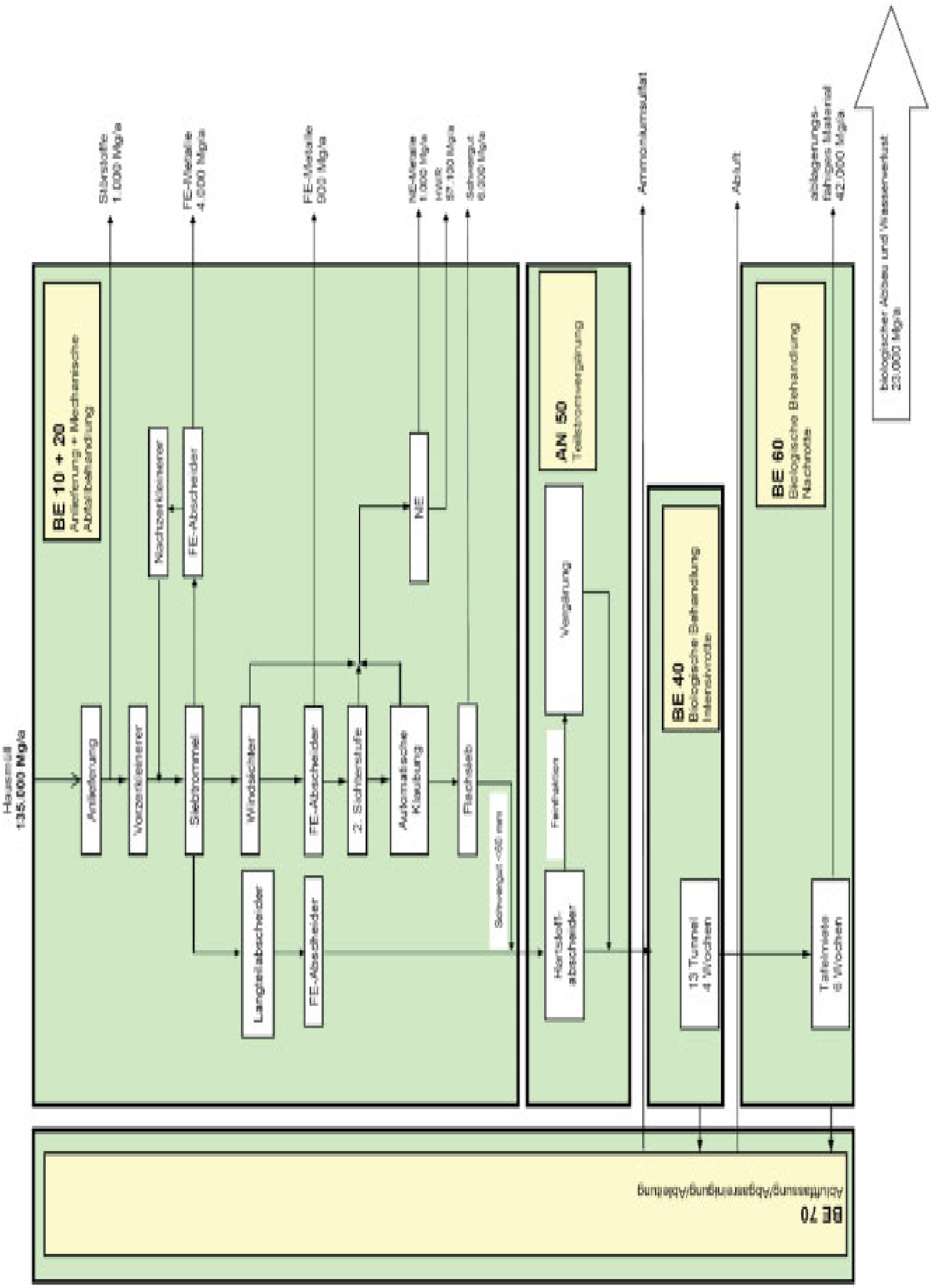

Abbildung 2: Verfahrensfließbild der MBA Rostock

Die Betriebseinheiten aus Abbildung 2 werden nachfolgend erklärt:

BE 10 + 20 Anlieferung + Mechanische Abfallbehandlung

- gekapselte Anlieferungs- und Aufbereitungshalle
- einlinige Ausführung: Organiklinie
- Zerkleinerungsaggregate
- Klassierung der Abfallströme
- Einsatz von Windsichtern und AutoSort-Systemen

AN 50 Teilstromvergärung

- Hartstoffabscheider
- Vergärung

BE 40 Biologische Behandlung Intensivrotte

- gekapselte Tunnelrotte; (13 Tunnelmodule, Umluftführung mit Kühlung, Rottedauer 4 Wochen)

BE 60 Biologische Behandlung Nachrotte

- geschlossene Tafelmiete (Rottedauer 6 Wochen); Ziel: Einhaltung der Ablagerungskriterien gemäß AbfAblV

BE 70 Abluftfassung/Abgasreinigung/Ableitung

- getrennte Erfassung und Weiterleitung von Abluft aus Hallenbereichen gegenüber Prozessabluft aus
- hoch- und minderbelasteten Bereichen der biologischen Behandlung
- weitestgehende Kreislaufnutzung der Luft zur Mengenminimierung
- Behandlung der hochbelasteten Prozessabluft in einer Verfahrenskombination aus saurem Wäscher u. RTO
- Behandlung der schwachbelasteten Prozessabluft in einer Verfahrenskombination aus Luftbefeuchter u. gekapseltem Biofilter
- gezielte Ableitung der Abluft über Kamin Ziel: Einhaltung der Emissionsgrenzwerte gemäß 30. BImSchV

3 Ergänzung der MBA um eine Vergärungsstufe – warum?

In Zeitraum von 1990 bis 2003 hat die Abfallwirtschaft ca. 45 Millionen Jahrestonnen CO_2-äquivalente Emissionsminderungen erbracht, fast 20 % der Gesamtreduktionen der Bundesrepublik (TROGE, 2007). Die Bundesregierung möchte bis 2020 den Anteil erneuerbarer Energien in Deutschland auf 16% erhöhen. Auch Biogasanlagen der Abfallwirtschaft werden hier ihren Beitrag leisten können und müssen. Die Umstellung aerober Verfahren auf anaerobe, bzw. die Ergänzung um anaerobe Stufen, soll im Bereich der Erzeugung elektrischer Energie zunehmend Bedeutung erlangen. Ökologisch macht dieses aus Sicht der Autoren nur dann Sinn, wenn auch die Wärme aus der Verstromung genutzt wird!

Folgende Möglichkeiten der Ausstattung der MBA mit einer anaeroben Stufe sind denkbar, die Betriebserfahrungen aber recht unterschiedlich:

- mit Teilstromtrockenvergärung (betriebsstabil)
- mit Vollstrom-Trockenvergärung (Prozesswasseraufbereitung nach Gärrestentwässerung)
- mit Vollstrom-Nassvergärung (Perkolation, aufwändig, Anlagen in Heilbronn und Buchen außer Betrieb) [DOEDENS u.a., 2007]

Auch der Sachverständigenrat für Umweltfragen(SRU, 2008) verweist in seinem Umweltgutachten 2008 „Umweltschutz im Zeichen des Klimawandels“ auf die Vorteile einer anaeroben Stufe in MBA hin.

Bei aeroben Verfahren wird der Energieinhalt der organischen Substanz vollständig in nicht nutzbare Wärme umgewandelt wird. Dagegen ermöglichen die verschiedenen Kombinationsverfahren mit anaeroben Teil- oder Vollstromkonzepten eine Energiegewinnung. Dadurch kann die Vergärungsstufe zur Verbesserung der ökonomischen und ökologischen Situation der MBA beitragen (SRU, 2008).

Die Förderung nach dem Erneuerbare-Energien-Gesetz (EEG) ist für gemischte Siedlungsabfälle nicht vorgesehen. §8 des EEG verweist auf die Biomasseverordnung „anerkannte Biomasse“; gemischte Siedlungsabfälle gehören nicht dazu (BiomasseV §3 Nr. 3). Nach § 3 Abs. 1 fördert das EEG die Gewinnung von Energie aus Biomasse. Trotzdem wird die Förderung der Biomassenutzung im Rahmen der Vergärung in MBA zunehmend ermöglicht. Auch die MBA Rostock wird gefördert.

Nach der weitgehenden Abtrennung der nativ organischen Substanz können eigenständige Abfallschlüsselnummern vergeben werden. Vergoren werden dann keine gemischten Siedlungsabfälle mehr. Die nativ organische Fraktion trägt dann die AVV-Nr.

191212, es werden als keine gemischten Siedlungsabfälle eingesetzt (TISCHER und GASSNER, 2006).

Im §2 Abs. 3 Nr. 5 der Biomasseverordnung wird definiert: „Unbeschadet von Absatz 1 gelten als Biomasse: … durch anaerobe Vergärung erzeugtes Biogas …“. Das ist dann förderbar.

Das Gesetz für den Vorrang Erneuerbarer Energien betont in §3 nochmals, was „Erneuerbare Energien“ sind: … „Energie aus Biomasse einschließlich Biogas, Deponiegas und Klärgas sowie aus dem biologisch abbaubaren Anteil von Abfällen aus Haushalten und Industrie“.

§ 64 des neuen EEG führt weiter aus, „dass der Anspruch auf Vergütung von Strom aus Biomasse nur besteht, wenn nachweislich …“bei der Erzeugung des Stroms aus der eingesetzten Biomasse eine bestimmte Treibhausgasminderung erreicht wird“. Diese Minderung ist nachzuweisen.

In der Begründung für das neue EEG wird diese zukünftig generell mögliche Honorierung für die MBA umfangreich erklärt:

„Der Begriff Biomasse wird im Gesetz selbst nicht abschließend definiert. … Der an dieser Stelle verwendete allgemeine Begriff „Biomasse“ umfasst biogene Energieträger in festem, flüssigem und gasförmigem Aggregatzustand. Es handelt sich allgemein um biologisch abbaubare Erzeugnisse, Rückstände und Abfälle pflanzlichen und tierischen Ursprungs aus der Landwirtschaft, der Forstwirtschaft und damit verbundener Industriezweige. ...

Die Klarstellung, dass als Biomasse hier auch Biogas verstanden werden soll, geht auf die Richtlinie 2001/77/EG des Europäischen Parlaments und des Rates zur Förderung der Stromerzeugung aus erneuerbaren Energiequellen im Elektrizitätsbinnenmarkt zurück, die Biogas als gesonderte Erneuerbare Energie aufführt. … Ebenfalls in Umsetzung der Richtlinie 2001/77/EG wird auch der biologisch abbaubare Anteil von Abfällen aus Industrie und Haushalten als Erneuerbare Energie definiert. Es gilt zu beachten, dass durch diese Erweiterung nur der anteilig daraus erzeugte Strom in den Anwendungsbereich des Gesetzes fällt. Darüber hinaus ist zu berücksichtigen, dass für die Vergütung von Strom weiterhin das Ausschließlichkeitsprinzip gilt und Strom aus gemischten Abfällen aus Industrie und Haushalten auch in Zukunft nicht vergütet wird.“

4 Vergärungsstufe der EVG

Die ökonomischen Rahmenbedingungen für Anaerobtechnologien haben sich in den vergangenen Jahren durch technische Entwicklungen und durch das EEG deutlich verbessert (TURK u.a., 2008)

In Rostock wurde die bestehende MBA um eine Teilstromvergärungsanlage mit Blockheizkraftwerk ergänzt. Dadurch ist eine Erhöhung der Inputkapazität von 120.000 t/a auf 135.000 t/a möglich. Es werden Reserven für saisonale Schwankungen und zusätzliche Verarbeitungsmöglichkeiten für organische Abfälle geschaffen. Mit dem Aufbau der Vergärungsstufe soll eine energetische Nutzung der biogenen Masse umgesetzt werden. Dazu wird ein 50-prozentiger Teilstrom der biogenen Masse, der bisher in die Intensivrottereaktoren geleitet wurde, in der Vergärungsanlage behandelt.

Das erzeugte Biogas wird in einem gasmotorisch betriebenen BHKW zu elektrischem Strom und Wärme umgewandelt. Die im BHKW erzeugte elektrische Energie von 12.000 MWh/a wird in das Netz eingespeist. Die Restwärme wird am Standort zur Vorheizung und Trocknung genutzt. Die Vergärungsstufe reduziert die Aufwendungen in der Abluftbehandlung in der nachgeschalteten Rotte.

Die MBA der EVG ist in M-V die erste Anlage, die Hausmüll zur Biomassevergärung nutzt und dadurch umweltschonend Energie „gewinnt“. In Kombination mit dem Heizkraftwerk für die Sekundärbrennstoffe aus der MBA, das von Vattenfall Europe New Energy GmbH betrieben wird, erfolgt durch die Vergärung eine weitgehende „Energierückgewinnung“ am Standort Rostock-Überseehafen. Auch die Abluft der MBA, die bislang aufwendig in einer Regenerativen Thermischen Oxidation gereinigt und verbrannt werden musste, wir demnächst gemeinsam mit den Ersatzbrennstoffen verbrannt. Die Nähe von MBA und thermischer Verwertung bringt zusätzlich ökologische und ökonomische Vorteile.

Das Investitionsvolumen für die Vergärungsanlage betrug 8 Mio. Euro. Mit dieser Investition ist die Grundlage für stabile Kosten und Entsorgungssicherheit geschaffen.

Auf diese Weise kann die EVG ihren gesamten Energiebedarf selbst decken und zusätzlich über 3.700 MWh/a in das öffentliche Netz speisen. Die Abwärme der Blockheizkraftwerke wird zur Beheizung der Fermenter und der anliegenden Gebäudeteile genutzt. Eine vollständige Wärmenutzung ist ab 2009 vertraglich gebunden.

Die Gärreste werden über einen kombinierten Trocken-/Nassaustrag der Verrottung zugeführt.

5 Die Vergärungseinheit - KOMPOGAS-Trockenvergärung

Für die Materialaufbereitung können die vorhandenen Aggregate wie Sieb, Shredder, Magnetabscheider herangezogen werden. Mit ihnen wird das angelieferte Material zerkleinert, von magnetischen Störstoffen befreit und auf ca. < 60 mm abgesiebt. Der Siebdurchgang wird in den Zwischenspeicher aufgegeben. Der Siebüberlauf kann nochmals zerkleinert oder einer anderen Verwertungsschiene zugeführt werden (z. B.

EBS, …). Die Aufbereitung soll so erfolgen, dass nur zerkleinerungsbedürftiges Material definiert zerkleinert wird. Speisereste, Bioabfälle etc. sollen möglichst nur gesiebt werden. Ziel ist, die eigentliche Materialstruktur zu erhalten.

Das Grundprinzip ist immer gleich: der liegende Pfropfenstrom-Fermenter, der eine sehr hohe Energieeffizienz und maximale Betriebssicherheit gewährleistet. Er wird in standardisierter Modulbauweise in Kompostwerke und MBA integriert (ZEIFANG, 2008).

Die Prozesstemperatur beträgt hierbei 55 °C, liegt also im thermophilen Bereich. Die dafür benötigte Wärme wird über die Abwärme des BHKW bereitgestellt.

Das ausgefaulte Material wird zur weiteren Konditionierung einer Abpressung zugeführt und dort in eine flüssig Fraktion (Rezirkulat) und eine fest Fraktion (Rohkompost) getrennt. Das Rezirkulat wird in der Regel für die Anmaischung des neuen Materials benutzt, so dass keine externen Flüssigkeiten eingesetzt werden müssen.

Die kontinuierliche Betriebsweise führt zu einer stabilen Biogasproduktion (Universität Rostock u.a., 2007).

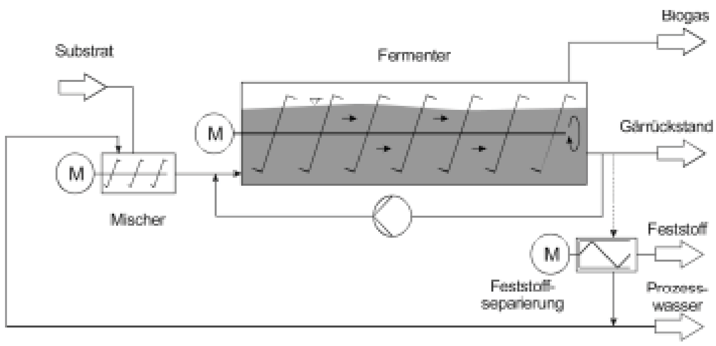

***Abbildung 3**: Kontinuierliche Trockenfermentation mit Pfropfenstrom-Fermenter (KOMPOGAS) (Gülzower Fachgespräche, 2006)*

6 Nutzen der Nachrüstung der MBA Rostock

Vorläufige Berechnungen zeigen schon heute, dass die Nachrüstung einen ökologischen Nutzen für die Hansestadt Rostock erzielt (EVERS, 2008).

Das EVG-BHKW wird 2008 ca. 8 Mio. Kubikmeter Biogas erzeugt haben. Bei einem Methangehalt von 58% ist mit einem Heizwert von rd. 46 GWh zu rechnen. Das BHKW wird daraus 11 GWh Strom (Netto) und 25 GWh Abwärme für Hilfskühler bzw. Fernwärme zur Auskopplung (zukünftig) erzeugen.

Dadurch können folgende CO_2-Emissionen vermieden werden:

- Strom: 6,8 Gg bezogen auf BRD- Strommix
- Fernwärme: 5,5 Gg bezogen auf Erdgasheizung bzw. nur 2,3 Gg bezogen auf KWK–Fernwärme aus Erdgas (fossiles Methan).

In der Maximalvariante bedeutet das eine Minderung der Gesamtemission von Rostock (z.Z. 810 Gg p.a.) um 12,3 Gg, also etwa 1,5 %.

Das Rostocker dynamische Klimabündnisziel strebt eine Emissionsminderung von 2% p.a. für Kohlendioxid an.

Der erzeugte elektrische Strom reicht zur Beleuchtung der Stadt Rostock aus; 10 bis 11 GWh Strom benötigt jährlich die Stadtbeleuchtung.

Laut Rahmenkonzept „Klimaschutz" benötigt ein Rostocker Bürger 0,75 MWh Strom pro Jahr im Haushalt. Theoretisch könnten also rd. 14.500 Einwohner Rostocks ihren Jahresbedarf an Haushaltsstrom kohlendioxidfrei von der EVB beziehen. So viele Einwohner hat z.B. die Südstadt.

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Erneuerung der KBA Hard mit dem SCHUBIO®-Verfahren

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Modernization of a Swiss MBT-plant with the SCHUBIO®-Process

Abstract

The only operation mechanical-biological Swiss treatment plant for municipal waste and biowaste (KBA Hard) will be modernized and the SCHUBIO®-Process will be implementet 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.

Inhaltsangabe

Im vorliegenden Beitrag wird die Erneuerung der KBA Hard, der einzigen in der Schweiz betriebenen MBA mit dem SCHUBIO®-Verfahren vorgestellt. Neben der Darstellung des Projektes werden die wesentlichen Merkmale des innovativen Verfahrens erläutert. Es wird die vollständige Verwertbarkeit der Produkte sowohl aus Restabfall als auch aus Bioabfall gezeigt.

Keywords

SCHUBIO®-Verfahren, Restabfall, Bioabfall, Waschverfahren, Schaffhausen, KBA Hard
SCHUBIO®-Process, Municipal Solid Waste, Biowaste, washing process, Schaffhausen, KBA Hard

1 Einleitung

Das SCHUBIO®-Verfahren beruht auf langjährigen Erfahrungen aus der mechanisch-biologischen Abfallbehandlung und hat seine Wurzeln in den aus dem WABIO-Verfahren stammenden Nassvergärungsverfahren, wie in Abbildung 1 dargestellt.

Restabfall wurde erstmals 1989 großtechnisch zusammen mit Klärschlamm in Vaasa, Finnland nach dem WABIO-Verfahren vergoren. Die DBA übernahm das Verfahren und baute in Bottrop die erste Bioabfallvergärungsanlage Deutschlands. Das DBA-WABIO-Verfahren wurde von Babcock nach dem Zusammenschluss der Umwelttechnik mit Steinmüller 1999 aufgegeben. EcoEnergy hat die Philosophie der Aufbereitungstechnik des DBA-WABIO-Verfahrens zu einem Waschverfahren weiterentwickelt und zur Marktreife gebracht. Das SCHUBIO®-Verfahren, vormals NMT-Verfahren, wurde durch die SCHU AG Schaffhauser Umwelttechnik 2008 von der EcoEnergy GmbH übernommen.

Die Inbetriebnahme der ersten großtechnischen Anlage in Schaffhausen, Schweiz ist für 2010 geplant.

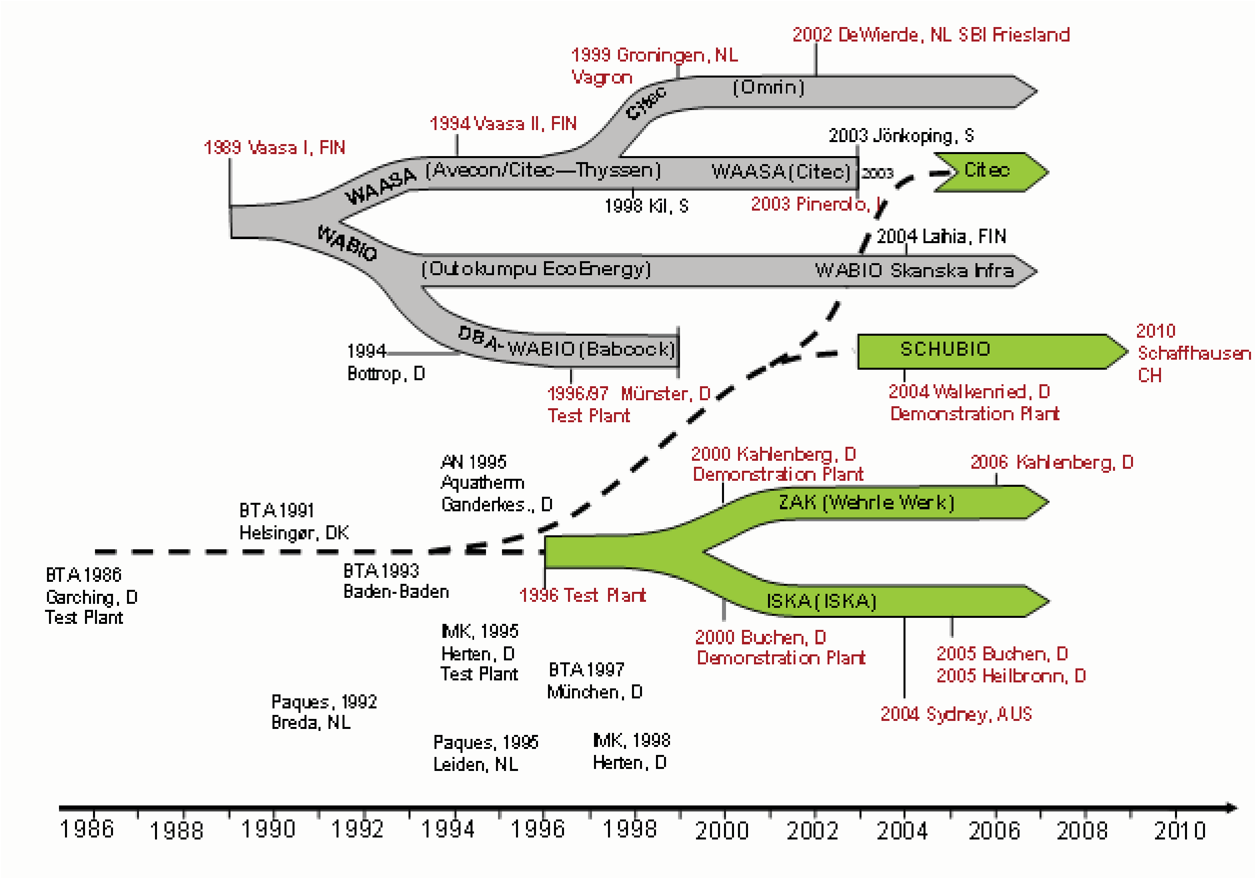

Abbildung 1: Entwicklung der Wasch- und Perkolationsverfahren

Die SCHUBIO®-Versuchsanlage wird seit 2004 im Technikum der EcoEnergy GmbH mit unterschiedlichem Inputmaterial betrieben. Die Anlage wurde im Rahmen eines von der Deutschen Bundesstiftung Umwelt geförderten Projektes gebaut und seit Abschluss des Projektes weiter betrieben (Tabelle 1).

Tabelle 1: Historie SCHUBIO®-Verfahren

Jahr	Entwicklung SCHUBIO-Verfahren
2000	Förderantrag an die DBU
2004	Bau der Pilotanlage und Versuche im AWZ Wiefels
2005 - 2007	Pilotphase des Verfahrens im Technikum EcoEnergy
2008	Auslegungsversuche, KBA Hard, Schweiz Übernahme des Verfahrens durch die SCHU AG Schaffhauser Umwelttechnik
2009	Baubeginn Erneuerung KBA Hard

Die Ausführung als Containeranlage ermöglicht einen problemlosen Standortwechsel. Zur Auslegung der neuen KBA Hard konnten daher Vor-Ort Versuche mit dem Original-Inputmaterial durchgeführt werden (siehe Abbildung 2).

Abbildung 2: Standorte der SCHUBIO®-Pilotanlage

2 Das SCHUBIO®-Verfahren

Das SCHUBIO®-Verfahren kann zur Behandlung von Restabfall/Schwarzabfall sowie Bioabfall/Grünabfall eingesetzt werden. Wie bei MBA-Technologien üblich, wird zunächst eine mechanische Grobaufbereitung mit Grobzerkleinerung und Siebung durchgeführt. Die Grobfraktion wird balliert und kann energetisch verwertet werden. Die Feinfraktion < 50 mm bzw. 50 – 100 mm wird mit dem SCHUBIO®-Verfahren in Inertstoff-Fraktionen, Organikfraktionen und eine Flüssigfraktion, die gelöste Stoffe sowie feinste Inertstoffe < 100 µm und Organikpartikel < 1 mm enthält, aufgetrennt. Als Trennmedium wird auf ca. 40 °C erwärmtes Kreislaufwasser verwendet. Durch die Erwärmung des Kreislaufwassers sinkt die Viskosität des Wassers, was dessen Trennwirkung verbessert und die Effizienz der Abpressung steigert.

Selbst bei Schwarzabfall arbeitet das Verfahren mit Wasserüberschuss. Aufgrund ihres fehlenden Wasserhaltevermögens können Inertstoffe bis auf einen Restwassergehalt < 5 % und organische Produkte bis zu einem Restwassergehalt von < 40 % mechanisch entwässert werden. Durch vorherige Fraktionierung und Inertstoffabscheidung wird eine Thermo-Mechanische-Zelllyse (TMZ) ermöglicht, die eine Zerfaserung und einen Zellaufschluss und damit einen erhöhten Entwässerungsgrad bewirkt.

Die Inertstoffe werden soweit mit Kreislaufwasser und Frischwasser gereinigt, dass sie einer Verwertung zugeführt werden können. Bei Bedarf kann die Qualität der groben Inertfraktion über eine Bauschuttaufbereitung verbessert werden. Aus den Inertfraktionen können folgende Produkte gewonnen werden:

- Steine - Kies - Sand - Feinsand - Schluff.

Die Organikfraktionen werden nach ihrer Absiebung in Schneckenpressen entwässert, wobei durch die speziellen Prozessbedingungen der Thermo-Mechanischen-Zelllyse das Zellwasser ebenfalls erfasst wird und so eine weitgehende Entwässerung erreicht wird. Zudem wird die lösliche, gut vergärbare Organik quantitativ in das abgepresste Wasser überführt. Abbildung 3 zeigt das Gesamt-Verfahrensfließbild des SCHUBIO®-Verfahrens am Beispiel KBA Hard für Restabfall (Schwarzabfall) und Bioabfall (Grünabfall).

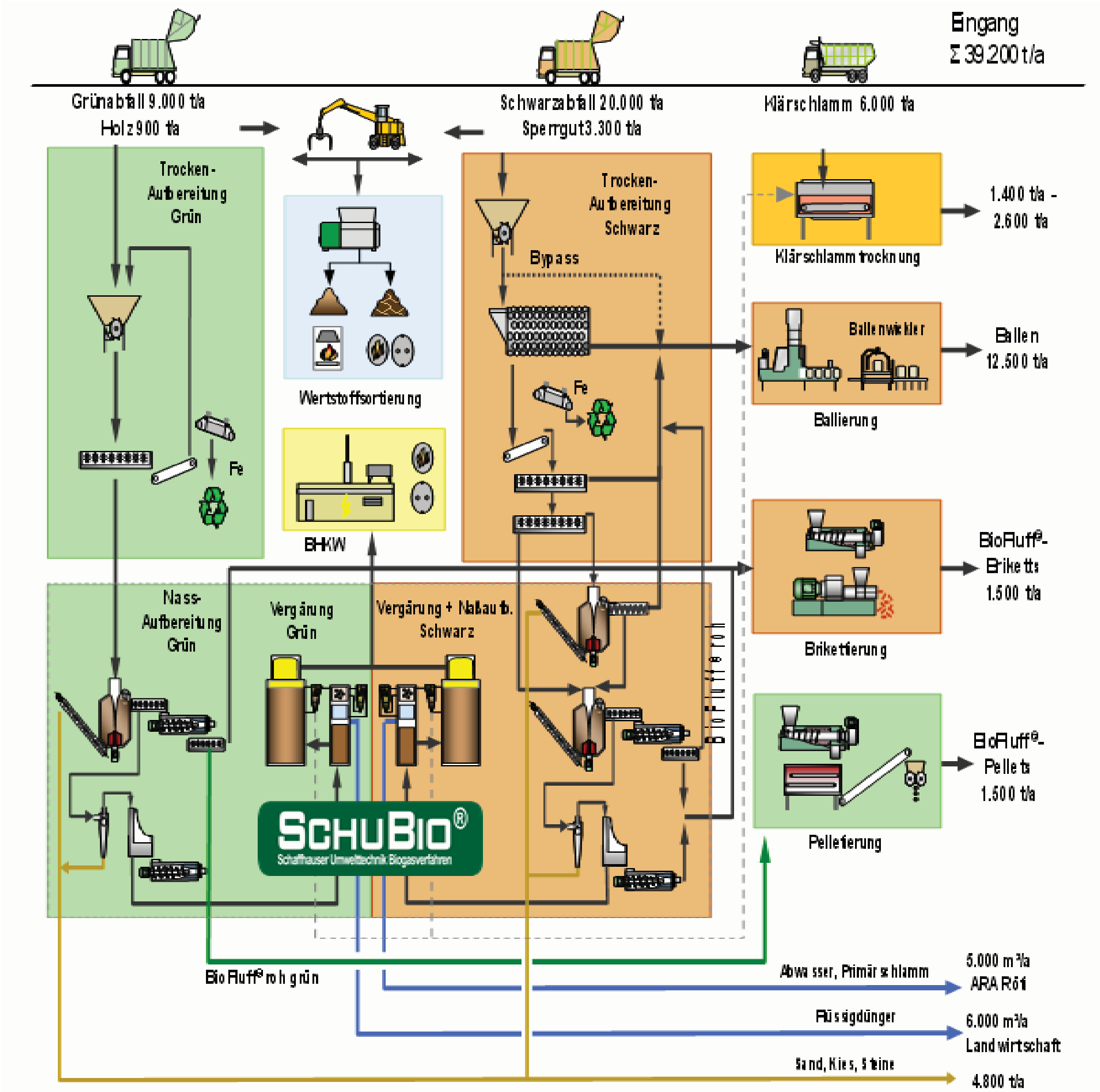

Abbildung 3: Verfahrensfließbild Erneuerung KBA Hard mit dem SCHUBIO-Verfahren

Der Schadstoffgehalt in den Biomassefraktionen (BioFluff®) ist verfahrensbedingt gering. Der Chlorgehalt ist aufgrund der Kunststoffabtrennung niedrig und ist lediglich als so genanntes „Hintergrundrauschen" aus gelösten Salzen vorhanden. Durch den hohen Entwässerungsgrad ohne thermische Trocknung werden alle löslichen Schadstoffe mit dem Press- und Waschwasser, je nach Waschwasseraufbereitungs- und Presskonzept, zu 50 % bis 90 % ausgetragen, die Qualität des BioFluff® wird somit erhöht.

Das Abpressen der Organikfraktionen 2 und 3 erfolgt zur Erhöhung der Effizienz der Abpressung bei Temperaturen von > 70 °C, wobei ein Teil der Wärmeenergie durch Dampf, erzeugt aus BHKW-Abwärme, und zusätzlich durch die Pressen in das Material gebracht wird.

Zur Pelletierung der Biomassefraktionen ist eine Trocknung erforderlich. Nach der Trocknung wird die Organik bei 15 mm gesiebt, wobei im Siebüberlauf die verbleibenden Kunststoffe abgetrennt werden.

Im Siebdurchgang befindet sich zu fast 100 % native Organik, der BioFluff®. Der getrocknete und gesiebte BioFluff® wird entsprechend dem vorgesehenen Verwertungsweg konfektioniert. BioFluff® ist eine schadstoffreduzierte, trockenstabilisierte, aufgefaserte Biomasse und als Rohstoff vielseitig einsetzbar. Für eine direkte energetische Verwertung des BioFluff® aus Restabfall/Schwarzabfall ist eine Brikettierung vorgesehen.

Beim SCHUBIO®-Verfahren wird die leicht vergärbare Organik des Abfalls quantitativ in das Kreislaufwasser überführt. Das Kreislaufwasser inkl. der suspendierten Organik < 1 mm wird der Vergärung zugeführt, wobei ein Vergärungsverfahren mit Biomasserückhaltung eingesetzt wird.

Der CSB-Abbau liegt, abhängig vom anaerob abbaubaren CSB-Anteil, bei 85 % bis 95 % und die Verweilzeit bei ca. 5 bis 10 Tagen gegenüber 18 bis 21 Tagen bei konventionellen Biogasanlagen. Das erzeugte Biogas wird im BHKW verwertet, der erzeugte Strom eingespeist und die Wärme zur Klärschlammtrocknung und Trocknung der Organik aus Grünabfall vor der Pelletierung verwendet.

Der Ablauf aus der Vergärung wird in einem Aerob-Reaktor mit Biomasserückführung nachbehandelt und kann als Waschwasser für das SCHUBIO®-Verfahren zurückgeführt oder als Überschusswasser der weitergehenden Abwasserbehandlung zugeführt und dann eingeleitet werden.

Der Klärschlamm, der in der Anaerob- und Aerobstufe der Abwasserbehandlung anfällt, ist die Schadstoffsenke des Gesamtverfahrens.

3 Projektbeschreibung

Die KBA Hard in Beringen wurde dieses Jahr 35 Jahre alt. Vor 20 Jahren wurde sie von einer KVA (Kehrichtverbrennungsanlage) zu einer KBA (Kehrichtbehandlungsanlage) umgerüstet. Das gewählte, zum damaligen Zeitpunkt sehr innovative, Rotteverfahren ist auch bekannt unter dem Schlagwort „Schaffhauser Modell“. In der Anlage werden zurzeit ca. 18.000 t/a Restabfall (Schwarzabfall), ca. 6.000 t/a Bioabfall (Grünabfall) und ca. 6.000 t/a Klärschlamm sowie 3.000 t/a Sperrabfall behandelt.

Zurzeit werden die festen Abfälle Hausmüll und Gewerbeabfall zunächst vorzerkleinert und durch Absiebung in eine trockene heizwertreiche Grobfraktion und in eine heizwertarme und feuchte Feinfraktion aufgetrennt. Die Grobfraktion wird balliert und direkt bzw. nach einer Zwischenlagerung in der KVA Buchs energetisch verwertet. Die Feinfraktion wird mit dem Klärschlamm vermischt und in der Rottehalle biologisch behandelt, wodurch eine Trocknung, Stabilisierung und Mengenreduktion erreicht wird. Das Rottegut wird ebenfalls in der KVA Buchs energetisch verwertet. Die Grünabfälle werden mechanisch aufbereitet und kompostiert.

Die Anlagen haben das Ende ihrer technischen Lebenszeit erreicht und müssen daher erneuert werden. Zudem ist eine Verbesserung der Abfallbehandlung bzgl. Ressourcenschutz und Energieeffizienz gewünscht.

Der Kläranlageverband Schaffhausen, Neuhausen am Rheinfall, Feuerthalen und Flurlingen hat daher entschieden, die bestehende Kehrichtbehandlungsanlage Hard nach dem SCHUBIO®-Verfahren zu erneuern.

Nachfolgende Abbildungen zeigen die geplante KBA Hard im Überblick:

Abbildung 4: Erneuerung KBA Hard Draufsicht

Abbildung 5: Erneuerung KBA Hard Ansicht

Die Erneuerung der Anlagentechnik wird vorrangig im bestehenden Betriebsgebäude durchgeführt, zusätzlich werden lediglich die Gärbehälter sowie zwei BHKW mit je 450 kW Leistung aufgestellt. Die bisherige Rottehalle wird abgerissen und die Fläche als offenes Ballenlager genutzt. Die Logistik der Privatanlieferung wird verbessert und z. B. die Sperrmüllzerkleinerung eingehaust. Die Gesamtinvestitionssumme beträgt ca. 30 Mio. CHF.

4 Nachhaltige Stoffstromtrennung

Das Verfahren hat als erklärtes Ziel die möglichst vollständige Verwertung der angelieferten Abfälle. Im Folgenden wird der Nachweis der Verwertbarkeit für die erzeugten Stoffströme und Produkte geführt.

4.1 Biomasse

4.1.1 Biomasse aus Grünabfall

Die Organikfraktionen aus Grünabfall (Bioabfall) weisen geringere Schadstoffgehalte als die meisten Komposte auf. In der folgenden Tabelle 2 sind die Schwermetallgehalte der Organikfraktionen im Vergleich zum Input (Grünabfall < 50 mm), zu dem zurzeit auf der KBA Hard erzeugten Kompost sowie zu dem Mittelwert der Schweizer Komposte für den Gartenbau (Kupper et al., 2007) dargestellt.

Die Werte sind den Grenzwerten der Deutschen Bioabfallverordnung sowie der Schweizer Stoffverordnung gegenübergestellt.

Die Schwermetallabreicherung ist deutlich zu erkennen. Ein Artefakt aus der Versuchsanordnung ist die Anreicherung von Chrom und Nickel in der Feinfraktion Organik 3, die durch Abrieb aus der aus Chrom-Nickel-Stahl konstruierten Versuchsanlage verursacht wurde.

Tabelle 2: Schwermetalle in den Organikfraktionen Grün im Vergleich zu Grünabfall–Input und Kompost der KBA Hard (Mittel)

Parameter (mg/kg TS)	Grünabfall < 50	Grün Organik 1	Grün Organik 2	Grün Organik 3	Kompost KBA Hard	Schweiz Kompost Gartenbau	Stoff-VO (CH)	Bio Abf-VO (D)
Blei (Pb)	21,0	16,0	11,6	15,8	47,5	69,7	120	150
Cadmium (Cd)	n.n.*	n.n.*	n.n.*	n.n.*	0,2	0,1	1	1,5
Chrom (Cr)	13,5	14,5	12,5	45,5	23,2	20,0	100	100
Kupfer (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
Zink (Zn)	94,5	57,0	95,0	94,0	215,3	155,4	400	400
Quecksilber (Hg)	0,1	n.n.**	n.n.**	n.n.**	0,1	n.n.	1	1

* Nachweisgrenze 0,4 mg/kg TS ** Nachweisgrenze 0,1 mg/kg TS

Bereits 2002 hat das Umweltbundesamt einen Vorschlag zur gestaffelten Grenzwertregelung für Düngemittel vorgestellt, der zum Ziel hatte, die langfristige Schadstoffanreicherung im Boden zu verhindern („Gleiches zu Gleichem“) (UBA, 2002). Bei einem Vergleich mit diesen bodenangepassten Grenzwerten zeigt sich, dass die Organikfraktionen aus Grünabfall diese ebenfalls problemlos einhalten könnten.

Tabelle 3: Schwermetalle in den Organikfraktionen Grün im Vergleich zu Grünabfall–Input und Kompost der KBA Hard (Mittel) mit den Werten „Gleiches zu Gleichem“

Parameter (mg/kg TS)	Grün-Abfall < 50	Grün Organik 1	Grün Organik 2	Grün Organik 3	Kompost KBA Hard	„Gleiches zu Gleichem“ Ton	Lehm	Sand
Blei (Pb)	21	16	11,6	15,8	47,5	71,75	50,45	29,15
Cadmium (Cd)	n.n.*	n.n.*	n.n.*	n.n.*	0,2	1,09	0,73	0,31
Chrom (Cr)	13,5	14,5	12,5	45,5	23,2	71,34	42,94	21,64
Kupfer (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
Zink (Zn)	94,5	57	95	94	215,3	173,71	138,21	74,31
Quecksilber (Hg)	0,1	n.n.**	n.n.**	n.n.**	0,1	0,72	0,37	0,08

* Nachweisgrenze 0,4 mg/kg TS ** Nachweisgrenze 0,1 mg/kg TS

Die erzeugten Biomasse-Fraktionen Organik 2 und 3 werden als Torfersatz regional an Privatabnehmer und Gartenbaubetriebe abgegeben. Die Fraktion Organik 1 wird als Biomasse-Brennstoff verwertet.

4.1.2 Biomasse aus Schwarzabfall

Die erzeugten Biomasse-Fraktionen (Organik 2 und Organik 3) aus Schwarzabfall sind so schadstoffreduziert, dass die Werte für Kompost ebenfalls eingehalten werden können.

In der folgenden Tabelle sind die Schwermetallgehalte der Organikfraktionen im Vergleich zum Input (Schwarzabfall < 50 mm) und zu dem Mittelwert Schweizer Komposte für den Gartenbau dargestellt.

Tabelle 4: Schwermetalle in den Organikfraktionen Schwarz im Vergleich zu Schwarzabfall–Input und Kompost der KBA Hard (Mittel)

Parameter (mg/kg TS)	Schwarz-abfall < 50	Schwarz Organik 2	Schwarz Organik 3	Kompost KBA Hard	Schweiz Kompost Gartenbau	Stoff-VO (CH)	BioAbfVO (D)
Blei (Pb)	190,0	62,8	57,0	47,5	69,7	120	150
Cadmium (Cd)	n.n.*	n.n.*	n.n.*	0,2	0,1	1	1,5
Chrom (Cr)	38,0	46,8	36,0	23,2	20,0	100	100
Kupfer (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
Zink (Zn)	400,0	227,5	130,5	215,3	155,4	400	400
Quecksilber (Hg)	0,4	0,1	0,2	0,1	n.n.	1	1

* Nachweisgrenze 0,4 mg/kg TS

Ein landwirtschaftlicher Einsatz ist dennoch bereits aufgrund der Herkunft aus Schwarzabfall ausgeschlossen. Im Projekt wird der Einsatz der Fraktionen als schadstoffarmer Ersatzbrennstoff in der Zementindustrie erfolgen. Die Annahmekriterien sind vergleichbar mit dem Einsatz zur Mitverbrennung in einem Kohlekraftwerk.

Zur Bewertung der Brennstoffeigenschaften der im SCHUBIO®-Verfahren erzeugten Organikfraktionen werden die Annahmekriterien für gütegesicherte Ersatzbrennstoffe (BGS) sowie die Annahmekriterien für Biobrennstoffe zur Mitverbrennung in einem Kohlekraftwerk den ermittelten Schadstoffgehalten gegenüber gestellt.

Tabelle 5: Schadstoffgehalte der Organikfraktionen im Vergleich zu den Kriterien der BGS und Annahmekriterien im Kohlekraftwerk in mg/kg TS

Parameter in mg/kg TS	BGS	Kohle-kraftwerk	Schwarz O1	Schwarz O2	Schwarz O3	Grün -O1	Grün-O2	Grün-O3
Arsen (As)	5	5	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.
Blei (PB)	190	70	84	61,3	58,8	16	13,3	16,2
Cadmium (Cd)	4	0,4	9,0	n.n.	n.n.	n.n.	n.n.	n.n.
Chrom (Cr)	125	125	94,5	39	36,3	14,5	13,2	45,3
Kupfer (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
Quecksilber (Hg)	0,6	0,6	6,3	0,14	0,2	n.n.	n.n.	n.n.
Antimon (Sb)	25	25	-	140	n.n.	n.n.	n.n.	n.n.
Zinn (Sn)	30	60	23	24	28	n.n.	n.n.	n.n.
Thallium (Tl)	1	1	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.
Kobalt (Co)	6	6	3	n.n.	n.n.	n.n.	n.n.	n.n.
Mangan (Mn)	250	250	108,5	90	110	185	97	155
Vanadium (V)	10	25	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.

n.n. = nicht nachgewiesen, unterhalb der Bestimmungsgrenze

Mit zunehmendem Kunststoffgehalt erhöht sich auch der Schwermetallgehalt. Nach Absiebung der Kunststoff-Fraktion aus Organik 2 ist der Siebdurchlauf < 10 mm von Kunststoffen und damit von Schadstoffen entfrachtet, so dass sicher die Einhaltung der Grenzwerte für die energetische Verwertung in einem Kohlekraftwerk möglich ist. Die Schadstoffentfrachtung nach der Siebung ist in Tabelle 6 dargestellt als Ergebnis eines Siebversuches bei 20 mm.

Die Schadstoffabreicherung nach der Siebung ist deutlich erkennbar, besonders bei Chrom, Kupfer und Cadmium, Antimon wird sogar um den Faktor 20 reduziert. Mit geringerem Kunststoffanteil sinkt auch der Chlorgehalt.

Tabelle 6: Siebversuch mit der Fraktion Organik 2 aus Restabfall, Absiebung bei 20 mm

Parameter	Organik 2 Restabfall >20 mm	Organik 2 Restabfall <20 mm	Organik 3 Restabfall
Blei (PB) mg/kg TS	73,9	91,4	92,7
Chrom (Cr) mg/kg TS	128,4	78,2	100,4
Kupfer (Cu) mg/kg TS	249,9	68,8	85,5
Nickel (Ni) mg/kg TS	78	52,2	74
Zinn (Sn) mg/kg TS	80,8	88,8	61,5
Mangan (Mn) mg/kg TS	205,9	189,7	259,1
Cadmium (Cd) mg/kg TS	5,3	1,4	0,1
Quecksilber (Hg) mg/kg TS	n.n.	n.n.	n.n.
Antimon (Sb) mg/kg TS	293	12,9	1,1
Chlor in % TS	1,45%	1,00%	0,38%
Heizwert Hu in kJ/kg	23.587	19.626	14.616

Ein weiterer wichtiger Parameter zur Eignung als Ersatzbrennstoff ist der Chlorgehalt. Durch die Abtrennung von Kunststoffen und damit des Chlorträgers PVC als auch durch die Reduzierung der Salzbelastung durch die Wäsche können Chlorwerte erreicht werden, die eine Mitverbrennung sogar im Kohlekraftwerk ermöglichen. Nur die Fraktion Schwarz-O1, die grobe Organikfraktion aus Schwarzabfall, enthält überwiegend Kunststoffe, daher ist der Chlorgehalt entsprechend hoch (siehe Abbildung 5).

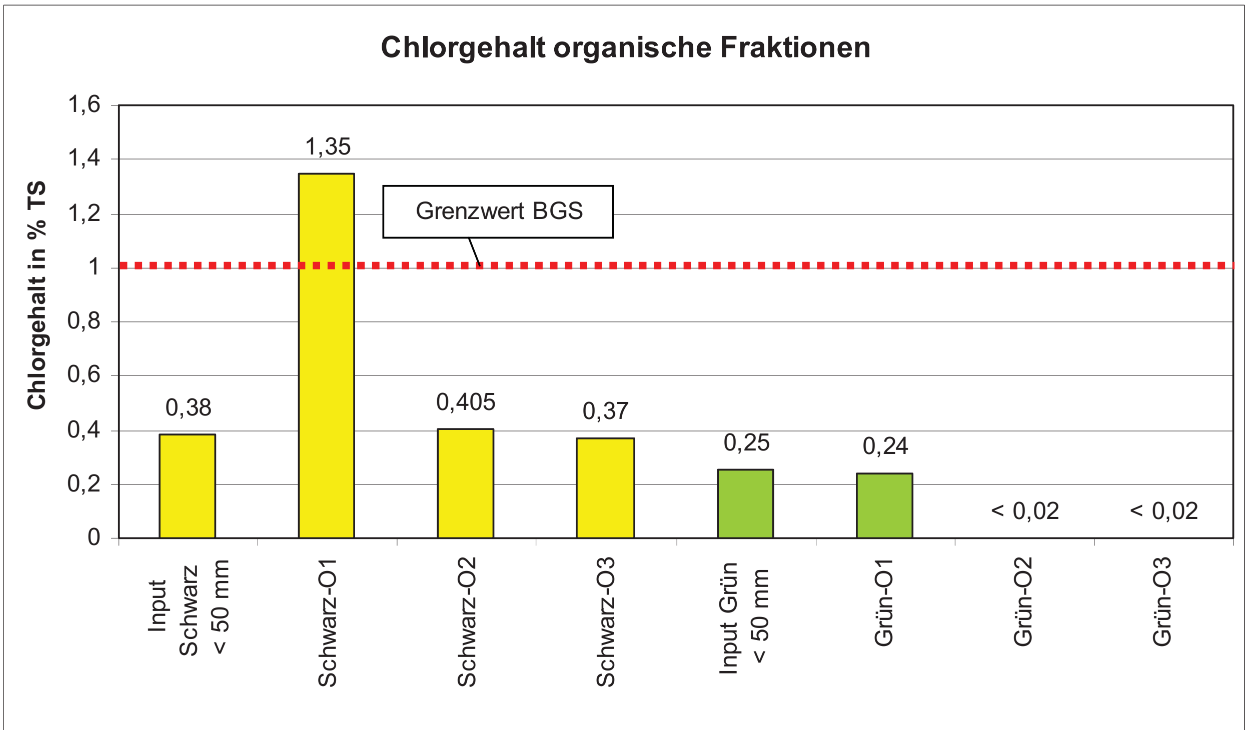

Abbildung 6: Chlorgehalt der organischen Fraktionen aus Schwarz- und Grünabfall

4.2 Biogas

Die Flüssigphase enthält die vergärbaren organischen Bestandteile und wird zur Biogaserzeugung genutzt. Ein Vergleich mit der Ausbeute von Vollstromvergärungsverfahren zeigt, dass das SCHUBIO®-Verfahren mindestens 75 % bis 85 % des Biogas-Energieertrages von optimalen Vollstromvergärungsverfahren erreicht.

Tabelle 7: Vergleich der Biogasausbeuten verschiedener Vergärungsverfahren für Bioabfall und Restabfall

Material / Verfahren	**Nm³ Biogas / t Input**	**Nm³ Methan / t Input**
Grüngut, Bioabfall		
SCHUBIO®	85 - 110	55 - 77
Kompogas - Garantiewert	115	63
Kompogas - Realwert	125	72-80
Dranco - Garantiewert	140	77
Dranco- Realwert	157	90
Strabag - Garantiewert	115	k.A.
Strabag- Realwert	100 - 135	55 - 81
Bekon - Realwert	87	48
Schwarzgut, Restabfall		
SCHUBIO®	75 - 90	49 - 63
Trockenvergärung		
Valorga - Realwert Hannover Input < 60 mm	100	55 - 60
Dranco - Realwert Bassum Input < 40 mm	130	72 - 78
Nassvergärung		
Schaumburg - Realwert	60	39 - 45
Lübeck - Planwert	100	k. A.
Perkolation		
ISKA - Realwert Buchen, Heilbronn	40 - 60	26 - 45
ZAK - Realwert Kaiserslautern	50 - 60	33 - 45

Das Biogas wird in zwei BHKW mit je 450 kW verstromt. Die Abwärme wird für die Prozesswärme der Thermomechanischen Zelllyse, zur Trocknung des angelieferten Klärschlamms sowie des Überschussschlamms aus der Vergärung genutzt. Gleichzeitig wird auch der im Verfahren abgeschiedene Feinschluff getrocknet. Das Wärmenutzungskonzept ist wärmegeführt, die Schlämme werden je nach verfügbarer Abwärme auf 65 % bis 85 % Trockensubstanzgehalt getrocknet. Die anfallende Wärme wird zu 100 % genutzt.

4.3 Abwasser

Nach der Vergärung enthält das Abwasser noch Stickstoff in erheblichen Mengen. Über einen mehrstufigen chemischen Abluftwäscher wird der Stickstoff aus der aeroben Abwasserreinigung der Grün- und Schwarzabfall-Linie als auch der bei der Trocknung aus dem Klärschlamm ausgetriebene Stickstoff zurück gewonnen und daraus ein Ammonium-Sulfat-Dünger produziert. Auch der Überschuss-Schlamm aus der Biomasserückhaltung der Vergärung wird mit dem Klärschlamm getrocknet und der Stickstoff zurück gewonnen. Ein Teil des vorgereinigten Wassers wird als Kreislaufwasser wieder im Verfahren genutzt.

Das überschüssige, vorgereinigte Abwasser wird in der verbandseigenen Kläranlage geklärt. Die Wasserbilanz des Verfahrens ist durch die hohe mechanische Entwässerung der Produkte und durch die Kreislaufführung des Waschwassers sehr günstig (siehe Abbildung 3).

4.4 Getrockneter Klärschlamm

Der Klärschlamm und der Überschussschlamm aus der Vergärung sind auch nach der Trocknung reich an wichtigen Düngekomponenten, vor allem an P, aber auch Mg, K und Ca sowie N, wobei ein Teil des Stickstoffs schon bei der Trocknung ausgetrieben wird.

Der getrocknete Schlamm wird in einer Klärschlammverbrennungsanlage energetisch verwertet. Es ist geplant, aus den bei der Verbrennung entstehenden Aschen durch nochmalige Erhitzung die Schwermetalle auszutreiben und integriert in die vorhandene Flugaschewäsche dabei sogar einzelne Schwermetalle zurück zu gewinnen (Schu und Seiler, 2008).

Die dann entstehenden Aschen sind schadstofffrei und können zur Düngung eingesetzt werden. Somit ist der Phosphatkreislauf nicht nur für Bioabfall und Klärschlamm sondern auch für Restabfall geschlossen. Die Rückgewinnung von Phosphat gewinnt vor dem Hintergrund der Ressourcenschonung immer mehr an Bedeutung.

4.5 Inertstoffe

Im Verfahren werden Inertfraktionen, getrennt nach Korngrößen, erzeugt, die entweder bereits Verwertungsqualität besitzen oder nach einer mechanischen Nachbehandlung diese erreichen können. Die Inertfraktionen Steine, Kies und Sand werden dennoch auf einer Deponie verwertet, da der Absatz als Recyclingbaustoffe zurzeit noch nicht gesichert ist. Stärker schadstoffbelastet aufgrund des ungünstigen Gewichts-/Oberflächenverhältnisses ist die Feinschluff-Fraktion < 100 µm, die separat erfasst und der Klärschlammtrocknung zugeführt wird.

5 nicht verwertbare Fraktionen

Alle bisher genannten Fraktionen können fast komplett verwertet werden. Selbst der schadstoffreiche Überschussschlamm aus der Vergärung und der Feinschluff, die als Schadstoffsenke des Verfahrens konzipiert sind, können teilweise stofflich verwertet werden.

Einzig für die Grobfraktion aus der mechanischen Vorbehandlung sowie die Fraktion Organik 1 gibt es keine Verwertungsmöglichkeiten. Diese Fraktionen bestehen fast ausschließlich aus Kunststoffen und werden balliert und in einer KVA (MVA) verbrannt. Es gibt zurzeit keine nachhaltige Lösung zur werkstofflichen Verwertung von gemischten Kunststofffraktionen. Aufgrund der hohen Schadstoffbelastung ist eine Entsorgung nur in einer KVA/MVA möglich.

Das SCHUBIO®-Verfahren hat zum Ziel, Kunststoffe von Biomassen zu trennen, um die Verwertbarkeit der Biomassefraktionen sicherzustellen. Dies wird durch mehrere Verfahrensschritte erreicht:

1. Selektive Zerkleinerung und Abtrennung einer kunststoffreichen Grobfraktion durch Siebung bei 100 mm
2. Aus der Fraktion 50 mm bis 100 mm wird durch Waschung und Pressung die Biomasse im Wesentlichen in der Fraktion < 50 mm angereichert und eine kunststoffreiche Fraktion > 50 mm abgetrennt.
3. In der Fraktion < 50 mm wird durch Waschung und temperaturgeführte Pressung Biomasse auf < 10 mm zerfasert und durch Siebung bei 10 mm abgetrennt. Die Kunststoffe verbleiben in der Fraktion > 10 mm.

Die abgetrennten Biomassefraktionen sind schadstoffarm und können in Biomassekraftwerken, Kohle- oder Zementkraftwerken energetisch verwertet werden bzw. landwirtschaftlich als Torfersatz genutzt werden.

Die in Kapitel 4.1 dargestellte Schadstoffabreicherung der Biomassefraktionen durch Siebung hat im Umkehrschluss eine Aufkonzentrierung der Schadstoffe im kunststoffhaltigen Siebüberlauf zur Folge. Diese Fraktion unterliegt der gleichen Problematik wie die übrigen kunststoffhaltigen Fraktionen.

Die Problematik der Entsorgung von Kunststoffen vor dem Hintergrund der Schadstoffbelastung wird in einer separaten Veröffentlichung dargestellt.

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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.

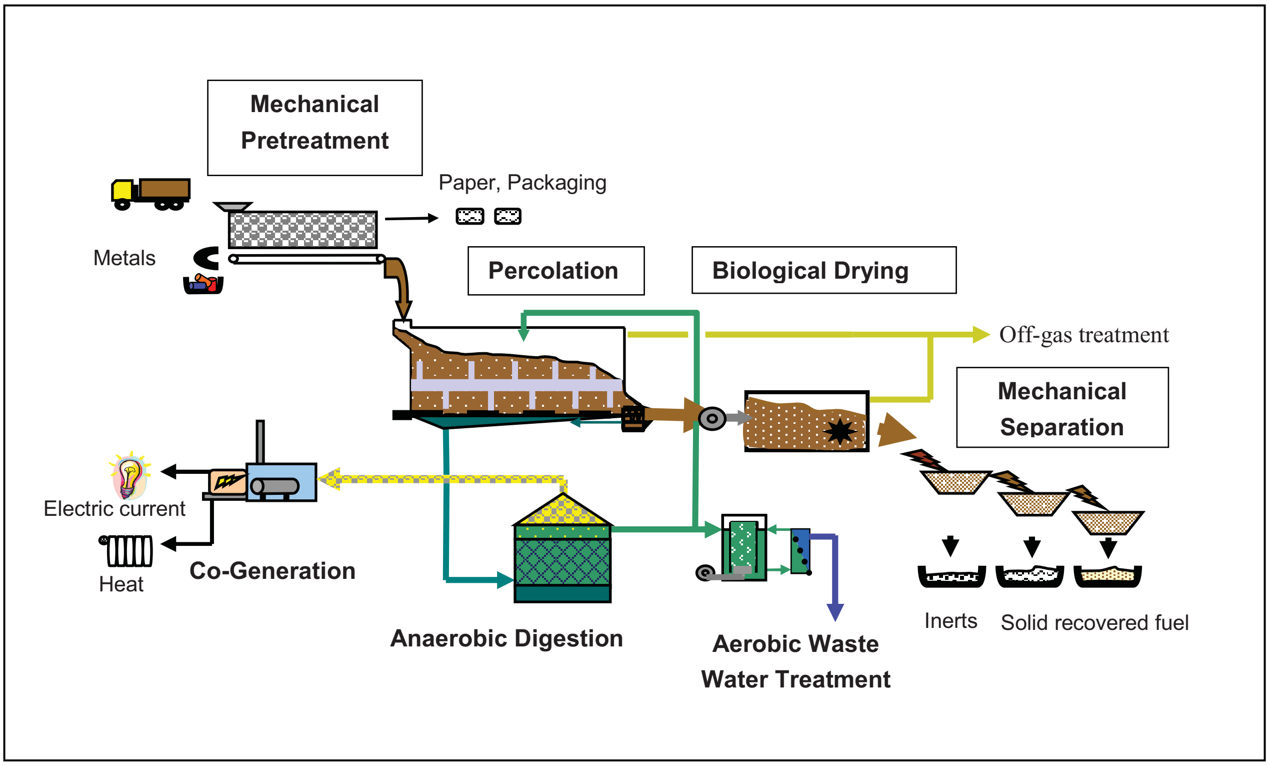

Fig. 1: MBT concept ZAK Kahlenberg

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.

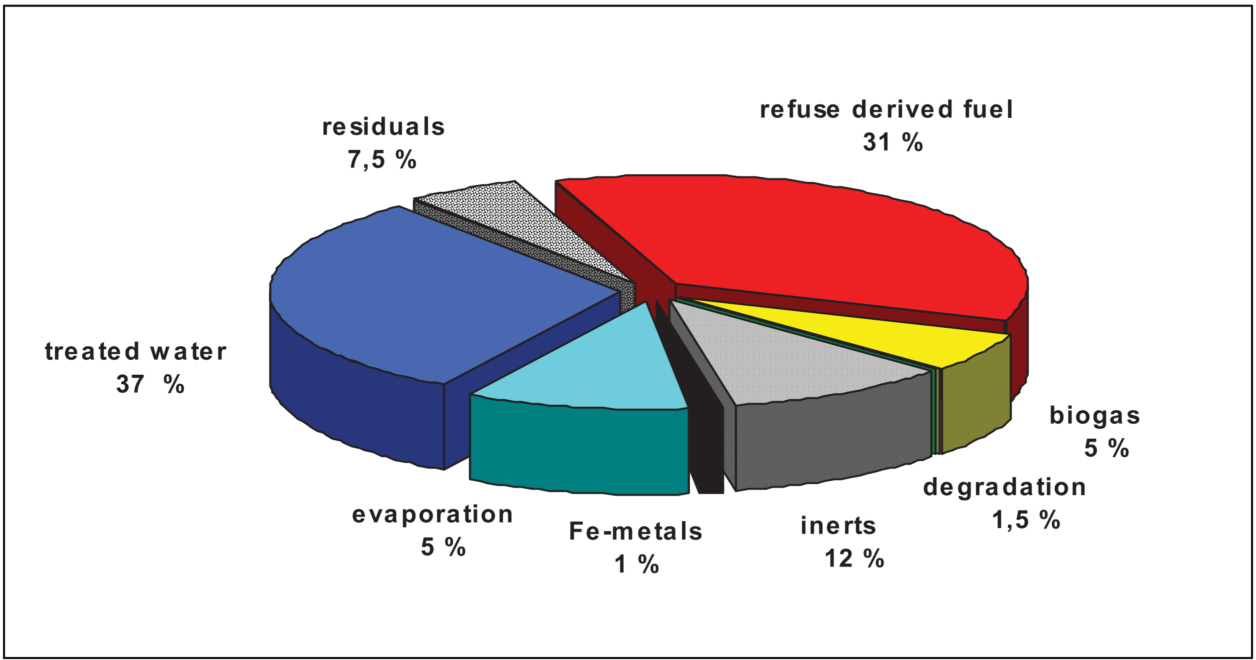

Fig. 2 Mass balance of the Kahlenberg concept (PERSON, SCHREIBER, GIBIS 2008)

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).

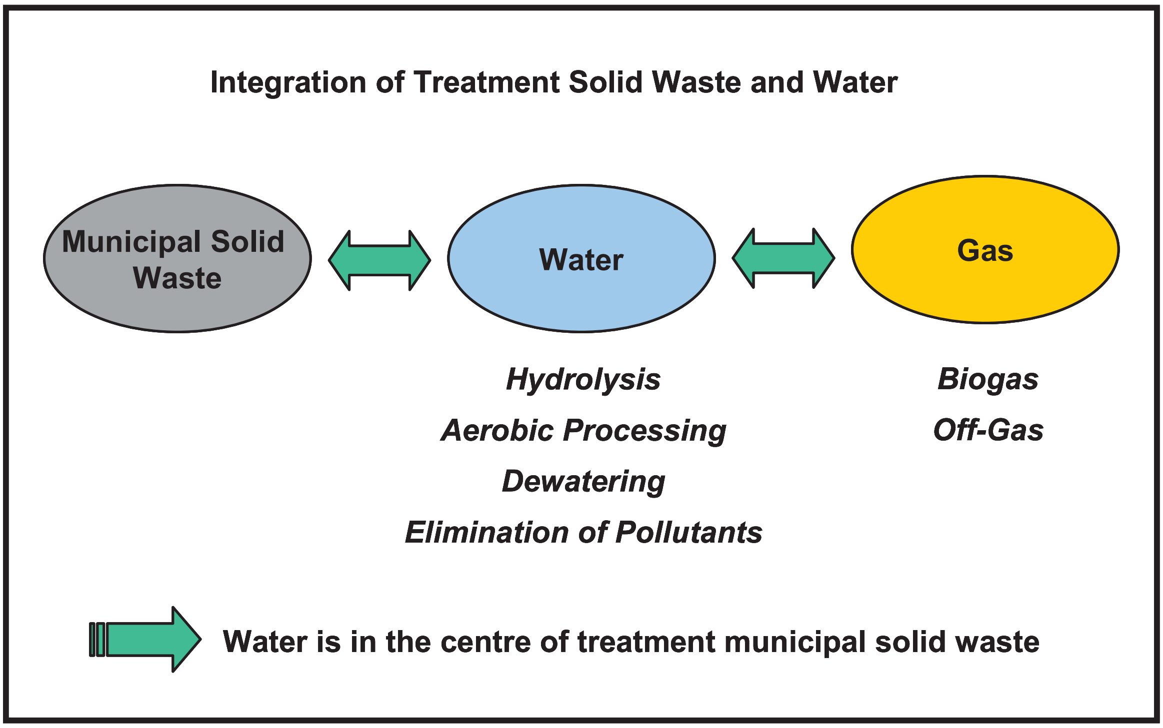

Fig. 3 Water in the centre of treatment of MSW

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.

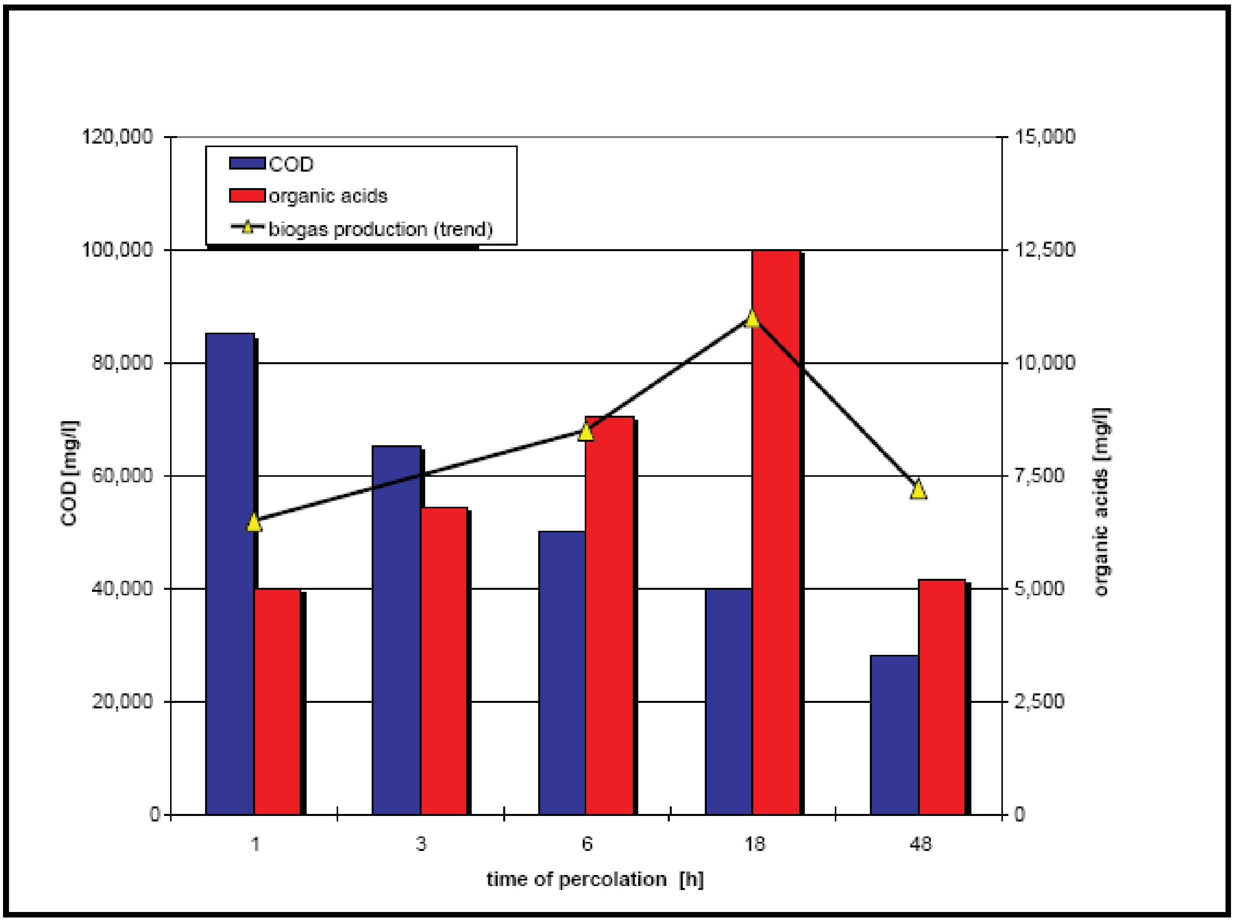

Fig. 4 COD and organic acids from leaching and biogas production

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.

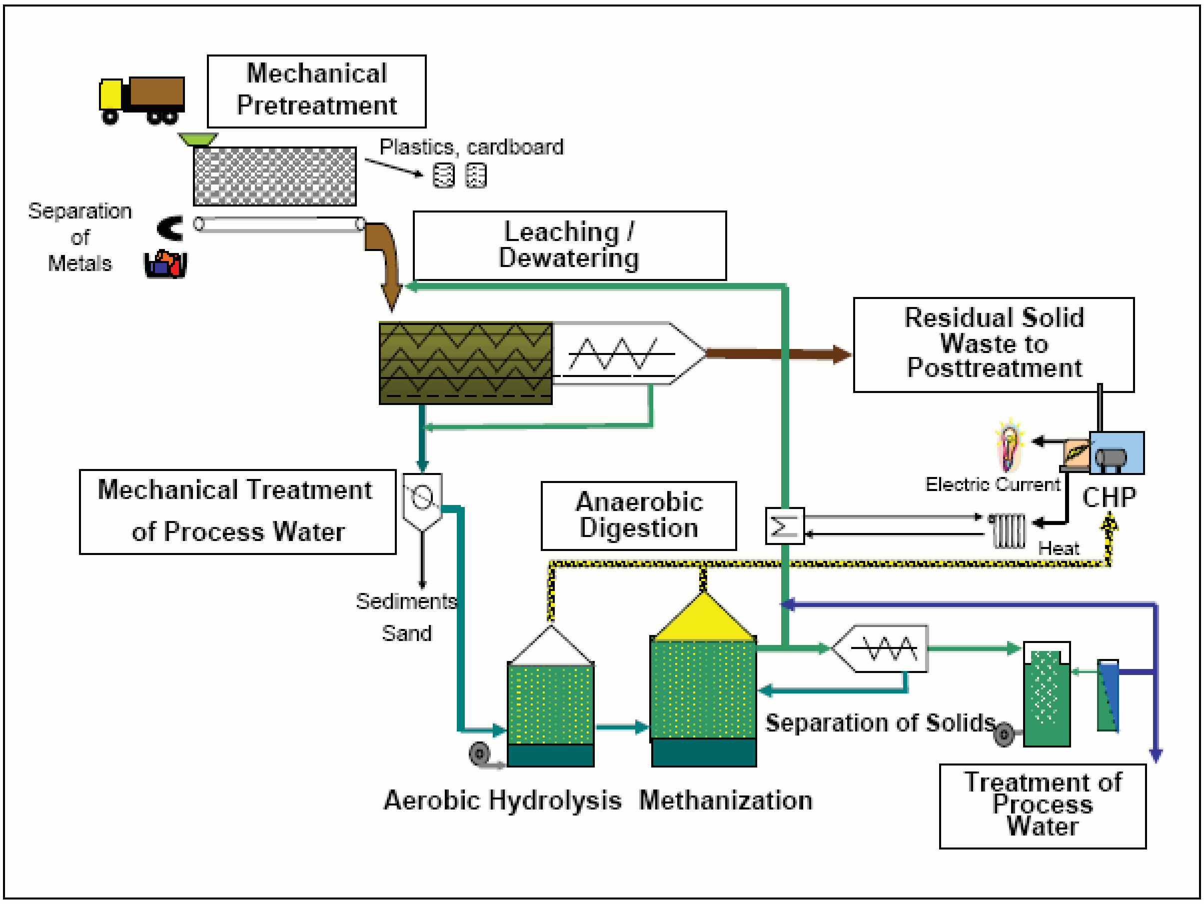

Fig. 5: BIOLEACHATE° process

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.

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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):

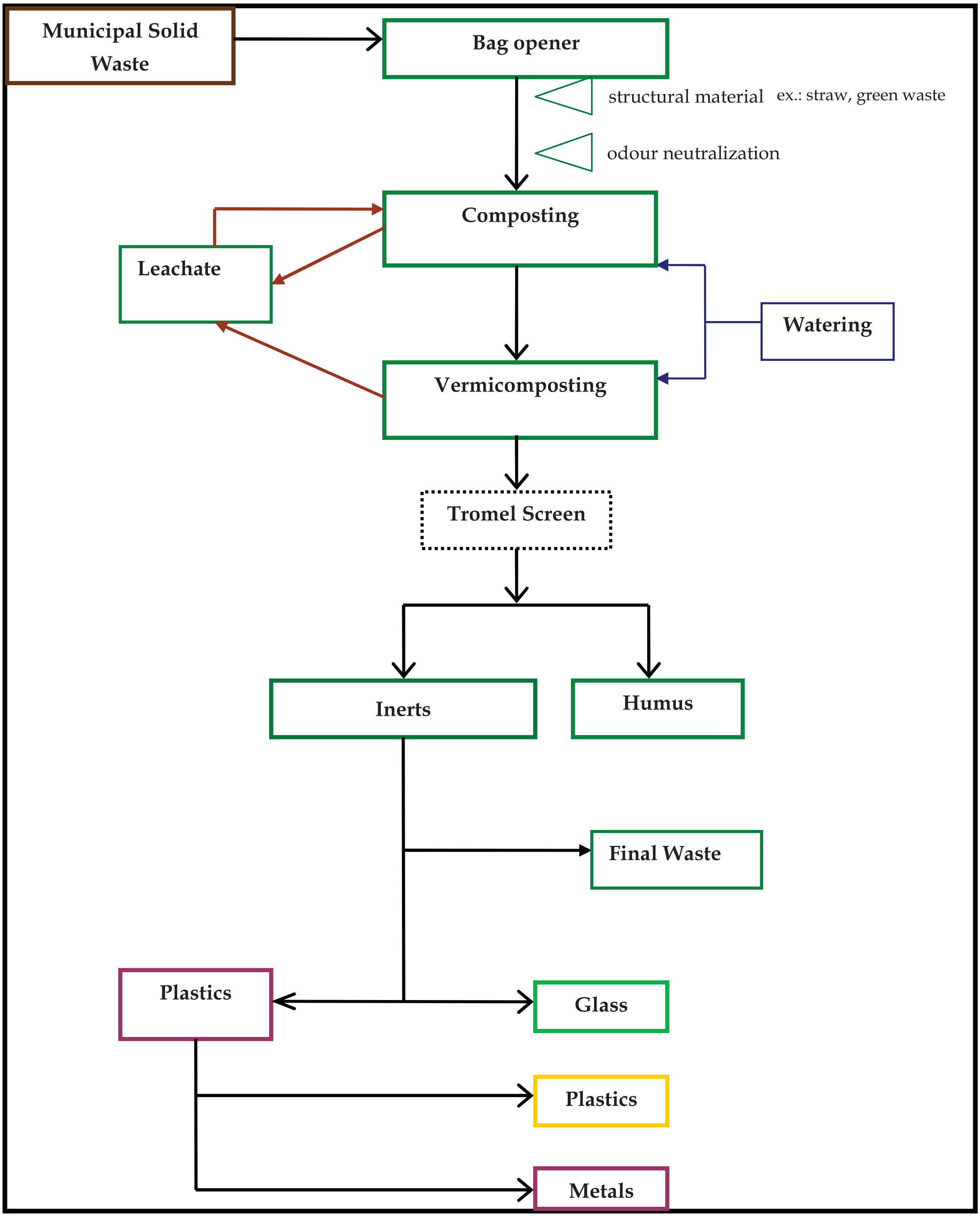

Figure 2 Schematic representation of MSW vermicomposting

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 pak-kaging 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.

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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.

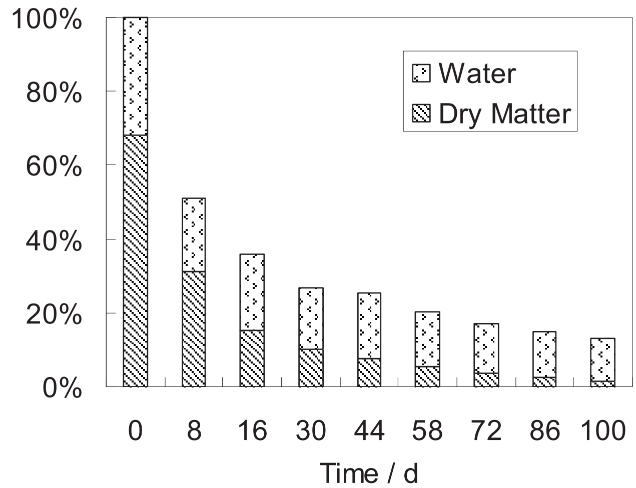

Figure 3 Evolution of MSW weight

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

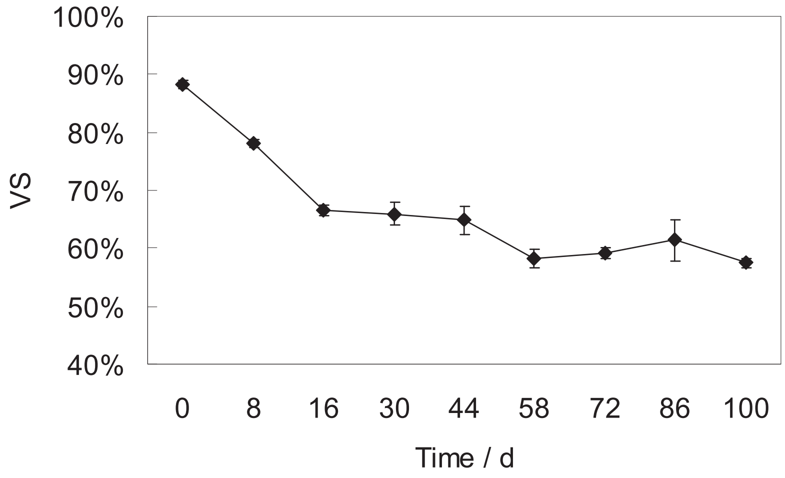

Figure 2 Evolution of VS

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.

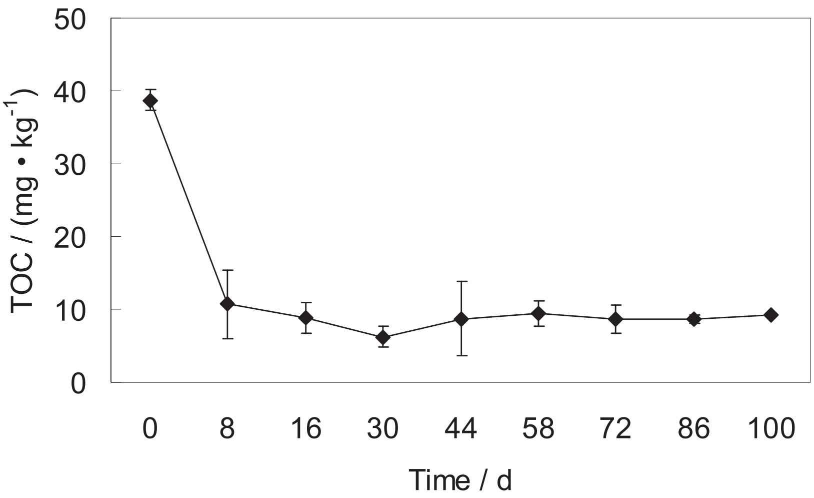

Figure 3 Evolution of TOC

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%.

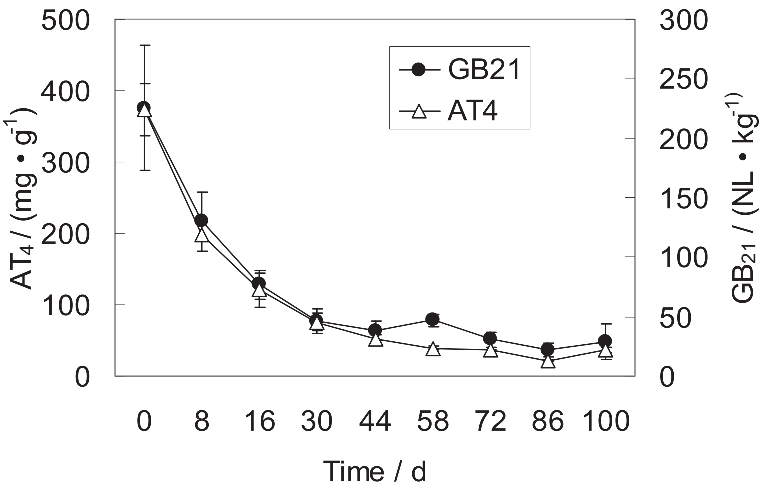

Figure 4 Evolution of biological stability indicators

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 $t \cdot d^{-1}$, 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 \$ $t^{-1}·d^{-1}$)	**Item**	**Cost** (10^4 \$$·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$·t^{-1}$ and 6.6 USD$·t^{-1}$ 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.

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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

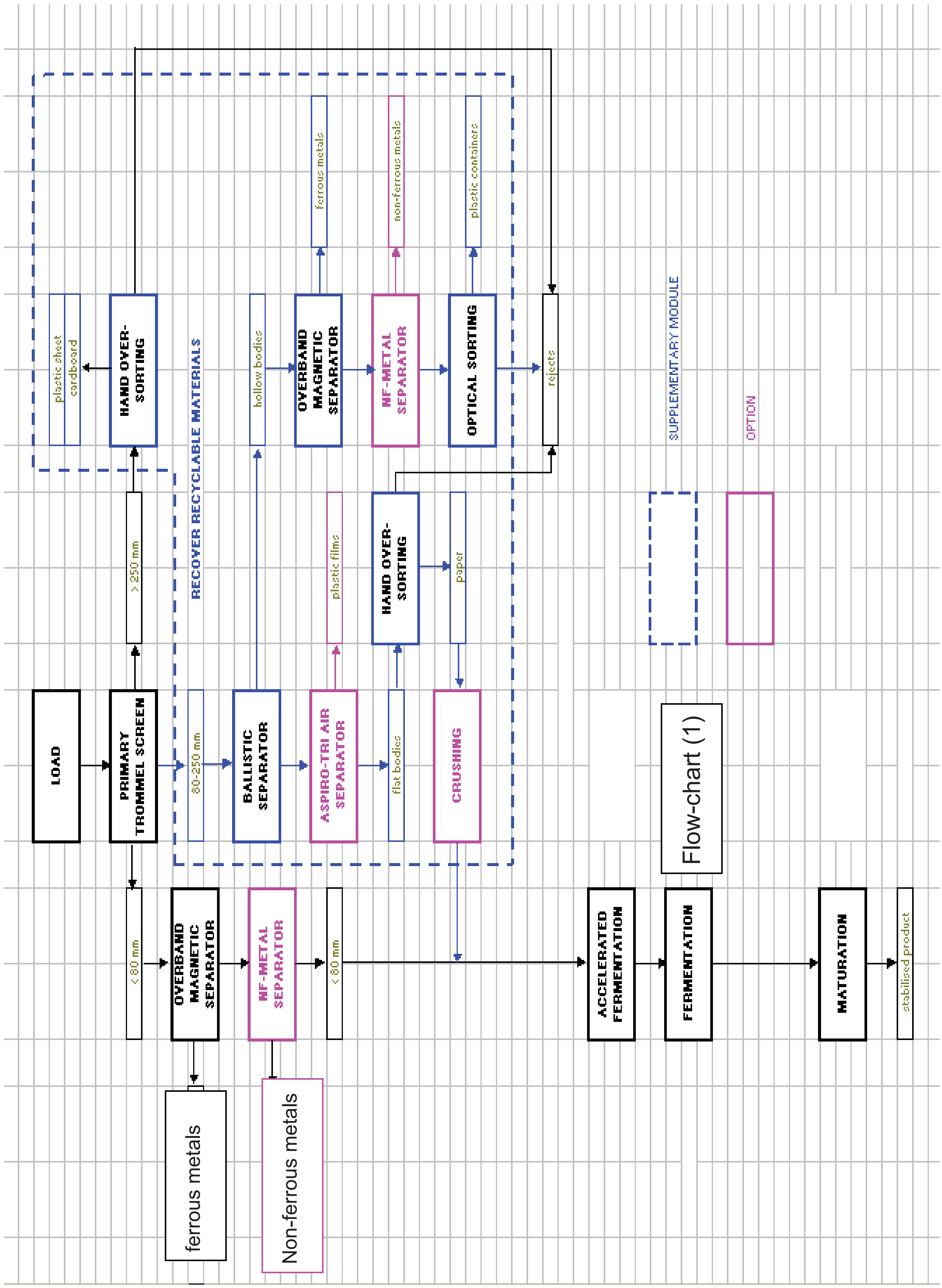
This first process, already developed, meets the following objectives:

- 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.

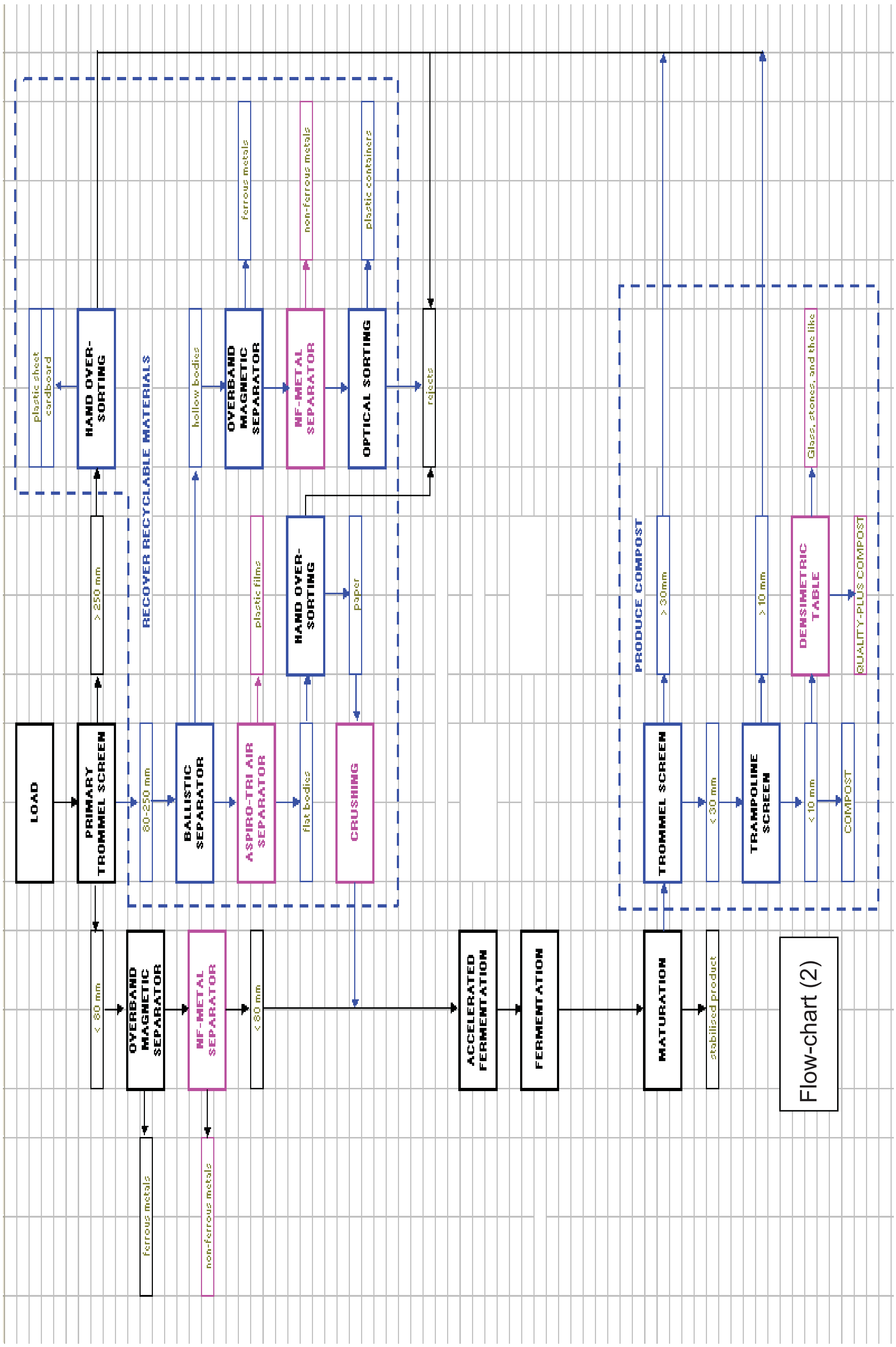
Here too, the particle sizes for the trommel screen and for the trampoline screen of the compost production module (i.e. for the ripening) will depend on the requirements concerning the compost (e.g. when a standard is to be complied with).

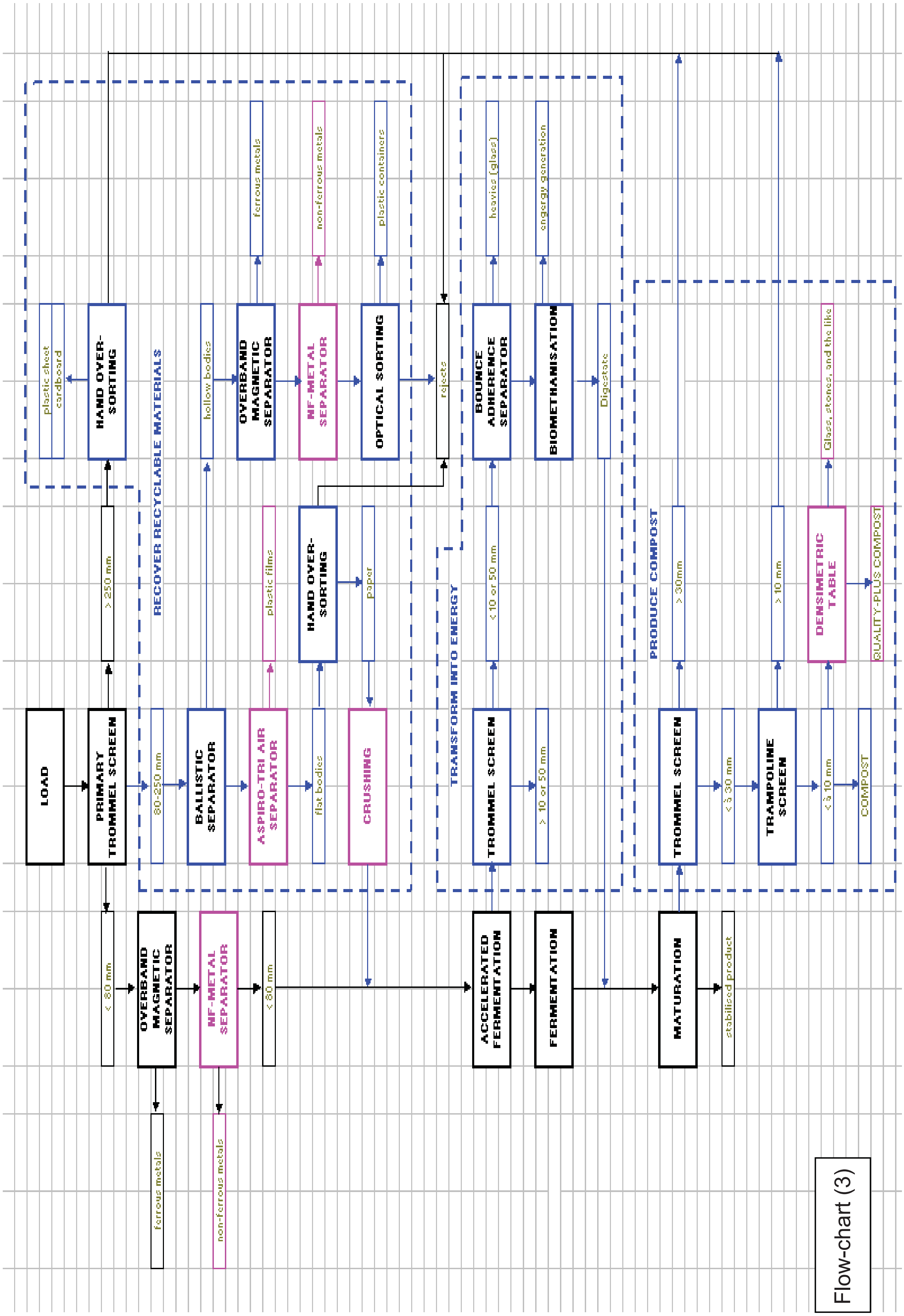
3.3 3rd process: 4 modules

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
HAND OVER-SORTING
plastic sheet
cardboard
RECOVER RECYCLABLE MATERIALS
80-250 mm
BALLISTIC SEPARATOR
hollow bodies
OVERBAND MAGNETIC SEPARATOR
ferrous metals
NF-METAL SEPARATOR
non-ferrous metals
OPTICAL SORTING
plastic containers
rejects
ASPIRO-TRI AIR SEPARATOR
plastic films
flat bodies
HAND OVER-SORTING
paper
CRUSHING
< 80 mm
OVERBAND MAGNETIC SEPARATOR
ferrous metals
NF-METAL SEPARATOR
non-ferrous metals
< 80 mm
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 (2)


LOAD
PRIMARY TROMMEL SCREEN
> 250 mm
HAND OVER-SORTING
plastic sheet
cardboard
< 80 mm
OVERBAND MAGNETIC SEPARATOR
ferrous metals
NF-METAL SEPARATOR
non-ferrous metals
< 80 mm
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
paper
CRUSHING
OPTICAL SORTING
plastic containers
rejects
TRANSFORM INTO ENERGY
TROMMEL SCREEN
< 10 or 50 mm
> 10 or 50 mm
BOUNCE ADHERENCE SEPARATOR
heavies (glass)
BIOMETHANISATION
energy generation
Digestate
ACCELERATION 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).

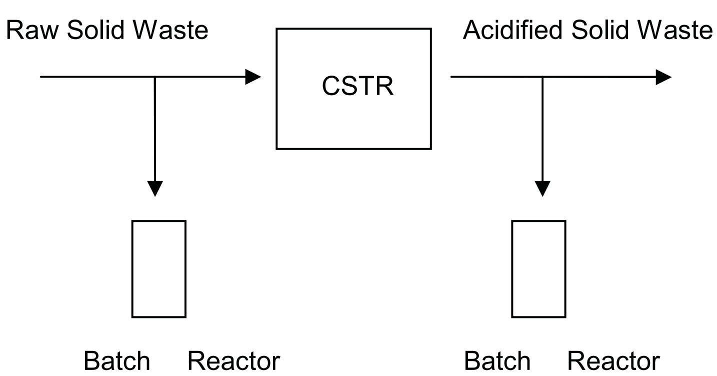

Figure 1 Schematic presentation of the experimental set up

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).

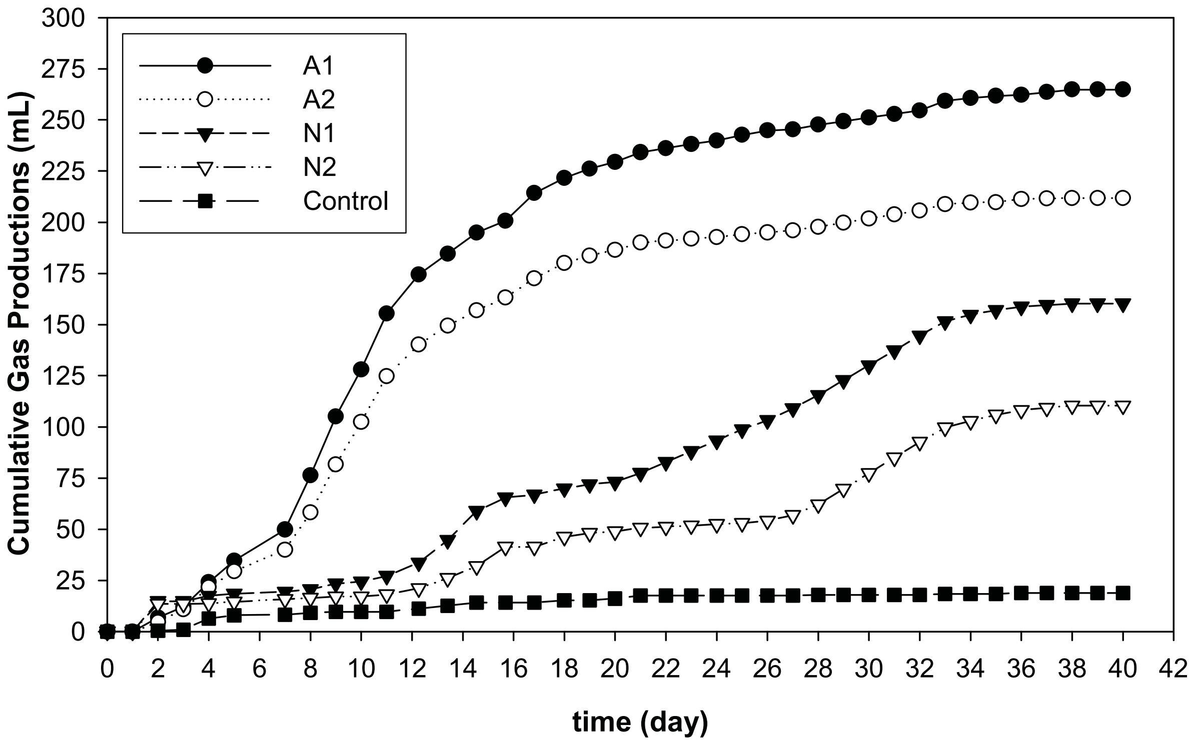

Figure 2 Cumulative gas productions measured throughout the experiments

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.

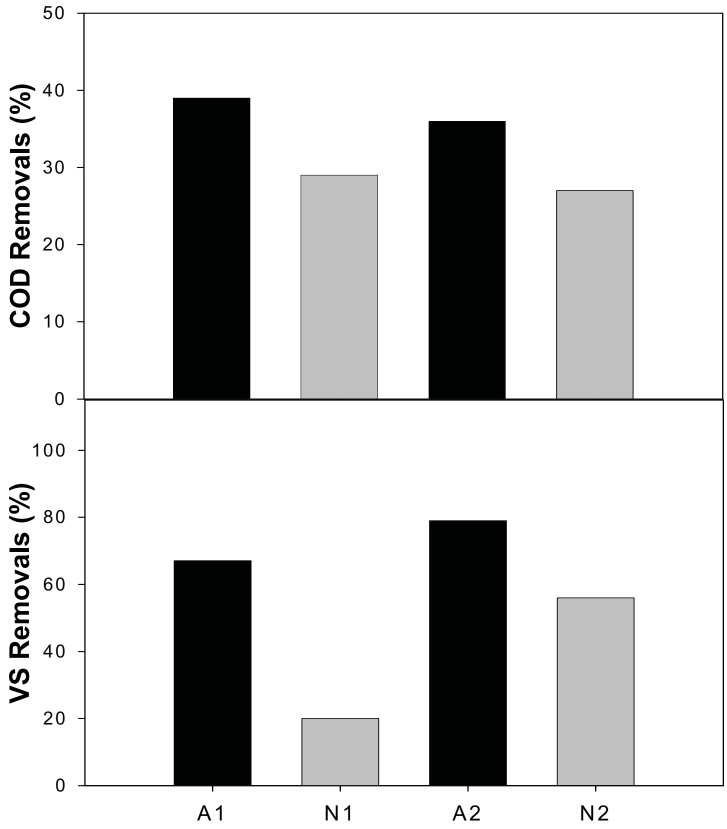

Figure 3 tCOD and VS reductions observed in the reactors

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.

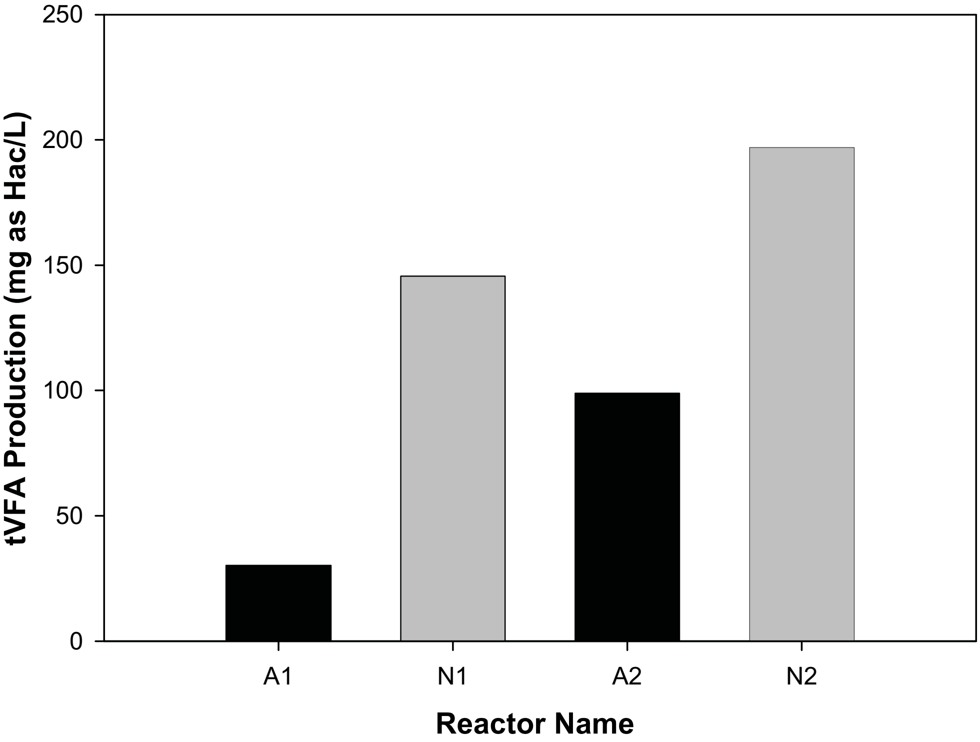

Figure 4 tVFA production of the reactors

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.

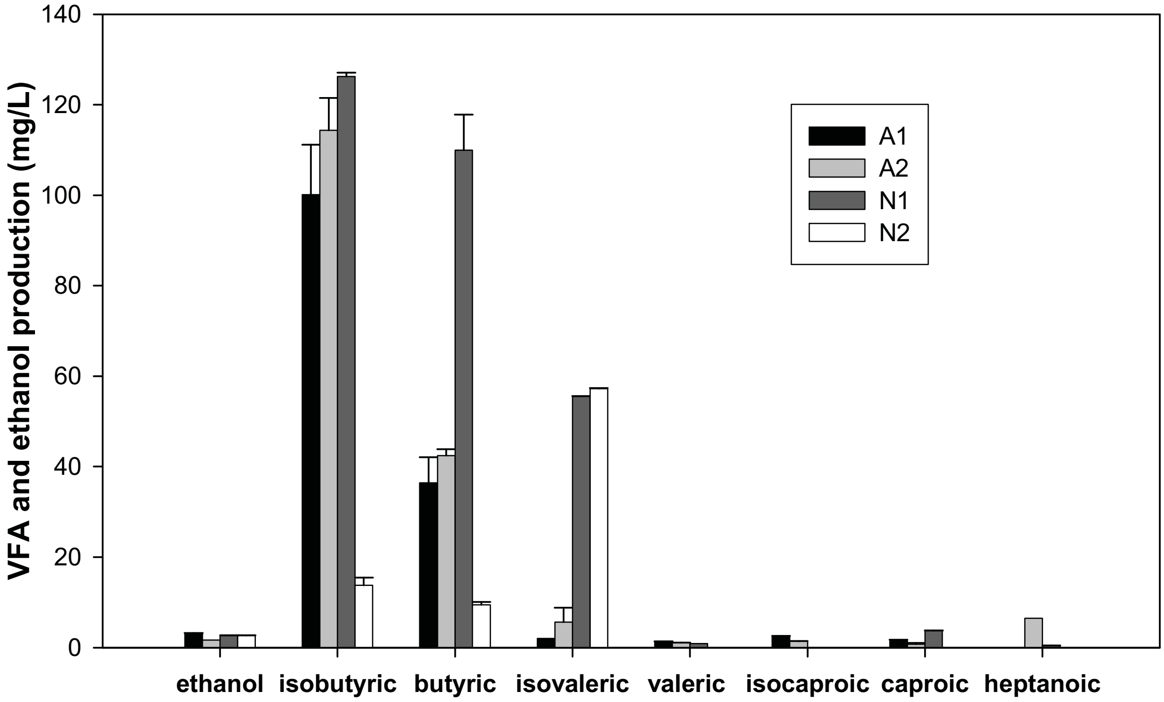

Figure 5 Different VFA productions in the reactors

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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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

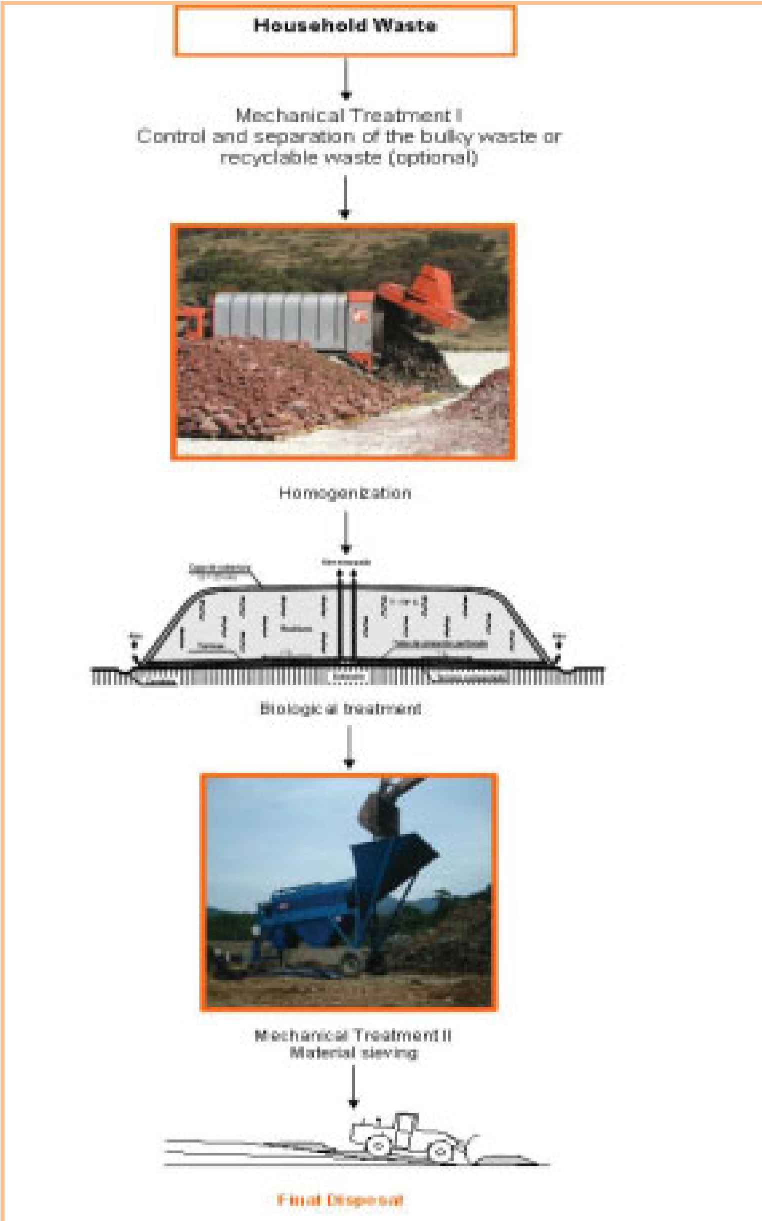
The MBT aim is the biological stabilization of organic fractions found in household waste up to reaching the characterization as an inert mass. It means that after the MBT the organic fractions will be microbiological inactive having as consequence gas emissions reduction and also reduction of the organic load at the leachate.

Waste treatment advantages

- 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 landfilled 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.

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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

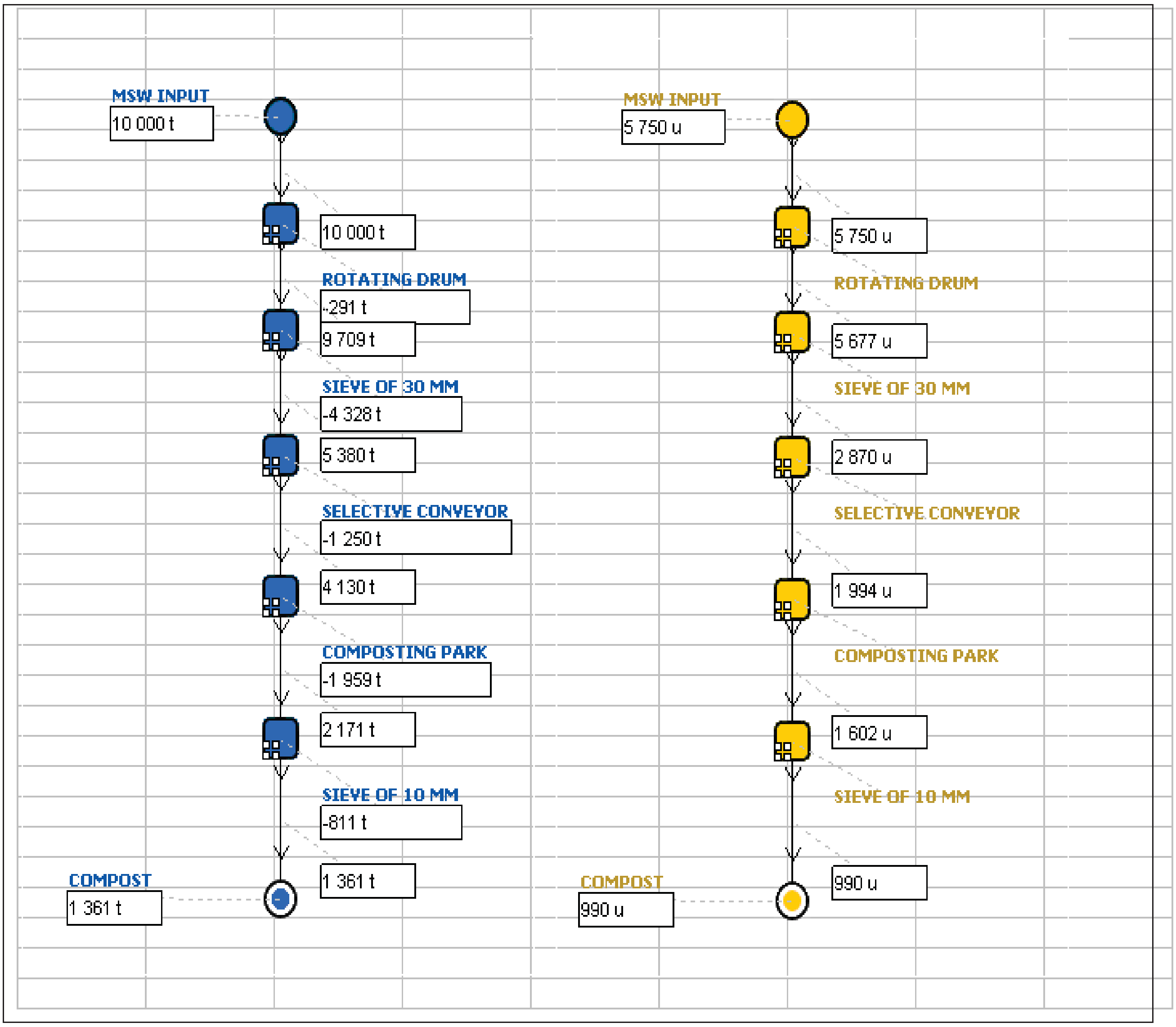

Figure 1 The graph drawing in wet and dry matter

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.

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RTO-Anlagen der neuesten Generation

Andreas Breeger

The latest Generation of RTO-plants

Abstract

The deadlines for the implementation of the 30th BImSchV for mechanical biological waste treatment have expired. In the meantime, the operating time of the required exhaust air cleaning plants (thermal post-combustion and biological systems) reach up to 4 years. Operating experience to comply with the limits, corrosion and difficulties due to siloxanes exist and will be presented in this essay. In particular, practical examples of operational RTO systems optimized for applications in the MBA field will be introduced.

Inhaltsangabe

Die Fristen zur Umsetzung der 30. BImSchV für mechanisch biologische Abfallbehandlungsanlagen sind abgelaufen. Die erforderlichen Abluftreinigungsanlagen (thermische Nachverbrennungsanlagen und biologische Systeme) weisen mittlerweile Betriebszeiten von bis zu 4 Jahren auf. Betriebserfahrungen zur Einhaltung der Grenzwerte, Korrosions- und Siloxanproblematik liegen vor und werden vorgestellt. Insbesondere wird auf Praxisbeispiele für betriebsoptimierte RTO-Anlagen für Anwendungsfälle im MBA-Bereich eingegangen.

Keywords

Regenerativ Thermische Oxidations-Anlagen, 30. BundesImmissionsSchutzVerordnung, Siloxane, Korrosion, Mechanisch Biologische Abfallbehandlung

Regenerative Thermal Oxidation Plants, Siloxanes, Corrosion, Mechanical Biological Waste Treatment

RTO-Anlagen der neuesten Generation

1 Emissionsminderung für MBA-Anlagen

Die Fristen zur Umsetzung der 30. BImSchV für Mechanisch-Biologische Abfallbehandlungsanlagen sind am 01. Juni 2005 abgelaufen. Zur Einhaltung der anspruchsvollen Grenzwerte, insbesondere der zulässigen Gesamt-Kohlenstoff-Frachten, sind RTO-Anlagen (Regenerativ-Thermische-Oxidationsanlagen) alleine bzw. in Kombination mit Biofiltern zum Einsatz gekommen. Die Betriebszeit der Abluftreinigungsanlagen beträgt zum Teil mehr als 4 Jahre. Ein Resümee zu den gemachten Betriebserfahrungen ist demnach heute möglich.

Abbildung 1: RTO-Anlage mit Wäscher

2 Einhaltung der Grenzwerte

Die Grenzwerte der 30. BImSchV lassen sich generell einhalten. Voraussetzung hierfür ist allerdings ein Regelbetrieb sowohl der MBA-Anlagen (Mechanisch-Biologische-Abfallaufbereitungsanlagen) als auch der Abluftbehandlungsanlagen. Die geforderten Verfügbarkeiten, 8 Stunden Stillstand am Stück bzw. 96 Stunden im Jahr, sind unter Berücksichtigung der vorgefundenen Abluftbedingungen bzw. anderer Rahmenbedingungen (Biogasqualitäten) und den bisherigen Abluftkonzepten teilweise nur schwierig zu erfüllen.

Geruch: Der Grenzwert von 500 GE/m³ wird in der Regel sicher eingehalten. Die Voraussetzung hierfür ist, bei Kombinationsanlagen einen ausreichend großen und richtig konzipierten Biofilter einzusetzen, sowie bei RTO-Anlagen eine effiziente Ammoniakabscheidung durch vorgeschaltete Wäscheranlagen durchzuführen.

Staub: Der Grenzwert von 10 mg/m³ TMW (Tages-Mittel-Wert) wird sicher eingehalten.

Dioxine/Furane: Der Grenzwert von 0,1 ng/m³ wird teilweise um Faktor 10 und mehr unterschritten.

Dickstickstoffoxid (N_2O): Die zulässigen Lachgasfrachten von 100 g/Mg werden eingehalten. Zur Verhinderung einer Lachgasbildung muss Ammoniak aus der Abluft abgeschieden werden. Hierzu kommen Wäscher, die im sauren Milieu betrieben werden, zum Einsatz. Einschränkend muss erwähnt werden, dass Lachgas, welches in den vorgeschalteten biologischen Rotte-Prozessen gebildet werden kann, nicht durch die installierten Abluftreinigungstechnologien abgeschieden wird.

Gesamtkohlenstoff (TOC): Für die Auslegung der Abluftreinigungsanlagen sind die Frachtenbegrenzung von 55 gC/Mg Abfallinput und nicht die zulässigen Emissionskonzentrationen von 20 mg/m3 (TMW) die zielführende Größe. Hieraus resultieren zum Teil Konzentrationswerte von 5 mg/m³. Diese sehr anspruchsvollen Grenzwerte lassen sich im Regelbetrieb der Abluftreinigungsanlagen einhalten. Die bisherigen Betriebserfahrungen zeigen jedoch, dass der Regelbetrieb durch Rahmenbedingungen der Abluft massiv eingeschränkt wird. Hierauf soll im Folgenden eingegangen werden.

3 Ablagerungen in RTO-Anlagen

In Rotteprozessen kann es zur Freisetzung von siliziumorganischen Verbindungen kommen. Die Konzentrationen liegen üblicherweise zwischen 0,1 bis 10 mg/m³. Mögliche Ursachen hierfür können unter anderem sein (Carlowitz, 0. et al., 2005 / Otterpohl, R. et al., 2005):

- Anaerobbedingungen in der Rotte
- Feuchtehaushalt in der Rotte
- Temperaturen in der Rotte
- Zusammensetzung des Abfalls

Das Silizium oxidiert in der RTO und setzt dem Wärmetauscher in Form von Belägen derart zu, dass eine Abluftübernahme nicht mehr oder nur in reduzierter Form möglich ist. Die Folge ist, dass die Einbauten der RTO in bestimmten Zyklen von diesen Ablagerungen befreit werden müssen. Je nach vorgeschaltetem Prozess müssen die Einbauten zum Teil in Abständen von 20 Tagen gereinigt werden. Der Reinigungsaufwand ist in der Regel zeitintensiv, da das Ab- und Wiederanfahren der RTO durchaus bis zu 24 Stunden in Anspruch nehmen kann. Durch diese häufigen Reinigungszyklen werden die Wärmetauscher verschlissen, so dass diese ca. alle 2 Jahre komplett gewechselt werden müssen. Der benötigte Zeitraum zum Austausch der Wärmetauscher beträgt je nach Anlagengröße bis zu 7 Tage je RTO-Linie.

Abbildung 2: Siloxanproblematik in RTO-Anlagen, zerstörte Wärmetauscher

Die eingesetzten RTO-Anlagen sind zur Einhaltung der geforderten Verfügbarkeiten in der Regel mehrlinig ausgeführt. Die Einhaltung der TOC-Frachten im Einlinienbetrieb hat sich teilweise als schwierig erwiesen.

Der Ansatz von Wessel-Umwelttechnik zur Lösung dieses Problemfeldes ist eine Reduzierung des Eintrages von siliziumorganischen Verbindungen in die RTO. Herkömmliche Verfahren zur Siliziumabscheidung wie z.B. Adsorberanlagen lassen sich aufgrund der Abluftqualitäten (feucht und staubhaltig) nicht einsetzen. Die Entstehung der siliziumorganischen Verbindungen lässt sich üblicherweise auf bestimmte Phasen des Rotteprozesses beschränken (z.B. Aerobisierung, in den ersten 24 – 36 h der Intensivrotte). Zur Reduzierung des Eintrages von Siloxanen in die RTO-Anlagen sollte eine Entfrachtung dieser Abluftströme realisiert werden, zumal nur ca. 10% des Gesamtabluftstromes behandelt werden müssten. Es konnte analytisch detektiert werden, dass von den gebildeten Siloxanen etwa 90% der so genannten D5-Verbindung zuzuordnen sind. Im Rahmen einer Diplomarbeit wurden im Jahr 2007 Untersuchungen mit speziellen Absorbentien in Wäschern im halbtechnischen Maßstab durchgeführt. Die Absorbentien wurden unter anderem nach dem Kriterium einer möglichen Wiederverwendung ausgewählt. Im Rahmen der Untersuchungen wurden Abscheidegrade von bis zu 80% für die D5-Verbindung erzielt.

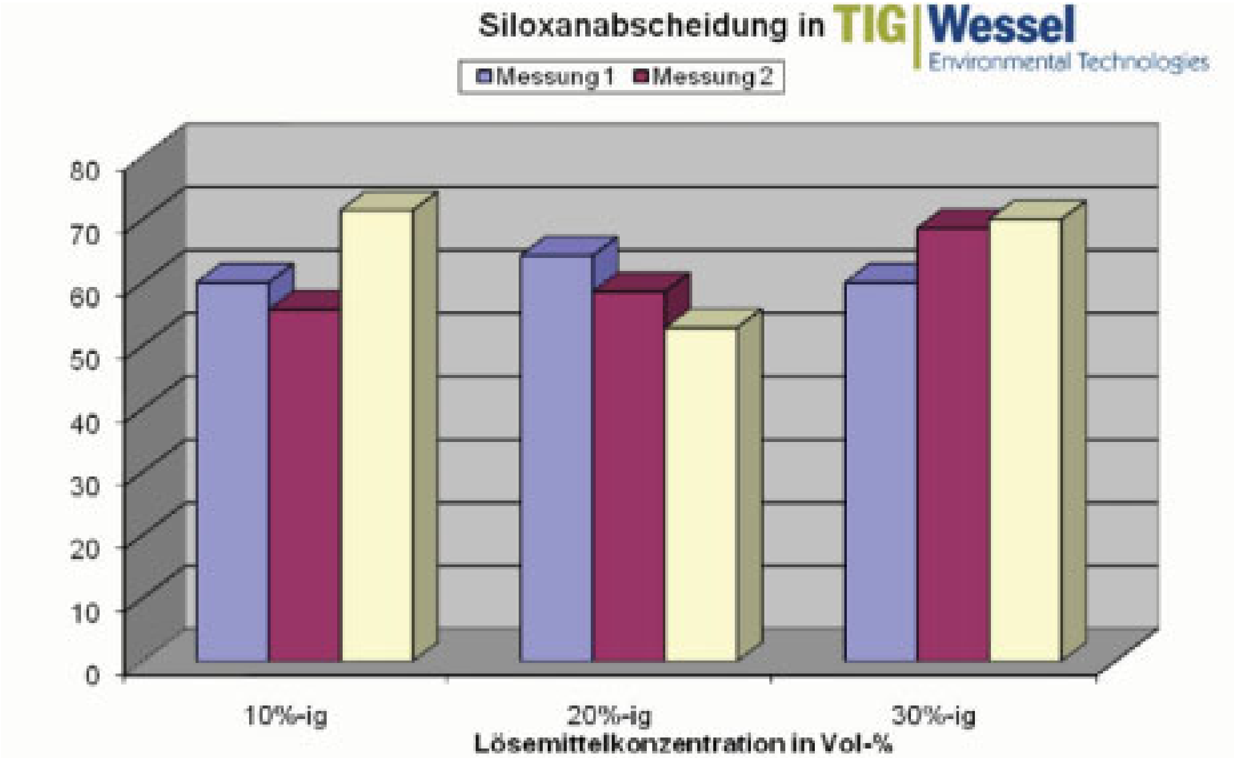

Abbildung 3: Abscheidediagramm für D5-Verbindungen

Im nächsten Schritt sollen jetzt Feldversuche vor Ort an MBA-Anlagen ausgeführt werden. Die Reinigungszyklen der RTO-Anlagen könnten dadurch signifikant verlängert und das Problemfeld der Einhaltung der TOC-Frachten und Anlagenverfügbarkeiten nachhaltig entschärft werden.

4 Problemfeld Korrosion

In biologischen Abfallbehandlungsanlagen besteht generell die Gefahr, dass es zu Korrosionsbildung kommen kann. Dies betrifft in starkem Maße Bauwerke wie Rottehallen (Fricke, K. et.al). Ursachen hierfür sind die feuchte und aggressive Atmosphäre. In der Prozessluft werden u.a. folgende korrosive Wirkkomponenten vorgefunden: Halogene (Chlor, Fluor), Ammoniak, Säuren. Die installierten RTO-Anlagen sind von Korrosionserscheinungen nicht verschont worden. Beachtlich ist der teilweise sehr kurze Zeitraum von nur 3 Monaten, in dem zum Teil massive Schäden aufgetreten sind. Betroffen sind insbesondere die Rohgaskanäle, in geringerem Umfang die Reingaskanäle und die Brennkammer. Das Schadensbild weist häufig Lochfraß verursacht durch Halogenkorrosion auf. Weitere Ursachen sind Salzablagerungen von Ammoniumsulfat, welches in den vorgeschalteten Wäschern gebildet wird.

Abbildung 4: Korrosion im Rohgaskanal

Da eine Vermeidung von korrosiven Stoffen in der Abluft mit wirtschaftlich vertretbarem Aufwand nicht möglich ist, müssen die RTO-Anlagen bestmöglich gegen korrosiven Angriff geschützt werden. Nach heutigem Kenntnisstand, wobei an dieser Stelle betont werden soll, dass eine Definition „Stand der Technik“ aufgrund der vergleichsweise kurzen Betriebszeit der Anlagen noch nicht möglich ist, sind folgende Maßnahmen zur Unterdrückung der Korrosion zielführend:

Feuchtigkeitseintrag: Reduzierung des Feuchteeintrages in die RTO-Anlagen durch Einsatz von Hochleistungstropfenabscheidern in den Wäschern. Abluftvorwärmung vor der RTO und nach den Wäschern, zur Absenkung der relativen Feuchte und Unterdrükkung von Kondensationseffekten in der RTO.

Brennkammer: Bei hohen Ablufttemperaturen (> 50 °C sind möglich) und dem damit verbundenen hohen Feuchtigkeitseintrag in die RTO-Anlagen, sollte zusätzlich zur erforderlichen Innenisolierung ebenfalls eine Außenisolierung vorgesehen werden. Hierdurch wird das Temperaturniveau der Stahlwand soweit angehoben, dass eine Kondensation nicht stattfinden kann und demzufolge Korrosion verhindert wird. Als weitere Schutzmaßnahme können diffusionsdichte Isoliermaterialien zum Einsatz kommen.

Rohgaskanal: Zur sicheren Verhinderung von Korrosion im Rohgasbereich müssten Sonderstähle wie Alloy 59 eingesetzt werden; normale Edelstahlsorten wie z.B. 1.4571 oder 1.4539 sind nicht dauerhaft gegen Halogenverbindungen beständig. Der Einsatz der Alloy-Werkstoffe ist finanziell nicht darstellbar. Aus diesem Grund werden häufig hochwertige Beschichtungen eingesetzt, wie sie z.B. in der chemischen Industrie verwendet werden. Bei der Auswahl ist neben der chemischen Beständigkeit auch den maximalen Einsatztemperaturen besondere Beachtung zu schenken. Im Rohgasbereich einer RTO können unter bestimmten Betriebsbedingungen Temperaturen bis 200°C auftreten. Als geeignet haben sich Mehrkomponenten-Polymerbeschichtungen erwiesen.

Abbildung 5: überarbeiteter Rohgaskanal

Die RTO-Anlagen für MBA-Anlagen jüngeren Datums werden in der Regel konstruktiv derart gestaltet, dass Verschleißbereiche leicht demontierbar und austauschbar sind.

5 Ausblick

Die Problemfelder bei dem Betrieb von Abluftreinigungsanlagen gemäß der 30. BImSchV sind erkannt. Erste Lösungsansätze zur Behebung der aufgetretenen Probleme im Bereich der Korrosion sind gefunden und werden umgesetzt. Die nach dem neuesten Stand der Technik errichteten RTO-Anlagen haben sich mittlerweile im 6-monatigen Dauereinsatz bewährt. Die ehemals aufgetretenen Korrosionsprobleme konnten bisher nicht festgestellt werden.

Abbildung 6: RTO-Anlage der neuesten Generation

Die Thematik der Siloxanproblematik in RTO-Anlagen bedarf noch weiterer intensiver Arbeit zur Findung von Lösungen. Hier sind die Betreiber von MBA-Anlagen, die Planer, Forschungsinstitute und die Anlagenbauer gemeinsam gefordert.

Anschrift des Verfassers

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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.

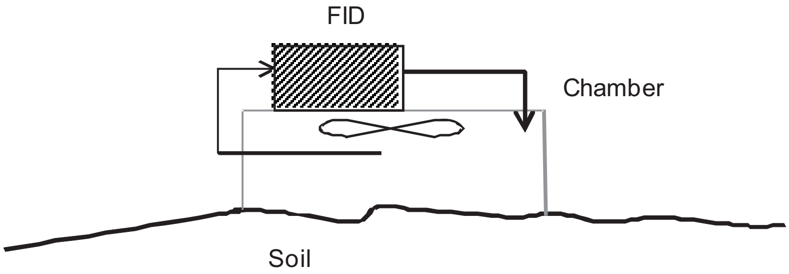

Figure 1 : apparatus for gaseous surface emissions (static chamber)

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.

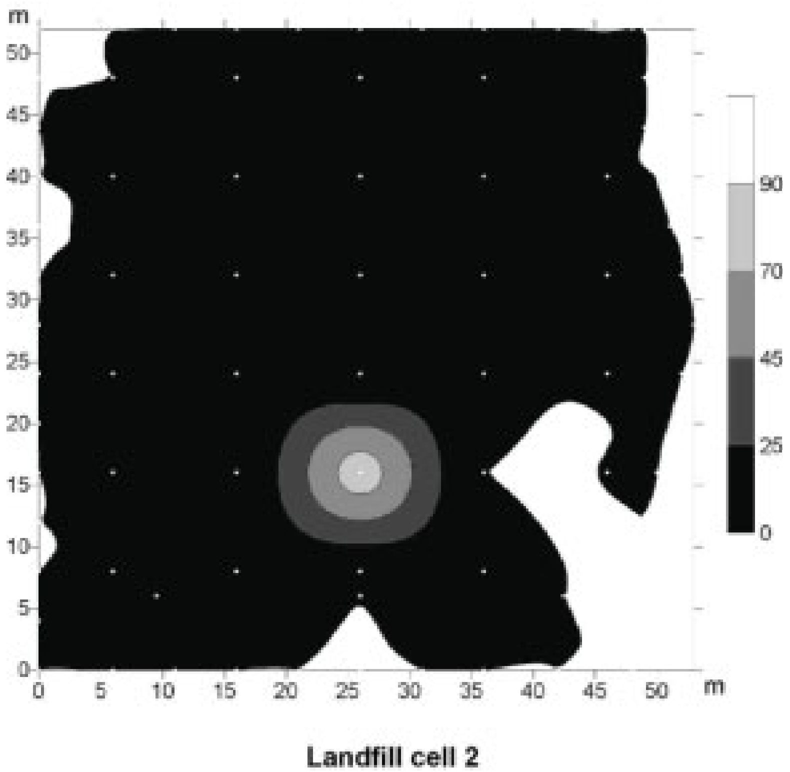

Figure 2 : Interpolated methane emissions on landfill cell 2, ml/m²/min

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.

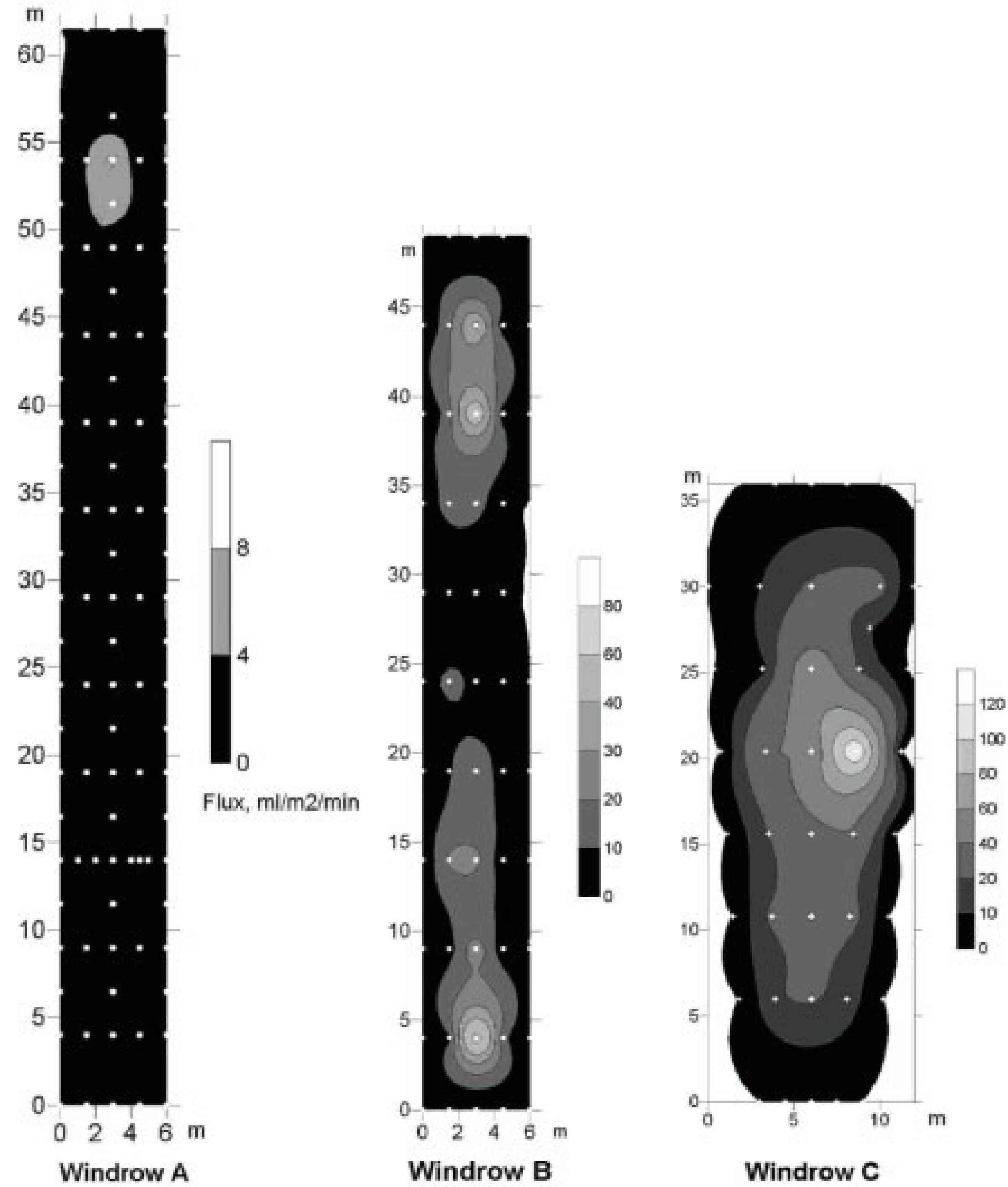

Figure 3 : Interpolated methane emissions on windrows, mL/m^2/min

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.

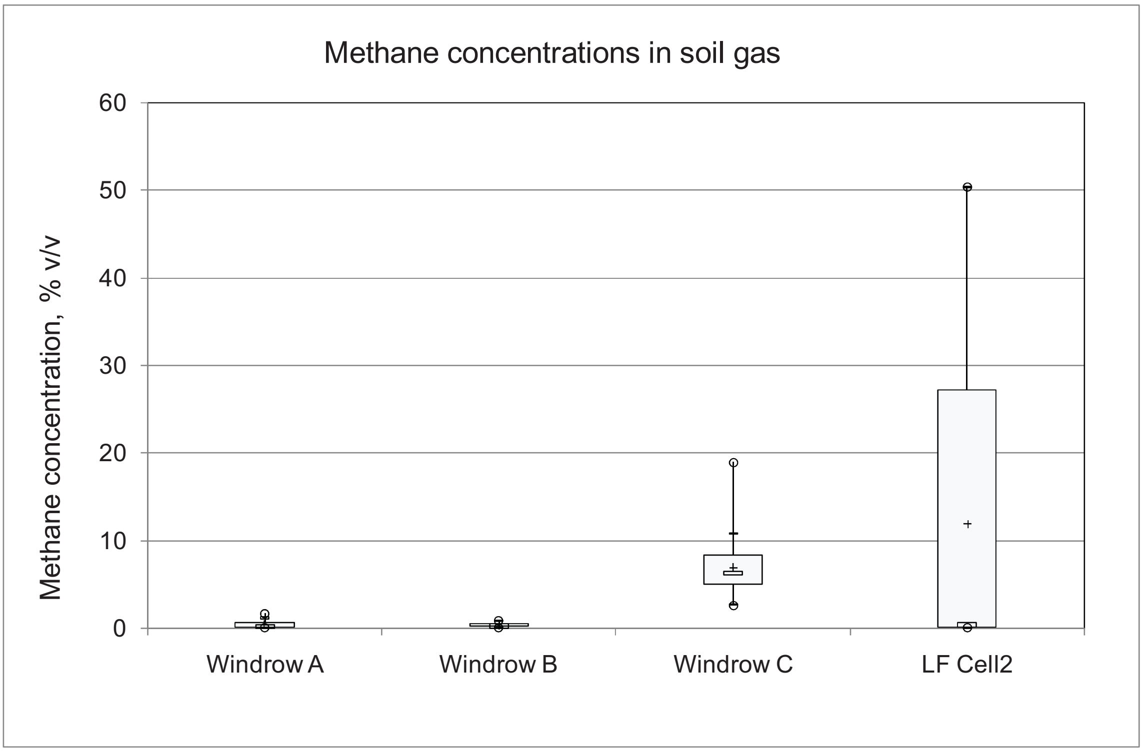

Figure 4 : repartition of methane values in soil gas, windrows and landfill cell

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.

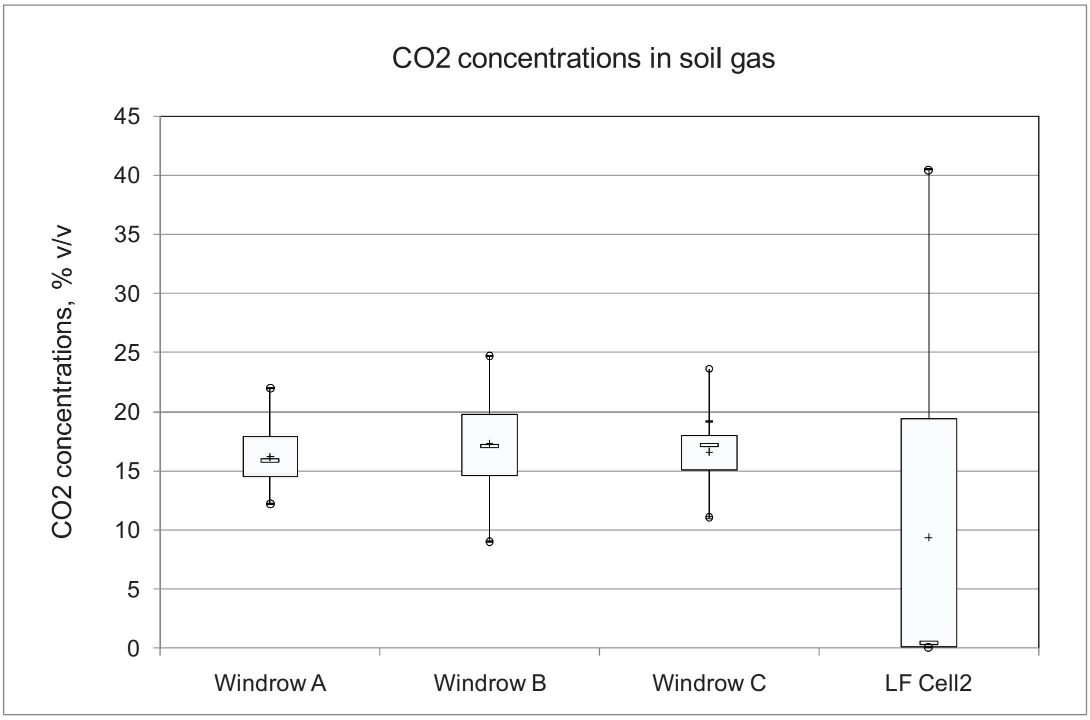

Figure 5 : repartition of CO2 values in soil gas, windrows and landfill cell

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.

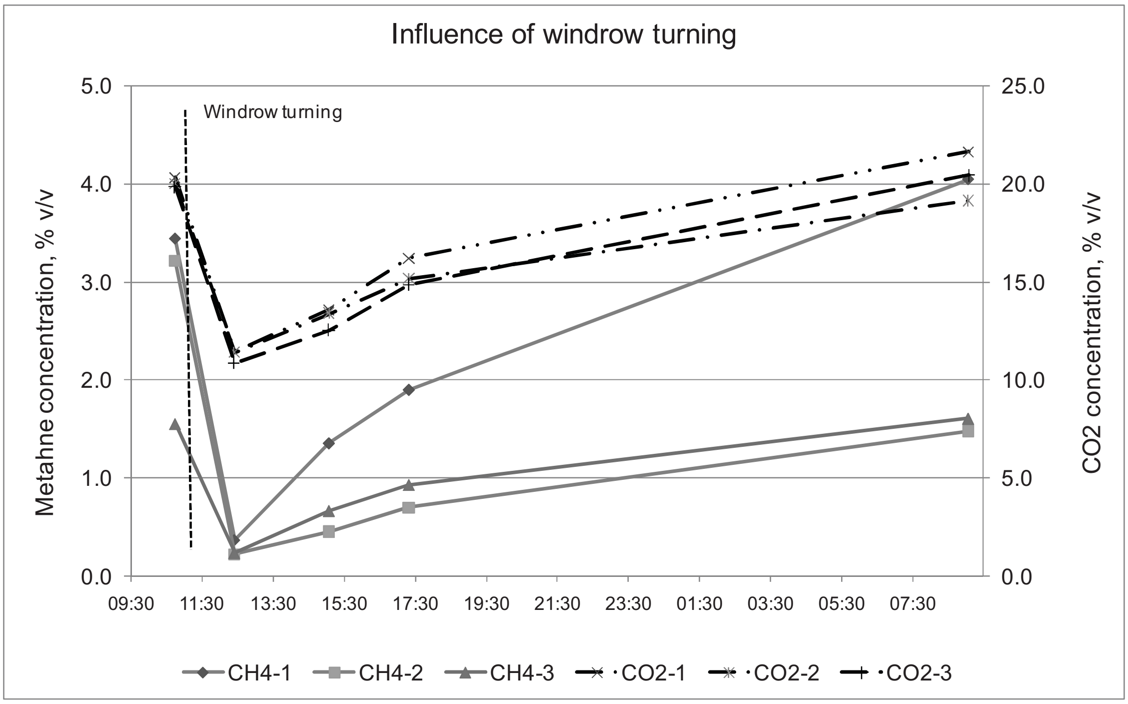

Figure 6 : effect of windrow turning on CH4 and CO2 concentrations in the compost

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.

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Löschanlagenkonzept für Recyclinganlagen

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Fire extinguishing concepts for recycling plants

Inhaltsangabe

Dieses Löschanlagenkonzept analysiert die Probleme bei Bränden in Recyclinganlagen und ermittelt verbesserte Verfahren zur sicheren und wirtschaftlichen automatischen Brandbekämpfung.

Keywords

Brandschutz, Recyclinganlage, Löschanlagenkonzept, fire extinguishing, recyling plants

1 Löschanlagenkonzept für Recyclinganlagen

1.1 Problemstellung

Angesichts wachsender Müllberge und damit verbundener Entsorgungsprobleme gewinnen Recyclingunternehmen in der Wirtschaft zunehmend an Bedeutung. Die zielgerichtete Aufbereitung von Abfällen und die Wiederverwertung der Rohstoffe leisten einen wichtigen Beitrag zur Schonung der Ressourcen unserer Erde. Die zur Zwischenlagerung verwendeten festen Fraktionen, wie Papier, Pappe, Kartonagen und Kunststoffen, mit teilweisen Soll-Heizwerten von über 14 MJ/Kg, bilden mit ihrer Brandlast ein erhebliches Gefahrenpotential für Menschen und Gebäude. Nach der Bestimmung der Art, der Menge und der Konfiguration der Brennstoffe geht es darum, diejenigen Anwendungsstoffe- und Methoden auszuwählen, die in Bezug auf das Ausmaß der zu schützenden Brandgefahren am wirkungsvollsten sind. Aus einer Studie des Instituts für Abfallwirtschaft Düsseldorf ist mittlerweile bekannt, dass es bei Recycling-Produkten unter bestimmten Bedingungen der Lagerung auch zu Selbstentzündungen kommen kann!

1.2 Brandgefährdung

Entstandene Brände können sich sehr schnell ausbreiten und bedeuten daher ein hohes Risiko für die in diesem Bereich tätigen Mitarbeiter und Sachwerte. Den Einsatzkräften der Feuerwehr bleibt oftmals nur sehr wenig Zeit, ein entstehendes Feuer unter Kontrolle zu bringen. Wie der Presse zu entnehmen ist, enden Brände in Recyclinganlagen häufig mit einem Totalschaden. Nicht selten sind Verletzte bzw. Tote zu beklagen. Darüber hinaus bedeuten die Verbrennungsprodukte (Dioxine, Furane) eine extrem gefährliche Umweltbelastung. Um Lagerhallen und Sortieranlagen für einen dauerhaften Betrieb nutzen zu können muss es das Ziel sein, verbesserte Brandmelde- und Brandlöschsysteme für Schwerpunktbereiche zur Anwendung zu bringen. Es können sich im Extremfall Brandsituationen ergeben, welche ein Vordringen der Feuerwehr zum Brandherd schwer oder gar nicht ermöglicht. Das Brandmelde- und Feuerlöschsystem muss in der Lage sein, bereits den Entstehungsbrand zu erkennen, und die betreffenden Halden, Bunker, Absetzcontainer und Shredder zu löschen, sowie eine Brandausbreitung des Lagergutes zu verhindern. Das heißt, hier soll auf eine Brandbekämpfungsmethode orientiert werden, welche das Gebäude, die Einrichtungsteile und das Lagergut abschirmt, kühlt und löscht.

2 Löschanlagenauswahl

2.1 Löschanlagenvorschläge

Zur Löschung von Recyclingbränden wurden bisher konventionelle Löschverfahren, wie Schwerschaum oder Sprühflutanlagen mit 1% Schaummittelzumischung verwenden. Auch mit Mittelschaum wurde in der Vergangenheit versucht dem Brand in Recyclinganlagen oder Müllverbrennungsanlagen mit mehr oder weniger großen Erfolg Herr zu werden.

2.2 Löschanlagenbewertung

Um eine Auswahl möglicher Feuerlöschsysteme unter Sicherheits-, Wirtschaftlichkeits- und Schadensverhütungsaspekten (Nachfolgeschäden) treffen zu können, müssen alle möglichen automatischen Feuerlöschanlagen in Betracht gezogen werden. Für die Untersuchungen, welche Löschvariante in Frage kommt, wurden die einschlägigen Vorschriften und Richtlinien, sowie Versuche und Erkenntnisse, zu Rate gezogen.

Eigenschaften/Typ	Schwerschaum	Sprühflut 1% S	Mittelschaum	ONE-SEVEN
Brandklasse	A-B	A-B	A-B	A-B-C
Wasserbedarf	60%	100%	30%	15%
Kühlwirkung	40%	80%	10%	100%
Stickeffekt	80%	10% (Dampf)	60%	100%
Netzfähigkeit	gut	gut	gering	gehr gut
Deckenbelastung	sehr groß	sehr groß	sehr groß	gering
Schaummittelzum.	5%	1%	3%	0,5%

2.3 Auswahlentscheidung

Da die bisher beschriebenen Feuerlöschanlagen entweder nicht anwendbar sind oder einen zu hohen wirtschaftlichen Aufwand bedeuten, soll im folgendem ein System beschrieben werden, welches das Brandrisiko beherrscht und sich im verhältnismäßig wirtschaftlichen Rahmen bewegt. Es handelt sich hier um ein ONE-SEVEN Druckluftschaumsystem.

Im Folgenden soll näher auf dieses System eingegangen werden:

3. ONE-SEVEN Druckluftschaumlöschanlage (DLS-LA)

Seit Jahrzehnten und heute im Besonderen wird dieses Druckluftschaum-Löschverfahren bereits in der Brandbekämpfung genutzt. Zwischenzeitlich ist dieses Verfahren Stand der Technik und in der DIN 14430 werden entsprechende Anforderungen gestellt. Aus Versicherungsrelevanten Gründen befindet sich dieses System zur Zeit beim VdS Köln im Prüfungsverfahren. Begünstigend für die baldige selbige Zulassung ist, dass dieses Verfahren beim FM Globel im abschließenden Stadium ist (voraussichtlich 1. Quartal 2009). Bei diesem Löschverfahren kann der fertig erzeugte Schaum (gleich bleibend 0,5 mm Blasendurchmesser) über weite Rohrlängen (1.000 m lang; 400 m hoch) transportiert und über jeweils geeignete Auswurfvorrichtungen verteilt (Wurfweite bis 30 Meter) werden. Durch seine vielfach höheren Löschwirkungen gegenüber den bekannten Wasserlöschverfahren, seinem sehr geringen Wasserverbrauch und einem Minimum an Nachfolgeschäden, ist dieses Verfahren für sehr hohe Brandlasten gut geeignet. Eine Gegenüberstellung einer Wasserlöschung und einer ONE-SEVEN Löschung in der Forschungsstelle für Brandschutz Karlsruhe ergab, bei gleichem Brandszenarium, folgende Werte:

ONE SEVEN® Test in der Forschungsstelle für Brandschutztechnik in Karlsruhe
Test mit DIN – C-Rohr mit 100 l/min

	Wasser	Druckluftschaum
Temperaturabsenkung	0,83 °/sek	10,3 °/sek
Wasserverbrauch für Löschvorgang	800 Liter	175 Liter
Wasserverbrauch zur Nachlöschung	600 Liter	235 Liter
Schaummittelverbrauch	0	1,24 Liter
Wasserrückstand	Große Mengen Restwasser	Kein unverdampftes Wasser 200 Liter verdampft 200 Liter im Brandgut

Abb. 1

Bei der ONE-SEVEN Löschung erfolgte die Temperaturabsenkung um das 12 fache schneller als die reine Wasserlöschung. Der kompakte Schaum verbleibt im Wesentlichen am Brandherd und kann mittels Nassstaubsauger entfernt werden. Am Brandherd werden vom verwendeten Wasser ca. 50 % verdampft und 50 % verbleiben im Brandgut. Dadurch wird ein Wasserschaden auf ein vielfaches minimiert. Die Löschung erfolgt durch eine erzeugte Schaumschicht, welche das Feuer erstickt und den Brandherd stark durch kühlt. Hierbei ist der hohe Kühleffekt des Druckluftschaums besonders ausschlaggebend. Ein positiver Nebeneffekt ist die sehr schnelle Unterdrückung bzw. Abschottung von freigesetzten toxischen Gasen und Rauchpartikel. Der alkoholverträgliche Schaumbildner ONE- SEVEN® Klasse B-AR unterliegt der Wassergefährdungsklasse 1.

Die stationären ONE-SEVEN Druckluftschaum - Löschanlagen bieten eine Reihe wesentlicher und z.T. entscheidenden Vorteile, die in ihrer Gesamtheit betrachtet, die Anwendung und den Einsatz dieser Löschanlage zur automatischen und halbautomatischen Brandbekämpfung prädestinieren:

- Unter Verwendung eines speziellen „class B“ – Schaumbildners, der eine Zumischung von nur 0,6% zum Löschwasser erfordert, wird ein Druckluft - Schaum erzeugt mit dem Brände, wie Kunststoffe und andere Recyclingmaterialien, wirksam bekämpft werden können.
- Die Konsistenz des Druckluft - Schaums kann durch unterschiedliche Druckluftzumischung zum Wasser-Schaumbildnergemisch von nass - fließend bis trocken - klebend variiert werden. Aufgrund der Lösch- und Nebeneffekte (Kühl-, Trenn-, Stick-, Netzeffekt) sowie des Fließverhaltens des Druckluft - Schaums werden bis zu 80% des eingesetzten Löschmittels löschwirksam (Sprinkler-/Sprühwasserlöschanlagen ca. 25 – 30%).
- Damit können Brände im Vergleich zu anderen Löschmitteln und –verfahren, sofern sie zur automatischen Recyclingmaterialbekämpfung überhaupt anwendbar sind, in kürzerer Zeit und mit geringem Löschmitteleinsatz gelöscht werden. Durch seine eindringende und sehr stark kühlende Wirkung können Glutnester weitestgehend erreicht und gelöscht werden.
- Im Gegensatz zu herkömmlichen Schaumlöschverfahren wird beim ONE-SEVEN Druckluftschaum - System der Schaum durch eine zentrale Verschäumungseinheit (Schaum- Generator oder Verschäumungsmodul), welcher sich außerhalb des Gefährdungsbereiches befindet und damit unabhängig von der Umgebungsluft ist, erzeugt. Dies hat insbesondere den Vorteil, dass Rauch- und Brandgase, die bei Kunststoffbränden in großen Mengen entstehen und sich sehr schnell ausbreiten, die Schaumerzeugung nicht zerstörerisch beeinflussen können.

- Durch eine frühzeitige Erkennung des Brandes und sehr schnellen Brandunterdrückung und Löschung wird in kürzester Zeit eine weitere Ausbreitung verhindert.

- Der fertige Schaum kann über Rohrleitungen zu den speziellen Rotoren transportiert, welche dann das Brandgut ausreichend beaufschlagen kann. Mit speziellen Rotoren lassen sich mit einem Gerät leicht Flächen von 100 bis 200 m² beschäumen, wodurch sich der Installationsaufwand für Rohrleitungen im Vergleich zu entsprechenden, einen Vollschutz gewährleistenden Wasserlöschanlagen erheblich reduziert.

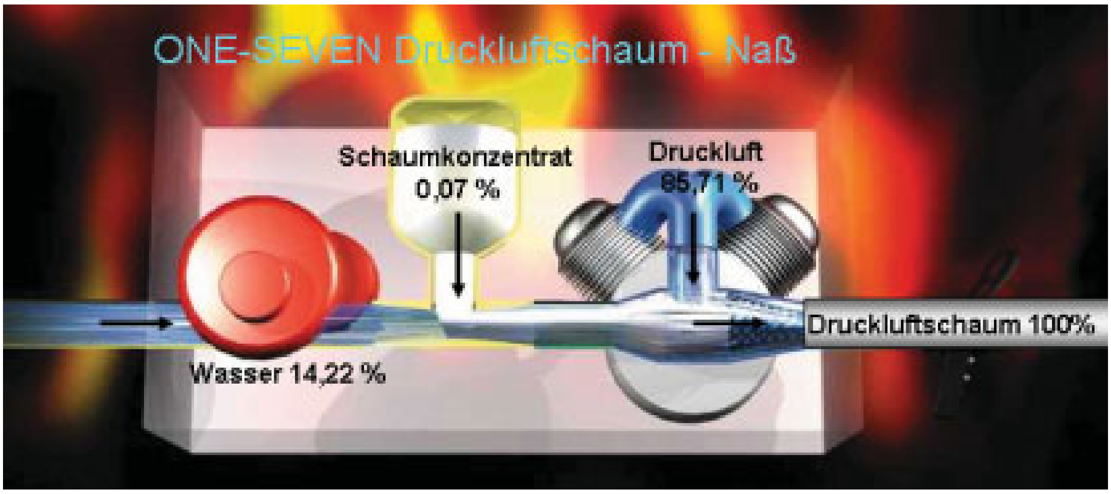

Abb. 2 : Druckluftschaum ONE SEVEN (Naß)

3.1 Löschvermögen

Im norwegischen Runehamar Tunnel führte im Jahre 2005 der Systemhersteller mit dem Esting and Research Institute umfangreiche Großbrandversuche durch. Überwacht und dokumentiert wurden diese Versuche von drei international anerkannten Testinstituten:

1. TNO aus den Niederlanden
2. NBL Sintef aus Norwegen
3. NRC aus Kanada

Zweck dieser Versuche war die Nachweiserbringung der Leistungsfähigkeit von ONE-SEVEN Feuerlöschsystemen bei der Löschung von verschiedenartigen Vollbrände

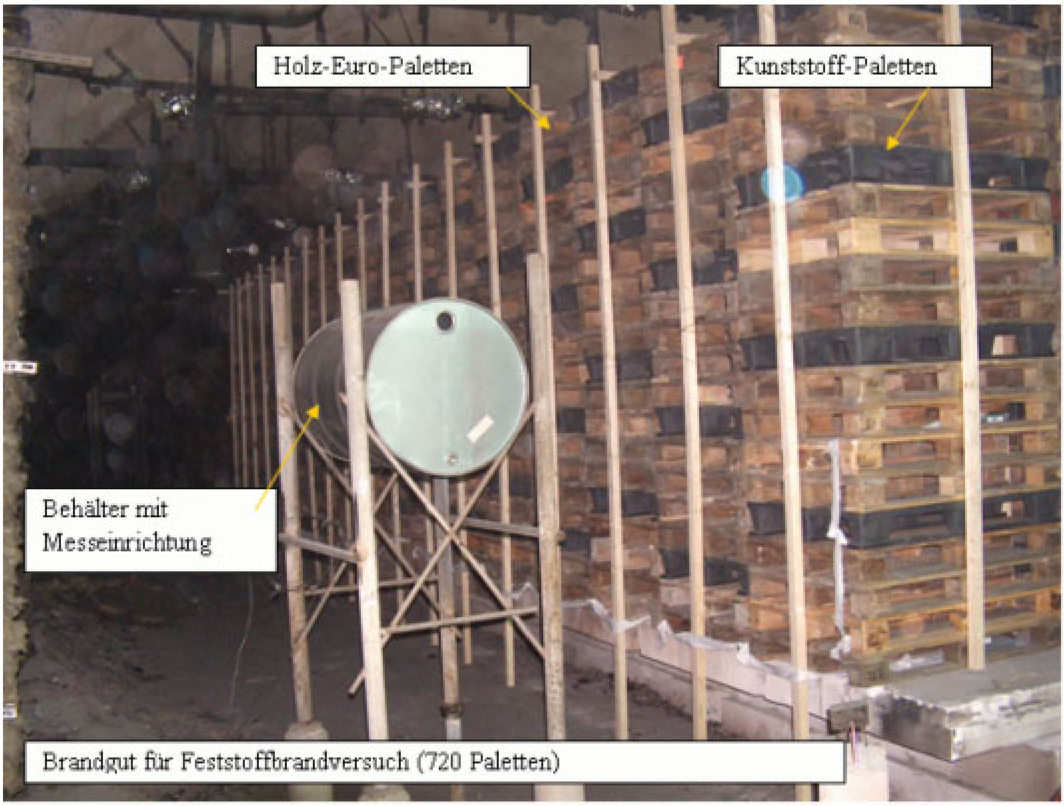

Abb.3: Versuch 1 (Feststoffbrand)

So wurde ein Brand eines voll beladenen Sattelschleppers simuliert. Dazu wurden 720 Euro-Paletten (80% Holz und 20% Polypropylen) auf 14,4 m Länge, einer Höhe von 3 m und einer Breite von 2,4 m gestapelt.

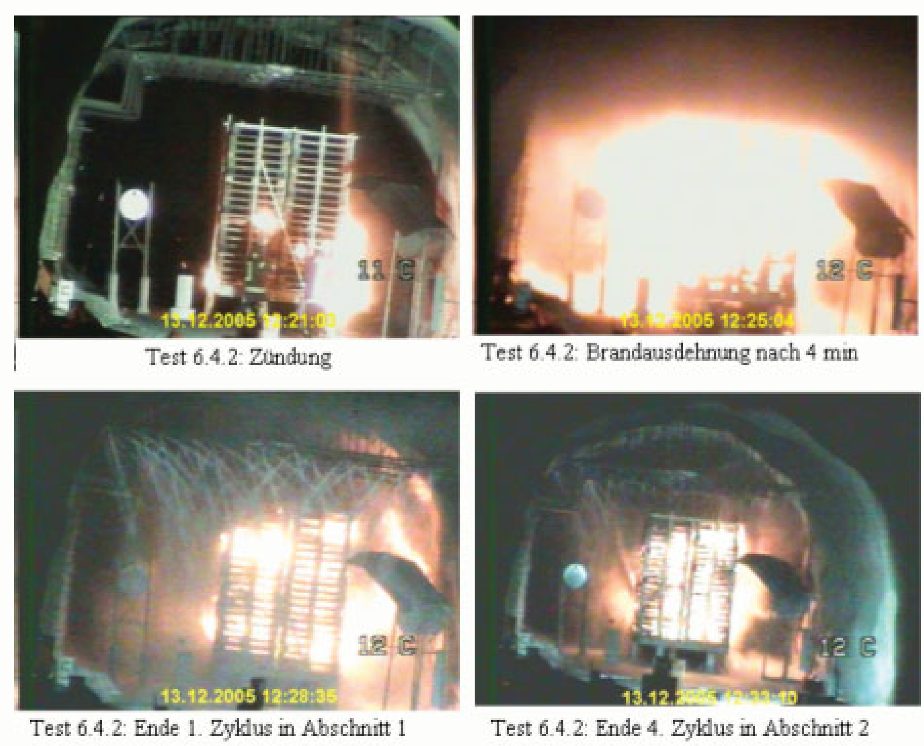

Abb.4: Testreihe - Feststoffbrand

Das One Seven System war in der Lage, dieses extreme Szenario zu beherrschen. Obwohl eine Wärmeausstoßrate von über 160 MW und Temperaturen von über 1.000° C erreicht wurden, konnte der Brand bereits nach weniger als 7 min unter Kontrolle gebracht werden. Nach nur knapp 22 min war das Feuer gelöscht.

Abb.5: Versuch 2 (Flüssigkeitsbrand)

Im zweiten Versuch wurde eine 25 m x 4 m Brandwanne mit 5.000 Liter Dieselkraftstoffgefüllt. Unmittelbar nach der Zündung des Brandgutes erfolgten ein rasanter Anstieg der Temperaturen im Brandbereich und eine extrem starke Rauchentwicklung.Die Versuchsergebnisse zeigten, dass der Vollbrand mit einer Wärmeausstoßrate von 140 MW und Temperaturen bis 1.200°C innerhalb von 2 Minuten gelöscht wurden.

3.2 Systemeignung und Anwendungen

Auf Grund seiner besonderen Löscheigenschaften für Recyclinghallen wurde beim Recyclinghersteller der Fa. Lober in Bayern, sämtliche Hallen und Lagerbereiche mit einer ONE-SEVEN Druckluftschaumanlage ausgestattet.

ONE SEVEN®-Löschanlage für die automatische Brandbekämpfung in einer Lagerhalle von Recycling-Produkten

Abb. 6

Weiterhin zeigte ein Realbrand von 13 Stück, durch Brandstiftung in Oranienburg gezündeten Reifenhalden, das durch eine One-Seven Anlage der Brand nach 1 ½ Tagen Branddauer, innerhalb von 6 Stunden gelöscht wurde. Zwischenzeitlich wurden für den Altstoffbunkerbereich im Kraftwerk der Stadtwerke Bremen und in Bitterfeld diese One-Seven Anlagen installiert.

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Erfahrungen zum Einbau von MBA Materialien und Untersuchungen zur Standsicherheit

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Stability and Operation of the MBP-landfill Hillern

Abstract

The technical requirements for landfilling of MBP-residues on landfills in Lower Saxony are described and the realisation of the requirements on the MBP-landfill Hillern is explained. In terms of a certain compliance with the geomechanical stability of the MBP-landfill body recommendations for the landfill operation are developed based on extensive site-specific investigations and stability calculations.

Zusammenfassung

Es werden die Anforderungen des Landes Niedersachsen an den Einbau von MBA-Material und die Umsetzung dieser Anforderungen im MBA-Deponieabschnitt der Deponie Hillern erläutert. Im Hinblick auf die sichere Einhaltung der geomechanischen Stabilität des MBA-Deponiekörpers werden auf der Grundlage umfassender standortbezogener Untersuchungen und Standsicherheitsbetrachtungen Empfehlungen zum Einbaubetrieb abgeleitet.

Keywords

MBA-Deponie, Einbautechnik, Stabilitätsbetrachtungen, Standsicherheitsnachweis, MBP-landfill, landfill operation, stability calculation, stability proof

1 Einleitung

Seit Mitte 2005 dürfen Hausmüll und hausmüllähnliche Siedlungsabfälle in Deutschland nur noch nach einer Vorbehandlung abgelagert werden. Aufgrund der Vorbehandlung unterscheiden sich die abzulagernden Abfälle bzw. Behandlungsrückstände signifikant von den bis dahin abgelagerten Abfällen sowohl hinsichtlich der chemisch-physikalischen und biologischen als auch der abfallmechanischen Eigenschaften. Die großtechnischen Erfahrungen zum Ablagerungsverhalten von mechanisch-biologisch vorbehandelten Abfällen (MBA) waren zum Zeitpunkt der Umstellung gering. Differenzierte Vorgaben zum Ablagerungsbetrieb und zum Aufbau entsprechender Deponiekörper mussten unter Berücksichtigung standortbezogener Randbedingungen, der jeweils spezifischen Abfallzusammensetzung und der physikalischen sowie mechanischen Eigenschaften erst entwickelt werden.

Der vorliegende Beitrag skizziert die Anforderungen des Landes Niedersachsen an den Einbau von MBA-Material und deren Umsetzung im MBA-Deponieabschnitt der Deponie Hillern im Landkreis Soltau-Fallingbostel. In diesem Zusammenhang werden die Ergebnisse geotechnischer Nachweise zum Aufbau des MBA-Deponiekörpers und die daraus resultierenden Vorgaben zum Einbaubetrieb dargestellt.

Das Ingenieurbüro für Abfallwirtschaft, *Prof. R. Stegmann und Partner* (IFAS), hat die Einbauversuche zur Ablagerung des MBA-Materials auf der Deponie Hillern Mitte 2005 koordiniert und begleitet seitdem den Einbaubetrieb (Hupe et al., 2006; Hupe et al., 2008). Die Durchführung der geotechnischen Untersuchungen und die geotechnischen Nachweise zum Einbau der MBA-Materialien erfolgten in Zusammenarbeit mit dem Ingenieurbüro Prof. Dr.-Ing. Walter Rodatz und Partner, Beratende Ingenieure für Geotechnik GmbH (RuP) und dem Institut für Grundbau und Bodenmechanik der Technischen Universität Braunschweig (IGB·TUBS).

2 Randbedingungen

2.1 Grundsätzliches zur Standsicherheit von MBA-Deponien

Standsicherheitsprobleme wie Böschungsbrüche sind bei Siedlungsabfalldeponien in Deutschland, auf denen bis Mitte 2005 Abfälle unvorbehandelt abgelagert wurden, bisher kaum aufgetreten. Maßgeblich dafür ist u.a. die vergleichsweise hohe Zugfestigkeit des frischen Hausmülls, insbesondere durch festigkeitserhöhende Fasern, die sog. Faserkohäsion (Kölsch, 1996) und teilweise grobstückige Deponate sowie die vergleichsweise hohe Durchlässigkeit infolge der heterogenen Struktur.

MBA-Material hat dagegen eine grundsätzlich andere strukturelle Zusammensetzung und geotechnische Charakteristik: Durch die Ausschleusung von bewehrungsartigen Fasermaterialien wird u.a. die Zugfestigkeit vermindert und durch die Vorbehandlung das Deponat wesentlich feiner, homogener und auch geringer durchlässig. Die mechanisch-hydraulischen Eigenschaften von MBA-Material können danach zwischen grobstrukturiertem konventionellem Hausmüll und feinstrukturiertem Klärschlamm erwartet werden.

Standsicherheitsprobleme in Deponien stehen häufig in engem Zusammenhang mit dem Wasserhaushalt und dem Entwässerungsverhalten der abgelagerten Abfälle. Rodatz und Oltmanns (1993) erläutern beispielsweise die Rutschung von 80.000 m^3 konditioniertem Klärschlamm (Festigkeit φ' = 34°, Durchlässigkeit $k_f = 1 \times 10^{-9}$ m/s) einer 19 m hohen Böschung infolge Porenwasserüberdruck bei Umlagerungsarbeiten.

Porenwasserdruck $u = \gamma_w \times h_w$ entsteht in wassergesättigten Deponaten, insbesondere bei hohem Einbauwassergehalt oder Vernässung und ungünstiger Dränage, und ist bei Standsicherheitsnachweisen zu berücksichtigen (s. a. NMU, 2007/8). Porenwasserüberdruck Δu entsteht bei Spannungsinkrementen $\Delta\sigma$ z.B. infolge weiterer Schüttstufen oder bei Deformationen des Deponiekörpers. Bei Totalspannungsanalysen muss u.a. die undränierte Festigkeit bekannt sein und darf der Porenwasserüberdruck vernachlässigt werden. Bei Effektivspannungsanalysen u.a. mit dränierten Festigkeiten muss der Porenwasserüberdruck berücksichtigt werden.

Praxisüblich werden von MBA-Materialien die dränierten Festigkeitsparameter Reibungswinkel φ' und Kohäsion c' sowie die Steifigkeit E_S labortechnisch ermittelt und nach den einschlägigen geotechnischen Methoden daraus charakteristische Werte für Standsicherheits- und Gebrauchstauglichkeitsnachweise abgeleitet. Mit den charakteristischen Festigkeiten, Wichten und ggf. Wasserständen werden dann für den geplanten Deponieaufbau

- die Standsicherheit, hier: die Böschungsbruchsicherheit, für erforderliche globale Sicherheiten (bis 2007) bzw. mit Partialsicherheiten (spätestens ab 2008) und
- die Gebrauchstauglichkeit, hier: systemverträgliche Deformationen, nachgewiesen.

Erforderliche Sicherheiten orientieren sich dabei im Allgemeinen an geotechnischen Situationen resp. Lastfällen.

2.2 MBA-Abschnitt der Deponie Hillern

Die mechanisch-biologische Abfallbehandlung der auf der Deponie Hillern abgelagerten Abfälle erfolgt in der RABA Bassum. Die Einbaufläche im MBA-Abschnitt beträgt an der Basis ca. 5.000 m^2. Bei einer Ablagerungsmenge von 26.000-30.000 Mg/a beträgt die jährliche Zunahme der Ablagerungsmächtigkeit ca. 4-5 m. Der MBA-Deponiekörper wird den angrenzenden Deponieabschnitt, der bis Mitte 2005 mit unvorbehandelten Siedlungsabfällen befüllt wurde, in zwei Böschungsbereichen überlagern.

Auf der Grundlage der im Sommer 2005 von IFAS betreuten Untersuchungen zur verordnungsgemäßen Ablagerung des MBA-Materials im MBA-Versuchsfeld erfolgt der Regeleinbau mit einer Raupe und einem 30 Mg-Kompaktor, der bereits vorher im Einbaubetrieb eingesetzt wurde. Die dabei erreichbare Einbaudichte im Regelbetrieb liegt bei 0,65 kg_{TM}/l (bzw. 95% des Wertes gemäß Anhang 3 AbfAblV) bei einem anzustrebenden Wassergehalt von 25-30 % bezogen auf die Feuchtmasse (Hupe et al., 2006). Im Einbaubetrieb wurde im Zeitraum 2005-2008 eine mittlere Einbaudichte von 0,66-

0,90 kg_{TM}/l bei einem Wassergehalt von 17-32% bezogen auf die Feuchtmasse erreicht. Damit liegen die ermittelten Einbaudichten in einer Größenordnung, die auch an anderen Standorten festgestellt werden:

- Einbaudichten für eine MBA-Reststofffraktion < 60 mm von 0,6-0,9 kg_{TM}/l (Kühle-Weidemeier, 2004)
- Trockendichten in Abhängigkeit von der Trockenrohdichte des Materials und der gewählten Einbautechnik: 0,75-0,88 kg_{TM}/l (Entenmann, 2007)
- Ergebnisse der Bestimmung der Trockendichten für 7 Deponien 0,75-1,12 kg_{TM}/l (Entenmann, 2008)

2.3 Abfallmechanische und -hydraulische Parameter

Für die geotechnischen Nachweise wie die Standsicherheit der Deponieaußenböschungen und das Last-Zeit-Setzungsverhalten, müssen die charakteristischen abfallmechanischen und -hydraulischen Parameter der abzulagernden Abfälle bekannt sein. Da diese Parameter für MBA-Material aus üblichen (geotechnisch) klassifizierenden Parametern nicht indirekt ableitbar sind, waren dafür projektspezifische Laboruntersuchungen erforderlich. Bei MBA-Materialien ist u.a. zu berücksichtigen, dass es sich um nicht bodenähnliche Abfälle handelt und die gegenüber herkömmlichen unbehandelten Siedlungsabfällen Zugkraft aufnehmenden und bewehrend wirkenden Abfallbestandteile weitgehend fehlen. Für die Nachweise der Standsicherheit und Gebrauchstauglichkeit wurden labortechnisch folgende Parameter analog zu geotechnischen Verfahren standortbezogen bestimmt (s. a. Abschnitt 4):

- Wassergehalt nach DIN 18 121
- Proctordichte und optimaler Wassergehalt nach DIN 18 127
- Korngrößenverteilung über Nasssiebung nach DIN 18 123
- Scherparameter im Scherversuch im Großrahmenschergerät nach DIN 18 137
- Durchlässigkeit gemäß DIN 18 130 (k-Wert-Bestimmung)

3 Anforderungen an den Einbau von MBA-Material

3.1 Niedersächsische Anforderungen

Das Niedersächsische Umweltministerium hat im April 2007 Festlegungen zum Einbau mechanisch-biologisch behandelter Abfälle getroffen. Die Festlegungen wurden vom Niedersächsischen Umweltministerium im Januar 2008 durch Hinweise zur Ermittlung der abfallmechanischen Parameter, zur Überwachung des Porenwasserüberdrucks und zur Minimierung der Sickerwasserbildung ergänzt. Im Folgenden werden die Anforderungen an die geotechnische Stabilität aufgegriffen sowie Maßnahmen zur Minimierung des Eintrags von Niederschlagswasser und zur Begrenzung der Sickerwassermenge in MBA-Deponien/Deponieabschnitten erläutert. Hinsichtlich der geotechnischen Stabilität werden dabei Anforderungen an folgende Parameter und Maßnahmen formuliert:

- Standsicherheit
- Prüfung und Einsatz geeigneter bautechnischer Maßnahmen
- Einbaubetrieb
- Monitoringmaßnahmen (in Verbindung mit betriebsbegleitenden Nachrüstungsmaßnahmen)
- Dokumentation und Auswertung der Betriebs- und Überwachungsmaßnahmen

3.2 Standsicherheit und Einbaubetrieb

Wesentliche Anforderungen zur Ablagerung von MBA-Material auf Deponien/ Deponieabschnitten in Niedersachsen sind:

Standsicherheit: „Es muss daher sichergestellt sein, dass die Standsicherheit durch Reibung im Deponiekörper oder durch Widerlager gewährleistet ist. Porenwasserüberdruck kann maßgeblich zur Reduzierung der Reibung beitragen und somit zur Gefährdung der Standsicherheit führen. Sofern kein ausreichendes Widerlager vorhanden ist, darf das Entstehen von Porenwasserüberdruck nur zugelassen werden, wenn nachweislich die Standsicherheit hierdurch nicht gefährdet wird. Anderenfalls sind Maßnahmen zu ergreifen, um das Entstehen von Porenwasserüberdruck grundsätzlich zu vermeiden."

Entwässerungselemente im Deponiekörper: „Der Gefahr der Bildung von Porenwasserüberdruck in gering durchlässigen Deponiekörpern kann auch durch Verkürzung des Fließweges des Sickerwassers begegnet werden. Hierzu können grundsätzlich linienförmige sowie horizontale oder senkrechte flächige Entwässerungselemente im Deponiekörper eingebaut werden. Für die Herstellung derartiger Dränkörper können auch geeignete Abfälle verwendet werden, wenn sie die Anforderungen der AbfAblV bzw. DepVerwV einhalten. Die Dränkörper sind unmittelbar an die Sickerwasserfassung der Deponie anzuschließen."

Zum Nachweis der Standsicherheit sind standortbezogen Laborversuche zur Bestimmung der Scherfestigkeit, Wasserdurchlässigkeit und Kompressibilität vorzunehmen. Alternativ können die Messwerte entsprechender Parameter aus Verbundprojekten zugrunde gelegt werden, wenn ein Sachverständiger die Übertragbarkeit zu der jeweiligen Einzeldeponie bestätigt. Auf dieser Grundlage erfolgt bezogen auf die Deponierandbedingungen der Nachweis, unter welchen Voraussetzungen ein Porenwasserüberdruck und eine Gefährdung der Standsicherheit nicht auftreten.

Bei den Nachweisen müssen die Aufbaugeschwindigkeit des MBA-Deponiekörpers und die möglichen Auswirkungen auf den Porenwasserdruck berücksichtigt werden. In diesem Zusammenhang ist durch Versuche nachzuweisen, dass zur Vermeidung von standsicherheitsgefährdendem Porenwasserdruck der Deponiekörper auch bei kompakter Lagerung eine ausreichende Wasserdurchlässigkeit bzw. zügige Konsolidation, d.h. einen zügigen Abbau der Porenwasserüberdrücke, aufweist.

Mit Blick auf kritische Porenwasserdrücke bzw. -überdücke wurden für die MBA-Deponie Hillern vorsorglich drainierende Zwischenschichten entwickelt und in die rechnerische Nachweisführung einbezogen (s. a. Abschnitt 5). Mit dieser konstruktiven Möglichkeit zur Minimierung potenzieller Porenwasserdrücke kann auf Messungen der Porenwasserdrücke während des Deponiebetriebs verzichtet werden.

3.3 Maßnahmen zur Minimierung des Niederschlagseintrags und der Sickerwasserbildung

Nach der Änderung der AbfAblV ist es nicht mehr zwingend vorgeschrieben, die Oberfläche des Einbaubereichs für MBA-Abfälle mit wasserundurchlässigen Materialien abzudecken. Nur „soweit erforderlich sind weitere bautechnische Maßnahmen zur Minimierung des Eintrags von Niederschlagswasser zu treffen“.

Für die Deponie Hillern hat es sich im Einbaubetrieb der MBA-Abfälle als vorteilhaft herausgestellt, wenn aus technischen wie betrieblichen Gründen auf eine temporäre Abdeckung des aktuellen Einbaubereichs mit wasserundurchlässigen Materialien verzichtet wird. Es werden dafür u.a. ergänzende Monitoringmaßnahmen zur Überwachung des Wasserhaushalts durchgeführt.

Gemäß den niedersächsischen Anforderungen zur Ablagerung von MBA-Material muss die Sickerwasserbildung in einem MBA-Deponieabschnitt so gering wie nach dem Stand der Technik möglich gehalten werden und darf die Größenordnung von 7% des Jahresniederschlags nicht übersteigen .

Der Einbaubetrieb auf dem MBA-Abschnitt der Deponie Hillern wird dieser Anforderung weitestgehend gerecht, indem folgende Maßnahmen ergriffen werden:

- Der offene Einbaubereich wird auf das Maß begrenzt, das für einen technisch einwandfreien, reibungslosen Einbaubetrieb erforderlich ist.
- Über längere Zeit nicht beschickte Bereiche werden im Winterhalbjahr nach Erfordernis mit einer temporären Abdeckung versehen, so dass Niederschlagswasser abgeleitet wird.
- Die MBA-Abfälle werden relativ trocken abgelagert und weisen eine nennenswerte Wasserhaltekapazität auf, so dass auch über die Verdunstung der offenen Einbau-

fläche wenig Niederschlag in den tieferen MBA-Deponiekörper eindringt und zur klimatischen Sickerwasserneubildung führt.

Die bisherigen Beobachtungen zum Sickerwasserabfluss bestätigen diesen Sachverhalt. Im Sommer 2006 und 2007 war über längere Zeiträume keinerlei Sickerwasserabfluss in der Basisdrainage festzustellen. Im Winter fließt Sickerwasser nur sehr geringfügig. Selbst nach Regenereignissen tritt kein nennenswert erhöhter Sickerwasserabfluss auf. Damit werden die Anforderungen an die Minimierung der Sickerwasserbildung erfüllt.

4 Laboruntersuchungen zur Bestimmung geotechnischer Parameter

4.1 Gesamtübersicht

Die Ergebnisse der projektspezifischen Laboruntersuchungen an repräsentativen MBA-Abfallfeststoffen, hier: frische MBA-Abfälle und drei Monate abgelagerte MBA-Abfälle aus dem Deponiekörper, sind in der Tabelle 4.1 zusammengestellt.

Tab. 4.1: Geotechnische Parameter an frischen und abgelagerten MBA-Feststoffproben der Deponie Hillern

MBA-Feststoff-probe	**Wassergehalt DIN 18121**		**Durchlässigkeit k_{10}**	**Steifemodul E_S**	**Proctordichte ρ_{pr}**	
	Mittelwert [% TM]	Mittelwert [% FM]	[m/s]	[MN/m²]	Bezug TM [g/cm³]	Bezug FM [g/cm³]
3 Monate abgelagertes MBA-Material (MBA-A mit je drei Einzelproben)						
MBA-A1	58	37	n.b.	n.b.	n.b.	n.b.
MBA-A2	64	39	3×10^{-10}	1,1 - 2,5	0,862	1,411
Frisches MBA-Material (MBA-N mit je drei Einzelproben)						
MBA-N1	47	32	n.b.	n.b.	n.b.	n.b.
MBA-N2	47	32	2×10^{-6}	1,4 - 2,1	0,856	1,260

TM: Trockenmasse; FM: Feuchtmasse; n.b.: nicht bestimmt

4.2 Wassergehalt

Von den vier Probenchargen wurden jeweils drei Einzelproben entnommen und auf die Wassergehalte untersucht. Die beiden Frischproben zeigen sehr homogene Wassergehalte von etwa 47 %-TM bzw. 32 %-FM. Die Abfallproben nach 3-monatiger Lagerung zeigen dagegen heterogene Wassergehalte, die den kleinräumig unterschiedlichen Wasserhaushalt im MBA-Deponiekörper widerspiegeln. Sie liegen im Mittelwert bei 58 – 64 %-TM bzw. bei 37 – 39 %-FM.

4.3 Verdichtbarkeit (Proctordichte)

Die Verdichtbarkeit des MBA-Materials wurde im Proctorversuch gemäß DIN 18127 (Proctorarbeit W ≈ 0,6 MNm/m^3, Versuchszylinder D = 20,4 cm) bestimmt.

Tab. 4.2: Ergebnisse der Laboruntersuchungen zur Proctordichte an MBA-Material der Deponie Hillern (IGB TUBS)

Parameter	**Frischmaterial MBA-N2**	**Abgelagertes Material MBA-A2**
Wassergehalt [%-FM]	32,1	38,9
Wassergehalt [%-TM]	47,2	63,8
Proctordichte ρ_{pr} [g/cm^3]	0,856	0,862
Dichte der feuchten Probe [g/cm^3]	1,260	1,411

FM: Feuchtmasse, TM: Trockenmasse

Die Untersuchungsergebnisse liegen im oberen Bereich der Proctordichten, die bereits bei vorangegangenen Untersuchungen im Bereich von 0,77 bis 0,84 g/cm^3 bei w_{Pr} von 47–52 % für frisches MBA-Material bestimmt wurden. Die Ergebnisse liegen in der praxisüblichen MBA-Bandbreite.

4.4 Durchlässigkeit

Die Ermittlung der Wasserdurchlässigkeit erfolgte nach DIN 18130-1 an zwei MBA-Feststoffproben über einen Zeitraum von fünf Wochen. Die bei den Laborversuchen ermittelten Durchlässigkeitsbeiwerte k_{10} (Elementversuch) betragen:

- Frischmaterial MBA-N2 $k_{10} = 2 \cdot 10^{-6}$ m/s
- Abgelagertes Material MBA-A2 $k_{10} = 3 \cdot 10^{-10}$ m/s

Aufgrund der stofflichen Zusammensetzung mit einem vergleichsweise geringen Feinanteil wurde unter Berücksichtigung der Literaturangaben für die Standsicherheits- und Deformationsnachweise für das MBA-Material der Deponie Hillern der Durchlässigkeitsbeiwert $k_f = 1 \cdot 10^{-9}$ m/s (mittlere Systemdurchlässigkeit) angesetzt. Zudem wurde als Grenzfallbetrachtung im Rahmen einer Sensitivitätsstudie die Standsicherheit für lokale Durchlässigkeiten $k_f = 1 \cdot 10^{-10}$ m/s untersucht.

4.5 Steifigkeit

Der Steifemodul ES wurde in Anlehnung an DIN 18135 unter den in Tabelle 4.3 aufgeführten Randbedingungen ermittelt. Die Kompressionsversuche erfolgten in acht Laststufen σ_V = 0,02-0,25 MN/m^2 mit Ent- und Wiederbelastungszyklen zwecks Simulation der in situ Spannungen (Verdichtungs- und Überlagerungsdruck) mit Spannungsinkrementen infolge Überschüttung sowie drei Zeitsetzungsaufnahmen an zwei MBA-Proben.

Tab. 4.3: Ergebnisse der Laboruntersuchungen zum Steifemodul ES an MBA-Material der Deponie Hillern (IGB TUBS)

Parameter	**Frischmaterial MBA-N2**	**Abgelagertes Material MBA-A2**
Einbau-Wassergehalt [%-TM]	47	64
Ausbau-Wassergehalt [%-TM]	41	48
Einbaudichte $\rho_{d,E}$ [g/cm^3]	0,85	0,86
E_S [MN/m^2] bei σ = 0,02 bis 0,06 MN/m^2	1	1
E_S [MN/m^2] bei σ = 0,06 bis 0,12 MN/m^2	2	2
E_S [MN/m^2] bei σ = 0,12 bis 0,25 MN/m^2	7	7

TM: Trockenmasse

Beim frischen wie beim abgelagerten MBA-Material wurden bei gleichen Belastungsstufen die gleichen Steifemoduli ermittelt. Bei beiden Feststoffproben trat ein ausgeprägtes Zeit-Setzungsverhalten auf. Der (geotechnische) Übergang von Konsolidationssetzungen (endliche Primärsetzungen) zu Kriechsetzungen ('unendliche' Sekundärsetzungen) war nicht eindeutig. Während bei dem abgelagerten Material im Versuch nach etwa drei Wochen die Primärsetzungen abklangen, waren bei dem Frischmaterial nach 4–5 Wochen gleiche bis teilweise zunehmende Setzungsgeschwindigkeiten zu verzeichnen. Die Ursache hierfür dürfte bei dem frischen Material der noch etwas aktivere biologisch-chemische Abbauprozess sein.

Bei den Nachweisen wurde die Steifigkeit der MBA-Deponate mit Blick auf das Zeit-Setzungsverhalten bzw. auf potenzielle Kriechsetzungen zur sicheren Seite angesetzt mit $E_{S,k}$ = 1 MN/m^2 bei $\Delta\sigma$ = 0,02-0,25 MN/m^2.

5 Geotechnische Nachweise

5.1 Annahmen und Randbedingungen

Die Nachweise resp. Berechnungen zur Standsicherheit und Deformation für den MBA-Deponiekörper erfolgten nach ingenieurtechnischer Beurteilung hilfsweise mit bewährten geotechnischen Methoden unter besonderer Berücksichtigung

- der standortbezogenen Randbedingungen,
- der Ergebnisse von Laboruntersuchungen,
- der geo- und deponietechnischen Vorschriften, Normen und Empfehlungen,
- einer Verkehrslast aus Einbaubetrieb auf dem Gelände,
- von Zwischenschichten als planmäßige Flächendränagen und

- des Versagens der drainierenden Zwischenschichten - auch zur Wertung der Standsicherheit ohne drainierende Zwischenschichten.

Für die geotechnischen Nachweise wurden aufgrund der eigenen Untersuchungen im Spiegel der Literaturrecherche gewählt:

- mittlere Feuchtwichte γ_k = 12 – 15 kN/m^3
- Sättigungsgrad S_R bei mittleren Korndichten ρ_s = 2,0 – 2,5 g/cm^3 für
  - Frisches MBA-Material S_R = 65 – 75 % bei w = 47 %
  - Abgelagertes MBA-Material S_R = 85 – 95 % bei w = 64 %
    mit Blick auf den max. Porenwasserdruck auf der sicheren Seite
  - MBA-Material Hillern S_R = 100 %

Weitere Randbedingungen der MBA-Ablagerung auf der Deponie Hillern sind:

- Einbaufläche an der Basis: ca. 5.000 m^2
- Ablagerungsmenge jährlich: 26.000 - 30.000 Mg/a
- Zunahme der Ablagerungsmächtigkeit jährlich: ca. 4 – 5 m/a
- Variation der Einbaumengen bzw. saisonal- oder witterungsbedingter diskontinuierlicher Einbaubetrieb resp. variierende Schüttgeschwindigkeit

Drainierende flächige Zwischenschichten sind im MBA-Deponiekörper mit 5 m vertikalem Abstand, 30 cm Mächtigkeit und mind. 1,5% Gefälle nach außen vorgesehen. In Verbindung mit der Sättigung des MBA-Materials bis S_R = 100 % ergibt sich danach bei den Regellastfällen mit sukzessivem Aufbau des Abfallkörpers u. a. ein jeweils auflastinduzierter Porenwasserüberdruck infolge 1 m mächtiger Schüttlage mit Konsolidation von 5 m mächtigen Lagen mit druckloser Entwässerung in die Flächendränagen.

5.2 Böschungsstandsicherheit

Die Standsicherheit der Außenböschung mit N = 1 : 3 wurde im Sinne der DIN 4084 unter Variation möglicher kreisförmiger und polygonaler Gleitflächen unter besonderer Berücksichtigung des lagenweisen Aufbaus mit zeitlich überschneidender Konsolidation der Schichten berechnet. Die nachzuweisende (in 2007: globale) Sicherheit war für den Betriebszustand $\eta \geq 1{,}3$ (LF 2: Bauzustand) und für den Endzustand $\eta \geq 1{,}4$ (LF 1). Für die Situation 'Ausfall der drainierenden Zwischenschichten' war $\eta \geq 1{,}2$ (LF 3) tolerabel.

Seit 2008 gilt das Partialsicherheitskonzept gem. DIN 1054-2005. Danach sind Einwirkungen E mit Teilsicherheiten γ zu multiplizieren und Widerstände R durch Teilsicherheiten γ zu dividieren. Nachzuweisen ist $E \leq R$ u. a. für den Grenzzustand des Verlustes der Gesamtstandsicherheit GZ 1C bzw. ein Ausnutzungsgrad

$$\mu = E/R \leq 1{,}0$$

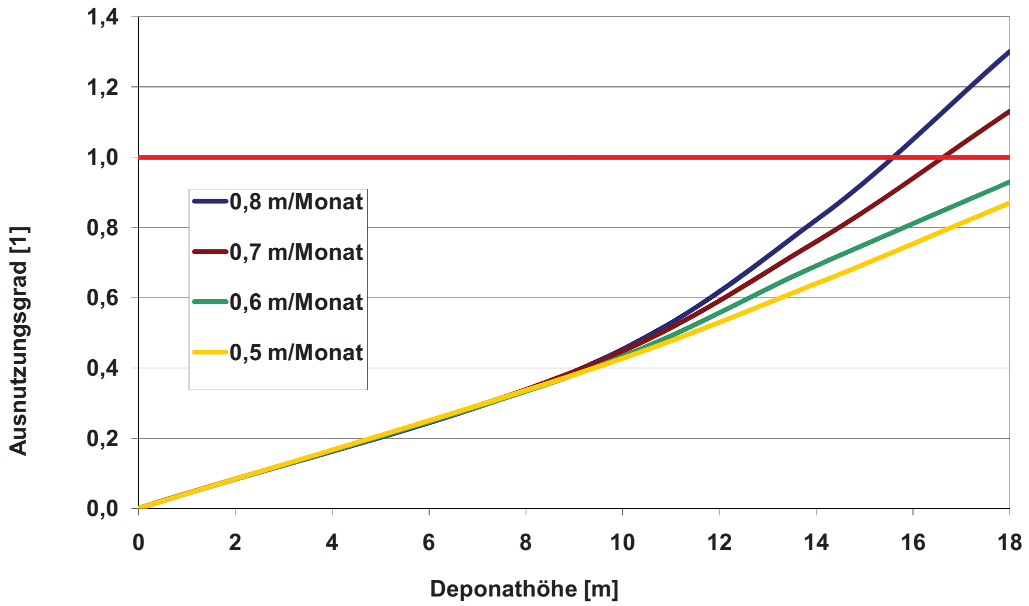
Für das MBA-Material wurden zunächst mangels genauerer Untersuchungen Teilsicherheitsbeiwerte γ in Anlehnung an die Werte nach DIN 1054-2005 verwendet und Lastfallkombinationen LF 1, LF 2 und LF 3 betrachet.

		LF 1	LF 2	LF 3
Ständige Einwirkungen	γ_G	1,00	1,00	1,00
Ungünstige veränderliche Einwirkungen	γ_Q	1,30	1,20	1,00
Reibungsbeiwert tan φ'	γ_φ	1,25	1,15	1,10

Die mittlere Durchlässigkeit des MBA-Materials wurde aufgrund der Untersuchungen generell mit $k_f = 1 \cdot 10^{-9}$ m/s, die Dichte mit ρ_k = 1,2 t/m^3 und die Steifigkeit mit $E_{S,k}$ = 1 MN/m^2 bei $\Delta\sigma$ = 0,02 - 0,25 MN/m^2 sowie der Reibungswinkel mit φ'_k = 35,0° angesetzt. Weil nach bis dato ausgewerteten Dokumenten eine pot. Kohäsion c' von MBA-Material nicht zuverlässig belegt ist, wurde c'_k = 0 gesetzt.

Die simulierten Schüttgeschwindigkeiten (Schütthöhenentwicklung über die Zeit) sind in der Abbildung 5.1 dargestellt. Die nachgewiesen zulässige maximale Schüttgeschwindigkeit beträgt anfangs max. v ≈ 8 m/a abnehmend auf max. v = 6 m/a bei Erreichen der Endhöhe bzw.

H_{MBA} = 0 – 3 m	v_{MBA} = 0,7 m/Monat
H_{MBA} = 3 – 13 m	v_{MBA} = 0,6 m/Monat
H_{MBA} = 13 – 18 m	v_{MBA} = 0,5 m/Monat



Abbbildung 5.1: Ausnutzungsgrad (Schüttgeschwindigkeit) vs. Deponathöhe

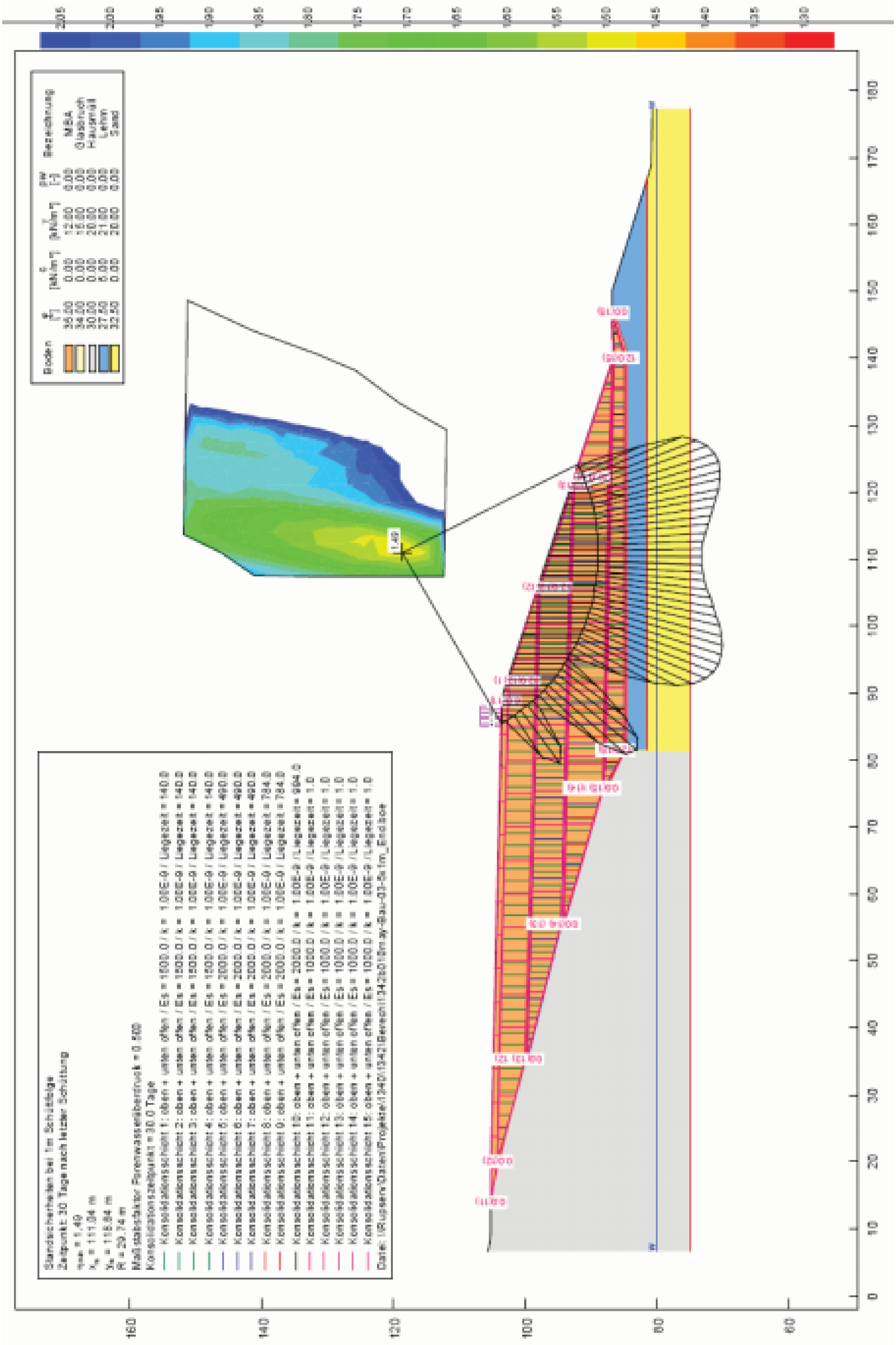


Abb. 5.2: Böschungsbruchnachweis für den MBA-Deponiekörper im Endzustand

Auszugsweise betragen für Betriebszustände H_{10} = 10 m + 1 m (Einbauhöhe) = 11 m Gesamthöhe, H_{15} = 16 m und max. H_{18} = 19 m Gesamthöhe mit $k_f = 1 \cdot 10^{-9}$ m/s sowie mit reduzierter Durchlässigkeit $k_f = 1 \cdot 10^{-10}$ m/s unmittelbar nach dem Einbau die Ausnutzungsgrade μ:

H_{10} = 11 m Gesamthöhe	$k_f = 1 \cdot 10^{-9}$ m/s	μ = 0,37	
H_{15} = 16 m Gesamthöhe	$k_f = 1 \cdot 10^{-9}$ m/s	μ = 0,59	
H_{18} = 19 m Gesamthöhe	$k_f = 1 \cdot 10^{-9}$ m/s	μ = 0,84	(LF 2)
H_{18} = 19 m Gesamthöhe	$k_f = 1 \cdot 10^{-10}$ m/s	μ > 1,0	(LF 2)

Mit wachsender Schütthöhe nimmt der Ausnutzungsgrad sukzessive zu resp. die Standsicherheit ab, ist jedoch auch im Endzustand noch nachgewiesen. Rechnerisch wäre allerdings bei reduzierter Durchlässigkeit $k_f \approx 1 \cdot 10^{-10}$ m/s bereits in einer 5 m - Schicht die Böschungsstandsicherheit unmittelbar nach Erreichen der Endhöhe und insg. vollständig gesättigtem MBA-Material nicht mehr nachgewiesen. Planmäßig und ohne weitergehende Nachweise, bspw. für – im Sinne der Standsicherheit positive – langsamere Verfüllungen oder teilgesättigte Deponate - muss die Durchlässigkeit des Materials $k_f \geq 1 \cdot 10^{-9}$ m/s betragen.

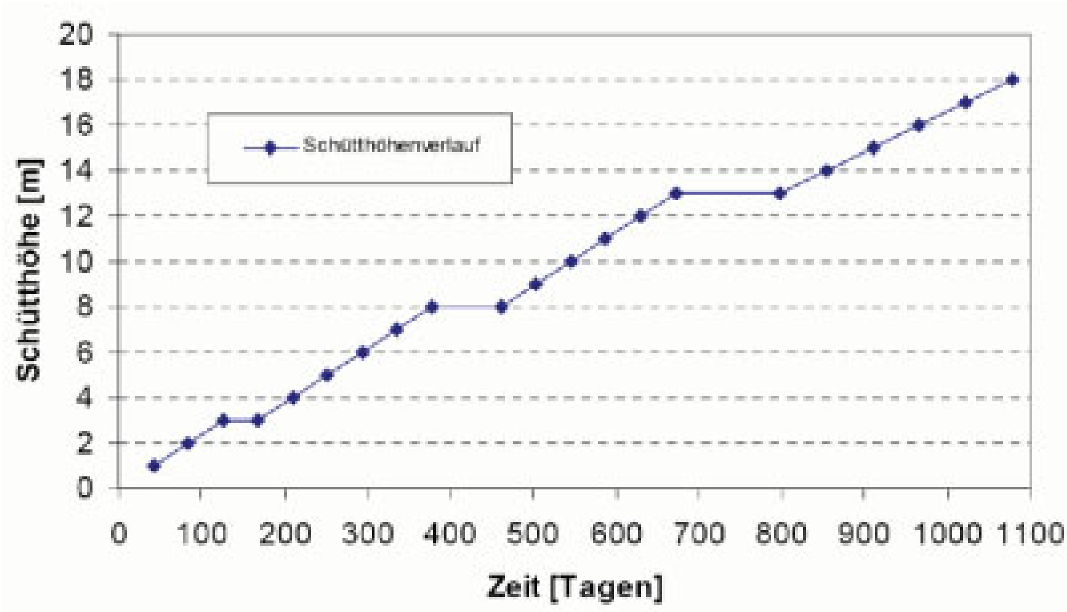


Abb. 5.3: Deponathöhe vs. Zeit

Als vorsichtige Annahme auf der sicheren Seite wurden bei den Standsicherheitsnachweisen hohe Verfüllgeschwindigkeiten von v_{MBA} = 0,7 - 0,5 m/Monat angesetzt. Bereits etwa einen Monat nach Abschluss der Verfüllung auf Endhöhe erhöht sich die Böschungsstandsicherheit resp. vermindert sich der Ausnutzungsgrad von μ = 0,84 auf μ = 0,75.

H_{18} = 19 m Endhöhe (1 Monat)	$k_f \approx 1 \cdot 10^{-9}$ m/s	μ = 0,75	(LF 1)

Bei Ausfall einer drainierenden Zwischenschicht bspw. betrüge die Sicherheit resp. der Ausnutzungsgrad $\mu = 0,97$ statt $\mu = 0,75$.

Die Berechnungen zeigen die positiven Effekte resp. das Erfordernis drainierender Zwischenschichten im MBA-Deponiebau mit verglw. scherfesten, aber kompressiblem und sehr schwach durchlässigem MBA-Material.

Die Berechnungen wurden mit dem Festigkeitsparameter $\varphi'_k = 35,0°$ durchgeführt. Die mind. erforderliche Scherfestigkeit für die notwendige Böschungsstandsicherheit beträgt unter sonst gleichen Bedingungen (Durchlässigkeit $k_f \approx 1 \cdot 10^{-9}$ m/s, Dichte $\rho_k = 1,2$ t/m^3, Sättigung $S_R = 100$ %, max. Schüttgeschwindigkeit $v_{MBA} = 0,8$ m/Monat bis 19 m Deponathöhe bei Böschungsneigungen 1 : 3) für das Material der MBA-Hillern für $\mu \leq 1,0$ erforderlich $\varphi'_k \geq 30°$. Diese Festigkeit - und die Durchlässigkeit - sollte validiert werden.

Weitere Vergleichsberechnungen mit schnelleren Schüttgeschwindigkeiten ergaben bspw., dass bei Schüttgeschwindigkeiten deutlich über 1 m/Monat bei gleichzeitig ungünstigem Wasserhaushalt und geringer Wasserdurchlässigkeit des Abfalls (rechnerisch) kurz nach der Verfüllung ein großräumiger Böschungsbruch eintritt. Dieses Szenario wird im Ablagerungsbetrieb auf der MBA-Hillern betrieblich und konstruktiv verhindert.

5.3 Deformationsprognosen

Für die drainierenden Zwischenschichten (Schichtstärke 0,3 m, jeweils nach maximaler MBA Ablagerungsmächtigkeit von 5 m, Neigung N ≈ 1,5 % nach außen) wurden unter Berücksichtigung des Aufbaus und jeweils zeitlich überschneidender Konsolidation der lagenweise eingebauten Schichten die Setzungen S ermittelt. Für die erläuterten Schüttgeschwindigkeiten wurden jeweils Konsolidationsgrade U = 50% (= 50 % Restsetzungen) der unteren MBA-Schichten beim Einbau der Flächendrainagen bzw. der oberen MBA-Schichten berücksichtigt. Zudem wurden als Orientierung die Setzungen für jeweilige Konsolidationsgrade U = 100%, also allein aus der Kompressibilität des MBA-Materials infolge weiterer Überbauung, als mindestens zu erwartenden Setzung ermittelt.

Die Durchlässigkeit wurde mit $k_f \approx 1 \cdot 10^{-9}$ m/s, die Steifigkeit mit $E_{S,k} = 1$ MN/m^2 und die mittlere Feuchtdichte mit $\rho_k = 1,2$ t/m^3 für das MBA-Material angesetzt. Entsprechend DIN 1054-2005 werden für den Nachweis des Grenzzustandes der Gebrauchstauglichkeit GZ 2, hier: Nachweis der Setzungen der Flächendränagen, die Teilsicherheiten für ständige und veränderliche Einwirkungen mit $\gamma_G = \gamma_Q = 1,00$ angesetzt.

Das Ergebnis der Setzungsberechnung ist in der Abbildung 5.4 im Querschnitt skizziert. Danach betragen die maximalen Setzungen über dem Böschungsfuß der Altdeponie unter bzw. bei höchster Überschüttung auf dem Niveau:

$H_{Drain} \approx 3$ m max. $S_{Drain} \approx 0{,}64$ m mind. $S_{Drain} \approx 0{,}60$ m
$H_{Drain} \approx 10$ m max. $S_{Drain} \approx 1{,}27$ m mind. $S_{Drain} \approx 1{,}06$ m
$H_{Drain} \approx 15$ m max. $S_{Drain} \approx 1{,}42$ m mind. $S_{Drain} \approx 0{,}86$ m
$H_{DOF} \approx 19$ m max. $S_{DOF} \approx 1{,}07$ m

H_{Drain} Höhenlage der drainierenden Zwischenschicht
H_{DOF} Höhenlage der Deponieoberfläche (Endhöhe MBA-Deponiekörper)
S_{Drain} Setzungen der drainierenden Zwischenschicht

Die berechneten Setzungen der Drainagen müssen durch Überhöhungen beim Einbau mit Blick auf die angestrebte Neigung N ≥ 1,5 % im Endzustand kompensiert werden. Die berechneten Setzungen der zwecks (tw.) Abfluss von Niederschlägen geneigten Deponieoberfläche können durch Überhöhung beim Einbau oder mit Nachprofilierungen kompensiert werden.

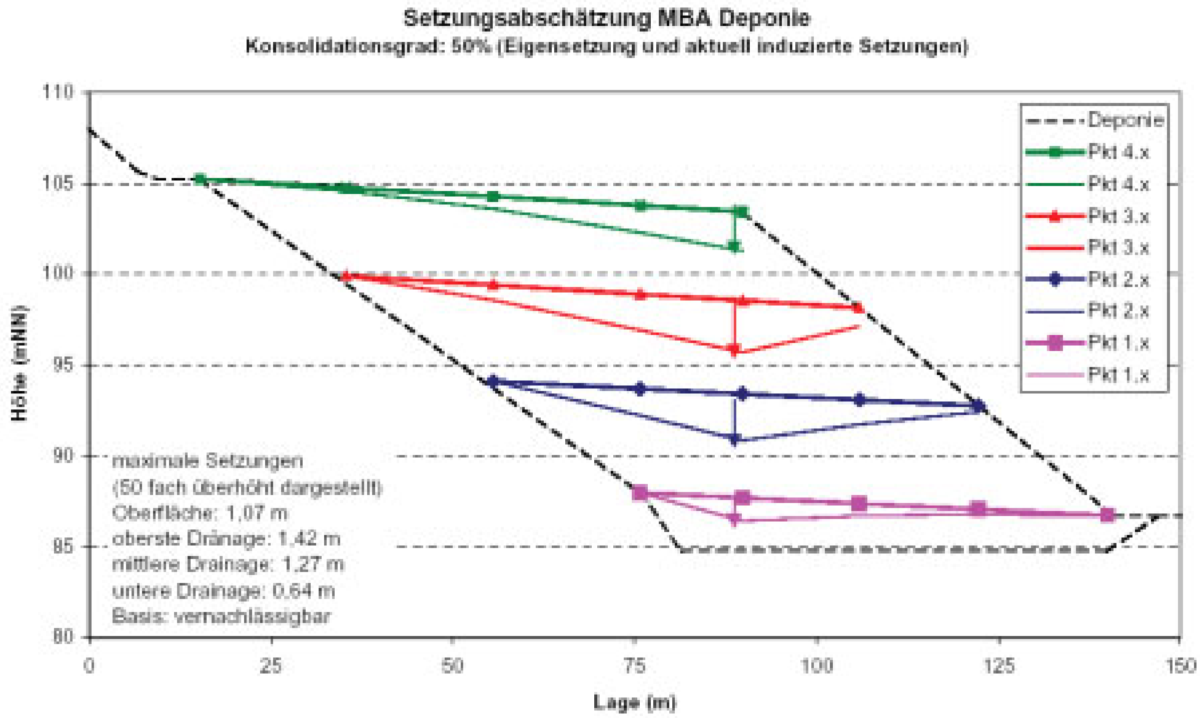


Abb. 5.4: Setzungsermittlung MBA-Abfallkörper der Deponie Hillern anhand der drainierenden Zwischenschichten, Setzungen überhöht dargestellt (RuP)

6 Empfehlungen

Durch die mechanisch-biologische Behandlung von Siedlungsabfällen werden neben der Zusammensetzung der abzulagernden Materialien auch deren chemisch-physikalische, biologische sowie abfallmechanische Eigenschaften verändert. So müssen für neue MBA-Deponien geotechnische Nachweise erbracht und neue Anforderungen an den Einbau der MBA-Materialien berücksichtigt werden.

Im Rahmen des Beitrages werden die niedersächsischen Anforderungen an den Einbau der MBA-Materialien diskutiert und deren Umsetzung exemplarisch für den MBA-Bauabschnitt der Deponie Hillern der Abfallwirtschaft Heidekreis im Landkreis Soltau-Fallingbostel dargestellt.

Im Hinblick auf die sichere Einhaltung der geomechanischen Stabilität des MBA-Deponiekörpers in Hillern und vergleichbarer MBA-Deponien leiten sich folgende Empfehlungen ab:

- Die Durchlässigkeit des MBA-Materials soll, insbesondere bei Veränderung des angelieferten MBA-Outputs, überprüft werden.
- Die Scherfestigkeit des MBA-Materials soll, insbesondere bei Veränderung des angelieferten MBA-Outputs, überprüft werden.
- Geotechnische Methoden (Kornverteilung, Wassergehalt, Verdichtbarkeit) haben bei der Klassifikation von MBA-Material orientierenden Charakter und sollten insb. hinsichtlich Festigkeit, Steifigkeit und Durchlässigkeit nicht überinterpretiert werden.
- Zur Entspannung potenzieller Porenwasserüberdrücke sollen drainierende Zwischenschichten mit Überhöhung zwecks Setzungskompensation entsprechend der Dimensionierung eingebaut werden; bei der Deponie Hillern sind dies angeordnet
  - in der Böschung zwischen dem MBA-Deponiekörper und dem angrenzenden Hausmüll (Altdeponiekörper) und
  - im MBA-Deponiekörper im vertikalen Abstand $\Delta H \approx 5$ m bei maximalen MBA-Schichtdicken $D \approx 5$ m sowie
  - mit Schichtstärke der Drainage mindestens 30 cm und
  - mit Neigung der Drainage nach Abklingen der Setzungen mindestens 1,5%.
- Die max. Schüttgeschwindigkeit soll im Regelbetrieb 5 m/Jahr nicht überschreiten.
- Die Verfüllung soll durch ein raumzeitliches Abfallkataster dokumentiert werden.
- Die geotechnischen Nachweise sollen, insbesondere wenn sich die technischen Randbedingungen auf der Deponie oder die Qualität des angelieferten MBA-Outputs ändern, überprüft und ggf. aktualisiert werden.
- Für den Einbaubetrieb sind weitere grundlegende Aspekte zu beachten:
  - Bei geringen Einbauwassergehalten und funktionstüchtiger Drainage sowie langsamer Aufbaugeschwindigkeit kann die Entstehung von Porenwasserüberdrücken minimiert werden. Damit werden die Standsicherheit erhöht und Deformationen reduziert.
  - Geneigte, glatte MBA-Oberflächen im Einbauzustand minimieren die Vernässung durch Niederschlag, mithin die ungünstige Sättigung.

- Längerfristig nicht beschickte Ablagerungsbereiche sollen mit einer temporären Abdeckung zur Ableitung von Oberflächenwasser versehen werden.
- Böschungen sollen im Betriebszustand maximale Neigungen von 1:3 aufweisen.

Zum Betrieb des MBA-Abschnitts auf der Deponie Hillern ist festzustellen, dass die Anforderungen des Niedersächsischen Umweltministeriums und der ZUS AWG an den Einbau von MBA Material erfüllt werden bezüglich

- der Standsicherheit,
- der Prüfung und des Einsatzes geeigneter bautechnischer Maßnahmen,
- des Einbaubetriebs,
- der Monitoringmaßnahmen (in Verbindung mit betriebsbegleitenden Nachrüstungsmaßnahmen),
- voraussichtlich der Begrenzung der Sickerwassermenge sowie
- der Dokumentation und Auswertung der Betriebs- und Überwachungsmaßnahmen.

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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 m³ / 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.

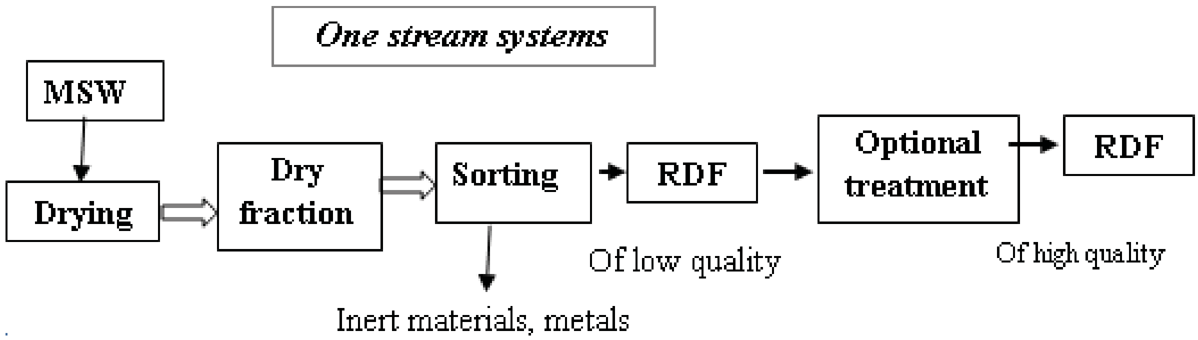

Figure 1 One-stream option based to MSW bio-drying

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.

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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.

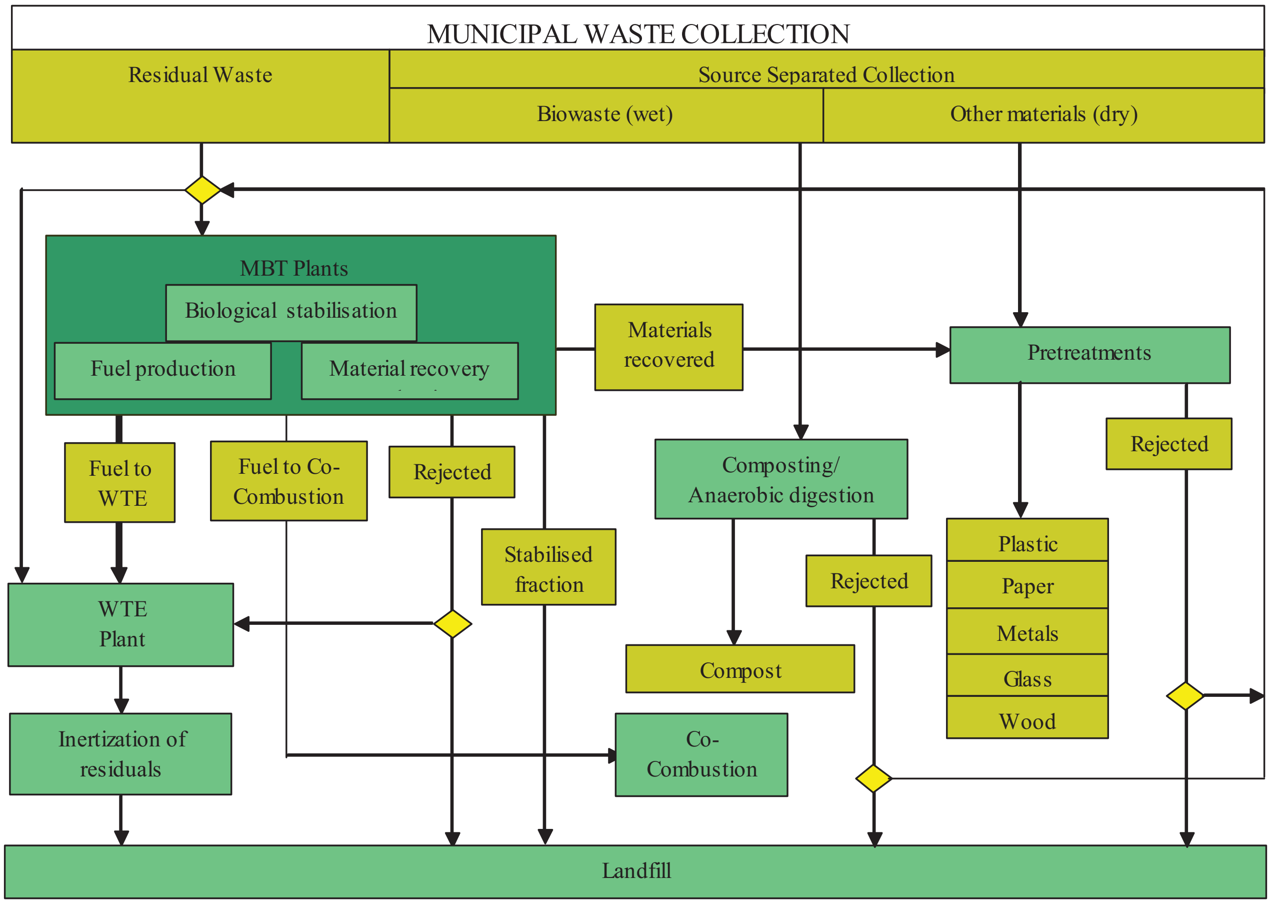

Figure 1 Simplified schema of Municipal Solid Waste management system

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.

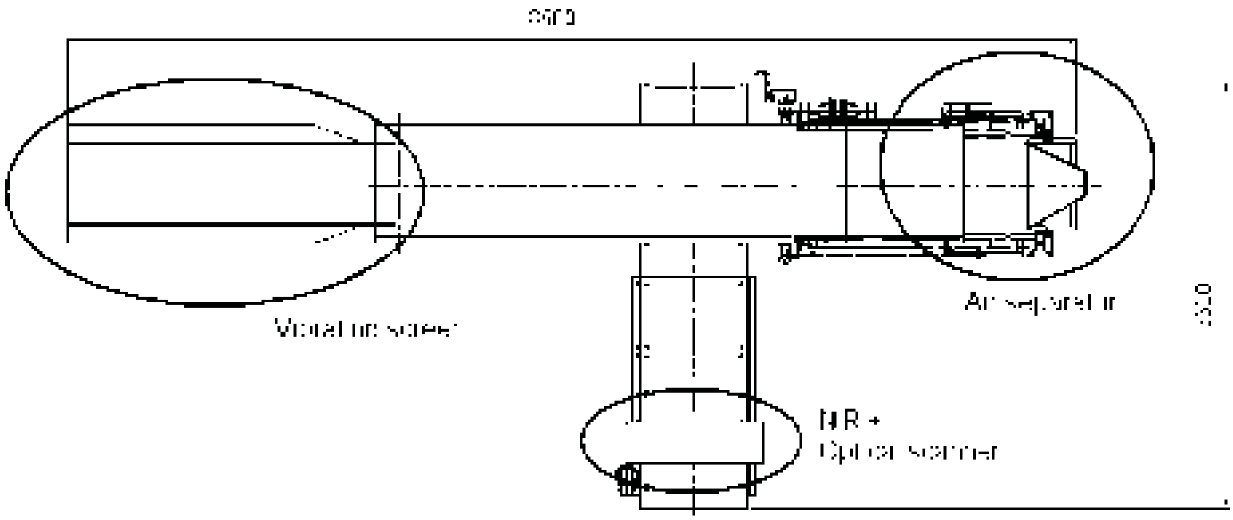

Figure 2 Layout of the Pilot Plant

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.

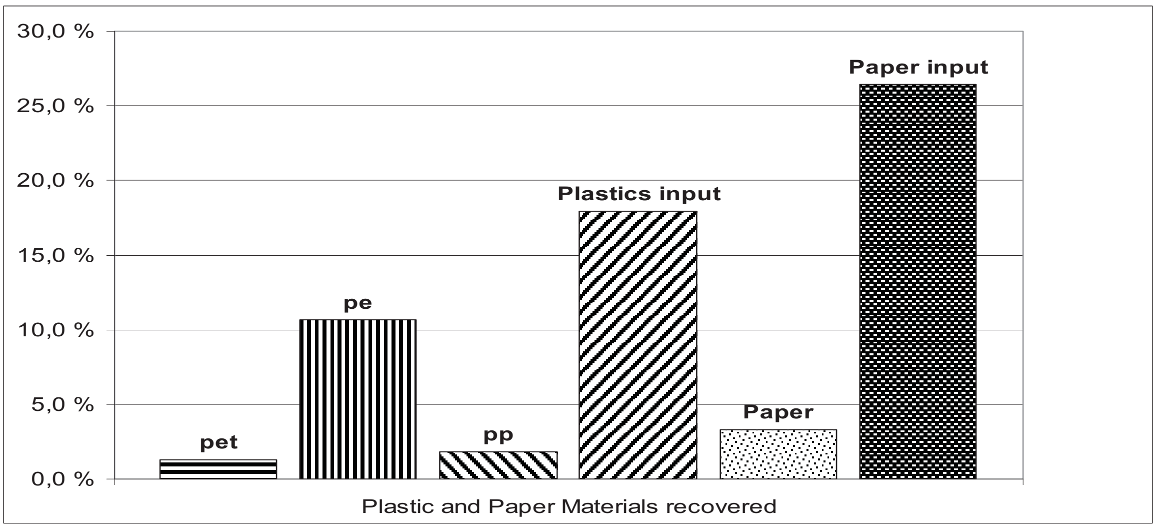

Figure 3 Recovery of Plastics and Paper compared with the input content

The historical data based upon 2008 average input/output materials coming from U.K. plants are shown in the following.

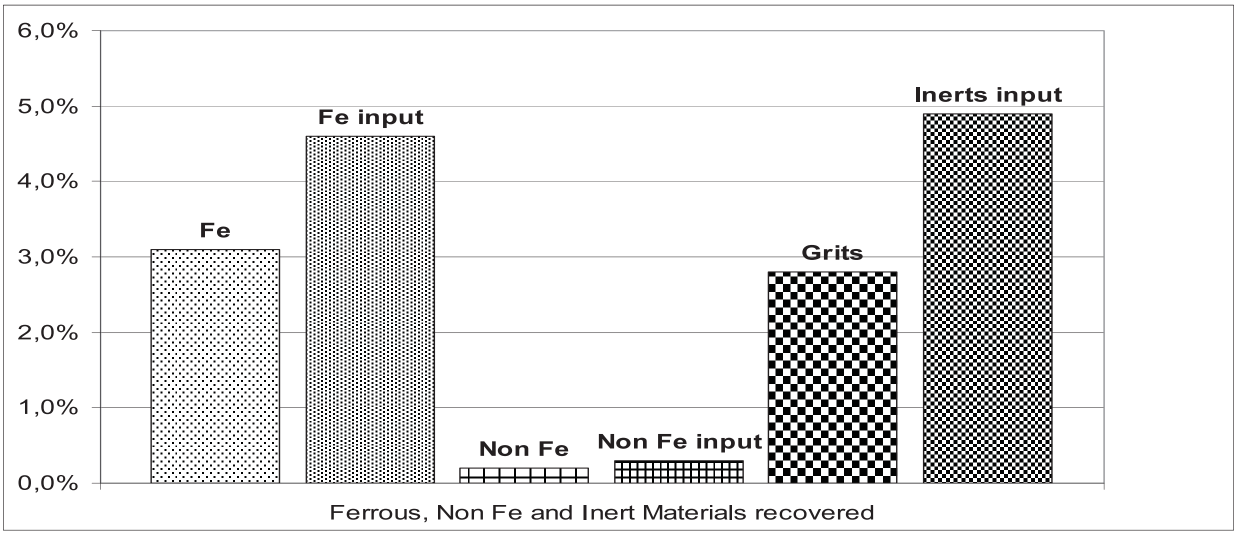

Figure 3 Recovery of Fe, non Fe, Grits compared with the input content

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

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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**).

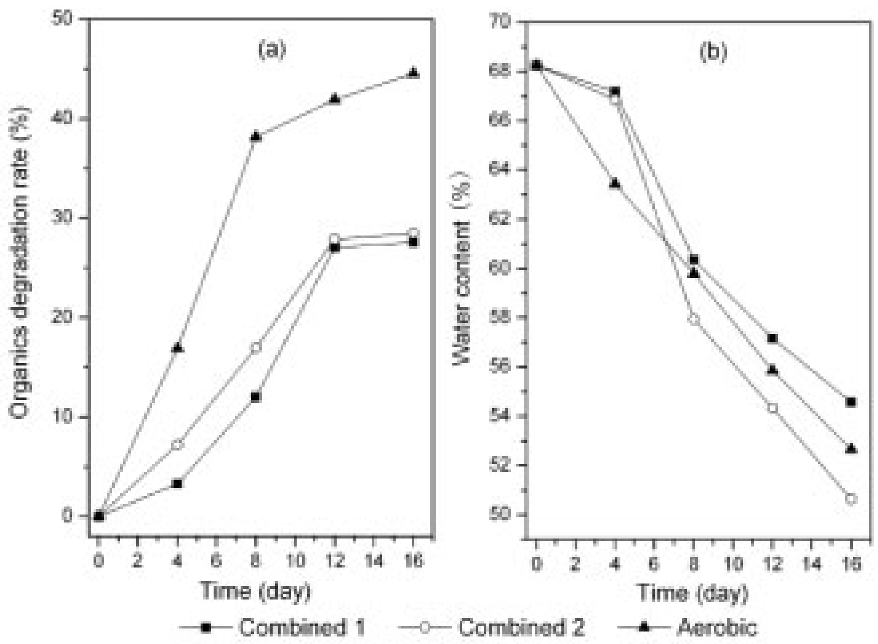

Figure 1 Organics degradation rate and water content during bio-drying

(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).

$$SE = \frac{P_{<60}}{W} \times 100\% \qquad (1)$$

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).

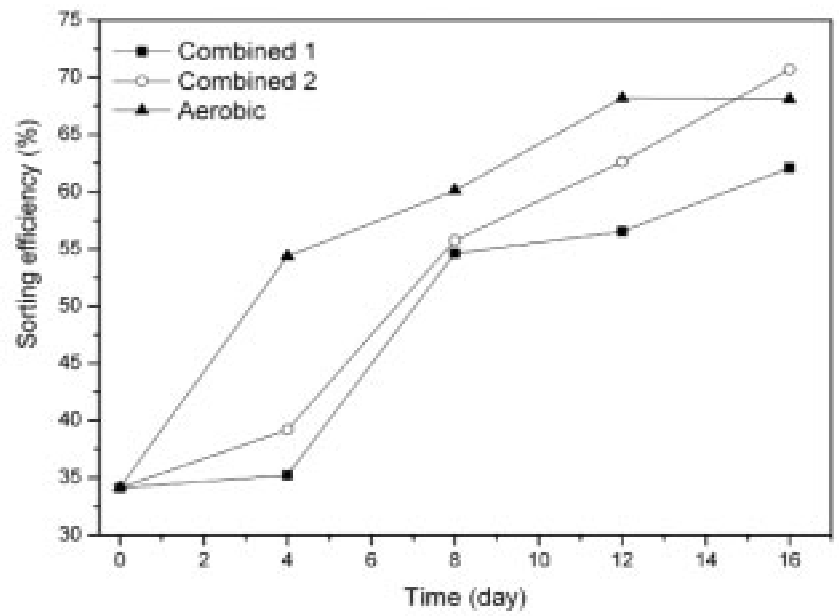

Figure 2 Evolution of the sorting efficiency of MSW during bio-drying

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).

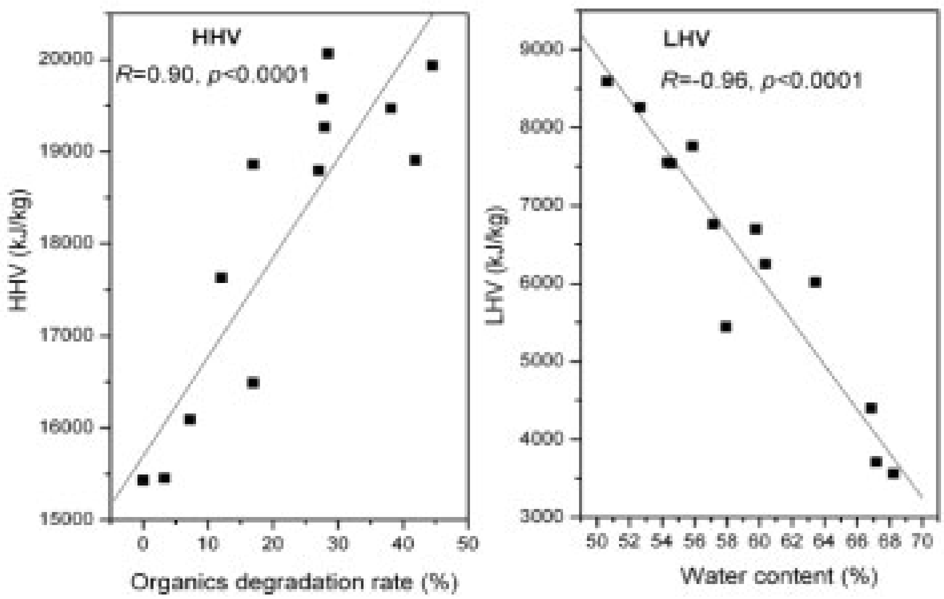

Figure 3 Correlation between the heating values with organics degradation rates and water contents during bio-drying

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.

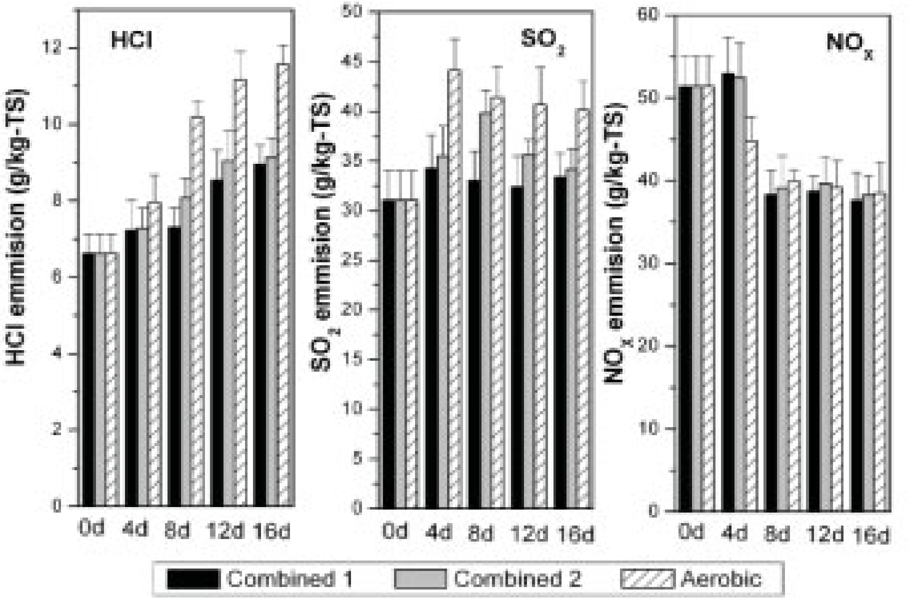

Figure 4 Combustion emissions of HCl, SO2 and NOx during bio-drying

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

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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.

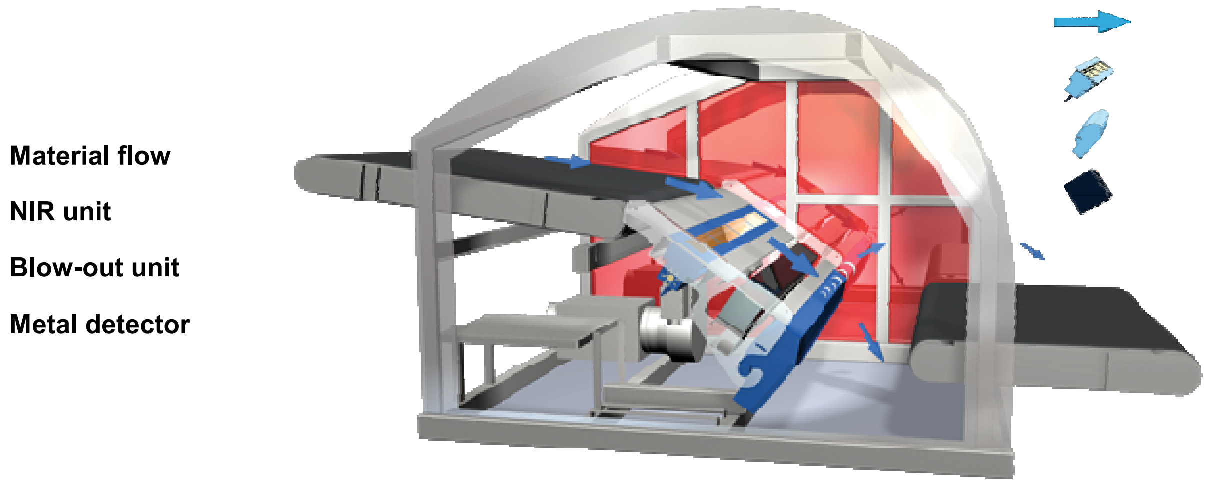

Figure 1 Sensorbased sorting machine

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.

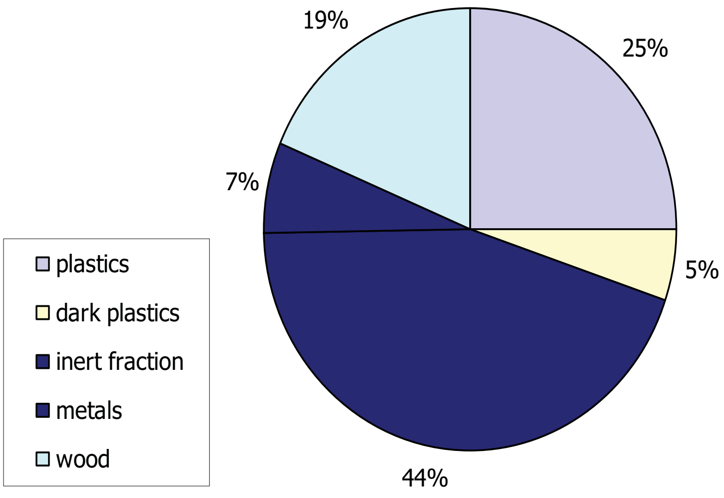

Figure 2 Waste composition input Umweltdienst Burgenland GmbH

AWV Liezen

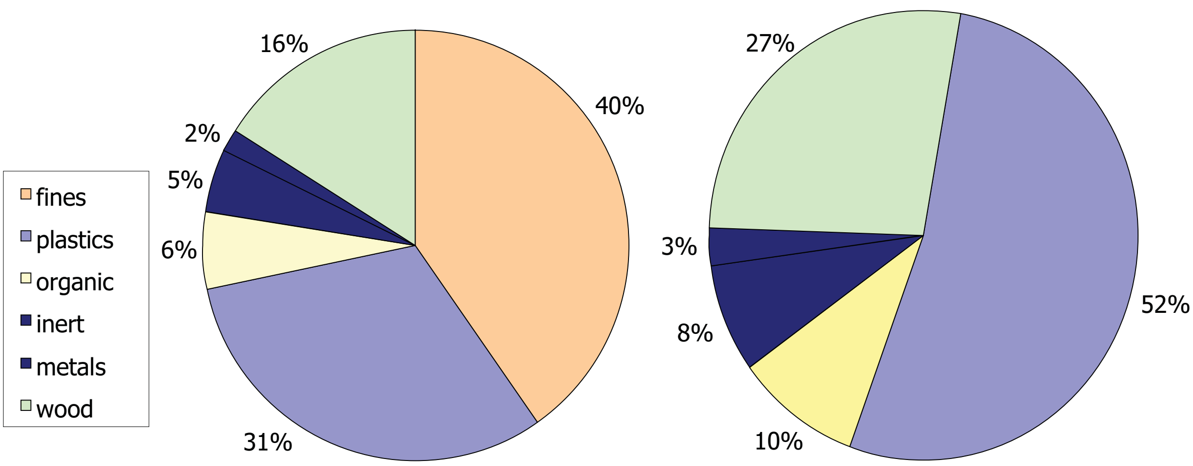

Figure 3 Waste composition after mechanical treatment incl. fine materials (left side) excl. fine materials (right side) AWV Liezen

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.

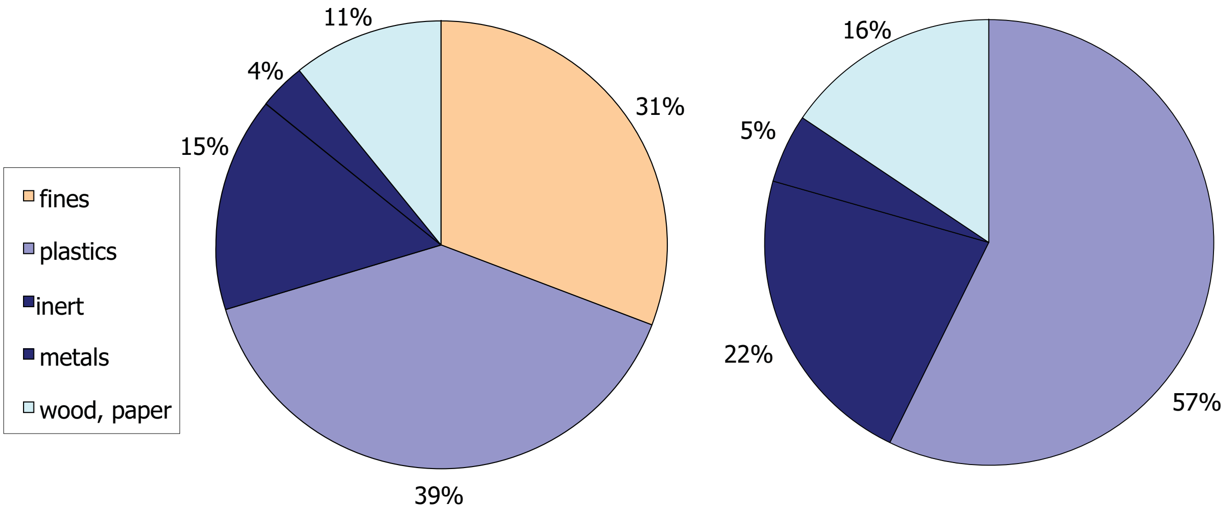

Figure 4 Waste composition (after mechanical-biological treatment) incl. fine materials (left side) excl. fine materials (right side) AWV Liezen

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.

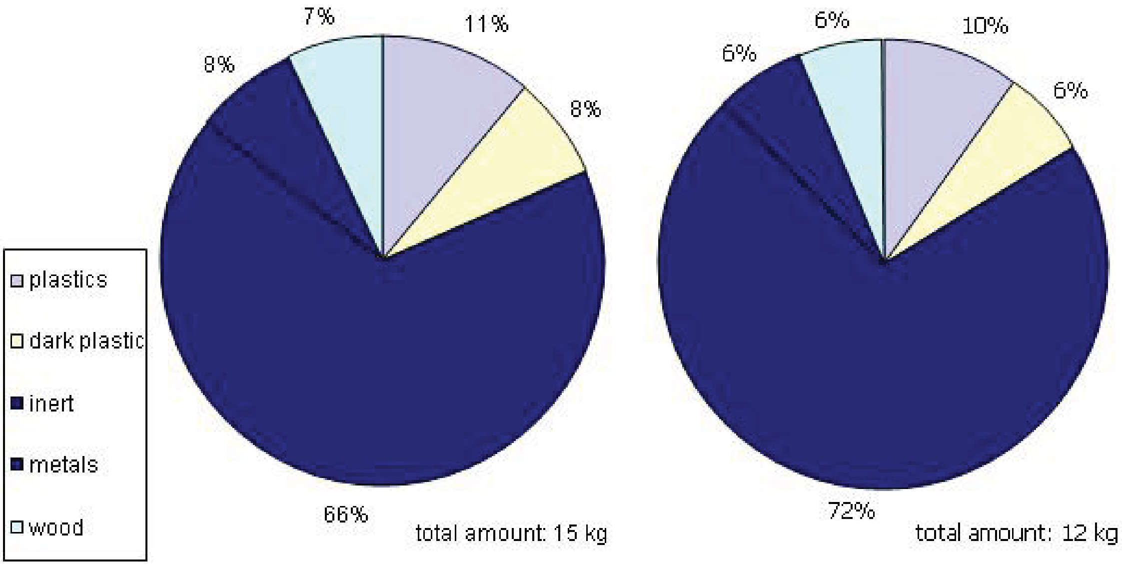

Figure 5 Waste composition pass stream single stage (left side) multistage (right side)

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.

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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.

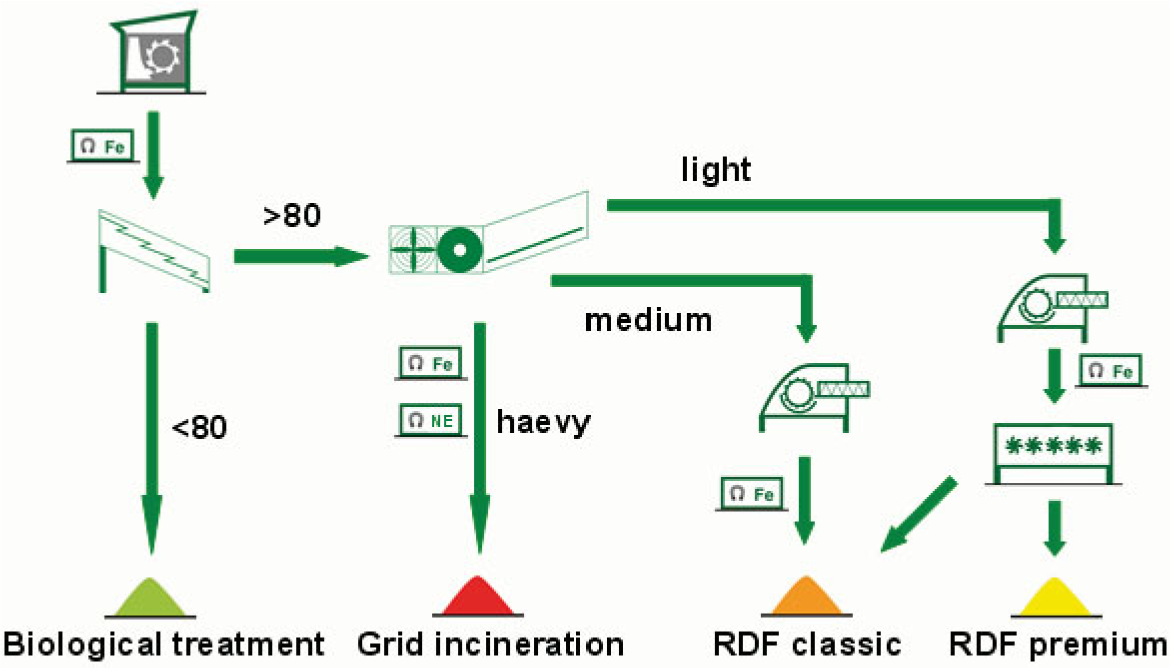

Figure 1 Example state of the art RDF plant, wind-sifter dominated

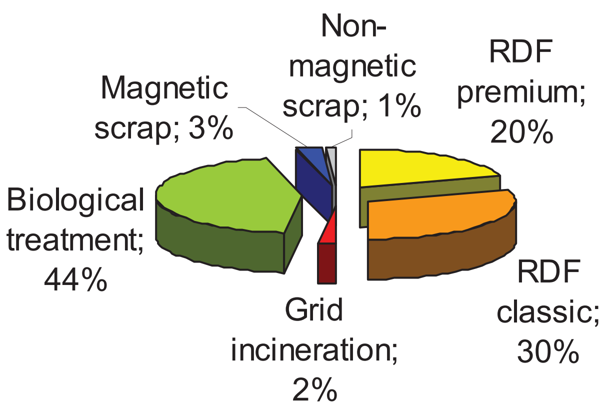

Figure 2 Output materials ration of wind-sifter dominated RDF plant

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.

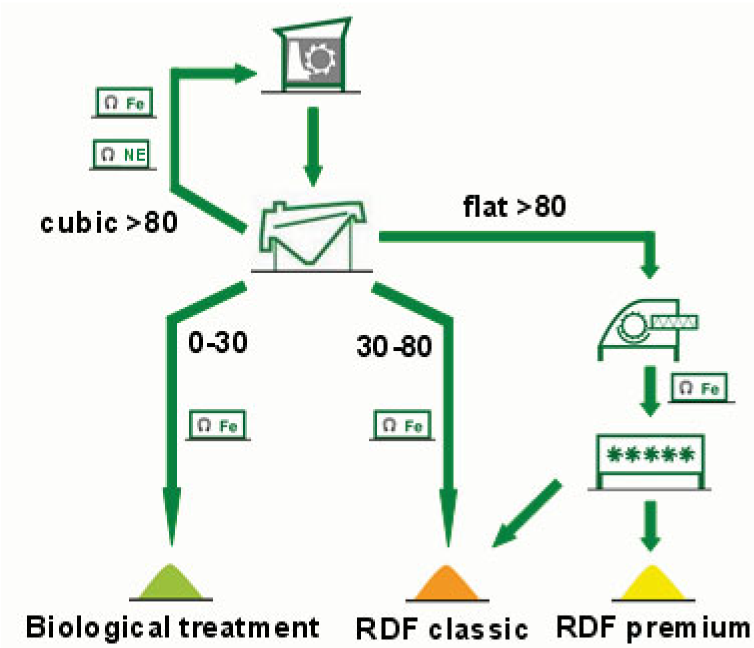

Figure 3 Ballistic-separator dominated RDF plant

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.

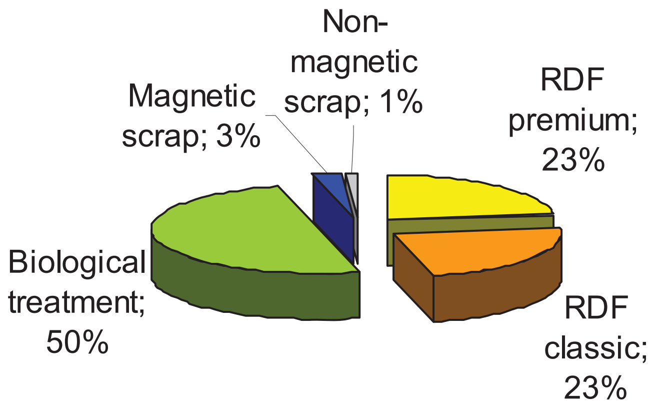

Figure 4 Output ratios of by-products of the ballistic-separator dominated RDF plant

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.

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Qualitätssteigerung von EBS und anderen Nicht-Metallprodukten durch Magnet- und Sensorsortierung

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Quailty improvment in RDF an other non-metalic-products through magnet and sensor sorting

Abstract

Solid waste has become a material source for various applications, such as Residue Derived Fuel RDF, polymers, or wood for the chip board production. The removal of quality reducing components is essential for the wide spreaded use of such materials. magnetic separation has been added by sensor sorting systems just recently, which has become a must for quality ensured RDF. Technologies today are inductive sensoring, x-ray transmission and near infrared spectroscopy.

Inhaltsangabe

Abfallstoffe werden mehr und mehr eine Rohstoffquelle für die verschiedensten Anwendungen, wie zum Beispiel Ersatzbrennstoff, Kunststoffe und Altholz für die Spanplattenfertigung. Die Entfrachtung von qualitätsmindernden Bestandteilen ist wichtig, um deren weitgestreute Nutzung zu ermöglichen,

Keywords

Magnetscheidung, Wirbelstromscheidung, Sensorsortiersystem, Ersatzbrennstoff, Holzrecycling

Magnetic Sorting, Eddy current separation, Sensor sorting systems, Residue derived fuel, wood recycling

1 Die Rohstoffquelle

Die weltweit anziehende Abfallwirtschaft zielt neben der reinen Rohstoffrückgewinnung sehr stark auf die Nutzung des Energiegehaltes der Abfälle. Um seine weitreichende Nutzung als alternativer Brennstoff zu ermöglichen, muss die Qualitätssicherung im Vordergrund stehen. Nur so lässt sich dieser Ersatzbrennstoff (EBS) als echte, von der Herkunft unabhängige Alternative zu fossilen Brennstoffen nutzen, ohne Risiken bei Betrieb und Emissionen zu verursachen. In Deutschland ist dies schon sehr umfänglich erfolgt und hat auch zum Einsatz modernster Sortiertechnik bei der Herstellung von EBS geführt. In anderen Ländern, allen voran den USA, befindet sich die umfassende energetische Nutzung von EBS gerade in der Startphase.

Auch müssen zahlreiche, andere Abfallstoffe frei von Störstoffen sein, gerade wenn es um deren werkstoffliche Nutzung geht. Da sind zunächst das Altholz als Brennstoff und

Spanplattenvorstoff aber auch Kunststoff zu nennen; Müllverbrennungsschlacke sollte ebenfalls frei von Metallen sein.

Werden diese Potentiale genutzt stehen erheblich Mengen hochwertiger Rohstoffe zur Verfügung. Die Abfalltonne steht daher nur als ein Beispiel als Rohstoffquelle.

2 Der Prozess

Wesentliche Verfahrensschritte einer Aufbereitung von Abfallstoffen ist deren Aufschluss und Zerklinerung, die Einteilung in Korngrößenklassen und die Sortierung. Beim Ersatzbrennstoff kommt dann noch häufig die Brikettierung für dessen Transport- und Dosierfähigkeit hin zu. Dies ist ein sehr Störstoff empfindlicher Prozess. Die Klassierung dient dabei im Wesentlichen dazu, die nachfolgenden Sortierschritte effizient durchführen zu können.

Dabei ist es vom Verfahrensaufbau fast gleichgültig, ob die abgetrennten Werkstoffe nun die Zielprodukt oder die Störstoffe darstellen. (Abb. 1)

Abbildung 1: allgemeines Aufbereitungsschema

Der Anlagenbetrieb wird sich hier allerdings unterscheiden, da Ausbringen und Reinheit je nach Verfahrensprinzip sehr stark gegenläufig sind. Vereinfacht gesagt, kann ein sehr hohes Ausbringen nur mit einer geringeren Reinheit erreicht werden und umgekehrt. Je nach gewählter Technologie können ergeben sich hier aber Unterschiede.

Mittels Überbandmagnetscheidern werden die groben Eisen-Komponenten abgetrennt. Manchmal werden zusätzlich noch eine Magnettrommel oder eine permanentmagnetische Bandrolle eingesetzt, bevor der Wirbelstrom die sehr werthaltigen Nichteisen-Metalle (NE-Metalle) gewinnt bzw. abtrennt. Je nachdem was das Ziel der Aufbereitung ist, die Metallgewinnung oder die die Abtrennung des Metalls als Störstoff (Abb. 2).

Sensor-Sortiersysteme folgen der klassischen Metallabscheidung. Sie haben je nach Technologie die Aufgabe Kunststoffe zu gewinnen oder als Störstoff abzutrennen, aber auch andere Metalle wie den Edelstahl auszuscheiden; z.T werden sie auch eingesetzt, um Steine und Glas abzutrennen.

Abbildung 2: Wirbelstromscheider in einer EBS-Anlage

3 Bisherige Sortierlösungen: Magnetscheidung im erweiterten Sinn

Je anspruchsvoller diese Maschinen sind, desto umfassender ist der Sortiererfolg. Im Ersatzbrennstoff werden häufig Korngrößen von 0 bis 25 mm oder 0 bis 40 mm verarbeitet. Das stellt an die Magnetscheidung und den NE-Scheider gleichermaßen hohe Ansprüche.

3.1 Überbandmagnetscheider

Überbandmagnetscheider müssen insbesondere freies, wenig verbundenes Eisen gewinnen, das vermarktbar ist. Verbundstoffe wie der Nagel in der Holzlatte bleibt dabei meist im Materialstrom. Das hängt aber entscheidend von dem Abstand zwischen Magnet und Förderstrom sowie der magnetischen Kräfte ab. Auch ist es wichtig immer wieder darauf hin zuweisen, das ein Überbandmagnet längs über dem Abwurf am Bandende gehängt werden muss und nicht quer irgendwo über dem Förderstrom(s. Abb. 3). Das Fördergut ist im Abwurf nämlich aufgelockert und das zu gewinnende Eisen kann sich ohne große Widerstände durch diese gelockerte Schicht bewegen. Der Abwurf und sämtliche Anlagenteile im Magnetfeld müssen aus unmagnetischem Werkstoff sein, z.B. VA. Das gilt insbesondere für die Bandrolle und das Scheitelblech im Austrag. Andernfalls bilden sich Sekundärmagnete aus, die die Eisenteile „festhalten“ und die deren Bewegung erheblich behindern.

Abbildung 3: Überbandmagnetscheider längs über dem Abwurf angeordnet

In Queranordnung, s. Abb. 4, wirken das Eigengewicht aber insbesondere das Gewicht der überlagernden Schicht der magnetischen Anzugskraft entgegen. Das Eisen-Ausbringen sinkt bei einer solchen Anordnung drastisch ab.

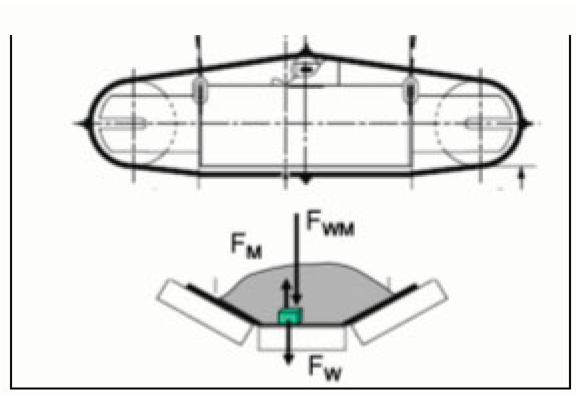

Abbildung 4: Belastung des Eisenpartikels mit ruhendem Fördergut:
FM Anziehungskraft, FW: Gewichtskraft,
FWM: Gewichtskraft des überlagerenden Materials

Das Magnetfeld sollte dann ausreichend lang sein, um die Verweilzeit zu erhöhen und die gesamte Breite des Gurtförderers abdecken. Mit rechteckigen Spulen lässt sich dies am ehesten erreichen.

3.2 Wirbelstromscheider

Der Wirbelstromscheider ist seit rund zwanzig Jahren der Standard in der Abfall-Aufbereitung und kann im weitesten Sinn auch als Magnetscheider gesehen werden, da die sortierende Kraft über magnetische Wechselfelder erzeugt wird. Das Material z.B. die Aluminiumdose wird allerdings abgestoßen. Das ganze erfolgt im Abwurf einer kurzen Bandförderstrecke.

Bei Auswahl und Betrieb sind daher verschiedene Parameter zu berücksichtigen. Da ist zunächst die Partikelbewegung im Abwurf zu betrachten, da sich große Teilchen wegen ihrer Massenträgheit früher vom Band lösen als kleinere, wie Abbildung 5 zeigt. Entsprechendes gilt für schwere und leichte Teile. In diesem Ablösepunkt muss durch den Wirbelstrom die Teilchenbewegung geändert werden, nicht davor und nicht dahinter.

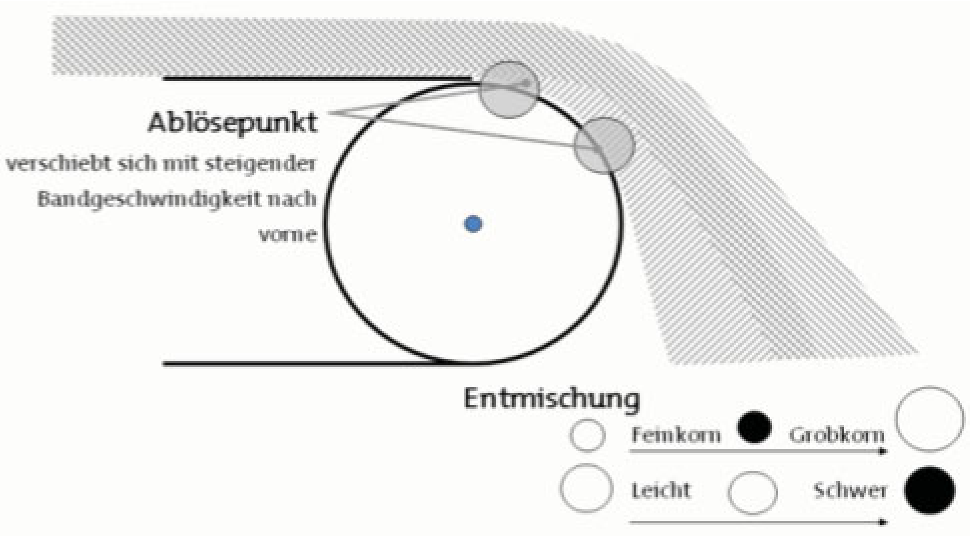

Abbildung 5: Teilchenverhalten im Abwurf; der Ablösepunkt verschiebt sich

Je feiner das Material ist, desto später löst es sich vom Band und fällt entsprechend nahe am Band herunter. Bei hohen Bandgeschwindigkeiten liegt der Ablösepunkt sehr weit oben. Die Wirkungstiefe des wechselnden Magnetfeldes ändert sich schon bei geringster Entfernung vom Band. Daher muss der Krafteingriffspunkt beim Wirbelstromscheider verstellbar sein, insbesondere wenn man Korngrößen oberhalb von 50mm abscheiden will. Das gleiche gilt für die Bandgeschwindigkeit. Daraus lässt sich auch schließen, dass eine gute Sortierung ein enges Kornband voraussetzt.

Nur ein Wirbelstromscheider mit exzentrischem Polsystem kann diese Bedingung erfüllen; nur hier ist eine Verstellbarkeit möglich und begründet den breiten Erfolg dieser Technologie. Um die exzentrische Anordnung zu ermöglichen, ist die Gurttrommel sehr groß (Abb. 6).

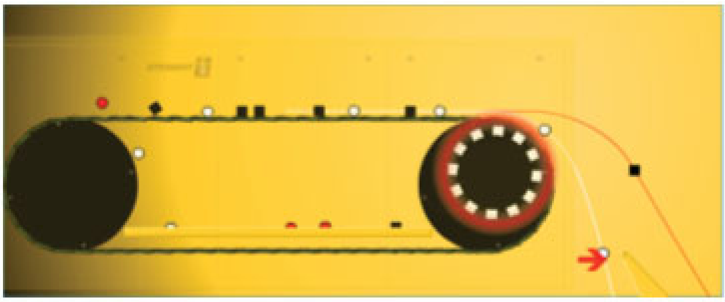

Abbildung 6: Wirbelstromscheider mit exzentrischem Polsystem; Verstellbarkeit ist gegeben und das Magnetfeld wirkt nur im Ablösepunkt; rot: Eisenteilchen sind frei beweglich

Da NE-Metalle wertvoll sind, kommt es darauf an eine möglichst hohe Verfügbarkeit des Wirbelstromscheiders zu gewährleisten. Sensibel können solche Maschinen sein, wenn es um Reste an Eisen geht. Wird ein Wirbelstromscheider mit zentrischem System (Abb. 7) eingesetzt, liegt um die ganze Gurttrommel ein hochfrequentes Magnetfeld an, das Eisenteilchen festhält und diese veranlasst sich drehend und bohrend zu bewegen. Erkennbar ist dies an einem „singenden" Geräusch. Das geht natürlich auf den Verschleiß vom Band aber auch von der Gurttrommel, wenn das Eisenteilchen unter das Band gerät.

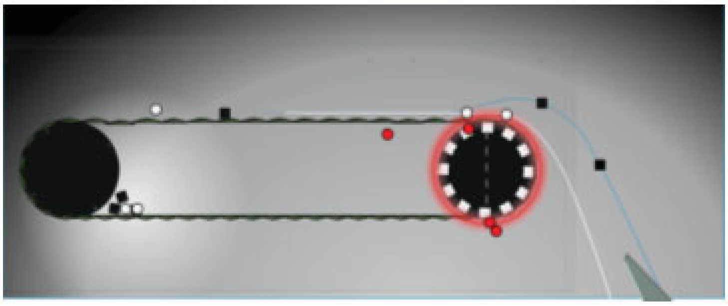

Abbildung 7: Wirbelstromscheider mit zentrischem Polsystem und Magnetfeld um die Gurttrommel; rot: anhaftende Eisenteilchen.

Um haftendes Eisenkorn vom Band zu entfernen, haben zentrische Wirbelstromscheider als äußeres Zeichen mehrere Abwurfleisten auf dem Gurt angeordnet. Diese werfen dann das Material irgendwo unter den Wirbelstromscheider, wo es dann manuell entfernt werden muss.

Dennoch ist die Haltbarkeit von Gurttrommel und Band solcher Wirbelstromscheider deutlich reduziert und ein häufiger Wechsel von beiden Komponenten die Regel.

Verfügbarkeit und Trennschärfe sprechen auch wirtschaftlich für sich, wie die folgende Tabelle sehr deutlich zeigt.

Tabelle: Vergleich der Wirbelstromscheider mit exzentrischem und zentrischem Polsystem

Aufgabe	10	t/h					
NE:	4	%					
Aufgabe pro Jahr	38.400	t/a	16h/d; 240d/ 2 Schichten				
	STEINERT exzentrisch		**andere; zentrisch**		**Unterschied zu STEINERT**		
Invest Maschine	85.000	€	60.000	€	-29	%	zusätzliches Invest
Verfgbarkeit	95	%	92	%	-3	%	wegen Trommelmantel und Band
Sonst. Invest, Personal, Energie, Abschreibung		ähnlich					
Ersatzteile,Personal	3.500	€/y	13.500	€/a	286	%	2 Trommelmäntel pro Jahr - zentrisch
spez. Kosten €/t	2,5	€/t	2,8	€/t	13	%	
Ausbringen	90	%	88	%	-2	%	wegen Verstellbarkeit
Reinheit	90	%	89	%	-1	%	wegen Verstellbarkeit
Produktion	1.313	t/y	1.244	t/y			
Wert	720	€/t	712	€/t			
Gesamt Einnahmen	945.562	€/y	885.404	€/y	-6	%	
Gesamtkosten p.Jahr	96.768,0	€/y	109.056,0	€/y	13	%	
Gewinn p.Jahr	848.793,6	€/y	776.348,5	€/y	**-9**	**%**	
Jährlicher Unterschied	**72.445,1**	**€/y**					Vorteil STEINERT

4 Die Sensor-Sortier-Systeme eröffnen neue Möglichkeiten

Nahinfrarot-Sortiersysteme folgen der klassischen Metallabscheidung, um polymere Wertstoffe zu gewinnen, aber auch um Störstoff wie PVC abzuscheiden. Hochauflösende Nahinfrarot-Sortiersysteme können dabei nur einen Teil der Chlorfracht mit dem PVC entfernen. Aber es ist wesentlich, da sonst überhaupt keine Chance besteht, die Grenzwerte einzuhalten.

Als weitere Option werden heute zusätzliche, Sensor basierte Technologien eingesetzt. Allen voran ist da das Induktions-Sortier -System ISS aber auch das Röntgen-Sortier-System XSS. Sämtlich genannte Systeme werden heute für Ersatzbrennstoff und andere Stoffe genutzt.

Die Notwendigkeit zu einer weitreichenden Metallabscheidung zeigt sehr anschaulich Abbildung 8. Deutlich erkennbar ist der von Brikettierpresse beanspruchte Edelstahl. Die zerstörerische Wirkung solcher Stücke ist unschwer erkennbar.

Abbildung 8: zerkleinertes Altholz mit Metall

Das Prinzip der Sensorsortiersysteme stellt die folgende Abbildung 9 dar. Sensoren, hier eine Vielzahl von Metalldetektoren, misst bestimmte Materieleigenschaften und steuert dadurch Druckluftdüsen, die im Bedarfsfall das erkannte Teilchen aus dem Förderstrom ausschleusen.

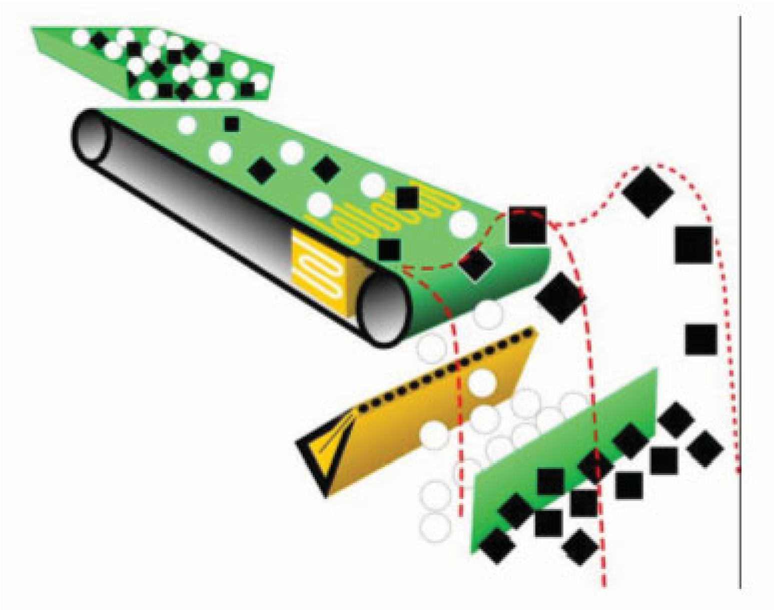

Abbildung 9: Prinzipskizze eines Sensorsortiersystems, Induktionssortierssytem ISS

Werden zum Beispiel unterschiedliche Werkstoffe bei einem Röntgensortiersystem erkannt, so kann an Hand einer Eichkurve wie in Abbildung 11 dargestellt, eine Sortierung erfolgen.

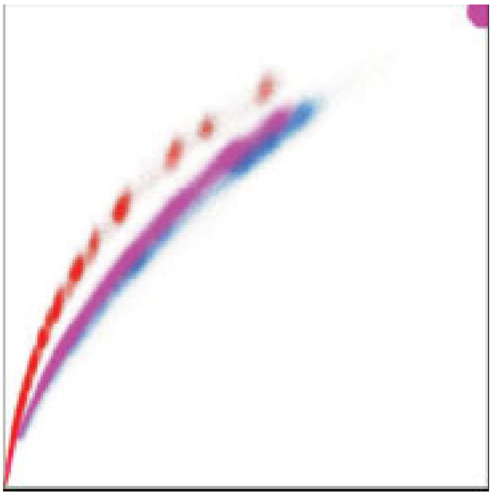

Abbildung 11: Eichkurven zur Unterscheidung von Werkstoffen an Hand unterschiedlicher Intensitäten bei unterschiedlichen Energien.

Im Fall von EBS und Holz können dies zum Beispiel Steine sein oder aber auch PVC und Gummi. Grundlage hierbei ist die Durchstrahlung (Transmission) von Partikeln mittels Röntgenstrahlen und die Analyse der stoffspezifischen Abschwächung der austretenden Strahlung auf zwei unterschiedlichen Energieniveaus (Dual Energy). Je schwerer das chemische Element ist desto größer ist die Adsorbtion der Strahlung. Durch Dual Energy werden Unterschiede zwischen Atommasse und Materialdicke ausgeglichen und somit eine Dickenunabhängige Auswertung ermöglicht

Die Stoffunterscheidungen erfolgt dabei maßgeblich aufgrund der Atommasse führenden chemischen Elemente (Abb. 12)

Abbildung 12: Periodensystem der chemischen Elemente als Grundlage für das Röntgensortiersystem XSS

Eine Hintereinander-Schaltung von Wirbelstromscheidung und Induktionssortiersystem-zeigt Abbildung 11 aus einer Ersatzbrennstoffaufbereitungsanlage in Deutschland. In diesem Fall ist das Induktionssortiersystem durch einen Nahinfrarot-Sensorik ergänzt worden, um neben Restmetallen auch PVC aus Verpackungsstoffen abzuscheiden.

Abbildung 11: Blick in eine EBS-Anlage mit Wirbelstromscheider, links, und Induktionssortiersystem mit Nahinfrarotkamera in Kombination, rechts

5 Schluß

In Kenntniss der einzelnen Sortierschritte und der Produkt-Notwendigkeiten können die Verfahren in ihrem aufeinander abgestimmt werden. Dies setzt aber voraus, dass die Technologien zum einen an ihren Schnittstellen verstanden werden und zum anderen ihre freie Auswahl erfolgen kann. Ein Angebot der kompletten Sortiertechnologien erleichtert.

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Automatische Sortierung verschiedener Metalle aus Ersatzbrennstoffen

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Automatic picking of different metals from RDC

Bahnbrechende Sortiertechnik unter Anwendung der Planaren Magnet-Induktions-Tomographie (PMIT) mit einem integrierten Echtzeit-Rechenwerk

Keywords

hohe Materialflüsse, sensorgestützt, präzise Erkennung, prozeßsichere Ausschleusung > 95%, Bandgeschwindigkeit ca. 3,2 m/sec., integriertes Rechenwerk im Sensor, Metallselektierung bei 14t EBS Material pro Stunde, geringer Druckluftverbrauch

Meine sehr verehrten Damen und Herren!

Wenn ich jetzt so in die große Runde des Auditoriums blicke, so sehe ich viele Zuhörer, die seit Jahrzehnten in der Recyclingbranche tätig sind, einige seit mehreren Jahren!

Und wieder Andere erst seit kurzer Zeit. Doch eines...eines haben Sie vermutlich alle in gleichem Maßen gemeinsam, das Unternehmen EXSOR, für das ich hier und heute stehe, das kennen Sie vermutlich alle nicht!

Um diese Tatsache nun grundlegend und eindrucksvoll für alle Zeiten zu ändern, dafür möchte ich Sie mit einer atemberaubenden Neuerung auf dem Gebiet der automatischen, sensorgestützten Sortierung vertraut machen.

Bevor ich nun umgehend konkret auf unsere neu entwickelte Technologie zu sprechen komme, erlauben Sie mir noch einen Satz zu der Entstehung und dem Umfeld des Unternehmens EXSOR:

Wie kommt ein fünfköpfiges Team, bestehend aus Unternehmern, Entwicklern und Ingenieuren auf die Idee, sich in einem gut besetzten Markt von Maschinenbauunternehmen aus dem Gebiet der Sortiertechnik, im Recyclingmarkt neu behaupten zu wollen ? Ist dieses nicht ein ebenso hoffnungsloses Unterfangen wie damals, vor vielen, vielen Jahren, die Gründung einer neuen Sportartikelmarke mit Namen NIKE ? Wer wagt es denn, sich mit Unternehmen wie Adidas oder Puma messen zu wollen? Doch trotz größter Hürden und pessimistischen Stimmen im Umfeld ließen sich die Gründer von NIKE nicht von Ihrem Vorhaben abbringen und starteten Ihr Unternehmen mit den Worten: „Let’s do it“.

Let's do it, treffender und konkreter kann man auch die Entscheidung zur Gründung des Unternehmens EXSOR nicht beschreiben.

Die EXSOR GmbH ist ein Tochterunternehmen der Dwenger und Grünthal GmbH. Dwenger und Grünthal ist ein rund 100 Mitarbeiter zählendes Unternehmen mit Stammsitz in Hamburg, ein Unternehmen, das seit 17 Jahren erfolgreich in Entwicklung und Produktion für namenhafte Firmen im Maschinenbau tätig ist.

Was ist nun aus der Gründung der EXSOR GmbH vor 3 Jahren entstanden?

Meine sehr verehrten Damen und Herren, dieses möchte ich Ihnen nun anhand unserer entwickelten Maschine mit Namen EX 900 erläutern:

Unser erklärtes Ziel war es, die Lücke in der sensorgestützten, automatischen Sortierung von Metallen in hohen Materialflüssen zu schließen. Das Ziel hieß, präziseste Erkennung aller Metalle bei hoher Geschwindigkeit. Das Ziel hieß auch, prozesssichere Ausschleusung von Metallen weit über 95%. Das Ziel hieß weiter, diese wichtigsten Parameter in einer hochwertig und präzisen Maschinenanlage zu vereinen. Meine Damen und Herren, ich verspreche Ihnen nicht zu viel, wenn ich Ihnen versichere, dieses ist uns mit der EX 900 in komplettem Maße gelungen. Da es hier und heute nur um das Thema der Aufbereitung und Metallentfrachtung von EBS Materialien geht, möchte ich hier auch nur auf die Leistungsfähigkeit der Anlage im Bereich von EBS Materialien eingehen, auch wenn das Feld der Anwendungen um ein Vielfaches weiter reicht, so weit, dass es uns möglich ist, unterschiedliche Metalle präzise zu unterscheiden.

Erstmals in einem Sensor verbaut, kommt in unserer EX 900 die Planare Magnetfeld Tomographie zur Erkennung aller Metalle zum Einsatz, welches zu einem patentierten Verfahren anerkannt wurde. Unserer Erkennung ist es völlig egal, in welcher Form die Metallfraktion vorliegt. Unabhängig von Oberflächenbeschichtung, Form oder Verbundmaterialien, wir detektieren im EBS Materialfluss alle Metalle und schleusen diese mit einer Reinheit von deutlich über 95% aus. Um die Leistungsstärke unserer EX 900 weiter zu Ihrem Nutzen zu verdeutlichen, möchte ich Ihnen den Massenfluss von 14 Tonnen pro Stunde reinem EBS Material nennen. Umso beeindruckender ist dieses Ergebnis bei dem Hinweis, dass wir dieses über eine Arbeitsbreite von gerade mal 900mm erreichen. Wir arbeiten mit einer Bandgeschwindigkeit von rund 3,2 Meter pro Sekunde. Die Erkennung von metallhaltigen Teilen und die Ausschleusung aus dem Massenfluss geschieht in wenigen tausendstel Sekunden. Dazu setzten wir selbstverständlich ein eigenes, intelligentes, im Sensor integriertes Rechenwerk ein, das selbst besten Industrie PC's um ein Vielfaches an Leistung überlegen ist. Abstürzende Programme sind dabei für uns ein Fremdwort.

Dieses Rechenwerk steuert die Befehle zur Ausschleusung der Metalle mittels 150 Hochleistungsventilen in unserer Ventilleiste, welche mit einem Ventilabstand von 6 mm zueinander verbaut wurden.

Wenn ich Ihnen jetzt noch versichere, dass wir die komplette Sortierung im heutigen Zeitalter energieeffizienter Denkweise mit extrem geringen Energieeintrag bewerkstelligen, dann habe ich Ihnen in kurzen Zügen beschrieben, was unsere entwickelte Technologie so einzigartig macht. Bei der Sortierung von EBS Materialien genügt uns in den meisten Fällen eine Druckluftversorgung von rund 22 KW, bei stark metallbelasteten EBS Materialien liegen wir maximal bei 43 KW, welche wir Ihnen selbstverständlich in einem eigens konzipierten Druckluftcontainer mit Luftaufbereitung liefern können.

Wir setzen unsere EX900 unter Anderem seit einigen Monaten bei einem großen EBS-Aufbereiter im Norden von Deutschland ein, Sie alle sind herzlich dazu eingeladen, die modernste, automatische Metallselektierung bei rund 14 Tonnen EBS Material pro Stunde live zu erleben und sich von meinen Worten zu überzeugen, um Ihre mögliche Skepsis in Begeisterung und Vertrauen zu verwandeln.

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New possibilities for fully automatic sorting of recyclables

Peter Mayer

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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.

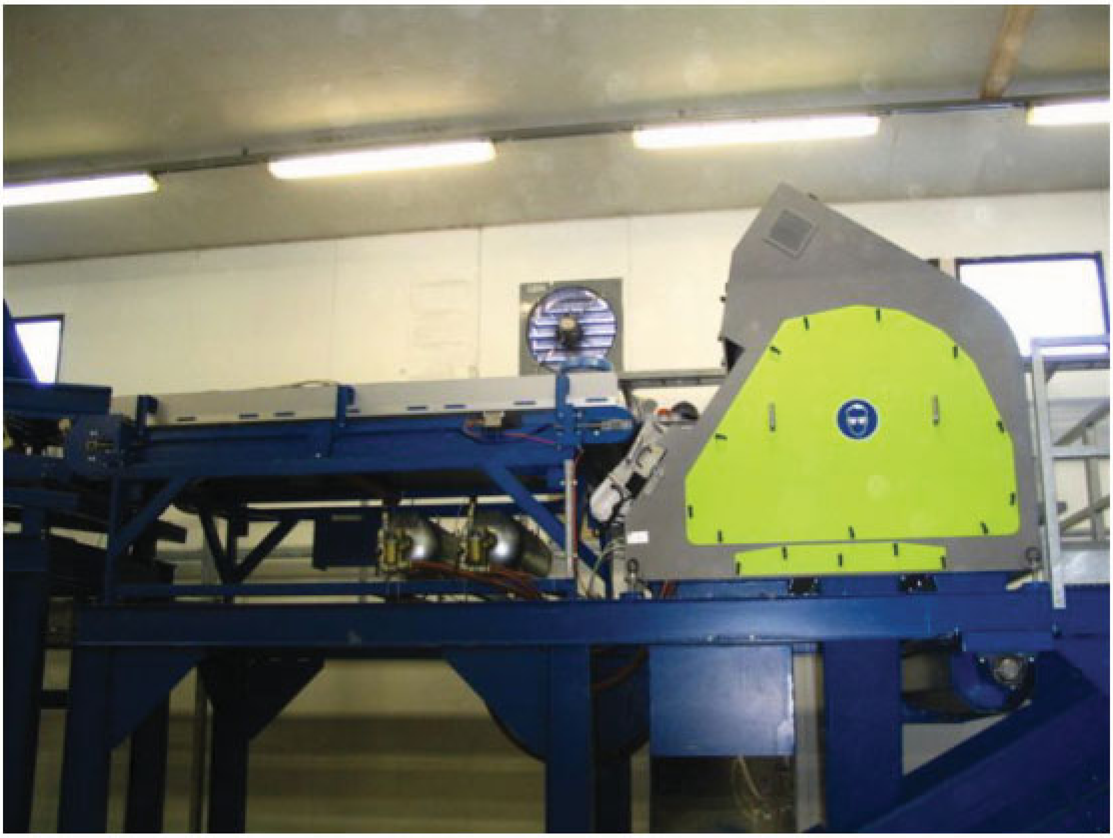
In the sorting process, it is often important to distinguish between transparent and non-transparent materials, for example, the detection of ceramic particles within the glass recycling process. For this purpose, S+S offers a special transmitted light sensor which scans the stream of material with high 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

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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].

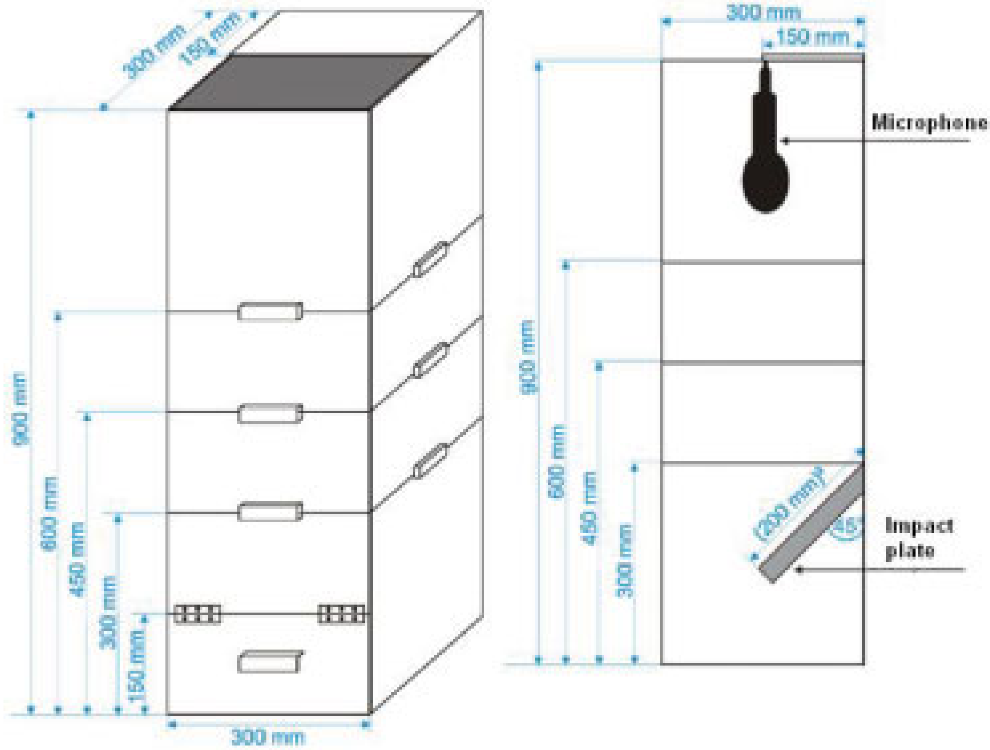

Figure 1 The Sketch of the experiment equipment for impact acoustics

Figure 2 Complete Equipment and the installation of microphone and impact plate

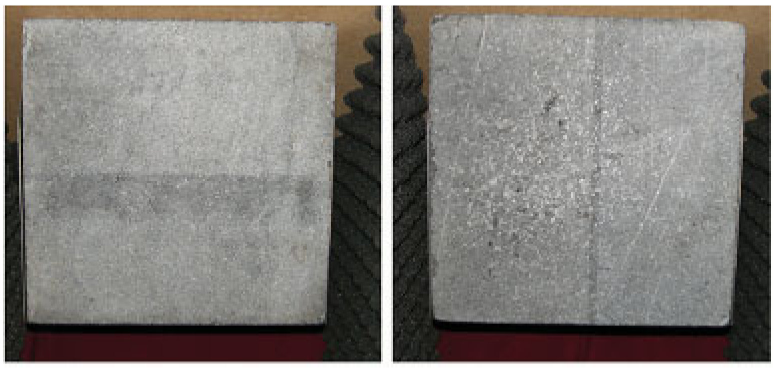

Figure 3 Impact plate for experiment (left: before experiment, right: after the experiment)

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.

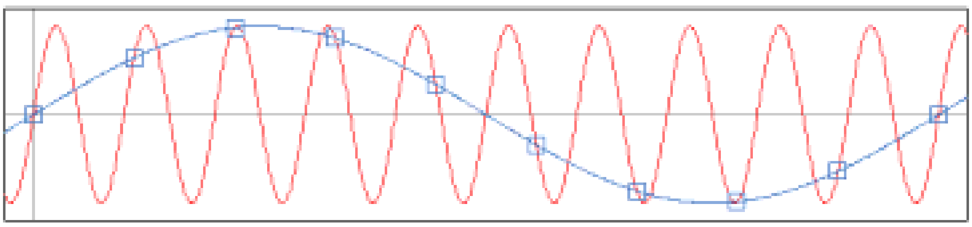

Figure 4 The generation of aliasing effect

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.

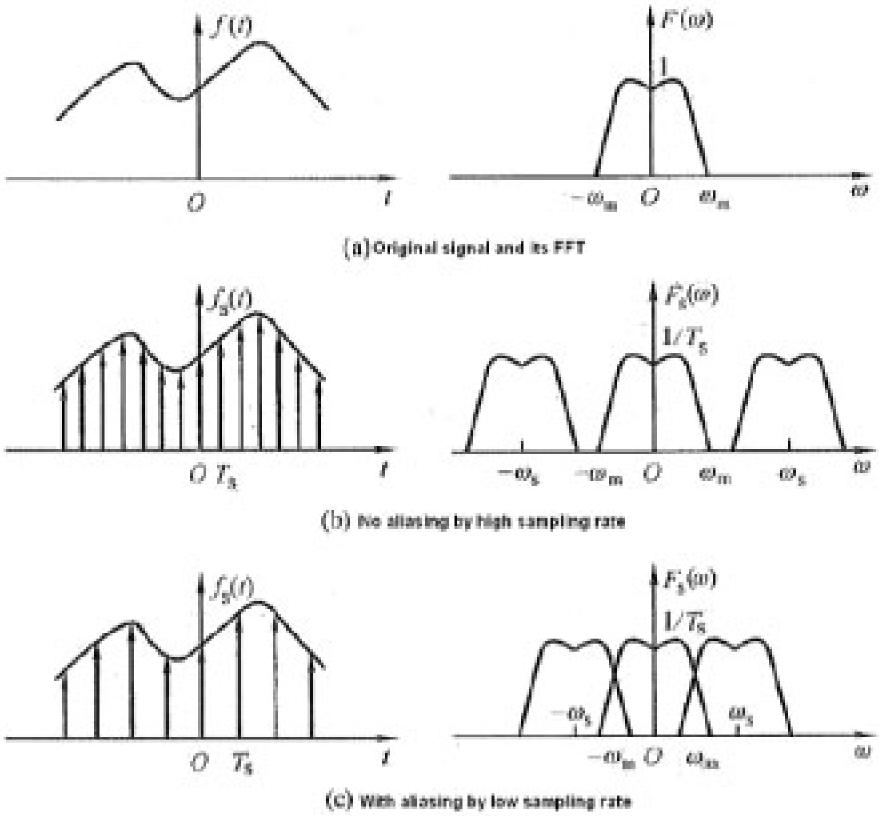

Figure 5 The aliasing in frequency domain and frequency spectrum

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.

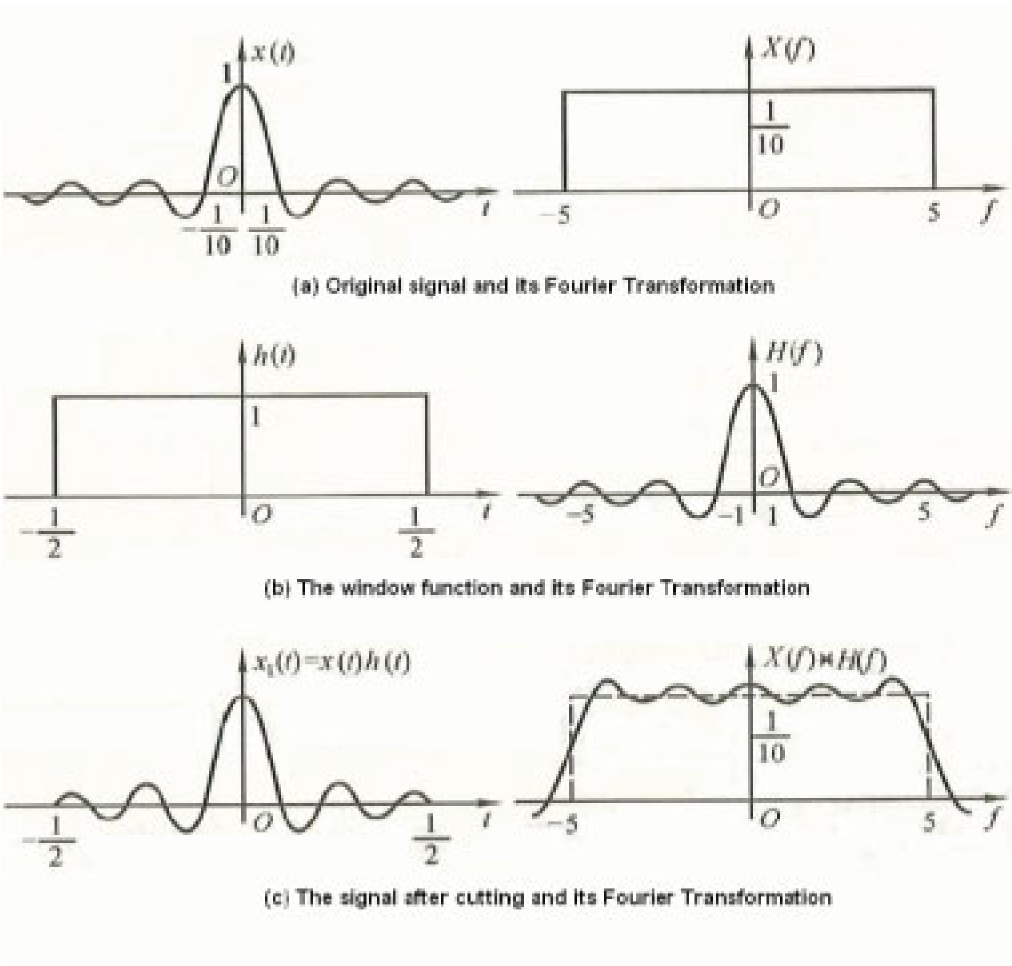

Figure 6 The leakage effect generated by rectangular window function

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.

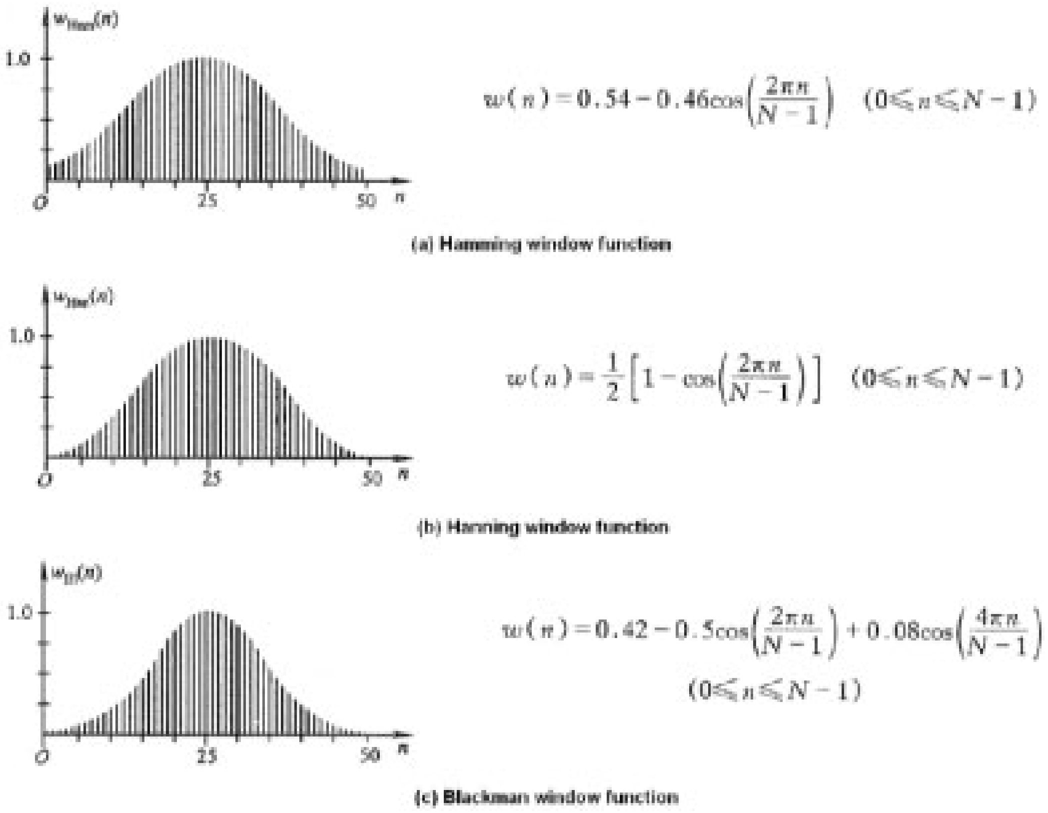

Figure 7 Three kinds of window functions

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 $0 \leq n \leq N-1$.

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:

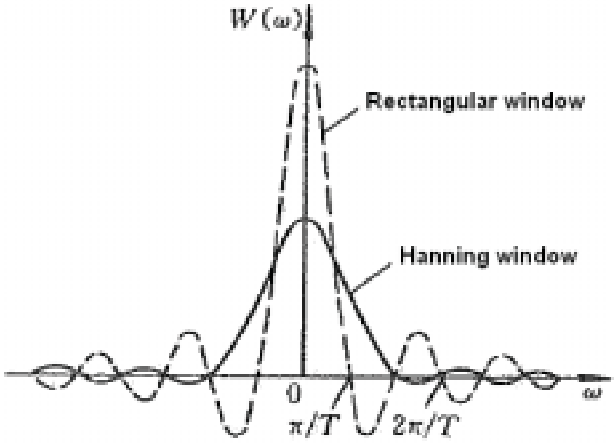

Figure 8 Comparison of Rectangular and Hanning window in frequency domain

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:

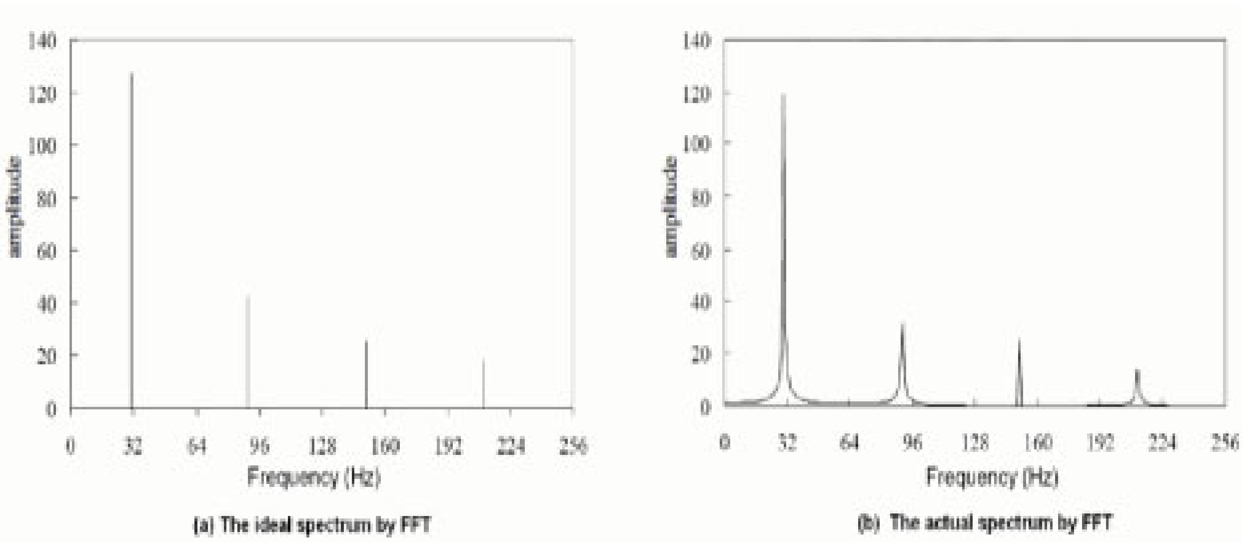

Figure 9 The Comparison of ideal and actual spectrum by FFT Analysis

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.

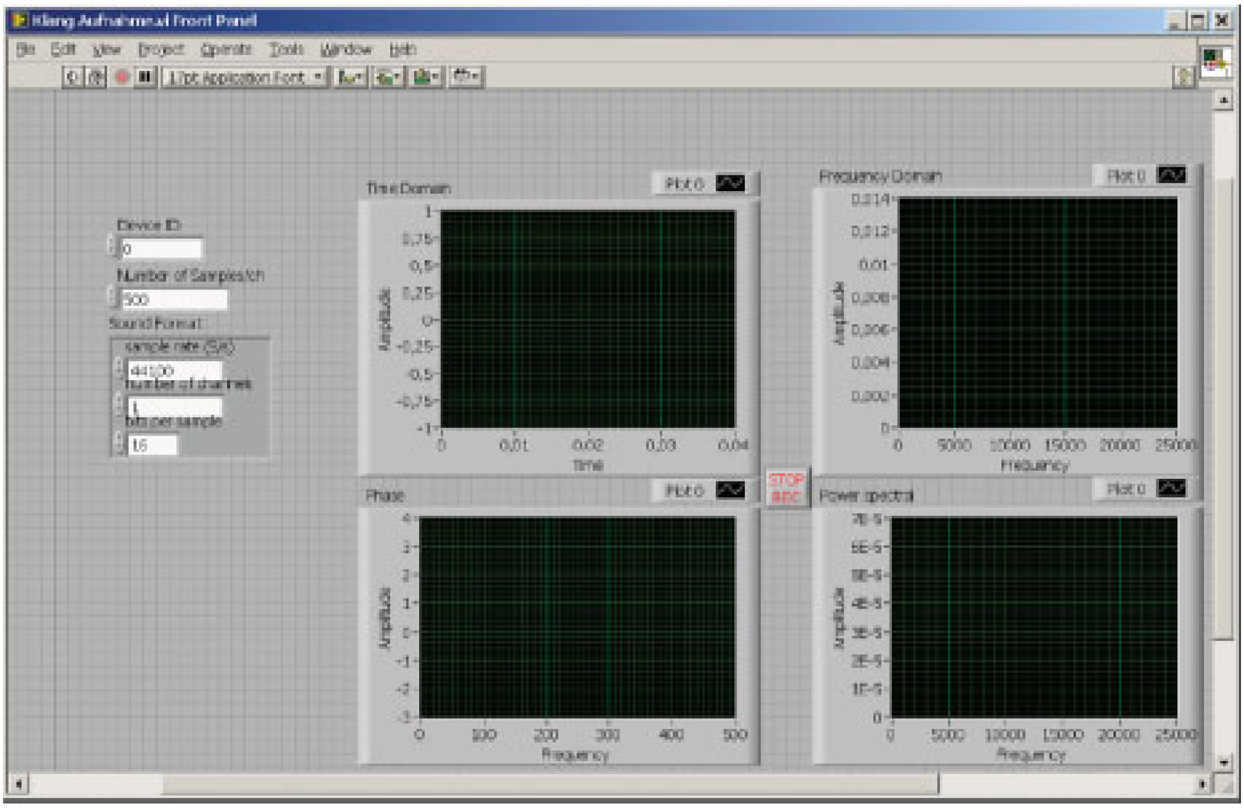

Figure 10 The front panel of signal acquirement program

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.

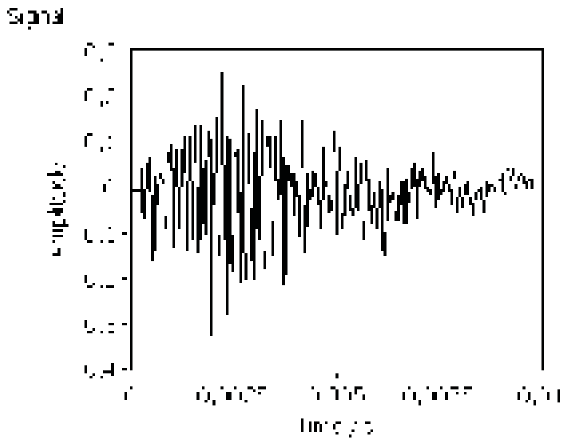

Figure 11 One example of impact acoustic signal from ABS plastic

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.

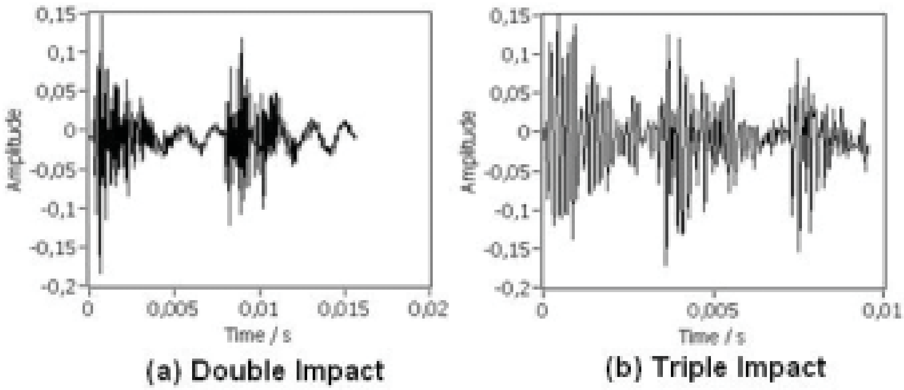

Figure 12 The abnormal Impacts generated by Particle Formats

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:

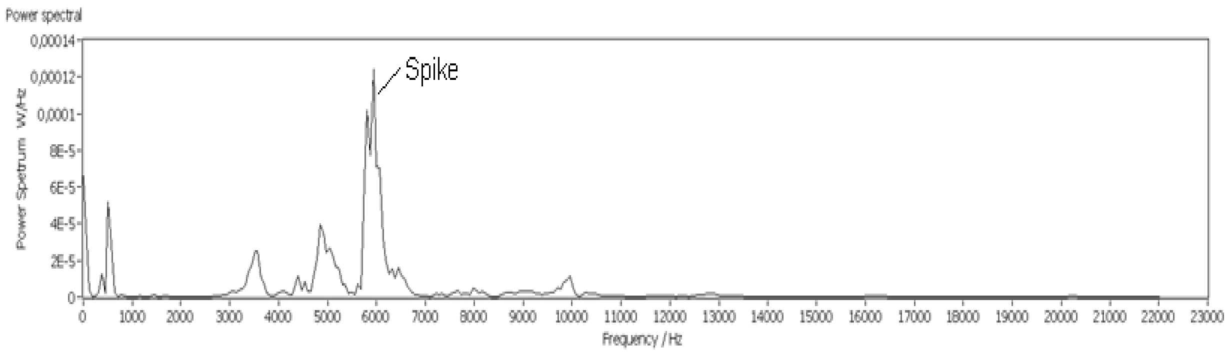

Figure 13 The influence of multi – impact on Power Spectrum

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.

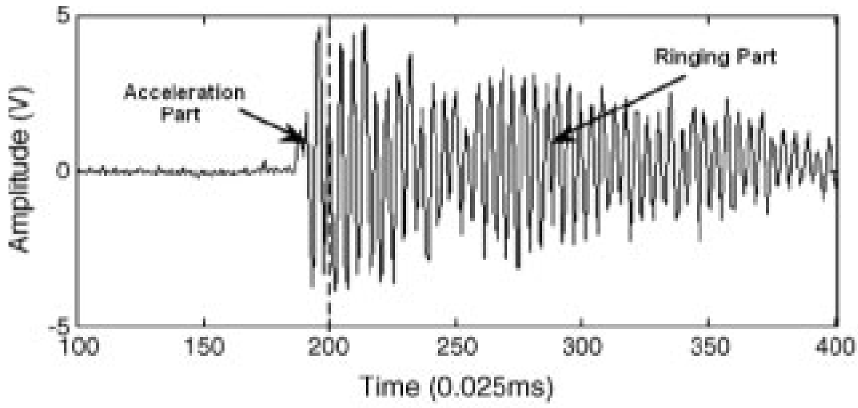

Figure 14 The acceleration and ringing parts of a sound signal

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:

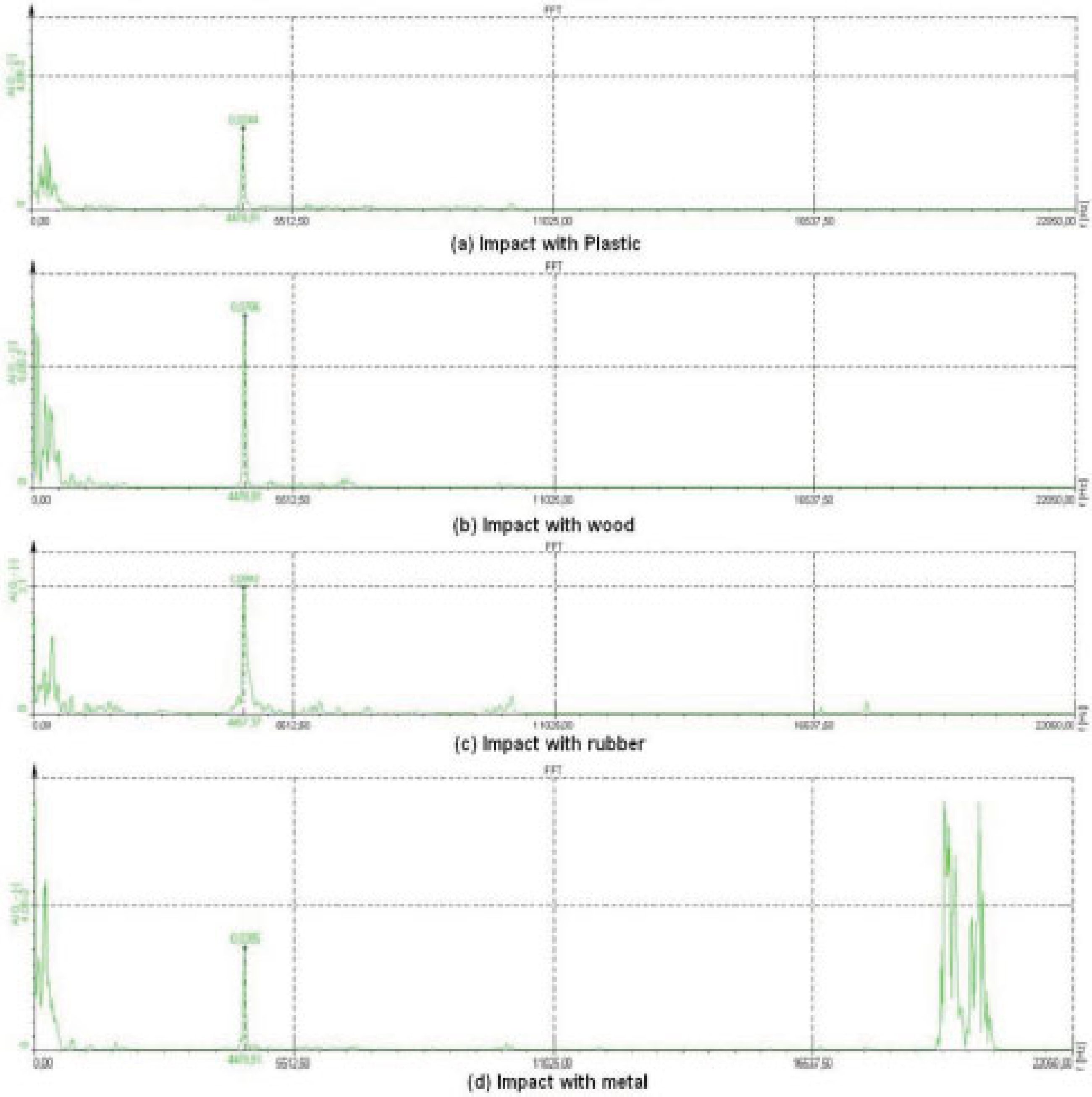

Figure 15 The FFT analysis of the eigen – frequencies of impact plate

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.

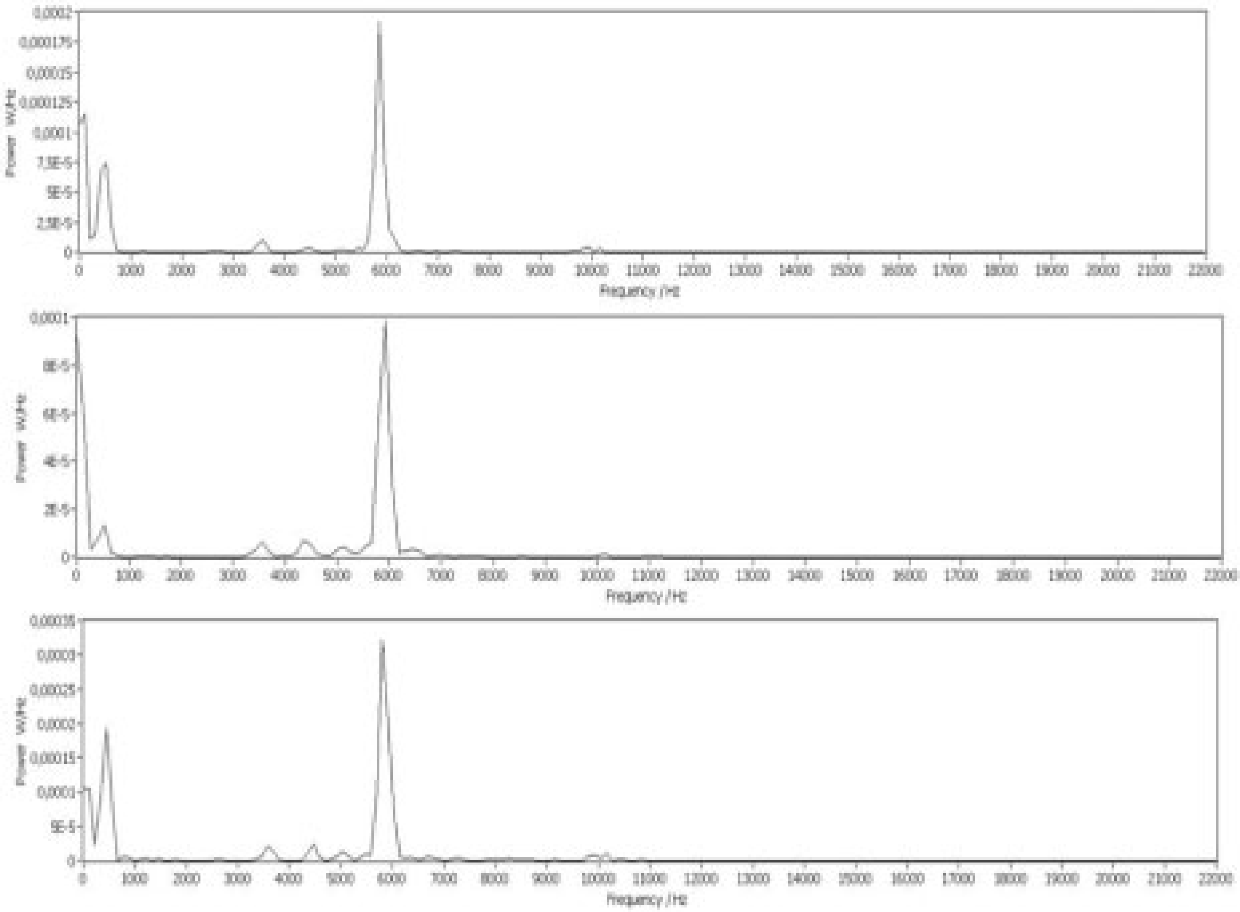

Figure 16 The power spectrum of Polypropylene (PP) pieces

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%.

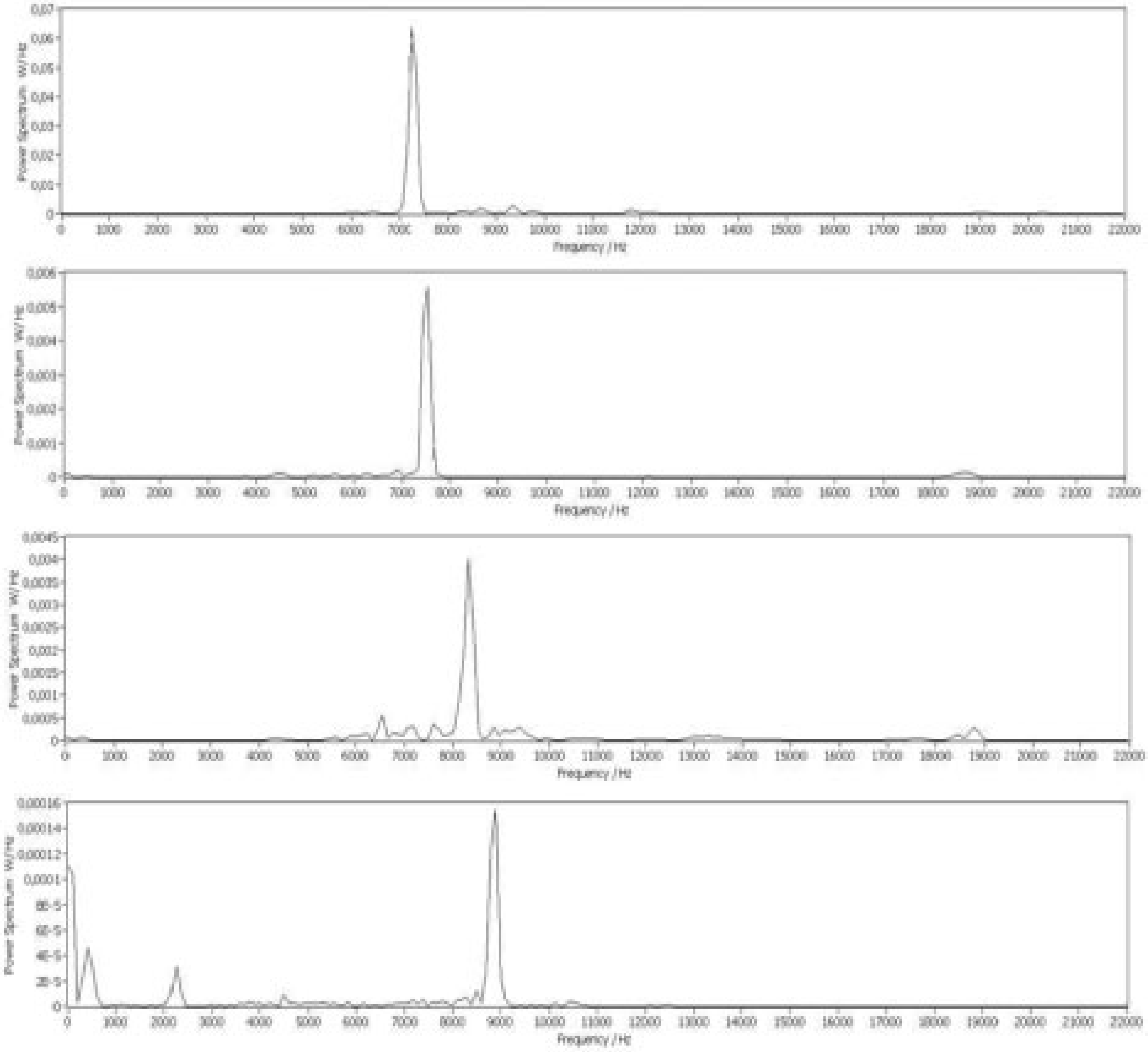

Figure 17 The power spectrum of Acrylonitrile butadiene styrene (ABS) pieces

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%

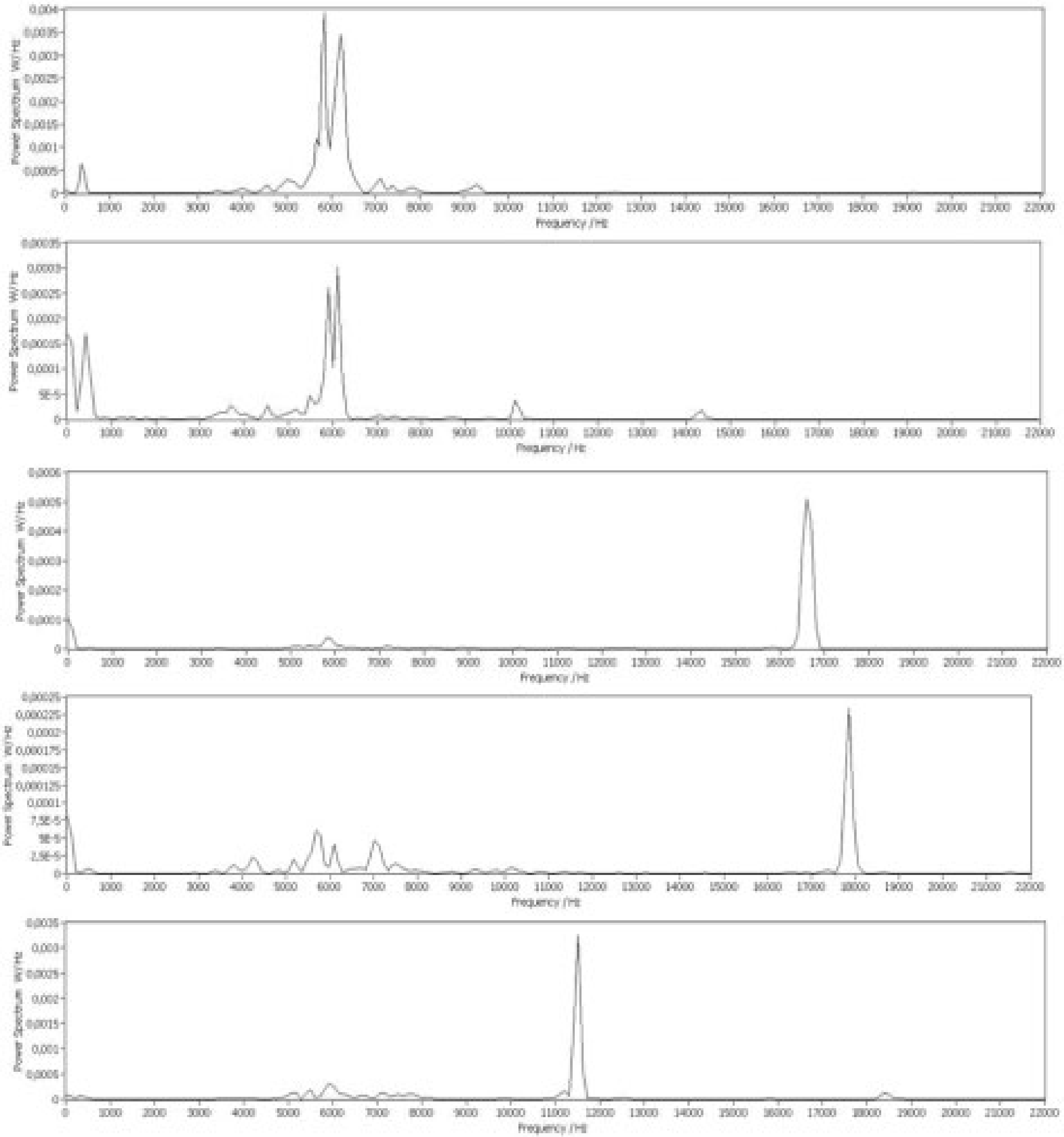

Figure 18 The power spectrum of Styrene maleic anhydride (SMA) pieces

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.

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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.

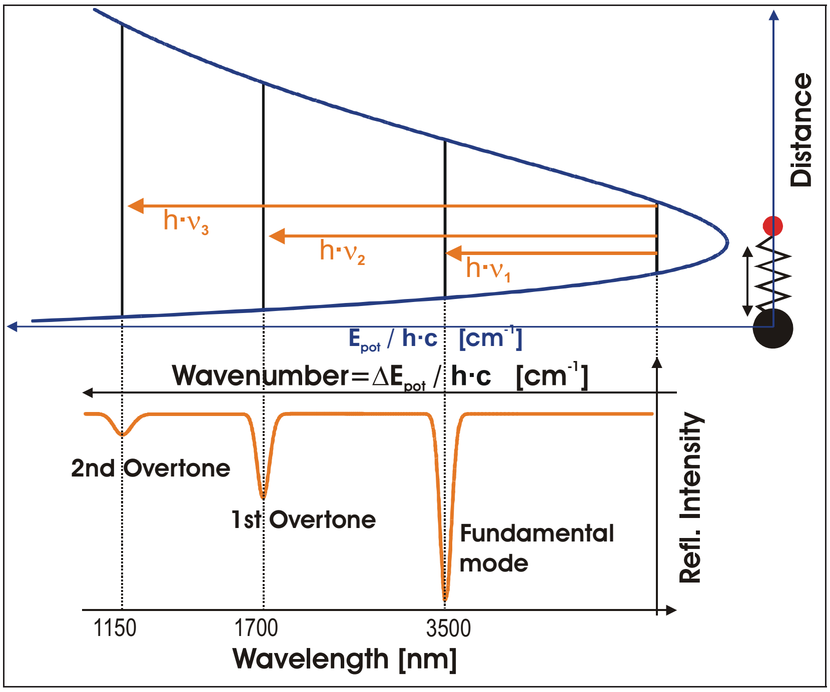

Figure 1: Schematic diagram of the vibrational modes and NIR absorption bands of a diatomic molecule.

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.

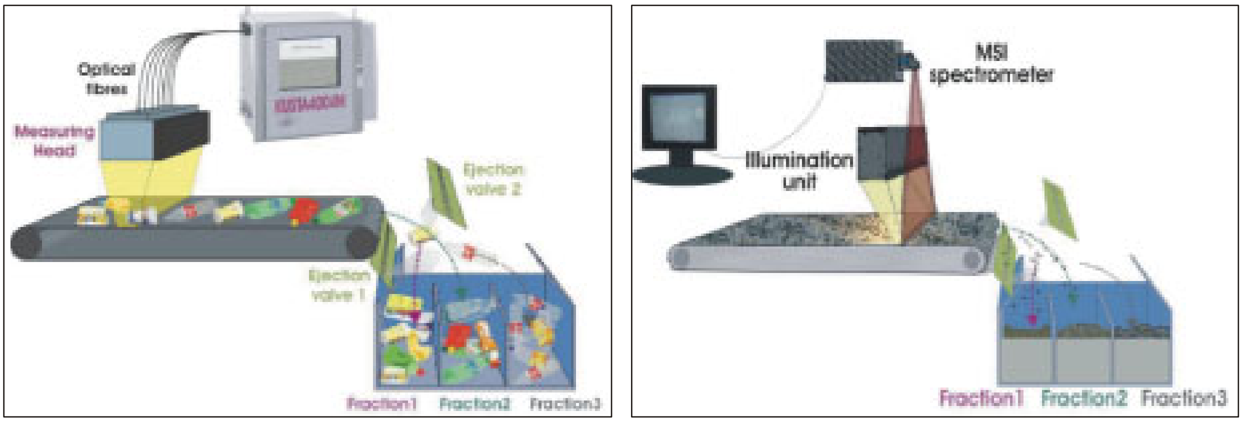

Figure 2: Schematic setup of the MPL system (left) and the MSI system (right).

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.

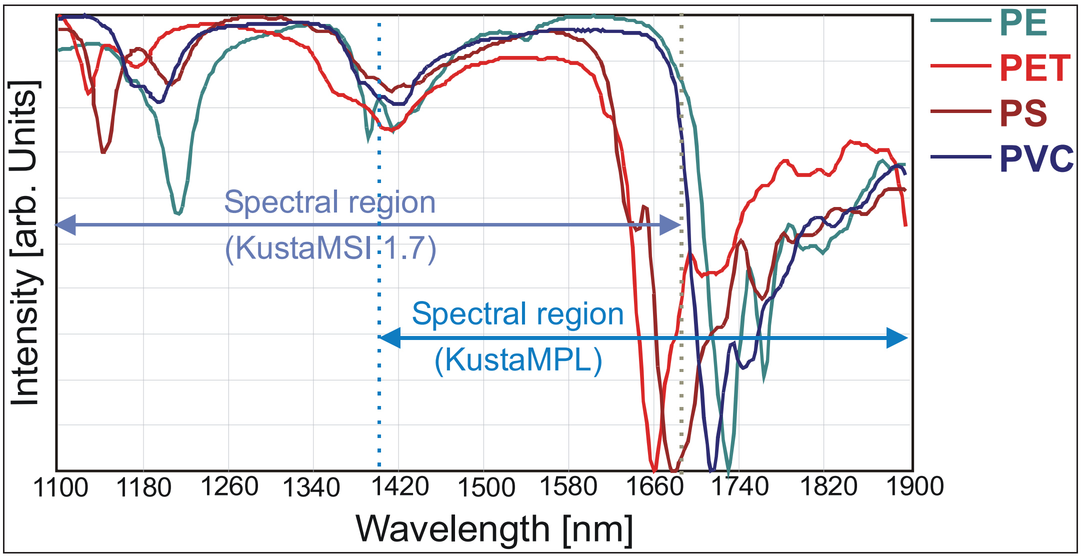

Figure 3: Spectral regions of KustaMSI and KustaMPL for spectra of common polymers.

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.

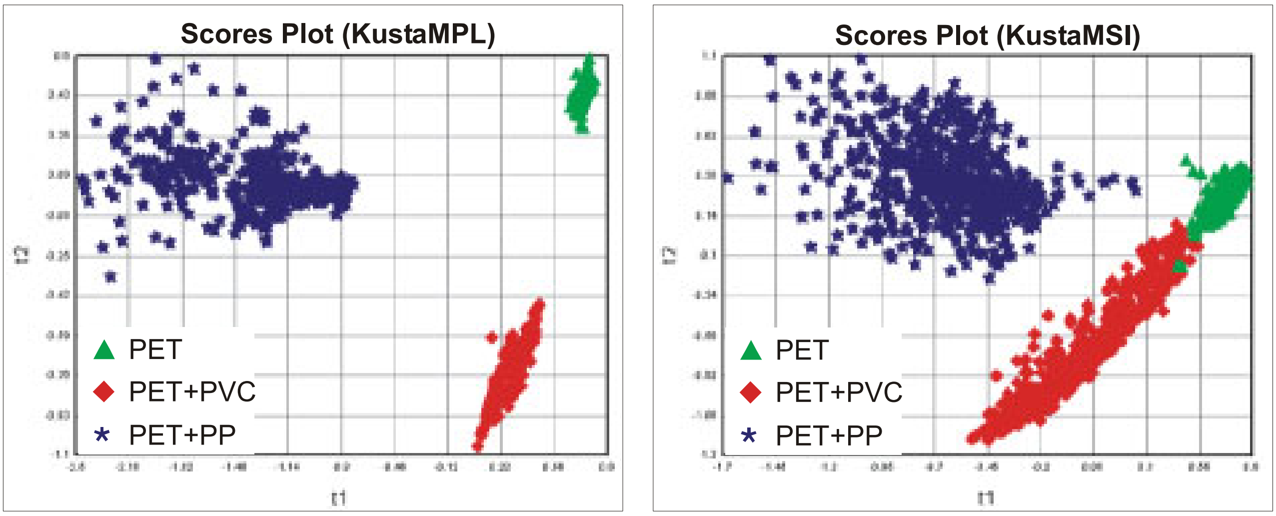

Figure 4: Scores plot of a PLS routine trained on PET bottles without label and with PVC- or PP-label for KustaMPL and KustaMSI.

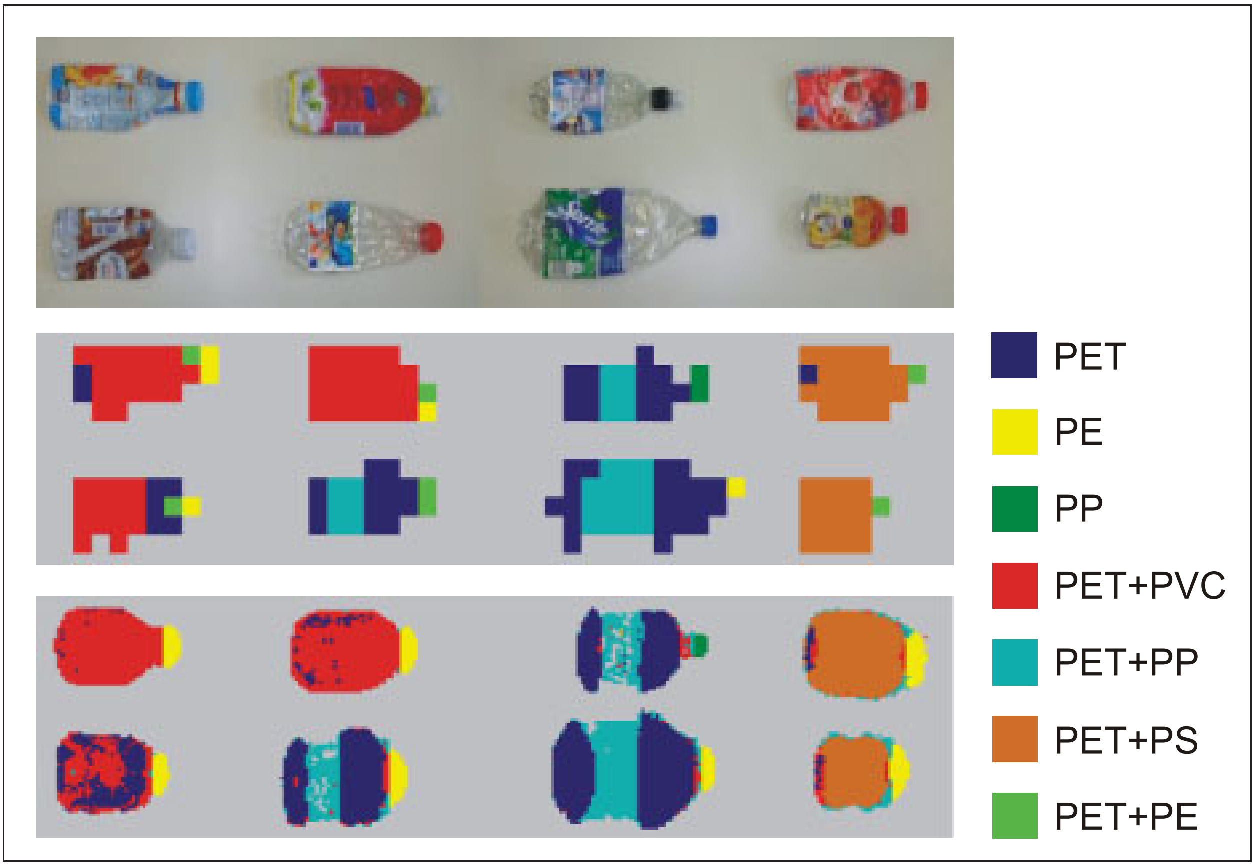

Figure 5: Process image (NIR identification) of PET bottles with different plastic labels and PE or PP-caps for KustaMPL (top) and KustaMSI (bottom). PVC- and PS-labels covered the complete bottle.

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.

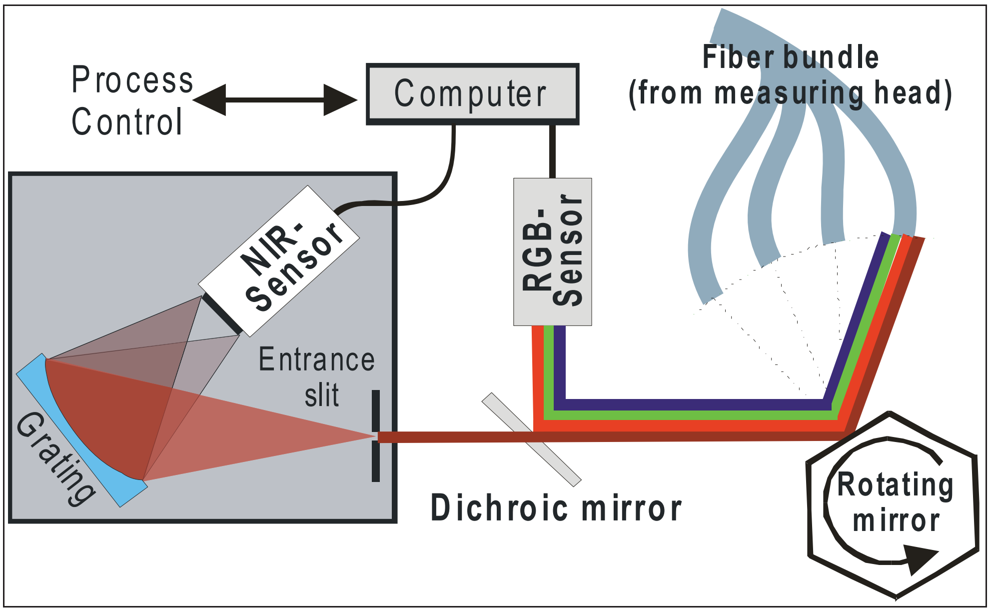

Figure 6: Schematic layout of the KustaMPL system with integrated RGB-sensor.

In contrast to other systems combining NIR- and RGB-sensors the present layout guarantees 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)

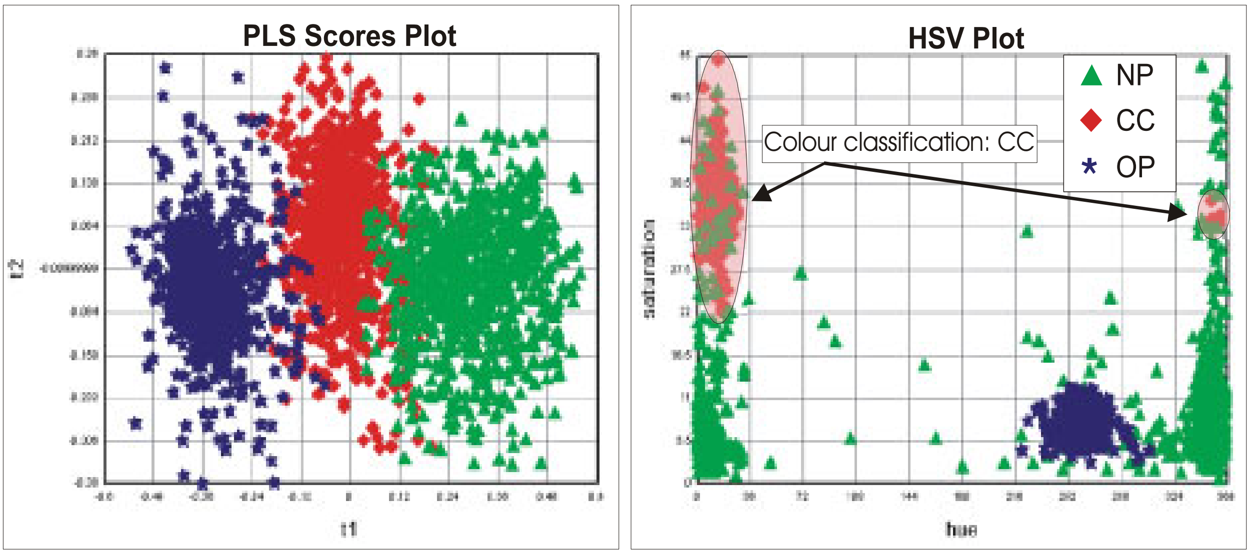

Figure 7: PLS scores plot and HSV plot for the separation of corrugated cardboard (CC), newspaper (NP) and office paper (OP).

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.

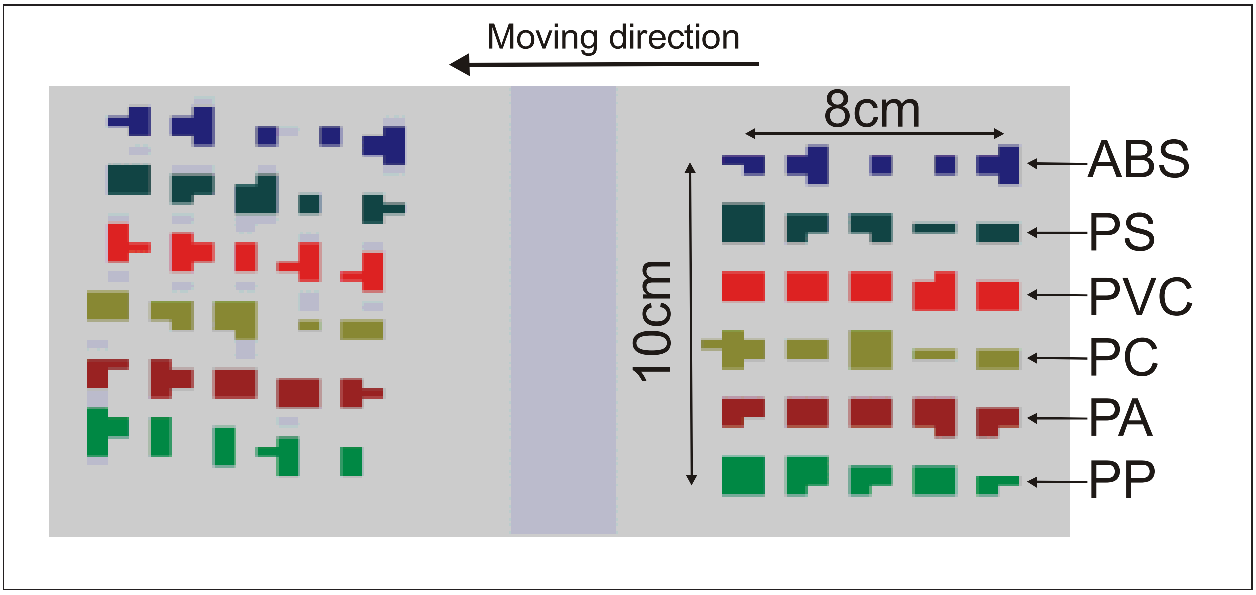

Figure 8: Shreddered plastic flakes (size 6-8mm) recorded with KustaMSI 1.7.

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.

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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 on-line 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.

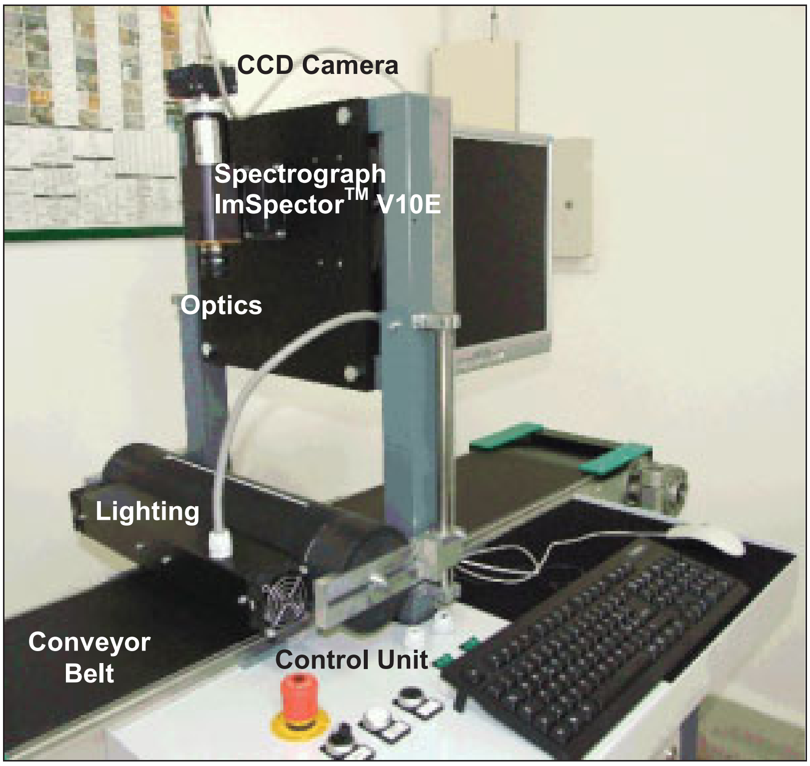


Figure 1 *Spectral scanner architecture utilised to acquire plastic waste particle spectra.*

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.*

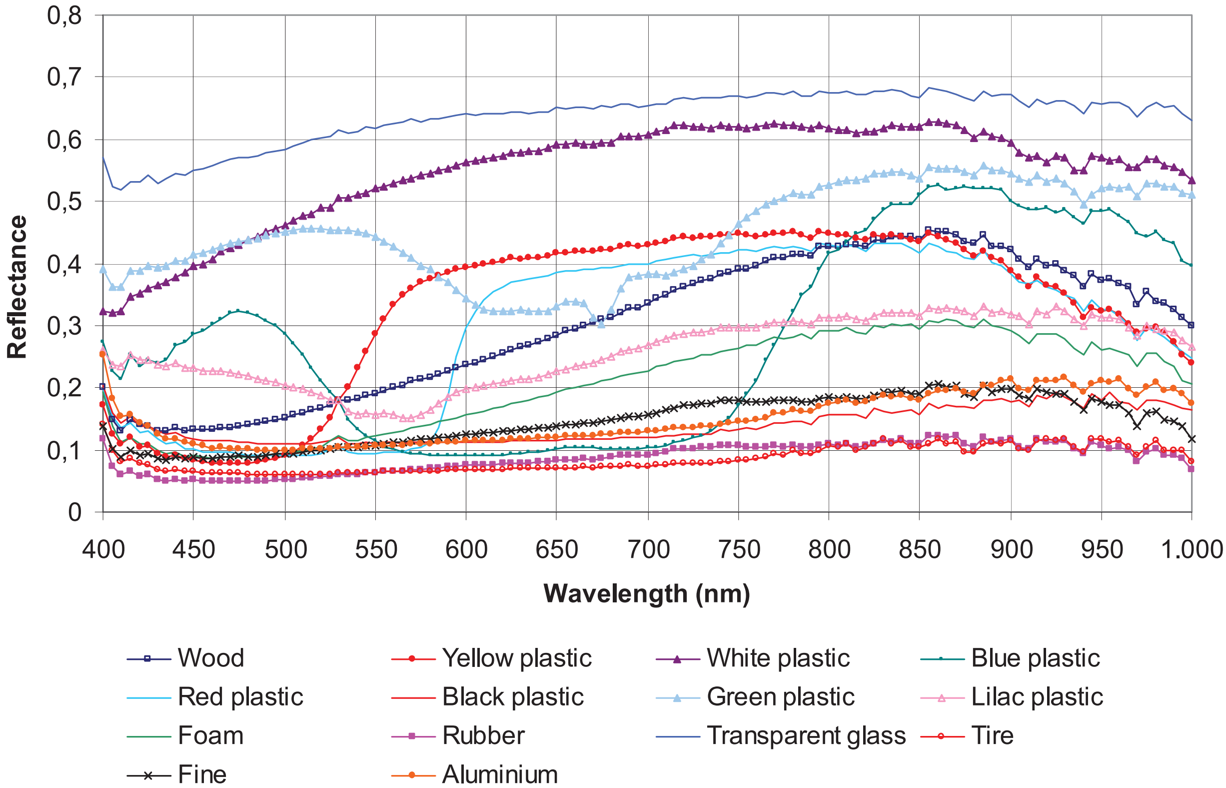
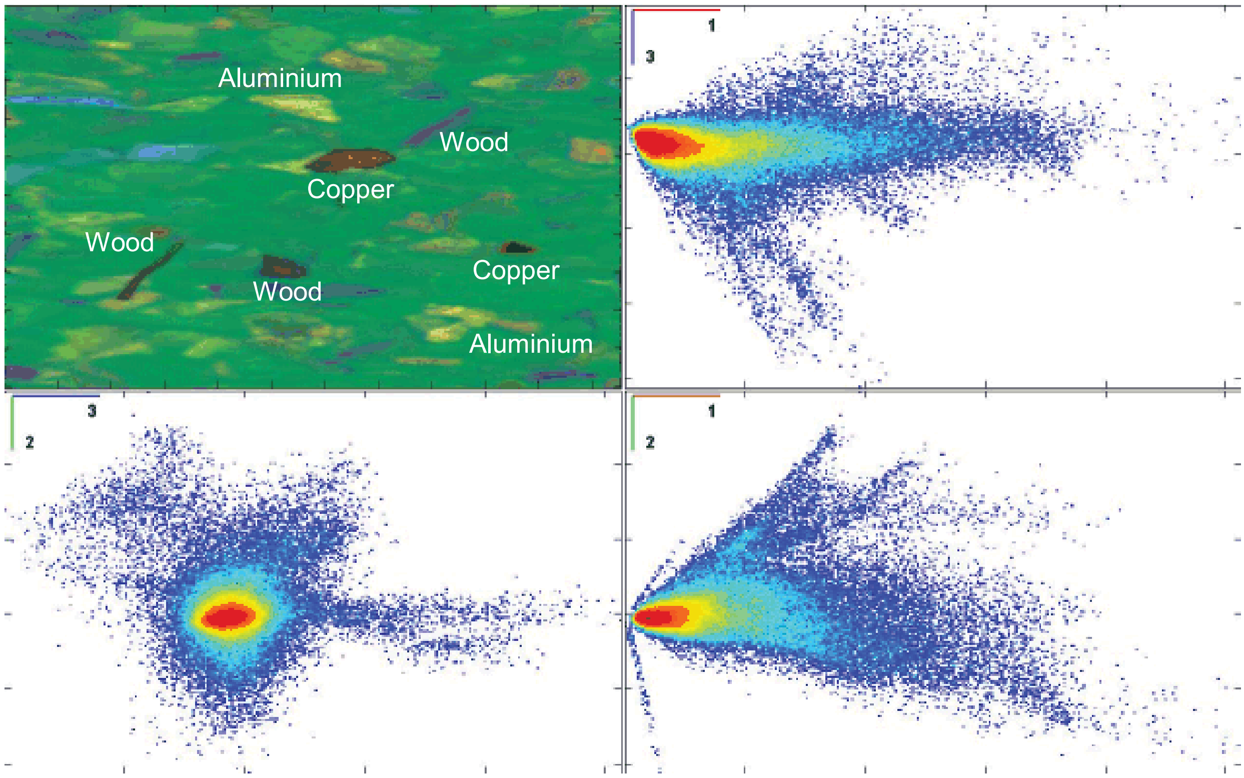


Figure 3 *Average reflectance spectra in the VIS-NIR field (400-1000 nm) of the different particulate solids present in the waste plastic feed, as resulting after car dismantling (shredding), detected by the hyperspectral imaging based architecture.*

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.

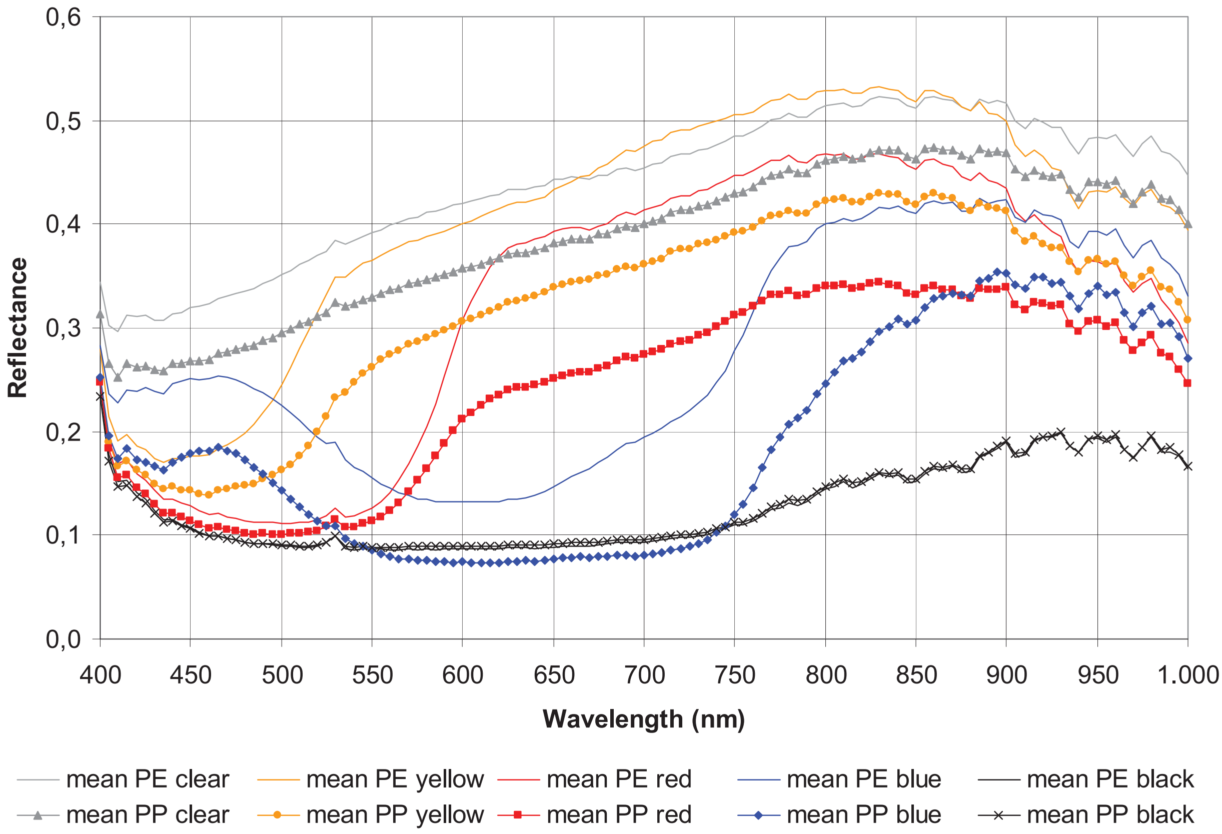


Figure 5 Average reflectance spectra of polyethylene (PE) and polypropylene (PP), collected in the VIS-NIR field by the hyperspectral imaging device.

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.

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Kontinuierliche Volumenstrommessung von Abfallstoffen

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Continuous measurement of waste material mass flow

Abstract

At the present time volume flow rates within waste treatment plants are determined solely discontinuous. 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.

Inhaltsangabe

Volumenströme in Abfallbehandlungsanlagen werden derzeit ausschließlich diskontinuierlich erfasst. Mit Hilfe eines berührungslosen, sensorgestützten Verfahrens kann das Volumen von Förderströmen kontinuierlich und in Echtzeit erfasst sowie eine Aussage zur Gutverteilung auf dem Förderband getroffen werden. Hieraus lassen sich Möglichkeiten zur Anlagenüberwachung und -steuerung entwickeln. Das Verfahren ist bei allen typischen Aggregaten von Abfallbehandlungsanlagen einsetzbar.

Keywords

Anlagensteuerung und –überwachung, Lasertriangulation, Sensorgestütztes Verfahren, controlling and monitoring of aggregates, laser triangulation, sensor based technology

1 Einleitung

In Entsorgungsanlagen werden Volumenströme von Abfallstoffen üblicherweise über den Massendurchsatz während eines festgelegten Zeitraumes und die Multiplikation mit der mittleren Schüttdichte ermittelt. Dabei werden Änderungen der Abfallzusammensetzung und kurzfristige Schwankungen in der Förderbandbeschickung nicht erfasst. Sowohl Überfrachtungen als auch Leerläufe der Förderbänder werden im Gesamtergebnis mit eingerechnet. Darüber hinaus sind keine Angaben zur Beladung der Förderbänder über den Querschnitt möglich.

Die genaue Kenntnis des zeitabhängigen Beladungszustandes von Förderbändern bietet die Möglichkeit einer zügigen und auf die aktuellen Bedürfnisse angepassten Optimierung von Verfahrensabläufen. Somit kann das Wertstoffausbringen erhöht und die Qualität der Aufbereitungsprodukte auf ein gleichmäßig hohes Niveau angehoben werden.

Ein Verfahren zur detaillierteren, zeitabhängigen und kostengünstigen Erfassung von Volumenströmen auf Förderbändern wird zurzeit am I.A.R. entwickelt. Mit diesem Verfahren werden Volumenströme kontinuierlich erfasst, gleichzeitig wird eine Auskunft über die aktuelle Gutverteilung auf dem Transportband gegeben. Die erhobenen Daten können über Zeiträume von mehreren Monaten statistisch erfasst und ausgewertet werden oder zur direkten Steuerung von Aggregaten genutzt werden. Im Folgenden werden der technische Hintergrund, die Art der erfassten Daten und die Möglichkeiten der Datennutzung dargestellt. Des Weiteren werden Einsatzmöglichkeiten für die Volumenstrommessung vorgestellt und ein Ausblick auf die zukünftige Entwicklung gegeben.

2 Technik

2.1 Lasertriangulation

Bei der kontinuierlichen Volumenstrommessung werden höhenbezogene Daten mit einer 3D-Kamera sensorisch erfasst. Die dabei betrachteten Oberflächen müssen Licht diffus reflektieren. Blanke, spiegelnde oder transparente Oberflächen sind zu vermeiden. Die zu Grunde liegende Technik basiert auf dem Prinzip der Laser-Lichtschnitt-Triangulation. Der schematische Aufbau ist Abbildung 1 zu entnehmen.

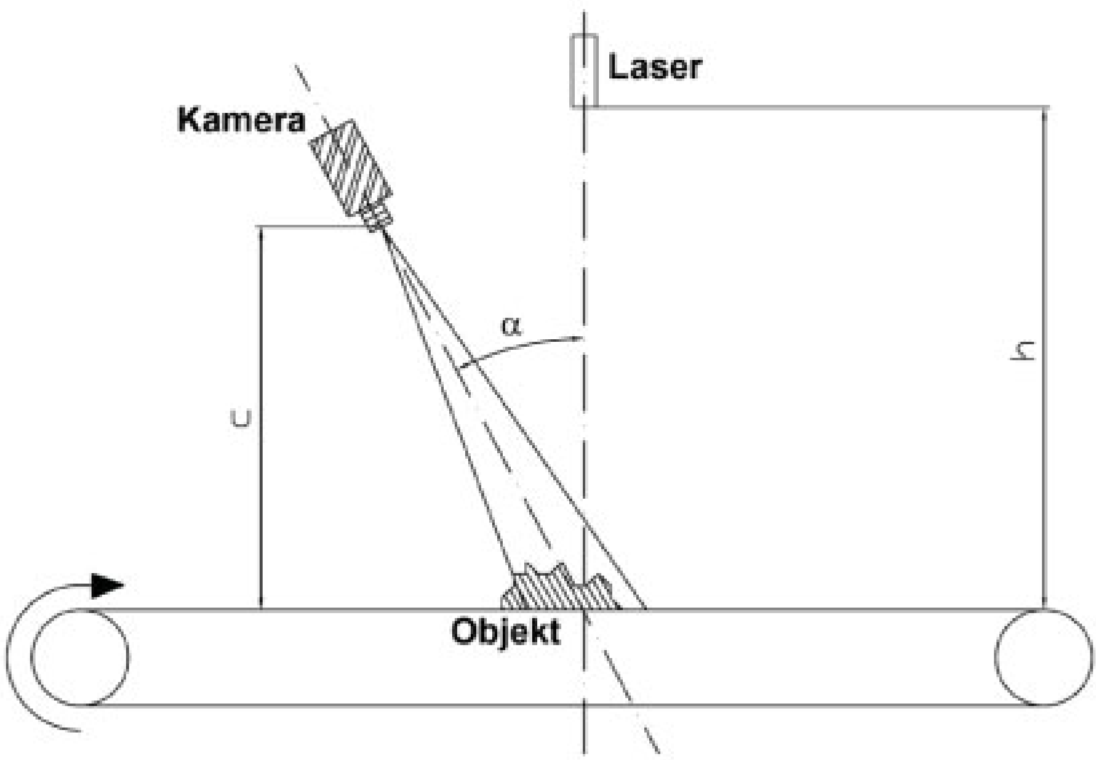

Abbildung 1 Messaufbau für die Volumenstrommessung auf Basis der Lasertriangulation

Bei der Lasertriangulation projiziert ein Linienlaser eine „Höhenlinie“ auf das zu messende Fördergut. Das Licht der Linie wird an den Materialoberflächen reflektiert und von einer Kamera kontinuierlich aufgezeichnet. Der Winkel, unter dem das Licht auf die Sensoren der Kamera fällt, dient unter Verwendung einer trigonometrischen Funktion der Bestimmung von Objektabständen bzw. der Höhenermittlung von Objekten.

Aus mehreren hundert Einzelbildern, die von der 3D-Kamera pro Sekunde aufgenommen werden, erzeugt eine Auswertesoftware ein lückenloses „Höhenbild“. Aufgrund der trigonometrischen Beziehungen kann dieses zur Ermittlung des Volumens herangezogen werden. Darüber hinaus ist eine Aussage zur Verteilung der Abfälle auf dem Förderband möglich.

2.2 Messaufbau

2.2.1 Laser

Zur Erzeugung der Höhenlinie wird ein Linienlaser senkrecht zum Förderstrom ausgerichtet. Der fokussierbare Bereich des Lasers reicht von der Bandoberfläche bis 40 cm oberhalb der Bandoberfläche. Die Kosten für Linienlaser mit der notwendigen Präzision liegen bei ca. 100 €.

2.2.2 Kamera

Die Position der Höhenlinie schwankt abhängig von der Höhe des aufgegebenen Fördergutes. Die exakte Erfassung der Höhenlinie erfordert daher die Betrachtung der gesamten Fläche oberhalb des Förderbandes. Diese Anforderung wird von einer marktüblichen Flächenkamera, die in einer Preisklasse von ca. 250 € bis ca. 1.000 € angeboten wird, erfüllt.

Die am I.A.R. eingesetzte Kamera besitzt einen VGA-CMOS-Sensor und weist eine Bildaufnahmerate von ca. 90 fps. auf. Bei einer Förderbandbreite von einem Meter und einer Fördergeschwindigkeit von 0,5 m/s liegt die erreichbare Auflösung bei ca. 8 mm^3 pro Voxel. Die Verbindung mit einem PC erfolgt über eine Gigabit Ethernet Schnittstelle.

2.2.3 Auswertesoftware

Die verwendete Auswertesoftware wurde in der Entwicklungsumgebung „LabVIEW“ von National Instruments (NI) erstellt und bietet die Möglichkeit „Messanwendungen mit Analysefunktionen“ Anwender- und Anwendungsorientiert zu erstellen. Am I.A.R. wurde ein Programm geschrieben, das die von der 3D-Kamera erfassten Höhenlinien zu einem kontinuierlichen Höhenbild zusammensetzt. Über weitere Algorithmen werden anschließend das Volumen und die Verteilung auf der Bandoberfläche ermittelt.

2.2.4 Eigenschaften des Messaufbaus

Der Messaufbau für die Volumenstrommessung ist berührungslos und kann in bestehenden Anlagenteilen nachgerüstet werden. Der grundlegende Aufbau ist in Abbildung 1 aufgeführt. Der Abstand des Lasers von der Bandoberfläche orientiert sich am Fokus und der Öffnungsweite der Laseroptik und beträgt mindestens die doppelte maximale Beladungshöhe. Die 3D-Kamera wird so ausgerichtet, dass sie zum Einen die gesamte Breite des Förderbandes und zum Anderen die Fläche zwischen dem Förderband und der maximalen Beladungshöhe erfasst.

2.3 Datenerfassung

Eine lückenlose Datenerfassung wird erreicht, wenn die Geschwindigkeit des Förderbandes mit der Aufnahmegeschwindigkeit (Bildrate) der eingesetzten Kamera abgestimmt wird. Diese ist abhängig von der Zeilenzeit, die sich aus Belichtungszeit, Verarbeitungszeit und Ruhezeit zusammensetzt.

Die Belichtungszeit wird vom Anwender eingestellt. Dabei werden die Helligkeit der Umgebung sowie die gewünschte Förderbandlänge pro Bild, über den das Volumen des Förderbandes betrachtet werden soll, berücksichtigt. Je länger die zu betrachtende Förderbandlänge sein kann, desto länger kann die Belichtungszeit gewählt werden.

Bei einer Aufnahmegeschwindigkeit von 90 Bildern in der Sekunde und einer Bandgeschwindigkeit von 0,5 m/s werden pro Bild Höheninformationen über ca. 6 mm Förderbandlänge aufgenommen. Das gewonnene Bild weist eine „verwischte“ Höhenlinie auf, die sich aus den einzelnen Oberflächenhöhen, die während dieses Zeitraumes erfasst wurden, zusammensetzt. Die Mittellinie dieser „verwischten Höhenlinie“ ist für die Volumenbestimmung ausreichend genau und kann für die Erstellung des Höhenbildes herangezogen werden.

Die Verarbeitungszeit, die für die Auswertung der Bildsignale benötigt wird, ist bei einer fest eingestellten Zeilenlänge konstant und beträgt wenige Millisekunden. Die Ruhezeit ist eine variable Größe und überbrückt die Wartezeit bis zur nächsten Belichtung.

Die optischen Oberflächeneigenschaften von Abfallströmen sind für die Sensorik der Volumenstrommessung überwiegend geeignet. Oberflächenmerkmale, die das Reflexionsverhalten des Laserlichtes verändern, wie z.B. spiegelnde, sehr dunkle oder durchsichtige Objekte, werden in der Regel durch die staubige Abfallumgebung mit einer messbaren Oberfläche benetzt.

3 Einsatzorte

3.1 Datennutzung

Die ermittelten Volumenstromdaten können, verbunden mit einem Warnsystem für das Personal, der Anlagenüberwachung dienen. Die Kenntnis des Volumenstroms dient der Vermeidung von Störungen und der Sicherstellung der Funktionsfähigkeit von Aggregaten. Darüber hinaus kann der Wirkungsgrad von Aggregaten durch Optimierung der zugeführten Menge auf ein gleichmäßig hohes Niveau stabilisiert werden.

Eine weitere Anwendungsmöglichkeit bietet der zeitgleiche Einsatz eines Systems zur Volumenstrommessung im Zu- und Ablauf von Aggregaten. Aus diesen Daten kann zum Einen der aktuelle Füllgrad der untersuchten Aggregate, zum Anderen das aktuelle Ausbringen ermittelt werden. Eine Übersicht der Verwendungsmöglichkeiten wird in Tabelle 1 gegeben.

Tabelle 1 Verwendungsmöglichkeiten der Volumenstromdaten

Aggregat	Verwendungsmöglichkeit der Volumenstromdaten
Klassierer	Abschätzung von Füllgraden; Vermeidung von Überfrachtungen, Verstopfungen und Leerlaufzeiten
Sortierer	Überwachung der zugeführten Schichtdicke; Sicherstellung einer gleichmäßigen Beladung von Aggregaten
Zerkleinerer	Vermeidung von Überfrachtungen und Leerläufen

3.2 Klassierer

Der Einsatz einer kontinuierlichen Volumenstrommessung im Zulauf von Klassierern kann unterschiedliche Ziele verfolgen. Bei Trommelsieben dient die Kenntnis über das zugeführte Volumen z.B. der Abschätzung des aktuellen Füllgrades sowie der Vermeidung von Verstopfungen während bei Decksieben oder Sizern insbesondere Überfrachtungen und Leerlaufzeiten vermieden werden sollen.

3.3 Sortierer

Bei Sortierern ist insbesondere eine gleichmäßige Förderbandbeschickung für eine effektive Sortierung erforderlich. Hier kann die kontinuierliche Volumenstrommessung für die Überwachung der Schichtdicke als auch der Verteilung des Gutstromes auf dem Förderbandquerschnitt eingesetzt werden. Weitere Beispiele können der nachfolgenden Tabelle 2 entnommen werden.

Tabelle 2 Übersicht der Einsatzmöglichkeiten einer Volumenstrommessung bei Sortierern

Sortierer	Einsatzmöglichkeiten der Volumenstrommessung
Magnetscheider	Überwachung der Schichtdicke; Überwachung der Fördergutverteilung
Sensorgestützte Sortierung	Sicherstellung eine Monoschicht; Überwachung der Fördergutverteilung
Windsichter	Überwachung der Beladung in der Zuführung des Sichtraumes
Wirbelstromscheider	Sicherstellung einer Monoschicht; Überwachung der Fördergutverteilung

3.4 Zerkleinerer

Neben einem Einsatz der Volumenstrommessung bei Klassierern und Sortierern bietet auch der Einsatz bei Zerkleinerungsaggregaten Vorteile. Durch Überwachung der zuführenden Bänder kann sowohl eine Überladung als auch eine Minderbeladung von Zerkleinerern vermieden werden. Somit wird sicher gestellt, dass die Zerkleinerer mit der optimalen Menge an Zerkleinerungsgut (pro Zeiteinheit) beladen werden.

4 Ausblick

Für die Abschätzung von Volumenströmen werden derzeit im Wesentlichen zwei Methoden angewendet. Zum Einen wird über den Anlagendurchsatz pro Zeit das Gesamtvolumen ermittelt. Zum Anderen besteht die Möglichkeit die durchgesetzte Masse z.B. mit Bandwaagen zu bestimmen und das Volumen über die mittlere Schüttdichte und den betrachteten Zeitraum zu ermitteln. Beide Methoden sind nicht geeignet, Volumenströme in Echtzeit zu bewerten und eignen sich daher nur bedingt zur Anlagensteuerung.

Dagegen bietet die kontinuierliche Volumenstrommessung zukünftig die Möglichkeit durch einen direkten Datentransfer zwischen der Messeinrichtung und den einzelnen Aggregaten die Anlagensteuerung zu unterstützen. Bei ungleichmäßigen Volumenströmen können Gegenmaßnahmen z.B. durch die Änderungen in der Gutaufgabe eingeleitet werden. Weitere Vorteile einer Steuerung über die Volumenstrommessung ergeben sich insbesondere bei der Vereinzelung von Materialströmen für sensorgestützte Sortiermaschinen.

5 Zusammenfassung

Die kontinuierliche Volumenstrommessung basiert auf dem Prinzip der Lasertriangulation und zählt zu den sensorgestützten Verfahren. Die Messeinrichtung setzt sich aus

Standardkomponenten zusammen und besteht aus einem Linienlaser, einer Flächenkamera mit einer Bildaufnahmerate von ca. 90 fps sowie einer Auswertesoftware, die individuell auf die Bedürfnisse des Anwenders eingestellt werden kann. Der Messaufbau ist berührungslos und kann in bestehenden Anlagenteilen nachgerüstet werden. Die Kosten für den gesamten Messaufbau liegen bei ca. 1.000 €.

Für die Volumenstrombestimmung werden mehrere Hundert Höheninformationen pro Sekunde in Form von „Höhenlinien" erfasst und durch eine Auswertesoftware zu einem Höhenbild zusammen gefügt. Dieses gibt Auskunft über den Volumenstrom und die Verteilung des Fördergutes auf dem Transportband. Selbst problematische Oberflächen werden aufgrund der staubigen Abfallumgebung erfasst. Die Auflösung pro Voxel liegt im Kubikmillimeterbereich.

Informationen zum Volumenstrom können sowohl im Zu- als auch im Ablauf aller typischen Aggregate in Abfallbehandlungsanlagen gewonnen werden. Die Verwendungsmöglichkeiten der Daten sind vielfältig und liegen im Wesentlichen bei der Anlagenüberwachung und -steuerung. Hierzu zählen u.a. die Abschätzung von Füllgraden, die Vermeidung von Überfrachtungen und die Überwachung von Schichtdicken. Informationen über Volumenströme können zukünftig für die Anlagensteuerung herangezogen werden.

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Modellierung von abfallwirtschaftlichen Prozessen zur Steigerung der Ressourceneffizienz – Perspektiven und zukünftige Anforderungen

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Abstract

Seit dem Verbot der Ablagerung unvorbehandelter Abfälle (TASI) im Juni 2005 nimmt in der Abfall- und Kreislaufwirtschaft die Komplexität der Verwertungs- und Beseitigungsstrukturen durch die Vielzahl von zu lenkenden Abfallströmen zu. Damit gewinnen die Themen Material- und Energieeffizienz zunehmend an Bedeutung. Ein Ansatz, um diese komplexen Vorgänge analysieren und optimieren zu können, bietet ein aktuelles Projekt an der Hochschule Bremen mit weiteren Partnern aus der Industrie. Hier wird als Basis für die Entwicklung von Softwareanwendungen ein Stoffstrommodell für die Kreislauf- und Abfallwirtschaft entwickelt, welches das abfallwirtschaftliche Stoffstrommanagement unterstützen soll und so eine wesentliche Grundlage für Ressourcen- und Kosteneffizienz in dieser Branche legt.

Keywords

Modellierung, abfallwirtschaftliche Prozesse, Ressourceneffizienz, Energieeffizienz, Materialeffizienz, Abfall, Anlagen, Stoffstromanalyse.

1 Handlungsbedarf

Vor dem Hintergrund komplexer Verwertungs- und Beseitigungsstrukturen in der Abfall- und Kreislaufwirtschaft mit einer Vielzahl von zu lenkenden Abfallströmen, die sich seit Juni 2005 (Verbot der Ablagerung unvorbehandelter Abfälle; TASI) entwickeln, gewinnt die Effizienzbewertung der verschiedenen Stoffströme zunehmend an Bedeutung. Abfälle müssen seitdem in mechanisch-biologischen oder thermischen Abfallbehandlungsanlagen vorbehandelt werden. Material-, Energie- und Kosteneffizienz in der Kreislaufwirtschaft sind daher wichtige Herausforderungen der nächsten Jahre. Für Unternehmen der Kreislaufwirtschaft ergibt sich mit dem Betrieb von verschiedenen Ver- und Entsorgungsanlagen die Notwendigkeit, unterschiedliche Stoffströme innerhalb oder zwischen den Anlagen zu managen. Hierbei bestehen deutliche Optimierungspotenziale in vielen Bereichen, insbesondere für die material- und energieeffiziente Nutzung der zur Verfügung stehenden Ressourcen (Abfallströme). Allerdings sind bisher für die Steuerung der Verwertungs- und Beseitigungs-Strukturnetzen (Entsorgungsnetze) nur Teillösungen vorhanden. So existieren verschiedene Modelle, die ihrerseits aber für eine ganzheitliche Betrachtung nicht ausreichende oder für die verschiedenen Prozesse nicht relevante Parameter beinhalten, z.B. EASEWASTE (vgl. KIKEBY ET AL., 2006). Die Komplexität eines entsprechenden geschlossenen, ganzheitlichen Lösungssystems wird zudem durch eine Reihe von Einflussfaktoren im abfallwirtschaftlichen System verstärkt. Hierbei sind insbesondere ökonomische, rechtliche und standortspezifische Faktoren zu nennen, wie sie nachfolgend in der Abbildung 1 dargestellt sind.

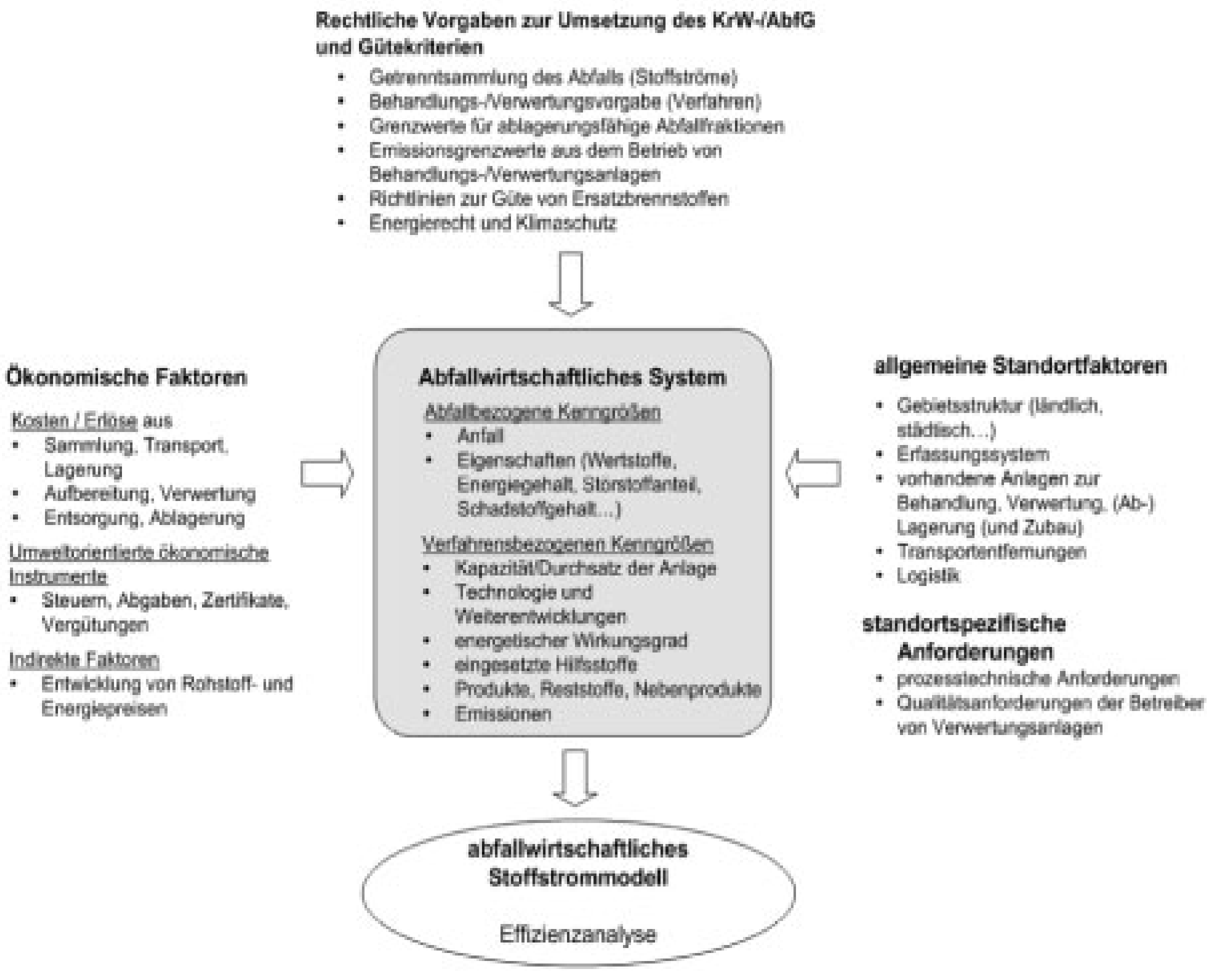

Abbildung 1: Rahmenbedingungen und Einflussfaktoren in der Kreislaufwirtschaft

Die Tatsache, dass ganzheitliche Lösungssysteme fehlen, ist auch dadurch begründet, dass sich seit der Umsetzung der TASi ein System einer stoffstromspezifischen Abfallwirtschaft entwickelt. Hieraus ergeben sich neue Anforderungen: So wird beispielsweise der Verwertungsweg des Abfalls wesentlich von seiner Art, Herkunft und Zusammensetzung beeinflusst. In vorhandenen Modellen wird aber die Zusammensetzung des Abfalls bzw. die Zuordnung von fraktionsspezifischen Kenngrößen zu einem Abfallstrom nur unzureichend berücksichtigt. Für abfallwirtschaftliche Unternehmen ist es jedoch von Interesse, Faktoren mit Einfluss auf die Stoffstromführung, wie Grenzwerte, Qualitätsanforderungen oder Aufschläge im Annahmepreis in Abhängigkeit von der Abfallqualität in ihre Bewertung einzubeziehen.

Ein weiteres Hindernis stellen die großen Datenmengen dar, welche aufgrund fehlender Auswertungstools zur Stoffstrommodellierung im „täglichen“ Geschäft kaum berücksichtigt werden. Für die Optimierung der Anlagen besteht allerdings die deutlich erkennbare Notwendigkeit zur Nutzung dieser Daten. Sowohl in der mittelfristigen Planung als auch in der täglichen Disposition der Abläufe zur Maximierung von Material- und Energieeffizienz sowie Minimierung der Kosten (z.B. Entsorgungsdienstleistungen). In Kooperation mit lokalen Partnern aus der (Software- und Abfall-)Wirtschaft soll hier Abhilfe geschaffen werden.

2 Projektbeschreibung

2.1 Ziele

Ein Ansatz, um die offenen Probleme zu lösen, Verknüpfungen zu schließen und die Effizienz zu steigern bietet ein aktuelles Projekt an der Hochschule Bremen, welches in Kooperation mit dem IKrW, Ecologix und weiteren Partnern aus der Industrie ein Stoffstrommodell für die Kreislauf- und Abfallwirtschaft entwickelt. Der Ansatz orientiert sich dabei an den verfahrenstechnischen Abläufen und einer darauf bezogenen Charakterisierung des Abfalls. In der Projektdurchführung besteht eine Kooperation mit namhaften Partner aus der Branche im Bremer Raum (Nehlsen, swb AG), die ihrerseits dazu beitragen, dass die einzelnen Bausteine für die Modellierung eines ganzheitlichen Lösungssystems den Bedarfen der Player entsprechend angepasst und in das Modell integriert werden. Hierzu zählen beispielsweise Features wie die Berechnung von Regenerativem CO2, eine Stoff- oder Ökobilanz oder die technische Simulation von geplanten Anlagen. Für die monetäre Seite und den täglichen Betrieb von Bedeutung ist die Frage nach sich ändernden Input-Stoffparametern und entsprechend das resultierende Ergebnis im Output (erhöhte Emissionen, Abfälle zur Beseitigung, usw.).

Dieses Projekt, gefördert vom Europäischen Fond für regionale Entwicklung und dem Förderprogramm ‚Angewandte Umweltforschung’ des Landes Bremen, versucht die Stoffströme der Kreislauf- und Abfallwirtschaft und die zugehörigen Verfahren und Prozesse zu erfassen, durch geeignete Parameter zu beschreiben und in einem Stoffstrommodell darzustellen. Damit sollen Optimierungspotenziale für die Steigerung von Energie-, Material- und Kosteneffizienz aufgezeigt werden. Im Ergebnis steht ein Stoffstrommodell zur Aufnahme, Darstellung, Bewertung und Optimierung von Abfallströmen und Strategien im abfallwirtschaftlichen System zur Verfügung.

Die angestrebten Ziele des Projekts im Einzelnen sind eine einheitliche Abfallcharakterisierung für verschiedenste Abfälle nach Nutz- und Schadkategorien und die Erfassung der Stoffströme der Kreislauf- und Abfallwirtschaft und damit Unterstützung zur Optimierung von Betriebsabläufen und Verfahren (MBA, thermische Anlagen, Verbundsimulation - Abbildung von Recyclingparks) in Betrieben und Regionen. Auch die Aufdeckung und Darstellung der Potenziale für die optimierte Nutzung der im Abfall enthaltenen Energie- und Materialressourcen durch energetische Verwertung in effizienten Prozessen und die Herstellung von Sekundärrohstoffen werden integriert. Darüber hinaus liefert das Modell für die Beurteilung der Umweltrelevanz einen Überblick über die Schadstoffverteilung im abfallwirtschaftlichen System und bewertet die ökonomische (z.B. Material- und Betriebskosten) und ökologische (z.B. Emissionen) Situation.

Das Projekt ist bestrebt die Basis für die Entwicklung von Softwareanwendungen zu bilden, die das abfallwirtschaftliche Stoffstrommanagement unterstützen soll und eine wesentliche Grundlage im Sinne der Nachhaltigkeit in der Kreislauf-, Abfall- und Energiewirtschaft legt. Die Ergebnisse der Modellierung und die Entwicklung eines Stoffstrommanagementsystems haben außerdem weit reichende Auswirkungen auf die gesamte Wertschöpfungskette. So können, neben Material- und Energieeffizienz, technische Innovationen in der Automatisierungstechnik und ein effizienter Transport in der Logistikbranche (abfallwirtschaftliche Logistikprozesse) aus diesem Projekt heraus angestoßen werden und damit ebenfalls zu einer umweltverträglichen wirtschaftlichen Entwicklung von Regionen beitragen.

2.2 Entwicklung einer Abfallcharakteristik

Allerdings fehlt für die Modellierung eine wichtige Grundlage: eine eindeutig prozessbezogene, einfach nutzbare und mit Stoffdaten unterlegte Abfallbeschreibung. Für produktionsspezifische Abfälle, Gewerbeabfälle und aufbereitete Fraktionen von Siedlungsabfällen liegt eine solche Beschreibung nicht vor. Lediglich eine umfangreiche Datengrundlage für Haushaltsabfälle existiert.

Aufgrund verschiedener Ansätze bei der Erhebung sind bisherige Daten nur bedingt vergleichbar bzw. übertragbar. Eine solche Abfallcharakterisierung ist allerdings vor dem Hintergrund der Beurteilung der Stoffverteilung und für Aussagen über An- bzw. Abreicherung bestimmter (Schad-) Stoffe im eingesetzten Abfallgemisch von groer Bedeutung und eine wesentliche Aufgabe der Modellierung. Hierzu bedarf es einer Vereinheitlichung der Ansätze zur Datenerhebung, eine Definition, welche Daten benötigt werden und wie die erforderlichen Parameter aus den vorhandenen Daten abgeleitet werden können. Am Ende steht eine Abfallcharakterisierung für verschiedene Abfälle nach Nutz- und Schadkategorien, die in das System implementiert wird.

Die Eigenschaften des Abfalls werden im Wesentlichen von der Stoffgruppenzusammensetzung bestimmt. Diese Fraktionen des inhomogenen Abfallgemisches können durch entsprechende Parameter charakterisiert werden. So sind beispielsweise Kornklasse und Schüttdichte wichtige Parameter für mechanische Prozesse, die eine Stofftrennung bewirken. Auch ferromagnetische Eigenschaften und Oberflächeneigenschaften werden zur Abtrennung von Metall- und Kunststofffraktionen genutzt. Ziel ist es, heizwertreiche Abfallfraktionen abzutrennen und durch weitere Konditionierung einen Brennstoff zu erzeugen. Die Vorgaben für diesen Ersatzbrennstoff sind abhängig von der Art der Verbrennung, der Art der Feuerung und der Art des evtl. eingesetzten Regelbrennstoffes. Im Wesentlichen sind die entscheidenden Parameter: Heizwert, Chlorgehalt, Schwermetallgehalt, Korngröße und Störstoffgehalt (vgl. ECKHARDT, 2005). Insbesondere die drei erstgenannten Parameter sind abhängig von der Zusammensetzung des Abfallinputs, während die letztgenannten Größen sich durch Nachzerkleinerung und Metallabscheidung zuverlässig erreichen lassen. Vor allem Kunststoffe, PPK und Verbunde sollen als heizwertreiche Fraktionen im Brennstoff angereichert werden. Allerdings sind Kunststoffe und Verbunde Quellen für Chlor und Schwermetalle, deren Gehalte nach Art des Kunst- und Verbundstoffes stark schwanken (vgl. KOST, 2001 und ROTTER, 2002). Für genaue Rückschlüsse auf die Zusammensetzung verschiedener Abfallarten ist daher eine Unterscheidung und Charakterisierung verschiedener Kunststoffgruppen sinnvoll.

Tabelle 1: Stoffparameter und ihr Einfluss auf die Verwertung

Stoffparameter	Thermische Verwertung	MBA
Kornklasse	X	X
Schüttdichte	X	X
Oberflächeneigenschaften		X
Ferromagnetismus		X
Heizwert	X	X
Chlorgehalt	X	
Schwermetallgehalt	X	X
Störstoffe		X
Aschegehalt	X	
Wassergehalt	X	X
Organische Substanz	X	X
Partikelgröße	X	
C, H, O, N, S	X	

Bei der thermischen Verwertung lassen sich die relevanten Parameter aus der stofflichen Zusammensetzung des Abfalls sowie seiner chemischen und physikalischen Eigenschaften ableiten. Physikalische Parameter sind Aschegehalt, Wassergehalt und Anteil an organischer Substanz. Verbrennungstechnische Eigenschaften werden durch Heizwert, stoffliche Zusammensetzung, Schüttdichte und Partikelgröße bestimmt. Eine Rolle bei der Beurteilung der Emissionen spielen Kohlenstoff, Wasserstoff, Sauerstoff, Stickstoff, Chlor und Schwefel.

Es wird deutlich, dass eine Vielzahl unterschiedlicher Stoffeigenschaften notwendig ist, um eine Abfallfraktion hinreichend zu beschreiben in abhängig von den möglichen verfahrenstechnischen Lösungen.

3 Fallbeispiel: Optimierung eines Müllheizkraftwerks

Aus betrieblicher Sicht ist ein Ziel von Betreibern thermischer Abfallbehandlungsanlagen, einen möglichst ökonomisch und ökologisch optimierten Betriebszustand ihrer Anlagen zu generieren. Unter Einhaltung der Emissionsgrenzwerte sind die wesentlichen Einflussfaktoren auf den Betriebszustand:

- optimale Energieauskopplung,
- hohe Verfügbarkeiten von Kesseln und
- hohe Durchsatzraten.

Diese Faktoren werden neben der vorhandenen Technik und Auslegung der Anlage vor allem durch die Eigenschaften des zu verbrennenden Abfalls beeinflusst. Die entscheidenden stofflichen Abfallparameter wurden bereits erwähnt, hinzukommen als wichtige Einflussgrößen noch ökonomische Parameter (z.B. Annahmepreis des Abfalls oder Entsorgungskosten).

Daraus folgt, dass mit der Wahl der Abfallfraktion für die Verbrennung auch der Betriebszustand der Anlage gesteuert werden kann, woraus sich wiederum die Frage ergibt, mit welchen Abfallfraktionen der für die ausgelegte Anlagentechnik optimale Betriebszustand erreicht wird? Aufgrund der komplexen Zusammenhänge kann dieses Optimierungsproblem nur softwareunterstützt gelöst werden. In der folgenden Abbildung ist ein Ausschnitt des Stoffstromanalysemodells dargestellt.

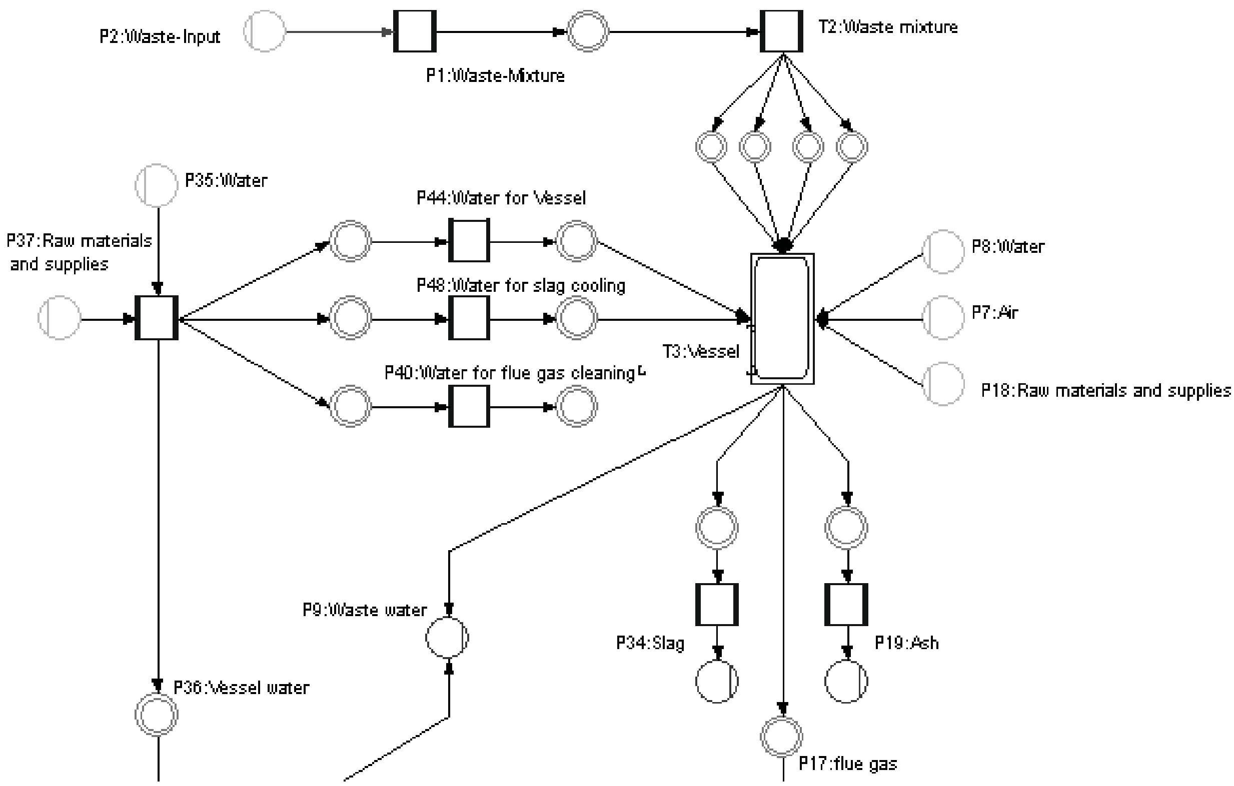

Abbildung 2: Stoffstromanalysemodells einer thermischen Abfallbehandlungsanlage

Für die Modellierung einer thermischen Abfallbehandlungsanlage müssen technische Grenzwerte und Randbedingungen berücksichtigt werden. Der Durchsatz auf dem Rost im Kessel wird in Abhängigkeit des Heizwertes der Abfallmischung und der gewählten Feuerungswärmeleistung berechnet. Über die eingebrachte Feuerungswärmeleistung wird eine spezifische Menge Dampf produziert. Diese ist entscheidend für die mögliche Auskopplung an thermischer und elektrischer Energie.

Im Ergebnis einer ersten Abschätzung zählen Abfallfraktionen mit relativ geringen Heizwerten, Asche- und Schwermetallgehalten sowie hohen Annahmepreisen zu den bevorzugten Fraktionen in der Abfallverbrennung. Allerdings reichen diese Kriterien allein für die Ermittlung eines optimalen Betriebszustandes nicht aus. Es ist entscheidend, dass die Grenzwerte und Randbedingungen bei der Verbrennung der Abfälle eingehalten werden (z.B. max. Feuerraumbelastung).

Im Rahmen eines Entwicklungsvorhabens der Hochschule Bremen wurde an dem Müllheizwerk der Abfallbehandlung Nord GmbH in Bremen (mittlerweile swb AG) versucht, mit Modellen die Optimierung der Anlage zu unterstützen. Dazu wurden die verfahrenstechnischen Prozesseinheiten der Anlagen mit allen relevanten Stoff - und Energieströmen sowie allen Kostenelementen in einem Modell abgebildet (siehe Abbildung 2). Der in die Anlage eingehende Abfall wurde nach Abfallarten fraktioniert und mit eigenen Messwerten und Literaturdaten charakterisiert (siehe auch SCHMIDT ET AL., 2008).

Tabelle 2: Ergebnisse einer Modellberechnung eines MHKW bei Variation des Abfallinputs

	MHW – Szenario 1	MHW – Szenario 2
Abfallinput [Mg]	491.000	500.000
Heizwert der Abfallmischung [MJ/kg]	11,8	11,6
Maximale Verbrennungskapazität [Mg]	493.000	502.000
Schlacke [kg/Mg]	242	257
Asche [kg/Mg]	15,9	16,9
Reststoffe RGR [kg/Mg]	29,4	31,9

Im ersten Szenario der Modellrechnung würde im MHW eine Gesamtmenge von etwa 491.000 Mg verbrannt werden. Die Abfallmischung verfügte dabei über einen Heizwert von ca. 12 MJ/kg. Im zweiten Szenario wurde die Abfallmischung dahingehend variiert, dass im MHW ca. 95.000 Mg heizwertreiche Fraktion durch Klärschlamm (75% TS), Schredderleichtfraktion und Gewerbeabfallsortierreste ersetzt wurden. Um in etwa auf einen vergleichbaren Brennwert der Abfallmischung zu gelangen, wurden in diesem Szenario 500.000 Mg Abfall verbrannt (vgl.Tabelle 2).

Im Ergebnis dieser Modellberechnung konnte folgendes gezeigt werden:

- Steigerung der Abfallerlöse durch eine erhöhten Abfalldurchsatz von 10.000 Mg in Szenario 2.
- Höhere Betriebskosten durch gesteigerte Zugabe an Hilfsstoffen für die Rauchgasreinigung (RGR) bedingt durch die höheren Schadstoffkonzentrationen der Abfallmischung in Szenario 2. Diese werden hauptsächlich durch Mitverbrennung von Klärschlamm und Schredderleichtfraktion verursacht.
- Anstieg der Entsorgungskosten durch einen erhöhten Anfall an Aschen und Schlacken in Szenario 2.

Diese Beispielrechnung macht die komplexen Zusammenhänge bei der Abfallverbrennung deutlich. Es konnte nachgewiesen werden, dass die entwickelten Modelle diese Zusammenhänge gut darstellen und bei der Optimierung eines MHW hilfreich sein können.

Um letztendlich den optimalen Betriebszustand eines MHW ermitteln zu können, bedarf es zusätzlich auch Methoden der Optimierung aus der BWL/Wirtschaftsinformatik. Ein im Rahmen des Projektes ‚KOMSA' (Kombination von Optimierungsmethoden und Stoffstromanalyse zur Verbesserung des betrieblichen Materialeinsatzes) von der

Hochschule Pforzheim entwickeltes Software-Instrument wurde deshalb in diesem Forschungsprojekt für die Lösung des Optimierungsproblems erprobt. Es galt, aus einer Auswahl von Abfallfraktionen mit unterschiedlichen Abfallparametern eine Abfallmischung zu generieren, mit der ein optimaler Betriebszustand unter Berücksichtigung der Grenzwerte und Randbedingungen erzielt werden kann. Mit Hilfe der in dem Optimierungsprototypen zur Verfügung gestellten Optimierungsalgorithmen wurden automatisch so viele Abfallmischungen generiert, bis die optimale Zusammensetzung für das MHW gefunden wurde. Für dieses Fallbeispiel wurden die Zahlen wurden anonymisiert, so dass diese nicht der Realität entsprechen. Die Abbildung ***3*** verdeutlicht mögliche ökonomische Betriebsergebnisse – und somit das Optimierungspotenzial - in Abhängigkeit der Zusammensetzung des Abfalls. Die Graphik zeigt zudem die verwendeten Optimierungsmethoden und die nötigen Berechnungsschritte.

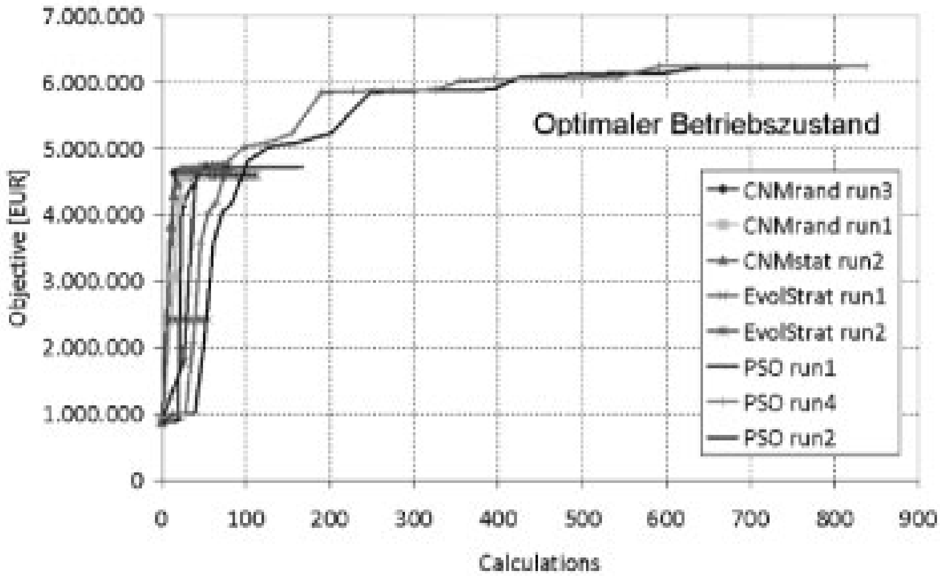

*Abbildung **3**: Anonymisierte Darstellung der Ergebnisse von sechs Optimierungsalgorithmen.*

Mit der Kombination aus Optimierungsmethoden und Stoffstromanalyse können die Abfall- und die zugehörigen Material-, Energie- und Kostenströme als Grundlage für die Effizienzbewertung von abfallwirtschaftlichen Systemen und Strategien zukünftig gut und zeitnah optimiert werden.

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Wertstoffe und Sortieranlagen am Markt – Besonderheiten des Kartell-, Vergabe- und Steuerrechts

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Recyclables and sorting plants at the market – Special aspects of anti trust law, public procurement law and fiscal law

Abstract

This article delivers a survey on questions arising in the fields of anti trust law, public procurement law, and fiscal law, when contracts of recyclables (incl. sorting) are drafted.

Inhaltsangabe

Der Beitrag beleuchtet ausgewählte Fragestellungen des Kartell-, Vergabe und Steuerrechts, die im Zusammenhang mit Verträgen über Entsorgungsdienstleistungen für Wertstoffe (einschl. ihrer Sortierung) interessieren.

Keywords

Wertstoff – Sortieranlage – Kartellrecht – Vergaberecht – Steuerrecht

recyclables – sorting plants – anti trust law – public procurement law – fiscal law

1 Einführung

Entsorgungsdienstleistungen beinhalten häufig kartell-, vergabe- und steuerrechtliche Herausforderungen für öffentliche Auftraggeber und private Entsorgungsunternehmen; dies gilt auch und besonders für die Entsorgung von Wertstoffen, einschließlich ihrer Sortierung.

Nach der kartellrechtlichen Spruchpraxis wird von der Eröffnung eines (Ausschreibungs-) Marktes erst dann ausgegangen, wenn ein öffentlicher Auftraggeber zur Leistungserbringung Dritte einschaltet (vgl. z.B. Bundeskartellamt, Beschluss vom 16.05.2007, Az.: B 4 – 90003 – Fa – 8/07, Rz. 61). Dies ist – jedenfalls für Deutschland – zunächst deshalb von Bedeutung, weil die Abfallentsorgung eine hoheitliche Aufgabe ist. Abfallbesitzer und -erzeuger können nur in Grenzen über ihren Abfall disponieren. Es besteht im Grundsatz eine sog. Überlassungspflicht des privaten Abfallbesitzers sowohl für Abfälle zur Beseitigung als auch für Abfälle zur Verwertung, für Besitzer von Abfällen aus sonstigen Herkunftsbereichen lediglich für Abfälle zur Beseitigung (ausführlich KUNIG/PAETOW/VERSTEYL, 2003, § 13 Rn. 1 ff.). Die Abgrenzung im Einzelnen ist – schon aus wirtschaftlichen Interessen der „Anbieter“ – sehr umstritten und soll an dieser Stelle nicht vertieft werden (näher hierzu: WENZEL 2008). Es wird jedoch der Hinweis gegeben, dass im Rahmen eines anhängigen Revisionsverfahrens eine Grundsatzentscheidung des Bundesverwaltungsgerichts zu wichtigen Fragen, insbesondere zu § 13 Abs. 1 Satz 1 KrW-/AbfG (Frage der sog. „Eigenverwertung“), unter Umständen auch zu § 13 Abs. 3 Satz 1 Nr. 3 KrW-/AbfG (sog. „gewerbliche Sammlungen“), erwartet wird (Az.: 7 C 16.08; nachgehend OVG Schleswig-Holstein, Urteil vom 22.04.2008, Az.: 4 LB 7/06).

Soweit Abfälle dem öffentlich-rechtlichen Entsorgungsträger überlassen werden, obliegt diesem eine Entsorgungspflicht nach Maßgabe von § 15 Abs. 1 KrW-/AbfG. Dem öffentlich-rechtlichen Entsorgungsträger wird dabei ein allgemeines Organisationsermessen zugesprochen, er kann also aus abfallrechtlicher Sicht entscheiden, ob er die maßgeblichen Entsorgungsdienstleistungen in Eigenleistung erbringt oder hiermit Dritte i. S. v. § 16 Abs. 1 KrW-/AbfG beauftragt (zu den Vor- und Nachteilen sowie zu den Voraussetzungen der unterschiedlichen Organisationsformen ausführlich: GAßNER/SIEDERER 2003, Rn. 393 ff.). Erbringt also ein öffentlich-rechtlicher Entsorgungsträger Abfalldienstleistungen ausschließlich in Eigenregie, bedarf es erstens keines Vergabeverfahrens, zweitens fehlt der für die Anwendung des Kartellrechts als Regelungsgegenstand erforderliche (Ausschreibungs-) Markt und drittens stellen sich auch keine steuerrechtlichen Fragestellungen, weil die hoheitliche Betätigung von der Besteuerung (noch!) ausgenommen ist. Aus staatlicher bzw. kommunaler Sicht stellen sich die nachfolgenden Fragen somit erst bei Einschaltung Dritter und ihrer Beauftragung mit Entsorgungsdienstleistungen.

Im Folgenden soll daher zunächst auf ausgewählte Besonderheiten des Vergaberechts, sodann des Kartell- und schließlich des Steuerrechts eingegangen werden. Dem Kartell- und dem Vergaberecht, die als Rechtsgebiete mittlerweile beide im Gesetz gegen Wettbewerbsbeschränkungen verankert sind (vgl. dort §§ 1 ff. und §§ 97 ff. GWB) ist gemein, dass sie im Ergebnis einen diskriminierungsfreien Wettbewerb gewährleisten sollen, wobei das Kartellrecht im Wesentlichen Mono- und Oligopolstellungen vermeiden bzw. beschränken soll sowie das Bundeskartellamt mit starken Eingriffs- und Regelungsbefugnissen versieht, und das Vergaberecht die wettbewerbskonforme Ausschreibung mit wesentlichen Pflichten für den öffentlichen Auftraggeber regelt. Beide Hauptakteure unterliegen jeweils auf Antrag gerichtlicher bzw. gerichtsähnlicher Kontrolle (vgl. §§ 63 ff. bzw. §§ 107 ff. GWB).

2 Vergaberecht

Die Verpflichtung zur Ausschreibungen von Entsorgungsdienstleistungen obliegt dem öffentlichen Auftraggeber im Sinne von § 98 GWB, der entweder originärer Abfallbesitzer/ –erzeuger ist oder aufgrund gesetzlicher Verpflichtung zur Entsorgung von Wertstoffen Dritter verpflichtet ist und diese Dienstleistungen nicht selbst erbringt (näher hierzu BYOK/BORMANN 2008, 843). Unter vergaberechtlichen Aspekten lassen sich in der Praxis folgende Punkte identifizieren, die den Auftraggeber bei der Ausschreibung von Wertstoffen und Sortierleistungen vor Probleme stellen und regelmäßig zu Auseinandersetzungen mit Bietern führen.

2.1 Besonderheiten für Wertstoffe

§ 8 Nr. 1 VOL/A formuliert eine Reihe von Anforderungen, die bei der Anfertigung der Leistungsbeschreibung zu beachten sind, die ihrerseits das Kernstück der sog. Verdingungsunterlagen bildet. Hierfür ist die Leistung „eindeutig und so erschöpfend zu beschreiben", damit ein einheitliches Verständnis der Bewerber und eine Vergleichbarkeit der Angebote gewährleistet ist (Abs. 1), ferner sind alle kalkulationsrelevanten Umstände mitzuteilen (Abs. 2) und es dürfen dem Auftragnehmer keine „ungewöhnliche Wagnisse" aufgebürdet werden (Abs. 3). Besondere Bedeutung kommt daher für die Ausschreibung der Entsorgung von Wertstoffen ihrer quantitativen und qualitativen Beschreibung zu. So können Mengen unstet und durch Umstände beeinflusst werden, auf die auch der Auftraggeber keinen Einfluss hat. Vom Auftraggeber wird jedoch erwartet, belastbare Prognosen für Mengenangaben zu erstellen. Den Bietern wird durch die Bildung sog. Mengenkorridore in Höhe von +/- 10 % die Möglichkeit gegeben, mengenspezifische Entgelte zu kalkulieren und anzugeben. Der qualitativen Beschreibung der Wertstoffe kommt gerade dann eine besondere Bedeutung zu, wenn ihre weitere Verwertung in Anlagen erfolgt, die auf die Einhaltung konkreter Qualitäten angewiesen sind. Erfolgt die Ausschreibung bereits erfasster und/oder vorbehandelter Mengen ab einem Übergabepunkt, sind zudem die Schnittstellen zwischen den jeweiligen Teilleistungen genau zu definieren, da zum einen gerade fehlgeschlagene bzw. verspätete Übergaben bzw. Abnahmen von Wertstoffmengen Folgekosten (insbesondere Schadensersatz) zur Folge haben können, zum anderen keine direkten Vertragsbeziehungen zwischen den jeweiligen Auftragnehmern der Teilleistungen mit der Folge bestehen, dass stets der öffentliche Auftraggeber die betreffenden Probleme zu beheben hat.

Soweit die Wertstoffe im Zeitpunkt der Übergabe an den Auftragnehmer bzw. infolge der ausgeschriebenen Entsorgungsdienstleistungen einen positiven Marktwert aufweisen, ist eine besondere Sorgfalt bei der Abfrage der Angebotspreise und ihrer Wertung geboten, da bereits aus der Verrechnung von Erlösen mit Entgelten Probleme für die Vergleichbarkeit der Angebote entstehen können, und es aufgrund steuerrechtlicher Fragestellungen (siehe dazu unter 4.2; siehe hierzu auch Vergabekammer des Landes Brandenburg beim Ministerium für Wirtschaft, Beschluss vom 28.01.2008, Az.: VK 59/07) gar zu unvergleichbaren Angeboten und damit einem Verstoß gegen die o.g. Vorgabe aus § 8 Nr. 1 Abs. 1 2. Halbs. VOL/A kommen kann. Eine besondere Sorgfalt ist auch bei der Prüfung der Voraussetzungen des § 15 VOL/A geboten, ob die Leistungen zu festen Preisen oder aber mit der Möglichkeit von Preisanpassungen vergeben werden sollen.

Soweit sich mit Wertstoffen Erlöse erzielen lassen und ihre Erfassung nicht ausschließlich hoheitlicher Natur ist, kann sich für den öffentlichen Auftraggeber die Frage stellen, wie eine konkurrierende Tätigkeit des Auftragnehmers ausgeschlossen werden kann, damit diese nicht zu Mengenveränderungen bzw. Erlösausfällen führt. Nach einer aktuellen Entscheidung des OLG Rostock (Beschluss vom 06.03.2009, Az.: 17 Verg 1/09) ist jedenfalls ein umfassendes Wettbewerbsverbot, das dem Auftragnehmer (bzw. mit ihm verbundenen Unternehmen) eine konkurrierende Tätigkeit während der Vertragslaufzeit im Entsorgungsgebiet zu demselben Leistungsgegenstand untersagt, unzulässig. Folgt man dieser Rechtsauffassung, sollte der Auftraggeber vom Auftragnehmer zumindest Angaben dazu verlangen, wie er ggf. die vorgenannten negativen Folgen einer gewerblichen Sammlung auszuschließen gedenkt.

2.2 Besonderheiten für Sortieranlagen

Die Sortierung erfolgt mit dem abfallwirtschaftlichen Ziel, mindestens eine Teilfraktion einer höherwertigen Entsorgung zuzuführen, und/oder mit dem betriebswirtschaftlichen Ziel, hierdurch einen ökonomischen Vorteil zu erwirtschaften, der jedoch nur erzielt werden kann, wenn die Summe der Erlöse aus den Teilfraktionen abzüglich der Sortierkosten den Erlös aus der unsortierten Gesamtfraktion übersteigt (was beispielsweise bei Altpapier in der Vergangenheit regelmäßig nicht der Fall gewesen ist). Der Einsatz von Sortieranlagen kann zwingender oder fakultativer Leistungsgegenstand sein. Ist er zwingender Bestandteil einer umfänglicheren Gesamtleistung, stellt sich die Frage, ob insoweit eine losweise Vergabe i.S.v. § 5 VOL/A erfolgen kann. In einem solchen Fall kommt der exakten Definition der Schnittstellen (Übergaben vor und nach der Sortierung) große Bedeutung zu.

Ist die Sortieranlage selbst Gegenstand der Ausschreibung, sind Bau (VOB/A) und Betrieb (VOL/A) vergaberechtlich zu unterscheiden. ÖPP sind hier, insbesondere bei einhergehender Beauftragung mit nachgehender Dienstleistung, nur nach Ausschreibung möglich, jedoch im Hinblick auf die seit der Änderung der EuGH-Rechtsprechung (vgl. Urteil vom 11.01.2005, Az.: Rs. C-26/03, „Stadt Halle“) mangels Inhouse-Fähigkeit für Nach- und Zusatzbeauftragungen nur noch in engeren Grenzen von wirtschaftlichem Interesse.

3 Kartellrecht

Im Folgenden soll zunächst das Konzept der Marktabgrenzungen erläutert werden, da die Definition des relevanten Marktes allen weiteren kartellrechtlichen Prüfungen tatbestandlich vorausgeht. Dabei ist im Weiteren grundsätzlich zu unterscheiden zwischen der sog. - infolge der zunehmenden Konzentration in der Entsorgungswirtschaft immer häufigeren – Fusionskontrolle (§§ 35 ff. GWB) und den allgemeinen kartellrechtlichen Regelungen, die wettbewerbsbeschränkende Vereinbarungen, abgestimmte Verhaltensweisen, wettbewerbsbeschränkendes Verhalten etc. verbieten (vgl. z.B. Bundeskartellamt, Beschluss vom 06.05.2004, Az.: 10 B 97/02 – „Altpapierentsorgung“).

3.1 Das rechtliche Konzept der Marktabgrenzungen

Für die Praxis von Bedeutung ist eine kartellrechtliche Prüfung insbesondere bei Kooperationsvorhaben, sei es auf einfacher vertraglicher Basis, als Bieter-/Arbeitsgemeinschaft oder sei es institutionalisiert (z.B. im Rahmen einer ÖPP-Gesellschaft).

Eine kartellrechtliche Marktabgrenzung erfolgt in der Regel zwei-, gelegentlich auch dreiseitig: sachlich, räumlich und zeitlich (ist der Markt nicht von Dauer).

Zur Abgrenzung sachlich relevanter Märkte ist das sog. Bedarfsmarktkonzept entwickelt worden, das im Wesentlichen auf die funktionelle Austauschbarkeit der Produkte aus Sicht der Marktgegenseite abstellt. Zu einem sachlich relevanten Markt gehören alle Waren, die sich nach ihren Eigenschaften, ihrem wirtschaftlichen Verwendungszweck und der Preislage so nahe stehen, dass der verständige Verbraucher sie als für die Deckung eines bestimmten Bedarfs geeignet in berechtigter Weise abwägend miteinander vergleicht und als gegeneinander austauschbar ansieht (vgl. BGH, Urteil vom 24.10.1995, Az. KVR 17/94, „Backofenmarkt“).

Die räumliche Marktabgrenzung erfolgt durch die geografische, entweder an politischen Grenzen (Bundesländer, Landkreise, Städte oder Gemeinden) oder konkreten Radien um Bezugspunkte (z.B. Anlagenstandort) ausgerichtete Beschreibung; Grundlage hierfür ist regelmäßig eine Auswertung kommunaler Ausschreibungen (s.a. LOTZE/MAGER 2007, 244).

3.2 Märkte für Wertstoffe und ihre Sortierung

Analysiert man die Spruchpraxis des Bundeskartellamtes in kartellrechtlichen Fragestellungen der Entsorgungswirtschaft, so ist zunächst festzustellen, dass eine sachliche Marktabgrenzung im Regelfall unter zwei Aspekten erfolgt: Zum einen dient die Fraktion ihrer Art nach als Charakteristikum (z.B. Altpapier, Verpackungen, vorbehandelte Siedlungsabfälle etc.), zum anderen der Entsorgungsschritt (z.B. Sammlung, Transport, Sortierung etc.). Unter Zugrundelegung des unter 3.1 vorgestellten Bedarfsmarktkonzeptes werden die fraglichen Entsorgungsdienstleistungen für die sachliche Marktabgrenzung einer genauen Analyse unterzogen. Im Einzelnen sind dabei in der Praxis von Bedeutung: Dauer der Verträge, Qualität und Menge der Abfälle, Sortenreinheit, Abfuhrrhythmus, eingesetzte Fahrzeuge, sonstige Betriebsmittel und Personalkräfte (vgl. z.B. Bundeskartellamt, Beschl. v. 16.05.2007, a.a.O.). In der kartellrechtlichen Spruchpraxis wurden in den vergangenen zehn Jahren insbesondere folgende sachliche Marktabgrenzungen festgestellt: Sammlung und Transport von LVP; Sortierung von LVP; Verwertung vorbehandelter Siedlungsabfälle; Behandlung von Bioabfällen; Sammlung, Sortierung und Verwertung von Altpapier; Sammlung und Transport von Altglas. Im Einzelnen ist es dabei auch zu divergierenden Entscheidungen des Bundeskartellamtes und des für seine gerichtliche Kontrolle zuständigen Oberlandesgerichts Düsseldorf gekommen. So hat beispielsweise das Oberlandesgerichts Düsseldorf die Einbeziehung von MVA und MBA in den gleichen sachlichen Markt bezweifelt (vgl. Beschluss vom 04.09.2002, Az.: Kart 26/02 (V)), während das Bundeskartellamt hiervon ausgegangen ist (vgl. Beschluss vom 17.03.2006, Az.: B 10-141/05).

Die räumliche Marktabgrenzung bedarf ebenfalls der Einzelfallprüfung. Während allgemein bundesweite Märkte nur in Ausnahmefällen festgestellt worden sind, erstreckt sich der räumliche Markt regelmäßig in Umkreisen von bis zu 100 km um eine Anlage oder Kommune, auf Bundesländer oder eine Mehrzahl von Bundesländern (vgl. z.B. „nördliche neue Bundesländer“, Bundeskartellamt, Beschluss vom 17.03.2006, Az.: a.a.O., Rn. 90).

Besonderheiten sind auch für Sortierleistungen bzw. Sortieranlagen festzustellen. Für die sachliche Marktabgrenzung interessiert aus technischer Sicht die Austauschbarkeit von Sortierleistungen, ob also die betreffende Sortieranlage nur bestimmte Abfallfraktionen zu behandeln vermag (vgl. Bundeskartellamt, Beschluss vom 22.06.2006, Az.: B 10-90003-FA-155/05). Im Hinblick auf die räumliche Marktabgrenzung kann der Einzugsbereich von Sortieranlagen in einem unmittelbaren Zusammenhang mit den Transportkosten stehen, die ihrerseits wieder von Gewicht bzw. Dichte des Sortiermaterials einerseits und den konkreten Transportkosten (insbesondere Kraftstoffe und Maut) abhängen.

Als Faustformel lässt sich zusammenfassen: Je kleiner der räumliche Markt ist, umso größer ist die Wahrscheinlichkeit einer kartellrechtlichen Problematik, da dem Auftrag bzw. dem Vorhaben, das Gegenstand der kartellrechtlichen Prüfung ist, in Relation zum sachlich und räumlich relevanten Markt eine größere Bedeutung zukommt, mithin der Marktanteil steigt.

4 Steuerrecht

Zwei wesentliche Fragestellungen werden unter steuerrechtlichen Aspekten diskutiert: die Privilegierung hoheitlicher Tätigkeit, deren Zulässigkeit unter wettbewerblichen Aspekten in Zweifel gezogen wird, und die umsatzsteuerliche Bemessungsgrundlage bei der Verrechnung von Entgelten und Erlösen. Andere Fragestellungen, wie z.B. die Bildung von Rückstellungen (vgl. hierzu Bundesfinanzhof, Urteil vom 21.9.2005, Az.: X R 29/03), können hier nicht vertieft werden.

4.1 Privilegierung von Hoheitsbetrieben

Körperschaftssteuerpflichtig ist nicht der Hoheitsbetrieb im Sinne von § 4 Abs. 5 Satz 1 KStG. Wie der Bundesfinanzhof jüngst erneut unterstrichen hat, ist die Vorschrift eng auszulegen (vgl. BFH, Urteil vom 29.10.2008, Az.: I R 51/07). Die Abgrenzung zum Betrieb gewerblicher Art gestaltet sich gleichwohl auch in der abfallwirtschaftlichen Praxis schwierig (vgl. z.B. BFH, Beschluss vom 6.11.2007, Az.: I R 72/06, zur Müllentsorgung im Rahmen des sogenannten Dualen Systems nach § 6 Abs. 3 VerpackV). Dabei ist anerkannt, dass jedenfalls die Hausmüllentsorgung als Hoheitsbetrieb zu beurteilen ist (BFH, Urteil vom 23.10.1996, Az.: I R 1-2/94); begründet wird dies im Wesentlichen mit der Überlassungspflicht (bzw. „Annahmezwang“). Denn unter der für die Definition von Hoheitsbetrieb maßgeblichen „Ausübung öffentlicher Gewalt“ sind „Tätigkeiten zu verstehen, die der juristischen Person des öffentlichen Rechts eigentümlich und vorbehalten sind. Kennzeichnend dafür ist die Erfüllung spezifisch öffentlich-rechtlicher Aufgaben, die aus der Staatsgewalt abgeleitet sind, staatlichen Zwecken dienen und zu deren Annahme der Leistungsempfänger aufgrund gesetzlicher oder behördlicher Anordnung verpflichtet ist“ (BFH a.a.O.). Ist eine Betätigung durch landesrechtliche Regelungen nur in einzelnen Bundesländern ausschließlich der öffentlichen Hand vorbehalten, kann nach der restriktiven Auffassung des BFH nur dann ein Hoheitsbetrieb i.S. von § 4 Abs. 5 Satz 1 KStG angenommen werden, „wenn der Markt für die angebotene Leistung örtlich so eingegrenzt ist, dass eine Wettbewerbsbeeinträchtigung steuerpflichtiger Unternehmen in anderen Bundesländern oder EU-Mitgliedstaaten ausgeschlossen werden kann“.

Nicht nur die Gewerbesteuer (§ 2 Abs. 1 GewStG) und die Grundsteuer (§ 3 Abs. 1 Nr. 1 GrStG), auch die umsatzsteuerliche Privilegierung folgt dieser Abgrenzung (vgl. § 1 Abs. 1 Nr. 1 i.V.m. § 2 Abs. 1 Satz 1, Absatz 3 Satz 1 UStG), so dass in der Praxis beispielsweise Abfallwirtschaftsdienstleistungen, die ein kommunaler Eigenbetrieb erbringt, im hoheitlichen Bereich steuerfrei bleiben, im Falle einer Drittbeauftragung eines privaten Entsorgungsunternehmens mit derselben Dienstleistung dagegen mit 19 % Umsatzsteuer belegt werden (vgl. hierzu auch BFH, Urteil vom 05.12.2007, Az.: V R 63/05). Im Rahmen von Organisationsvergleichen für (Re-) Kommunalisierungs- bzw.

Privatisierungsmodelle führt dies in der Praxis zu einem Kostenvorteil kommunaler Betriebe, der (teilweise) Kostenvorteile privater Modelle, die z.B. durch untertarifliche Bezahlung des Personals generiert werden, zu kompensieren vermag.

Verbände der privaten Entsorgungswirtschaft kritisieren diese Privilegierung auf politischer Ebene und haben – parallel zu erfolglosen Anträgen der FDP im Deutschen Bundestag (vom 21.09.2006, BT-Drs. 16/2657, und vom 19.06.2007, BT-Drs. 16/5728) - den Versuch unternommen, diese Frage unter Verweis auf Rechtsprechung des EuGH (Urteil vom 16.09.2008, Rechtssache C-288/07) zum Gegenstand eines Beschwerdeverfahrens der EU-Kommission zu machen. Die Kommission hat in einer Zwischeninformation (vom 08.01.2009 an das Europäische Parlament, Az.: E-6246/08) Zweifel an dieser Rechtsauffassung erkennen lassen, eine abschließende Entscheidung steht jedoch noch aus.

4.2 Umsatzsteuer und tauschähnlicher Umsatz

Außerhalb des hoheitlichen Bereichs (dazu 4.1) unterliegen abfallwirtschaftliche Dienstleistungen der Umsatzsteuer. Lassen sich mit Wertstoffen Erlöse erzielen, kann die Bestimmung der Bemessungsgrundlage (vgl. § 10 UStG) Schwierigkeiten bereiten (ausführlich hierzu: THIMM 2008). Dies soll an folgendem Beispiel erläutert werden: Verursacht eine Entsorgungsdienstleistung Kosten in Höhe von 100,00 € und lassen sich in ihrem Rahmen mit dem überlassenen Wertstoff 50,00 € Erlöse erzielen, so reduzieren sich Steuer- und Angebotspreis um 9,50 €, ist das um die Erlöse geminderte Entgelt Bemessungsgrundlage (100 ./. 50 = 50 x 1,19 = 59,50 €) gegenüber dem Ansatz, die Kosten als Bemessungsgrundlage zu verwenden und erst von dem Bruttobetrag die Erlöse abzuziehen (100 x 1,19 = 119 - 50 = 69,00 €). Vor dem Hintergrund dieser Problematik hat sich das Bundesministerium der Finanzen veranlasst gesehen, mit Schreiben vom 01.12.2008 (Gz.: IV B 8-S 7203/07/10002) die Anwendung der Grundsätze des tauschähnlichen Umsatzes zu erläutern. Mit dem Schreiben werden die einzelnen Voraussetzungen (einschließlich Bagatellgrenzen) dargelegt. Im Regelfall ist für die Ermittlung der Bemessungsgrundlage der wirtschaftliche Wert des Wertstoffes anzusetzen und im Falle der sog. Baraufgabe diese hinzuzusetzen. Zahlt also ein Abfallbesitzer für eine Entsorgungsleistung 5,00 € und beläuft sich der wirtschaftliche Wert des übergebenen Abfalls auf 20,00 €, ist der Umsatz in Höhe von 25,00 € zu besteuern (5 + 20 = 25 x 1,19 = 29,75 €). Mit dem Schreiben ist der Finanzverwaltung aufgegeben, für einen Übergangszeitraum bis zum 31.12.2010 nicht zu beanstanden, wenn Vertragsparteien von vor dem 01.07.2009 abgeschlossenen Verträgen davon ausgehen, dass kein tauschähnlicher Umsatz vorliegt.

5 Zusammenfassung und Ausblick

Ohne Kenntnisse des Vergabe-, Kartell- und Steuerrechts gefährden Vertragspartner den rechtssicheren Abschluss von Verträgen über die Entsorgung von Wertstoffen. Mit einer zunehmenden Liberalisierung der Entsorgung von Wertstoffen und der einhergehenden Zurückdrängung öffentlicher Auftraggeber nimmt die Bedeutung des Vergaberechts ab. Zugleich „motiviert" ein immer komplexeres und für den Auftraggeber risikoreicheres Vergaberecht, bislang ausschreibungspflichtige Entsorgungsdienstleistungen wieder in Eigenregie zu erbringen. Zwar tritt in diesen Tagen eine Vergaberechtsnovelle mit dem erklärten Ziel einer Stärkung der Rechtssicherheit in Kraft (ausführlich hierzu: v. BECHTOLSHEIM 2009). Ob dieses Ziel jedoch in der Praxis erreicht wird, bleibt abzuwarten. In liberalisierten Märkten gewinnt zugleich das Kartellrecht an Bedeutung für die Aufrechterhaltung von materiellem Wettbewerb. Dabei tendiert die kartellrechtliche Spruchpraxis zwar zur Annahme regionaler Märkte, die die Wahrscheinlichkeit einer Wettbewerbsrelevanz von Kooperationen bzw. Fusionen aufgrund des entsprechend ansteigenden Marktanteils allgemein erhöht. Jedoch greift eine Analyse von kommunalen Ausschreibungen zur Abgrenzung relevanter Märkte gerade von Wertstoffen zu kurz, da hier – insbesondere im Bereich der Altpapier- und Metallentsorgung durch sog. gewerbliche Sammlungen – Marktanteile von Wettbewerbern im unmittelbaren Kontakt mit Abfallbesitzern hinzugewonnen worden sind, die in der Bewertung letztlich unberücksichtigt bleiben und damit einer Festigung der Oligopolbildung in der Entsorgungswirtschaft Vorschub leisten. Das Steuerrecht bereitet bei positiven Marktwerten für Wertstoffe in der Praxis größere rechtliche Probleme und beinhaltet damit bei üblichen Gewinnmargen übersteigenden Steuersätzen im Falle von Fehleinschätzungen erhebliche wirtschaftliche Risiken. Mit zunehmender Liberalisierung der Wertstoffentsorgung ist die Frage der Steuergleichheit mit der Folge in den Vordergrund gerückt, für den Abfallbesitzer im Zweifel lediglich eine weitere Kostenposition darzustellen. Dabei ist zu überlegen, ob nicht gerade das Steuerrecht durch eine Privilegierung der Verwertung wieder zur Erreichung abfallwirtschaftlicher Zielstellungen eingesetzt werden – und damit wieder „Steuer-Recht" im eigentlichen Sinne sein sollte.

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Aussagesichere Bestimmung von Elementgehalten in heterogenen Abfallgemischen

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Reliable determination of element contents in heterogeneous waste fractions

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 erforder-

lich 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 Einleitung

In den vorangegangenen Jahren haben wir eine Vorgehensweise für die aussagesichere sortiertechnische Charakterisierung von Massengehalten in heterogenen Abfallgemischen entwickelt und publiziert [KETELHUT 2006, KETELHUT 2008]. Dabei zeigte sich, dass bei der Probengewinnung für die Bestimmung von Element-gehalten in heterogenen Abfallgemischen drei Faktoren von Bedeutung sind:

- der Stückzahlgehalt der Frachtträger in der Probe
- das Verhältnis der Artikelgewichte bei Frachtträgern und in der Grundgesamtheit
- die Differenz der Elementkonzentrationen bei Frachtträgern und im Hintergrund

Mit diesem Ansatz ist die sortieranalytisch unterstützte Bestimmung des Chlorgehal-tes von Abfällen gegenüber der rein chemisch-analytischen Bestimmung durchaus konkurrenzfähig, da innerhalb von wenigen Stunden nicht nur ein Chlorwert sondern dessen Vertrauensbereich und Aussagesicherheit angegeben werden können.

Gleichzeitig ist die Weiterentwicklung tragbarer RFA-Schnellanalysatoren so weit gediehen, dass einzelne Anbieter bereits Vor-Ort-Untersuchungen für heterogene Stoffgemische anbieten. Aus der Kombination von Sortieranalysen und RFA-Schnellanalytik ergibt sich in Zukunft unter Umständen die Möglichkeit, auch in heterogenen Abfällen schnell und aussagesicher die Gehalte von 30 verschiedenen Elementen zu ermitteln.

Um die Möglichkeiten dieser Vorgehensweise zu prüfen, wurde ein Ersatzbrennstoff parallel sortieranalytisch und mittels eines mobilen RFA-Analysators charakterisiert. Die Ergebnisse werden hier vorgestellt.

2 Sortieranalyse

Eine Tagesmischprobe eines sortieranalytisch gut bekannten Ersatzbrennstoffes mit einer Korngröße von d_{95} < 50 mm wurde in die nachfolgend dargestellten Fraktionen sortiert:

- Fe-Metall
- NE-Metall
- Mineralik
- Organik (PPK, Holz, Biomasse)
- Kunststoffe halogenfrei (NFT)
- Kunststoffe halogeniert (FT)
- Feinmaterial < 15 mm

Die Unterscheidung in Bezug auf den Halogengehalt der Kunststoffe erfolgte mittels Beilsteintest.

Von den Sortierfraktionen wurden Stückmassenverteilungen erstellt und mit Hilfe angewandter statistischer Methoden die Massengehalte ermittelt. Die Chlorgehalte der Fraktionen sind aus mehreren Untersuchungen reproduzierbar bekannt. Die Sortierprobe zeigt nachfolgende Zusammensetzung und Charakteristika:

080910 RFA Versuch	Gewicht [g]	Anzahl in Probe	Mittel-wert [g]	Anteil n	Anteil Masse	Anteil Masse total	Anteil masse stat	Cl Konzen-tration	Chlor-fracht	Anteil Chlor-fracht
Fe-Metall	0,0	0	0,0	0,1%	0,0%	0,0%				
NEMetall	51,8	109	0,5	3,8%	2,5%	1,5%	1,9%			
Mineralik	52	13	4,0	0,4%	2,5%	1,5%	1,5%			
Organik	701	993	0,7	34,3%	33,5%	20,6%	20,7%	0,3%	0,1%	4,1%
FT	234	147	1,6	5,1%	11,2%	6,9%	6,5%	19,8%	1,3%	80,9%
NFT	1.052	1.629	0,65	56,3%	50,3%	30,9%	30,7%	0,4%	0,1%	6,8%
Summe sortiert	2.090	2.891	0,72	100,0%	100,0%	61,4%	61,3%	2,4%	1,5%	91,8%
< 15 mm	1.315					38,6%	38,6%	0,3%	0,1%	8,1%
Total	3.405					100,0%	99,9%	1,6%	1,6%	99,9%

Der Chlorgehalt der Sortierprobe kann unter Rückgriff auf die Chlorgehalte der Fraktionen sowie der ermittelten Massengehalte der Fraktionen als Verteilung unter Angabe aller statistischen Rahmendaten dargestellt werden. Sie entsteht durch Aggregation von Stückzahlgehalt, Gewichtsverhältnis von mittlerem Artikelgewicht der Chlorfrachtträger und mittlerem Artikelgewicht aller Bestandteile sowie den Chlorgehalten der Sortierfraktionen.

Die für das untersuchte Material erwartete Verteilung ist in nachfolgender Grafik dargestellt.

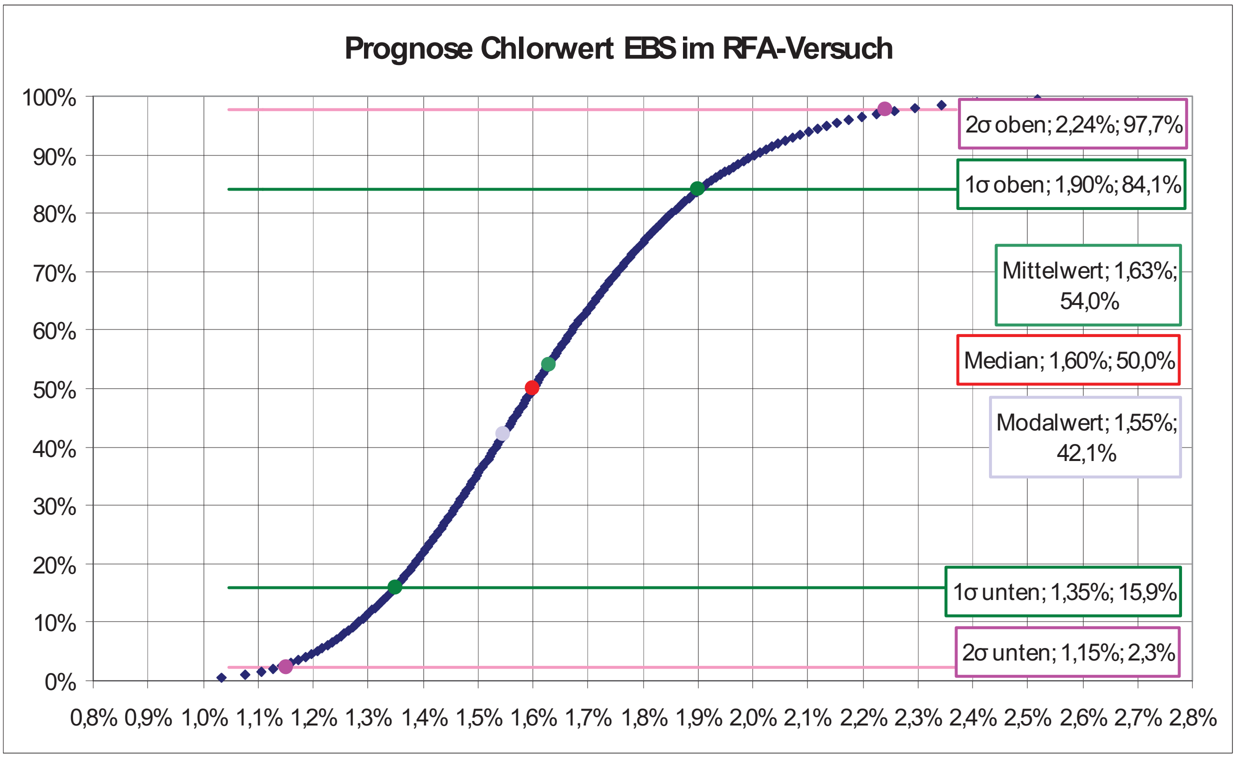

Abbildung 1: Prognose des Chlorgehaltes

3 Röntgenfluoreszenzanalyse

Die RF-Analytik erfolgte durch Herrn Stefan Rutsch von der Firma UBeRU (Umweltberatung Rutsch) mit einem RF-Spektrumanalysator der Serie XL3t 900 des Herstellers Thermo – NITON, der von der Firma AnalytiCON Instruments GmbH in Deutschland vertrieben wird.

Aus der Organikfraktion sowie aus den beiden Kunststofffraktionen wurde jeweils eine größere Zahl von Einzelpartikeln vermessen und verwogen. Die Feinfraktion < 15 mm wurde im Haufwerk analysiert. Im Einzelnen wurden 299 Untersuchungen vorgenommen und ausgewertet. Bezogen auf die Sortierfraktionen handelt es sich um:

- organische Partikeln 53 Stück
- Kunststoffe halogenfrei (NFT) 85 Stück
- Kunststoffe halogeniert (FT) 131 Stück
- < 15 mm im Haufwerk 30 Stück

Die vermessenen Stückzahlen spiegeln nicht die Stückzahlanteile der Gesamtfraktionen wider. Die Fraktionen der Metalle und der Mineralik wurden nicht vermessen.

3.1 Ergebnisse Chlor

In Bezug auf den Parameter Chlor zeigten sich in insgesamt 287 der 299 durchgeführten Einzeluntersuchungen folgende Werte:

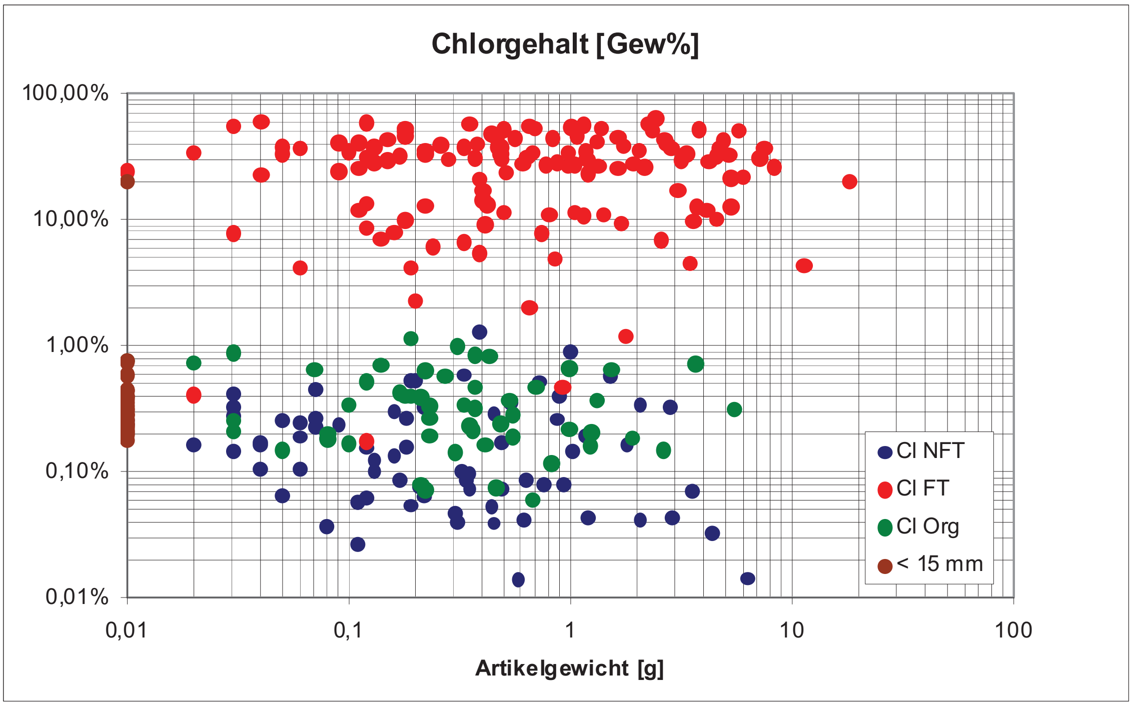

Abbildung 2: Überblick Resultate Chlor

Die Einzelwerte können auch in einer Summenhäufigkeitskurve dargestellt werden:

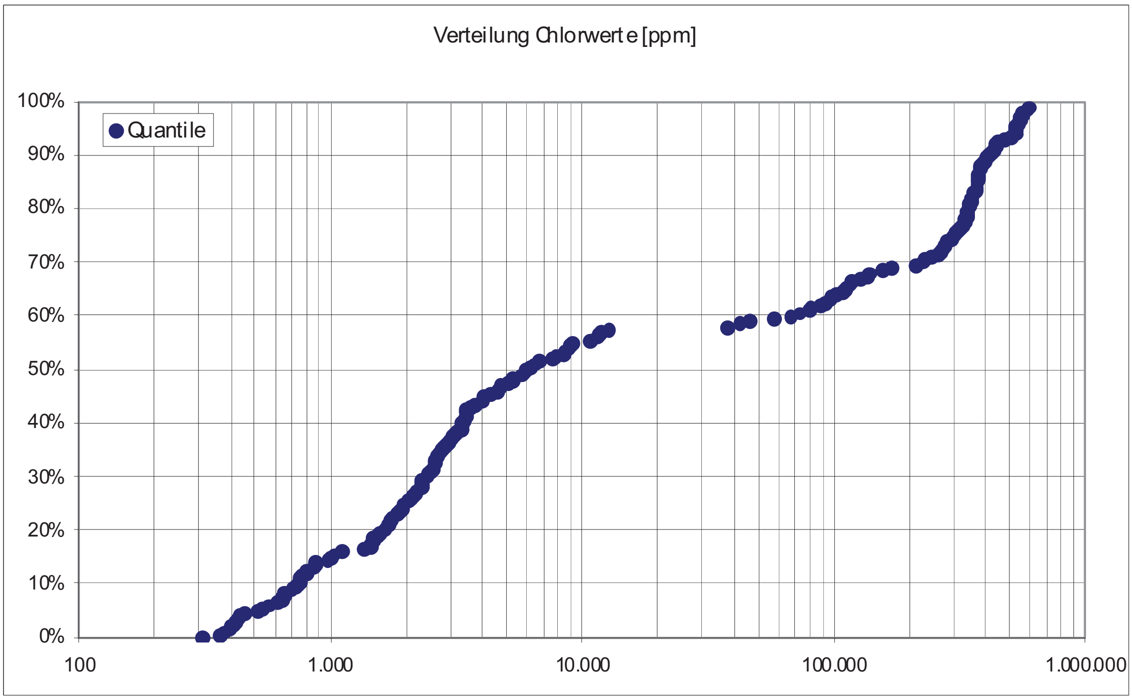

Abbildung 3: Chlorwerte Summenhäufigkeit

Es ist ersichtlich, dass das Element Chlor im Ersatzbrennstoff sehr heterogen verteilt vorliegt. Auffällig ist insbesondere der Schnitt zwischen 2 und 4% Chlorgehalt (20.000 und 40.000 mg/kg). Auf dieser Differenz des Chlorgehaltes basiert die Unterscheidung in Chlorfrachtträger und Nichtfrachtträger. Die genauere Analyse offenbart, dass sich hinter der gefundenen Verteilung der Chlorkonzentrationen möglicher Weise vier verschiedene Einzelverteilungen verbergen.

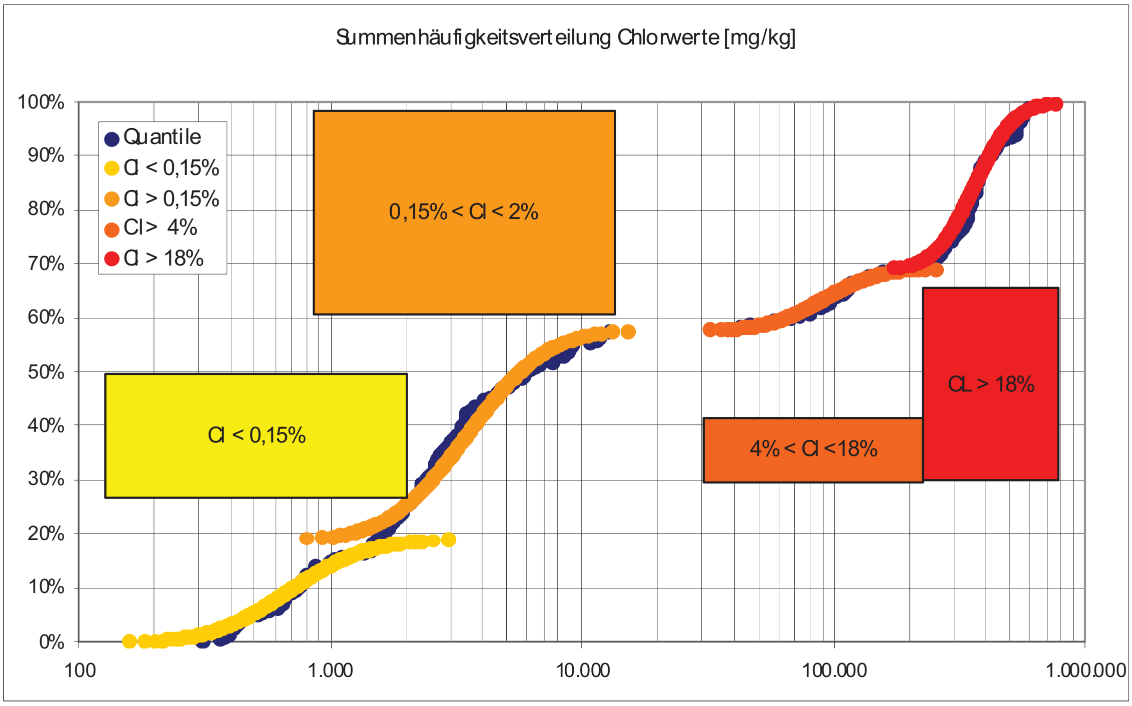

Abbildung 4: Annäherung der Verteilung mit vier Einzelverteilungen

Chlorwerte > 18% finden sich in der Frachtträgerfraktion. Ein einzelner Wert von 22% wurde auch bei der Messung des Haufwerkes < 15 mm ermittelt. Der mit der RFA gemessene mittlere Chlorgehalt liegt bei 37,4%. Der Erwartungswert für das Auftreten hoch chlorierter Artikel liegt bei 3,5%. Es handelt sich wahrscheinlich um PVC.

Die in orange angenäherten Chlorkonzentrationen zwischen 4 und 18% zeigen ein vergleichsweise breites Spektrum. Der mittlere Chlorgehalt liegt bei knapp 10%. Auch diese Partikel finden sich ausnahmslos in der Fraktion der Halogenfrachtträger. Die Häufigkeit des Auftretens dieser Partikel liegt in der Größenordnung von 1,3%. Es könnte sich beispielsweise um halogenierte Gummiprodukte handeln.

Die Chlorgehalte kleiner 2 Gew% lassen sich ebenfalls in zwei Gruppen unterteilen. Die Grenzkonzentration liegt in diesem Fall bei 0,15% bzw. 1.500 mg/kg. Werte unterhalb von 1.500 mg/kg werden vor allem bei Nichtfrachtträgern und vereinzelt bei organischen Partikeln gefunden. Die verbleibenden 29 Chlorwerte für das Haufwerk < 15mm und eine Vielzahl von Messungen organischer Partikeln sowie halogenfreier Kunststoffe finden sich allesamt im Bereich zwischen 0,15 und 0,8% Chlor. Der Mittelwert dieser Verteilung liegt bei etwa 0,4%.

Chlor ist mit Ausnahme einiger halogenfreier Kunststoffe in allen Messungen nachweisbar. Die Frachtträger kommen zu mehr als zwei Dritteln aus dem Bereich PVC sowie zu knapp 30% aus dem Bereich niedriger chlorierter Kunststoffe.

Chlorfrachtträger sind erfahrungsgemäß schwerer als die Durchschnittspartikel und weisen in Bezug auf das Artikelgewicht eine große Streuung auf. Für eine aussagefähige Chlorgehaltsbestimmung (+/- 20% Abweichung vom wahren Wert) wird empfohlen, mindestens 100 Frachtträger in die Analysenprobe zu überführen.

Um auch die Chlorfrachtträger mit Chlorgehalten zwischen 4 und 18% aussagesicher zu berücksichtigen sollte eine Analysenprobe zur Chlorgehaltsbestimmung etwa 7.500 Artikel umfassen.

3.2 Ergebnisse Blei

Bleigehalte sind in insgesamt 67 von 299 Analysen nachweisbar.

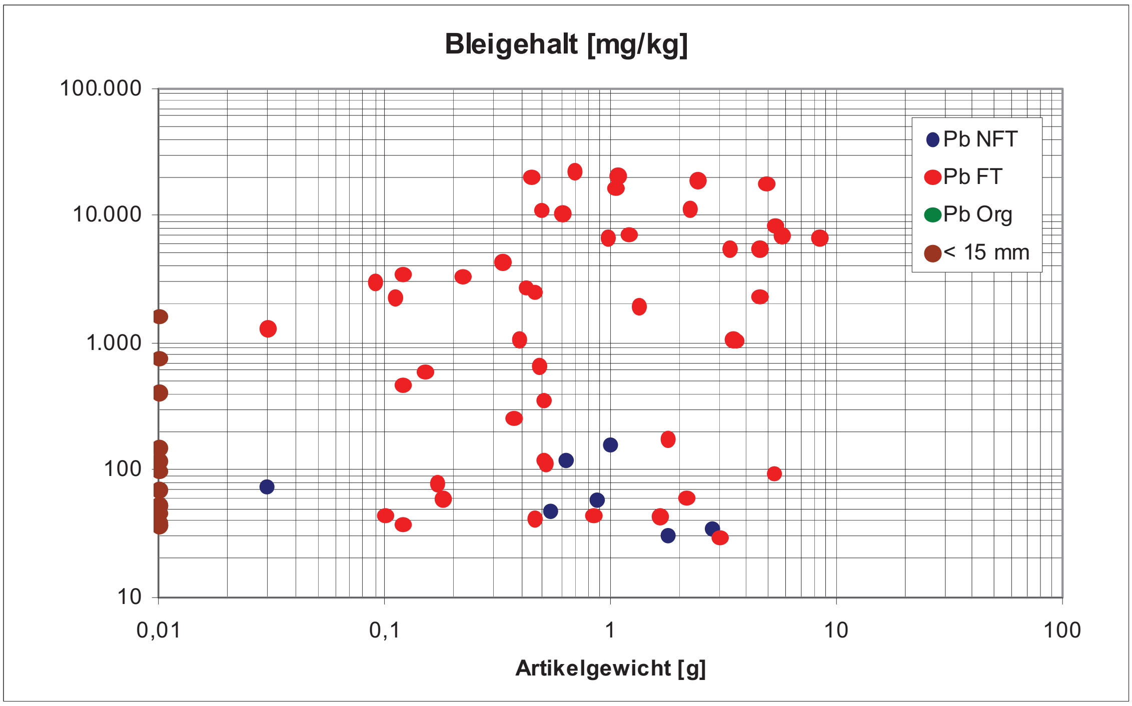

Abbildung 5: Überblick Ergebnisse Blei

Auch die gefundenen Bleiwerte offenbaren die Präsenz verschiedener Verteilungen. Im Bereich der Werte kleiner 200 mg/kg stellt sich ein Mittelwert von etwa 72 mg/kg ein. Diese Werte finden sich in halogenierten und halogenfreien Kunststoffen sowie im Feinkorn < 15 mm.

Bleigehalte > 200 mg/kg finden sich in Bezug auf vermessene Artikel ausschließlich in den halogenierten Kunststoffen. Dort werden Bleiverbindungen als Additiv eingesetzt. Weiterhin weisen drei von 30 Haufwerksanalysen < 15 mm Werte > 200 mg/kg auf. Der Mittelwert der Bleigehalte oberhalb von 200 mg/kg liegt bei etwa 7.000 g/kg.

Insgesamt weisen etwa 1,2% aller Artikel Bleigehalte > 200 mg/kg auf. Für die aussagesichere Bestimmung des Bleigehaltes sollte die Analysenprobe etwa 8.500 Artikel > 15 mm umfassen.

3.3 Ergebnisse Cadmium

Bei einer Nachweisgrenze von 10 mg/kg wurde in 44 Untersuchungen Cd gefunden.

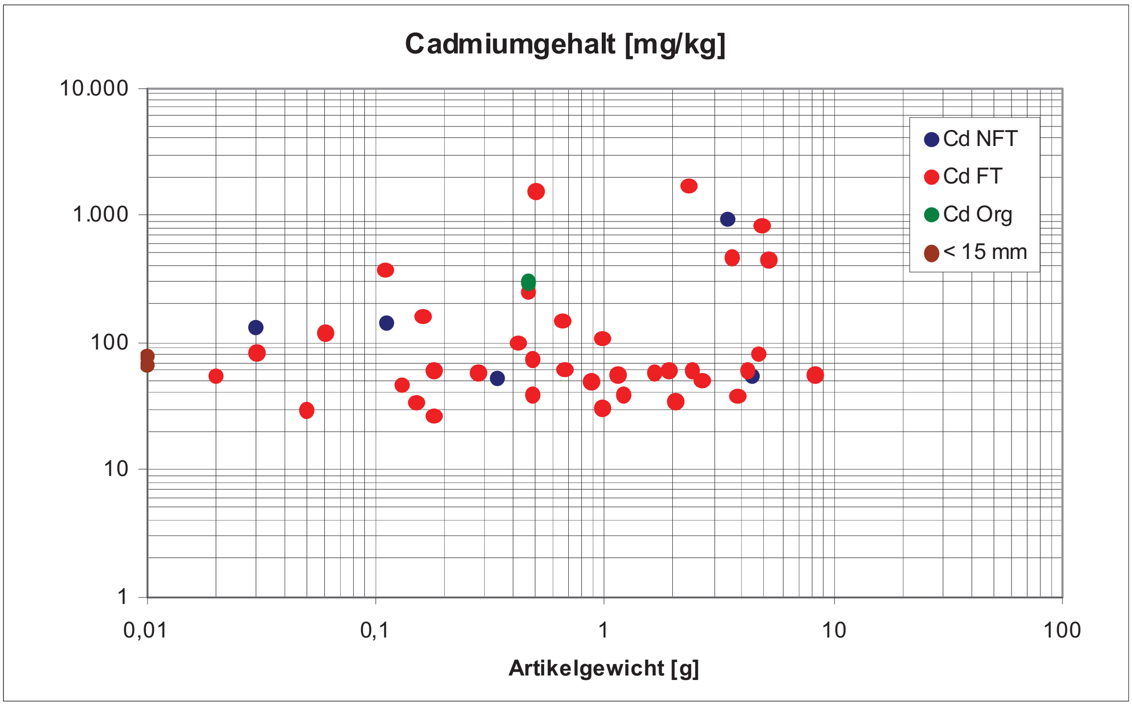

Abbildung 6: Überblick Ergebnisse Cadmium

Die Werte kleiner 80 mg/kg machen 26 der 44 positiven Messungen aus. Zwei Messungen kommen aus dem Haufwerk< 15 mm, zwei weitere Werte entstammen den halogenfreien Kunststoffen. Bei der mit 22 Einzelwerten überwiegenden Anzahl der Messungen handelt es sich um chlorierte Kunststoffe. Der Konzentrationsbereich von 80 bis 160 mg/kg enthält weitere acht Messwerte. Zwei Messwerte finden sich bei den halogenfreien Kunststoffen und 6 Werte bei den halogenierten Kunststoffen.

Im Konzentrationsbereich von 160 bis zu 500 mg/kg werden sechs Werte ermittelt. Davon ergibt sich einer für einen organischen Partikel und fünf für chlorierte Kunststoffe. Cadmiumgehalte größer 500 mg/kg werden in 4 Artikeln nachgewiesen, wovon einer zu den halogenfreien und drei zu den halogenierten Kunststoff zählen.

Diese Befunde decken sich mit der Präsenz von Cadmiumverbindungen als Stabilisator im PVC sowie als Pigment in Kunststoffen. Die Belastung im organischen Partikel ist nicht unmittelbar erklärlich.

Unter der Zielsetzung 100 Frachtträger in eine Analysenprobe zu überführen, ergeben sich Probenumfänge in der Größenordnung von 13.000 Artikeln bzw. 15 kg Probenmasse des hier betrachteten Beispiels. Bei geringerem Probenumfang kann die Präsenz von Artikeln mit hoher Fracht den Analysenwert signifikant beeinflussen.

3.4 Ergebnisse Antimon

Ein Antimongehalt ist in 61 der 299 Untersuchungen nachweisbar.

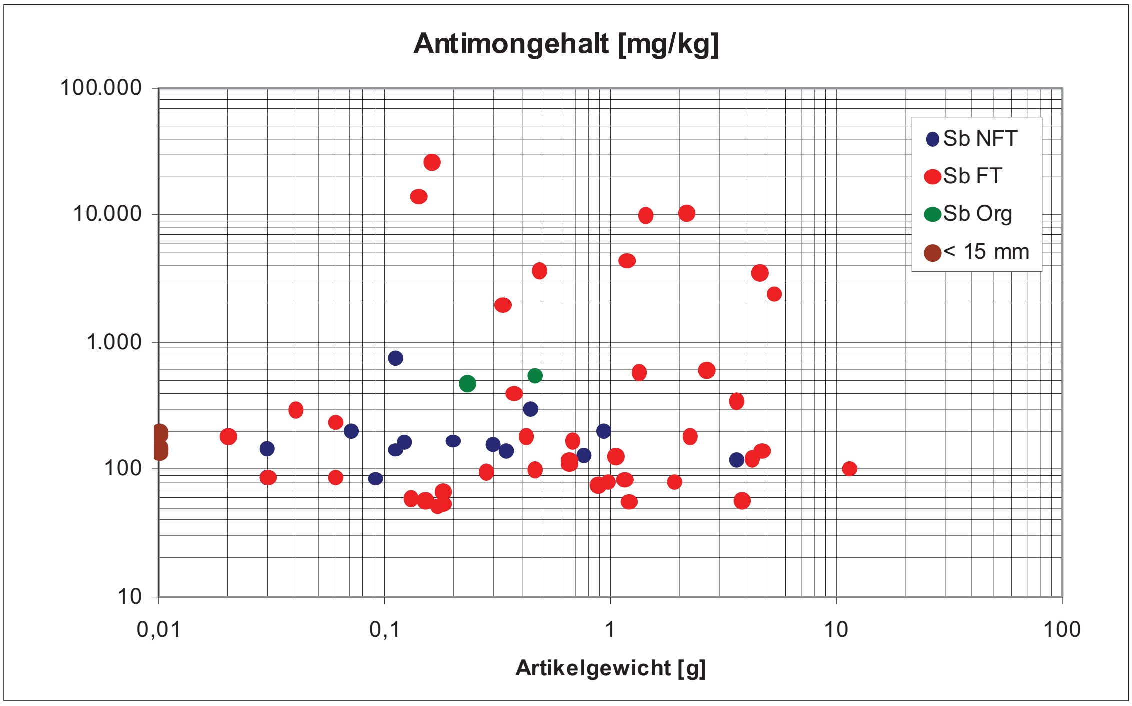

Abbildung 7: overview results for antimony

40 der 61 Analysenwerte liegen bei Werten < 200 mg/kg, Es handelt sich um 6 nicht halogenierte Kunststoffe sowie 29 Analysen aus dem Bereich der chlorierten Kunststoffe. Fünf Analysen stammen aus der Haufwerksmessung < 15 mm. Der mittlere Antimongehalt dieser Verteilung liegt bei 117 mg/kg,

Die 12 Analysen mit Werten zwischen 200 und 800 mg/kg Antimon entstammen den Fraktionen NFT (4), FT (6) und überraschender Weise Organik (2). Der mittlere Antimongehalt dieser Werte liegt bei etwa 420 mg/kg.

Werte > 800 mg/kg finden sich in neun Fällen. Es handelt sich in allen Fällen um Partikel aus der Fraktion der chlorierten Kunststoffe. Hier werden Antimongehalte zwischen 0,5 und 2,5 Gew% angetroffen. Sehr wahrscheinlich entstammen diese hohen Konzentrationen der Anwendung von Antimon als Flammschutzmittel.

Der Stückzahlgehalt ist mit nur 3 von eintausend Artikeln sehr gering. Für eine aussagesichere Bestimmung des Elementgehaltes sind daher sehr hohe Probenmengen erforderlich. In diesem Fall wird ein Probenumfang von > 32.000 Artikeln empfohlen.

Es ist sehr wahrscheinlich, dass die Schwierigkeiten bei der Erzeugung reproduzierbarer Antimonwerte in Ersatzbrennstoffen [FLAMME 2009] auf die beschriebenen Aspekte zurückgehen.

3.5 Ergebnisse Chrom

Für das Element Chrom liefern 110 der 299 Analysen Werte.

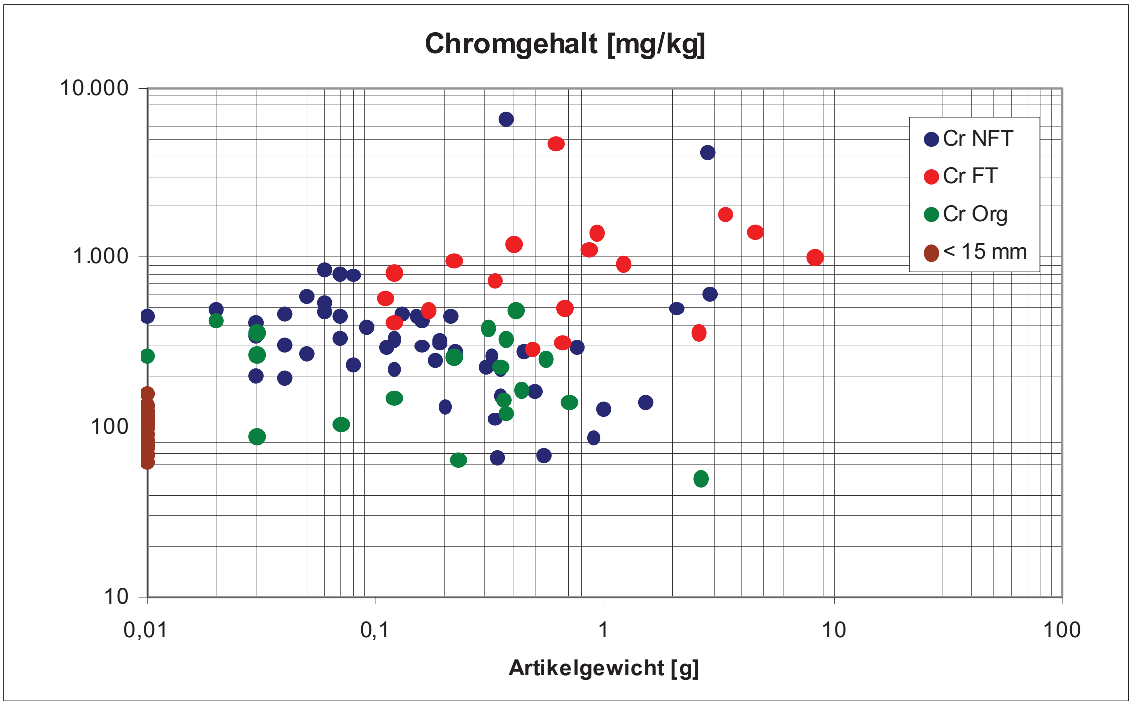

Abbildung 8: Überblick Ergebnisse Chrom

Auch hier zeigt sich eine sehr differenzierte Verteilung:

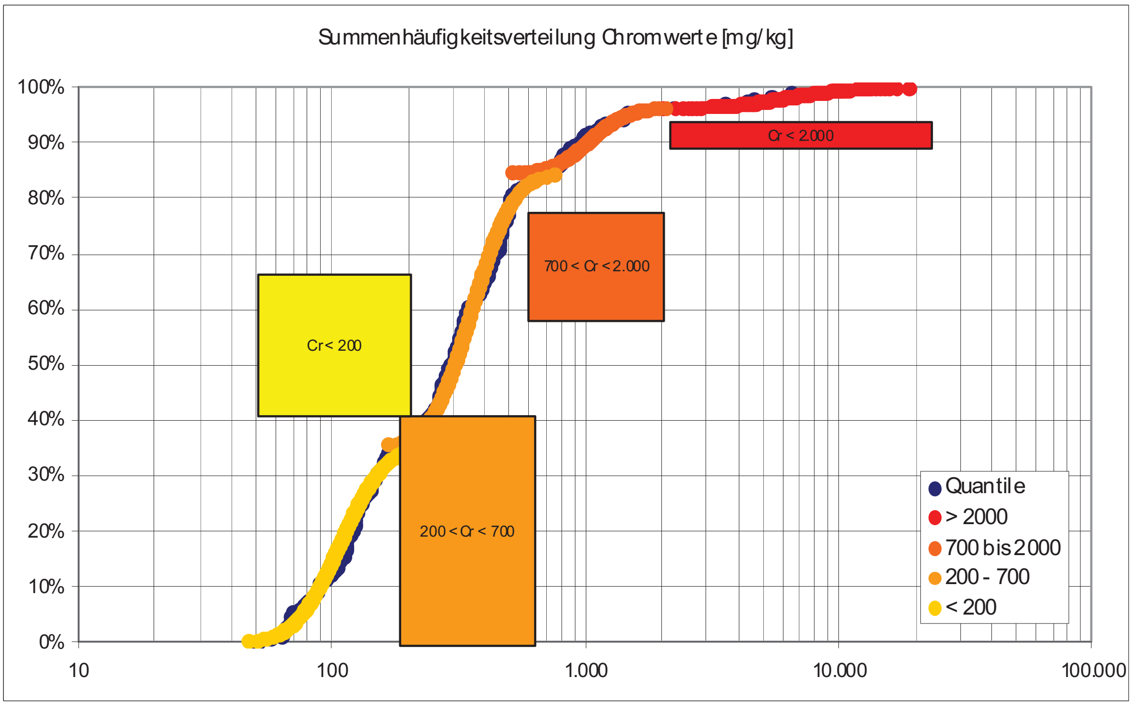

Abbildung 9: Näherung der Verteilung für Chrom mit vier Einzelverteilungen

Auf Werte < 200 mg/kg entfallen 39 Analysen. Dort finden sich alle Haufwerksanalysen, 9 von 19 Organikwerten sowie 10 der 53 NFT-Werte. Der Mittelwert liegt bei 112 mg/kg. Der Bereich zwischen 200 und 700 mg/kg umfasst 54 Werte, davon kommen 37 aus der Gruppe NFT, 10 aus organischen Partikeln und 7 aus der Gruppe der halogenierten Kunststoffe. Der mittlere Chromgehalt liegt hier bei etwa 370 mg/kg.

Echte Frachtträger finden sich im Bereich oberhalb von 700 mg/kg. Im Bereich bis 2.000 mg/kg liegen 13 Werte bei einem Mittelwert von 1.070 mg/kg, Alle Werte sind kunststoffgebunden. 10 stammen aus halogenierten Kunststoffen, 3 aus halogenfreien. Im Bereich oberhalb von 2.000 mg/kg finden sich noch vier Werte. Drei davon entstammen den NFT und einer der Gruppe FT. Der mittlere Chromgehalt erreicht einen Wert von 6.700 mg/kg bzw. 0,67%. Hier könnte es sich um chromhaltige Pigmente handeln.

Die Stückzahlhäufigkeit erreicht Werte zwischen 4 und 5%, so dass eine 5.000 Artikel umfassende Analysenprobe akzeptable Aussagesicherheiten liefern sollte.

3.6 Ergebnisse Zink

Beim Zink liefern 179 von 299 Messungen Ergebnisse.

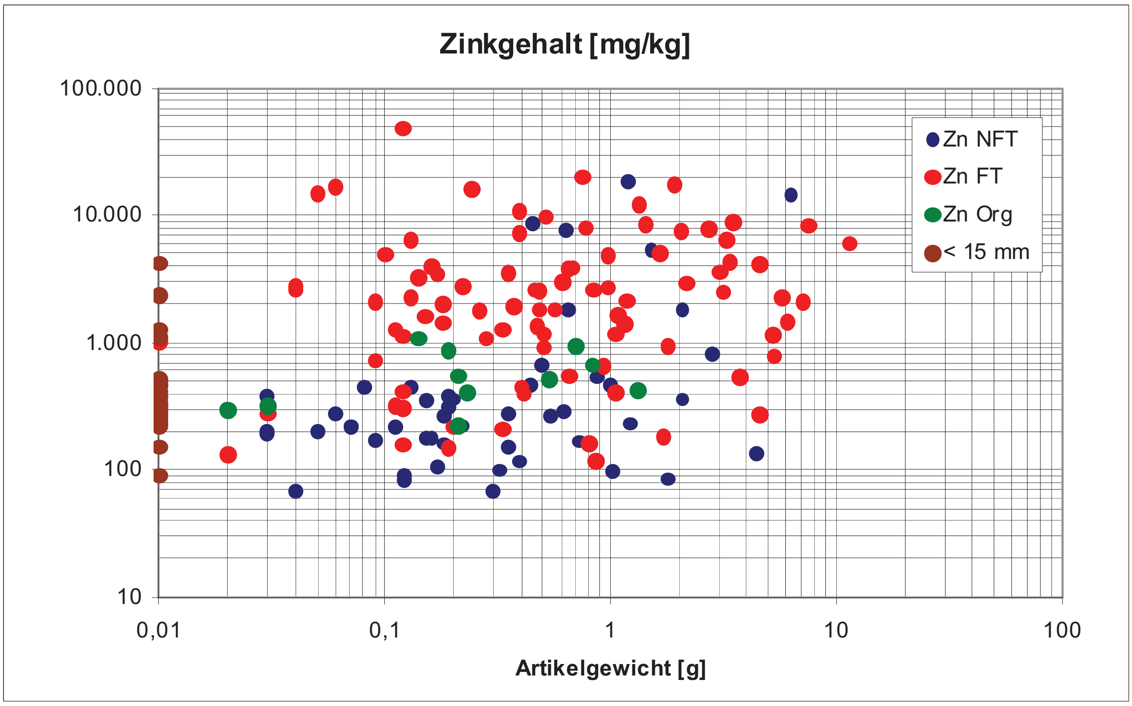

Abbildung 10: Überblick Ergebnisse Zink

Eine akzeptable Kategorisierung ergibt sich für eine Einteilung in drei Bereiche.

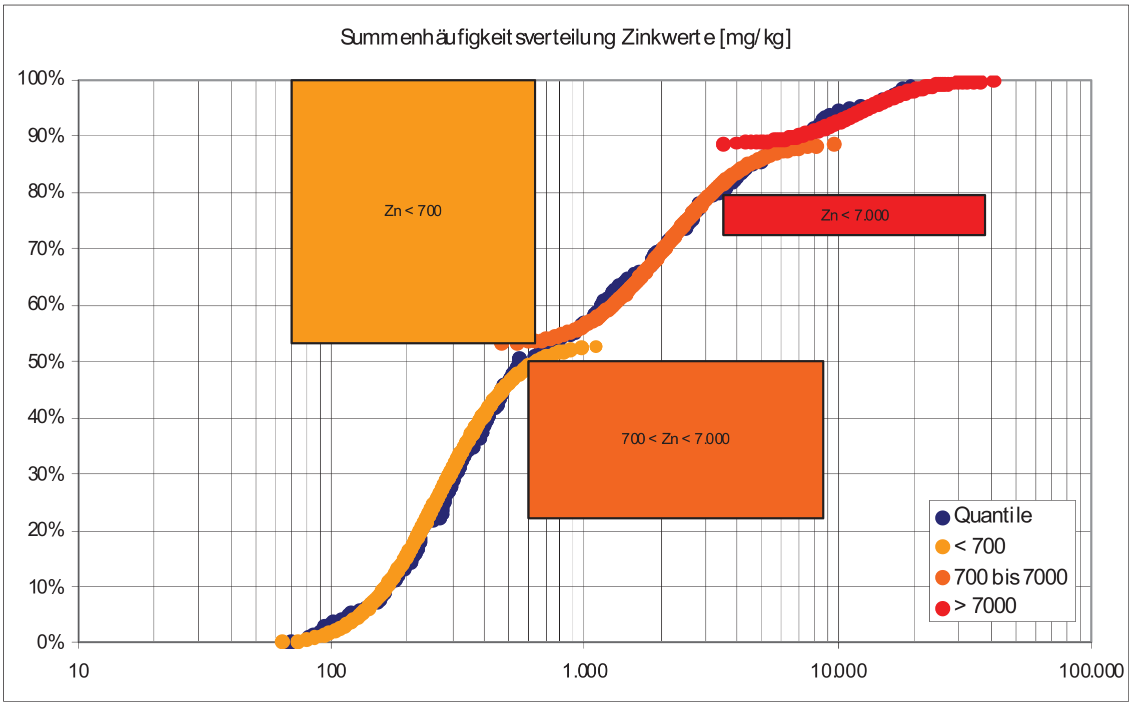

Abbildung 11: Näherung der Verteilung für Zink durch drei Einzelverteilungen

Der Bereich bis 700 mg/kg umfasst insgesamt 95 Werte. Es handelt sich um 23 von 27 Haufwerksmessungen < 15 mm sowie 45 von 53 Messungen halogenfreier Kunststoffe. Die Organik liefert in diesem Bereich 8 von insgesamt 11 Messungen und die halogenierten Kunststoffe steuern 19 von insgesamt 88 Messungen bei. Der mittlere Zinkgehalt ergibt sich zu etwa 300 mg/kg.

Das mittlere Spektrum deckt von Bereich von 700 bis 7.000 mg/kg Zink ab. Hier finden sich 64 Analysen, von denen die halogenierten Kunststoffe mit 53 den Haupanteil liefern. Aus allen anderen Bereichen kommen 3 bzw. 4 Werte. Der Mittelwert liegt hier bei etwa 2.500 mg/kg,

Im Bereich oberhalb von 7.000 mg/kg finden sich noch 20 Werte. Sie stammen zu 80% aus halogenierten und zu 20% aus halogenfreien Kunststoffen. Der mittlere Zinkgehalt liegt hier bei 1,35% bzw. 13.500 mg/kg.

Zinkverbindungen werden sowohl als PVC-Additiv als auch als Füllstoff bzw. Weißpigment eingesetzt. Aufgrund der Tatsache, dass sieben von einhundert Artikeln einen signifikanten Zinkgehalt aufweisen, sind vergleichsweise geringe Probenumfänge erforderlich.

4 Frachtanteile und empfohlene Mindestprobenmassen

Ein Vergleich der durch die unterschiedlichen Konzentrationsfenster eingetragenen Elementfrachten zeigt, dass mehr als 50% der Gesamtfracht der Elemente von sehr wenigen Partikeln mit hoher Elementkonzentration eingetragen werden.

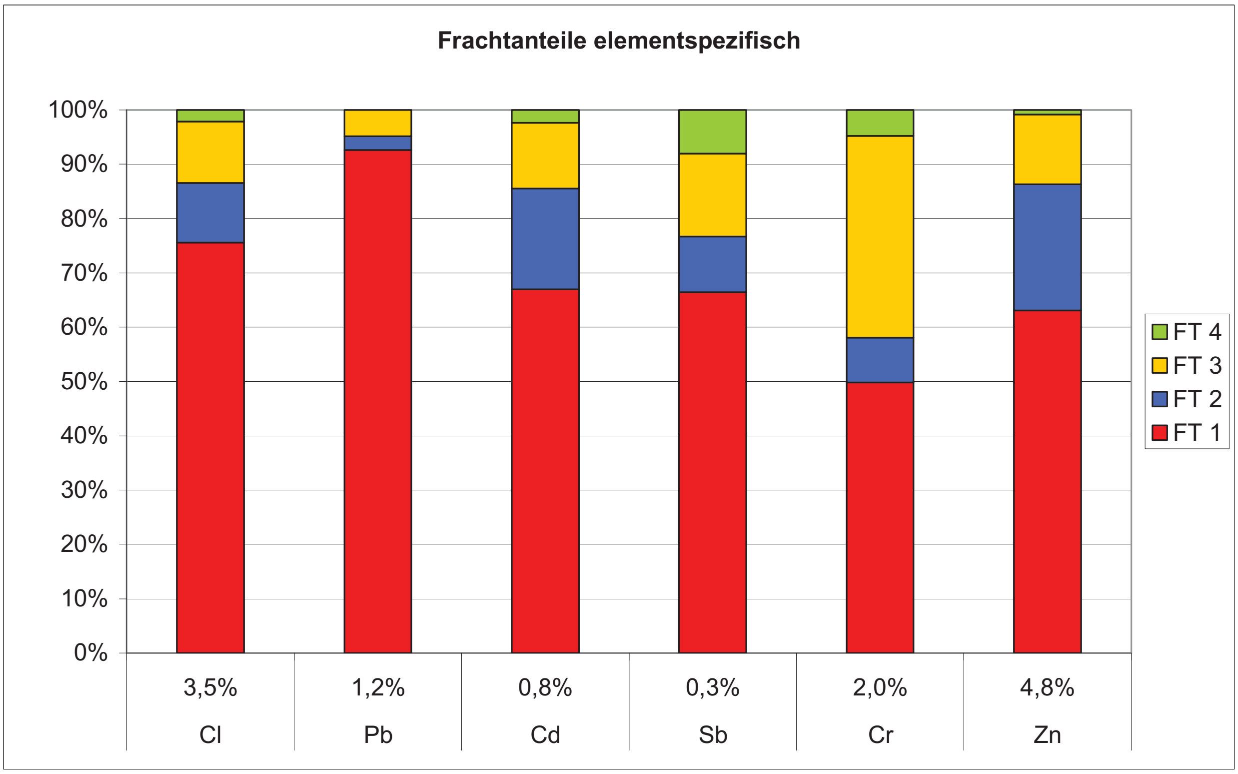

Abbildung 121: Elementspezifische Frachtanteile für einzelne Konzentrationsfenster

Während der Frachtanteil des Fensters mit hohen Konzentrationen für Chrom etwa 50% der Gesamtfracht ausmacht, sind es für die Elemente Zink, Antimon und Cadmium bereits zwischen 60 und 70%. In Bezug auf Chlor werden mehr als 80% der Fracht von PVC-Artikeln eingetragen. Beim Blei kann es sogar um die 90% sein.

Damit wird klar, dass die in einer Einzelanalyse gemessenen Konzentrationen für die einzelnen Elemente unterschiedliche Aussagesicherheiten aufweisen. Oder anders herum formuliert: Um einen gewissen Grad an Aussagesicherheit zu erreichen ist für jedes einzelne Element ein spezifischer Probenumfang erforderlich.

Die nachfolgende Abbildung vergleicht die empfohlenen Mindestprobenmassen für den betrachteten Ersatzbrennstoff basierend auf der Anforderung, elementspezifisch die Gegenwart von 100 Frachtträgern in einer Analysenprobe sicherzustellen.

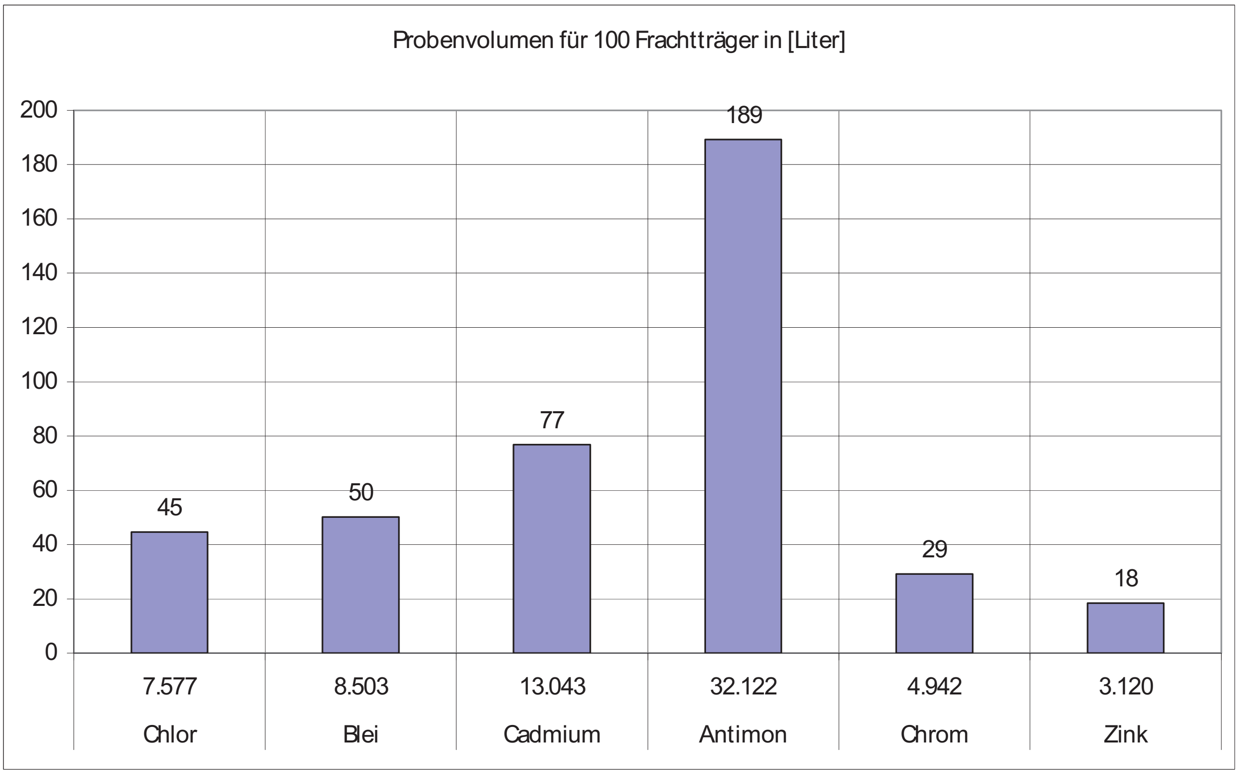

Abbildung 132: Empfohlene Mindestprobenmassen für 100 Frachtträger

Der Vergleich zeigt, dass für den betrachteten Ersatzbrennstoff mit einer Kantenlänge von d_{95} < 50 mm Probevolumina von weniger als 20 Litern nicht ratsam sind. eine Probe von 50 Litern führt für die Elemente Zink, Chrom, Blei und Chlor zu akzeptablen Ergebnissen, während die Ergebnisse für Cadmium und Antimon nicht den gleichen Grad an Aussagesicherheit erreichen. Die Ergebnisse können die „wahren Werte“ der Elementgehalte sehr leicht unter- oder aber auch überschreiten.

Eine Probe von 190 Litern ist in diesem Fall erforderlich, um einen ähnlich Aussagesicheren Antimonwert zu generieren. Dabei ist zu beachten, dass die Probe keinesfalls ohne vorhergehende Zerkleinerung verjüngt werden darf.

Die Kombination von stückbezogener Röntgenfluoreszenzanalyse und Sortieranalyse führt auf einige interessante Ergebnisse hinsichtlich der Quellen für einzelne Elementfrachten. Der Versuch eine schnelle Vor-Ort-Messung zu erreichen, führte letztendlich nicht zu Erfolg. Für die hier vorgefundenen Partikelgrößen kann die RFA lediglich Screeningwerte liefern. Für die aussagesichere Definition von Elementgehalten ist entweder eine extrem hohe Zahl von Einzelanalysen oder aber eine Zerkleinerung des Materials erforderlich.

Die mobile RFA findet ihr Einsatzgebiet in erster Linie bei der Identifikation einzelner großer Frachtträger. Hier leistet sie sehr wertvolle Dienste.

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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

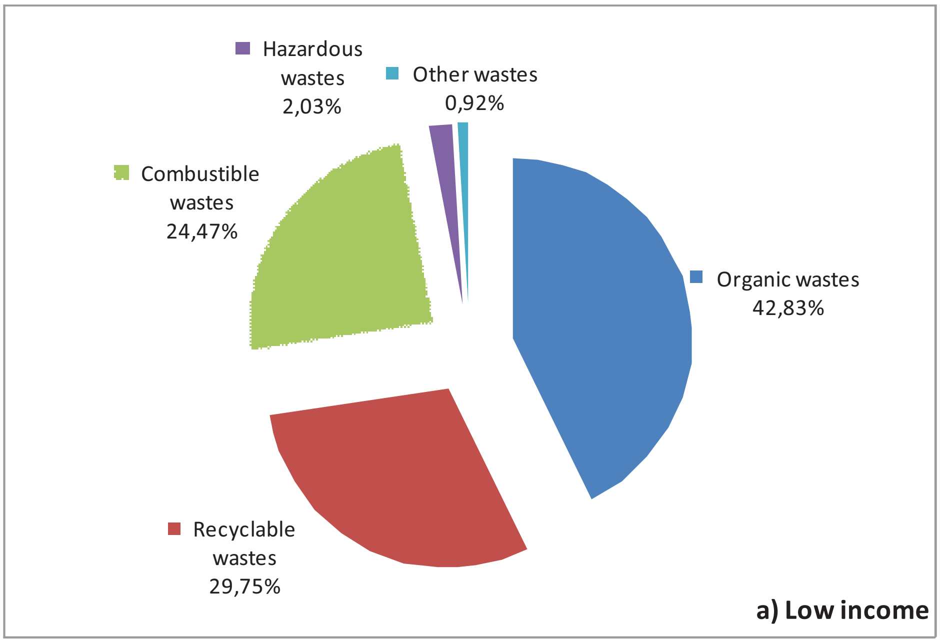
Waste class	Waste components	Waste constituents
Organic	Kitchen wastes	Food wastes, bread, fruits, vegetables
	Yard wastes	Yard trimmings, leaves, grass, crop residues
Recyclable	Paper	Newspaper, magazines, office paper
	Cardboard	Milk boxes, juice boxes
	Cardboard boxes	Various types of cardboard boxes
	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

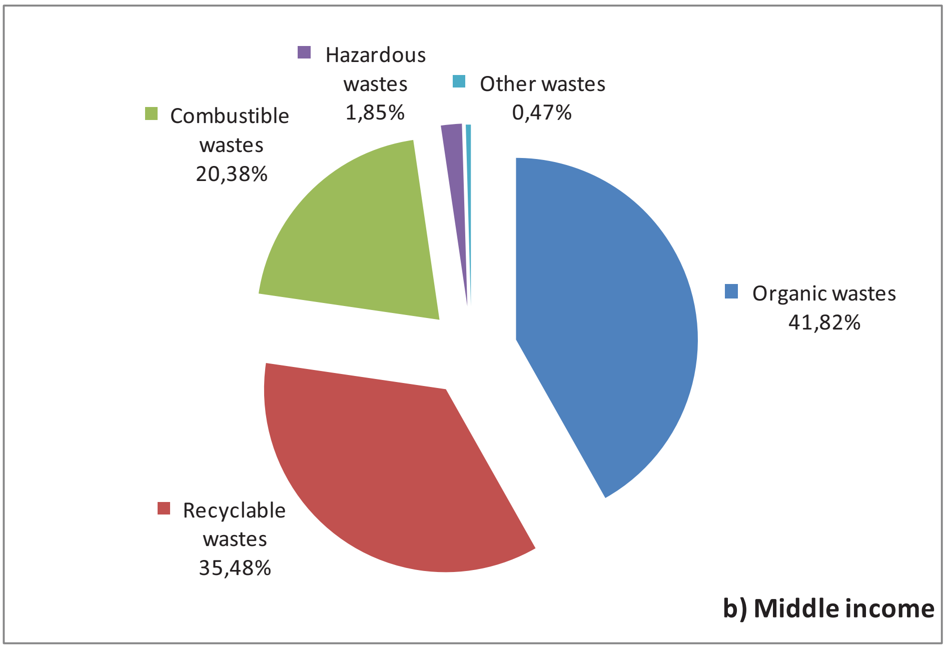
The sampling is repeated in summer and winter of 2008. Approximately 1 m^3 of samples are taken from the collection vehicles at disposal sites. To carry out the analysis, the wastes in the samples are sorted according to the 17 categories listed in Table 1. In the sorting process, each type of waste 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.

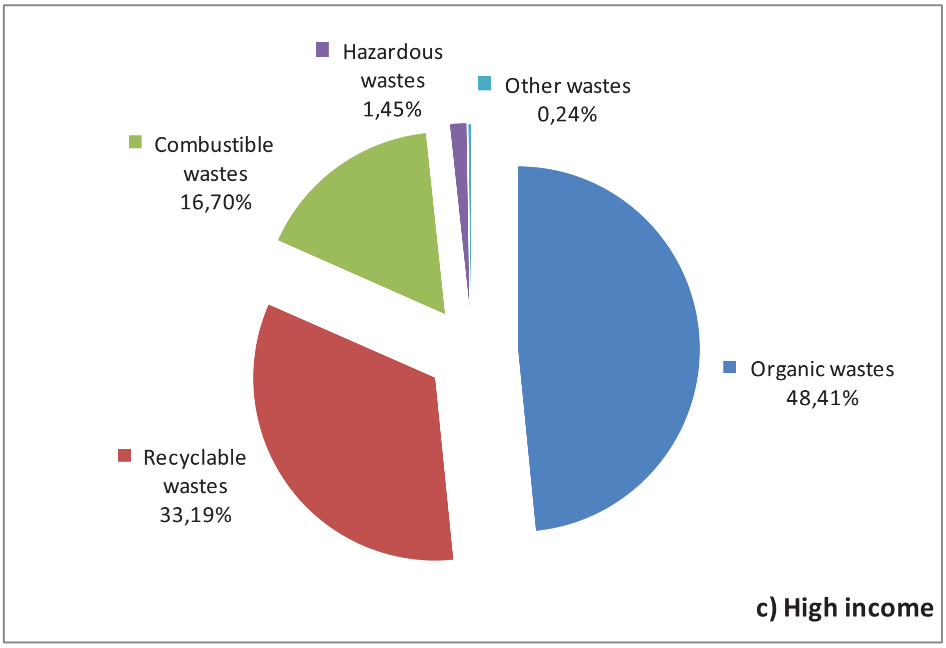
Figure 2 MSW Sorting process

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.







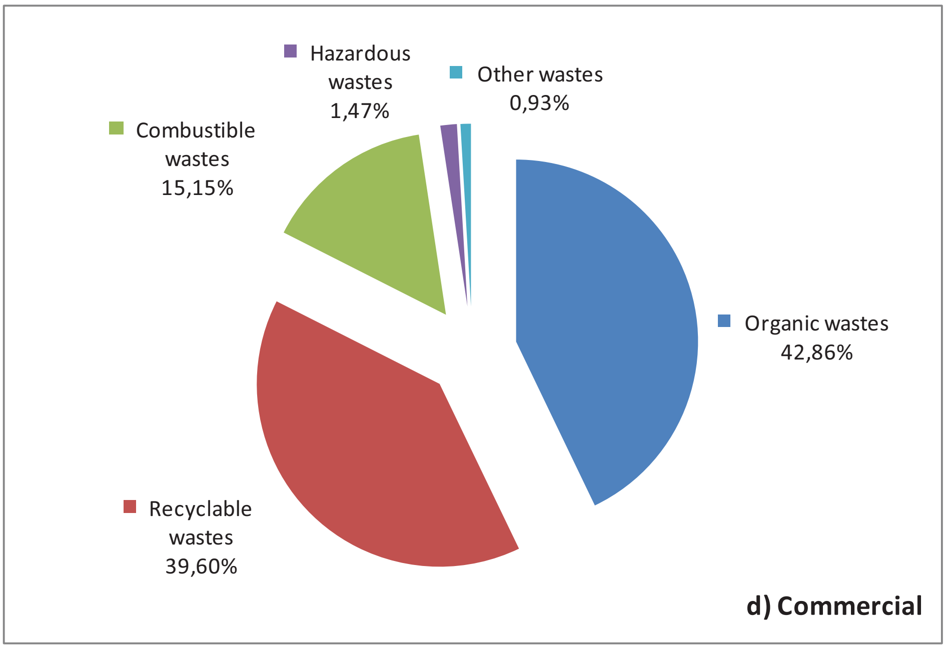
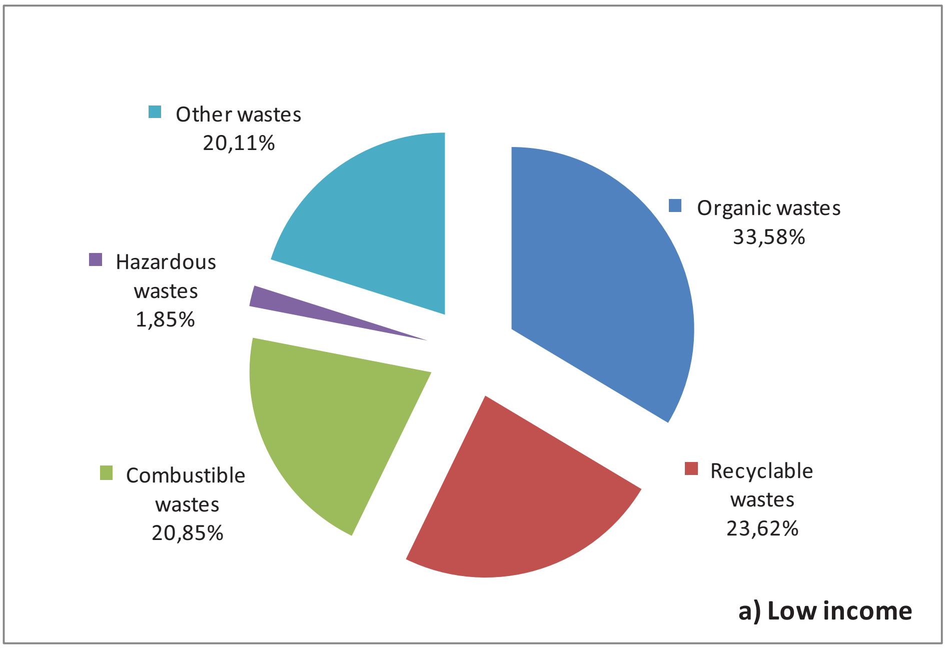
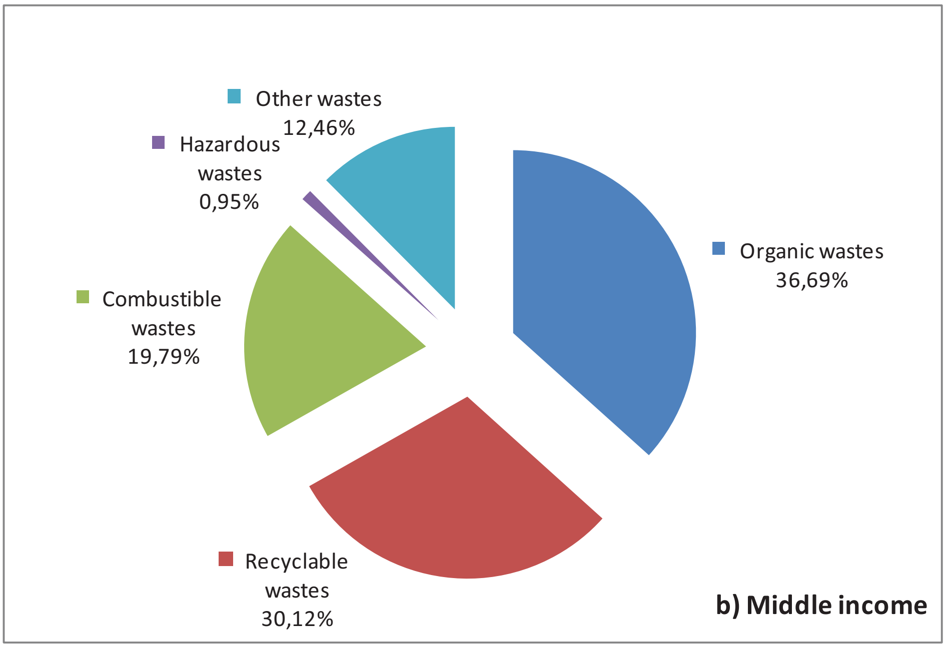


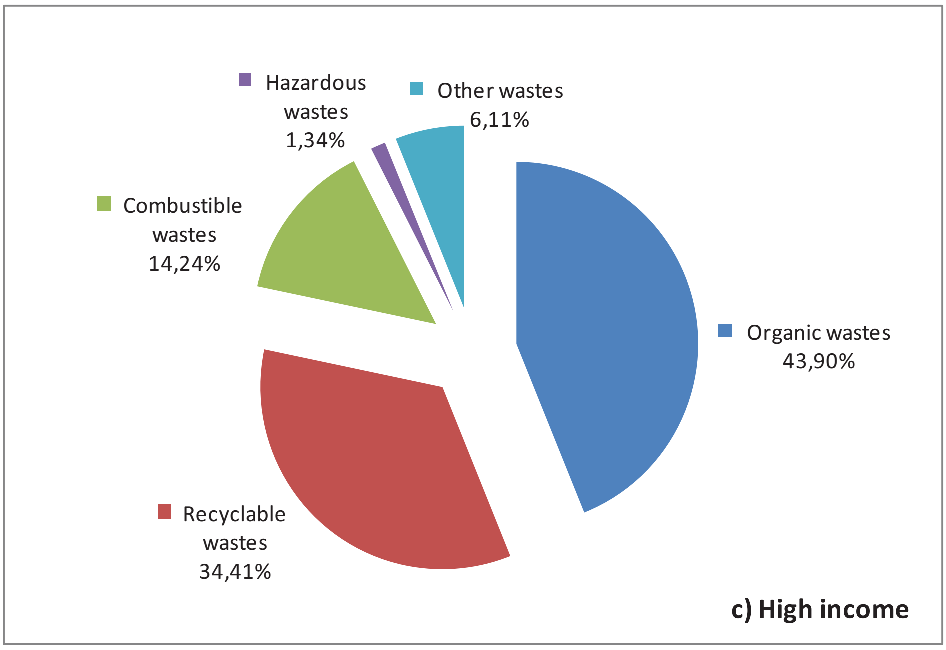
Figure 3 Average MSW compositions for Kocaeli in sumer

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.







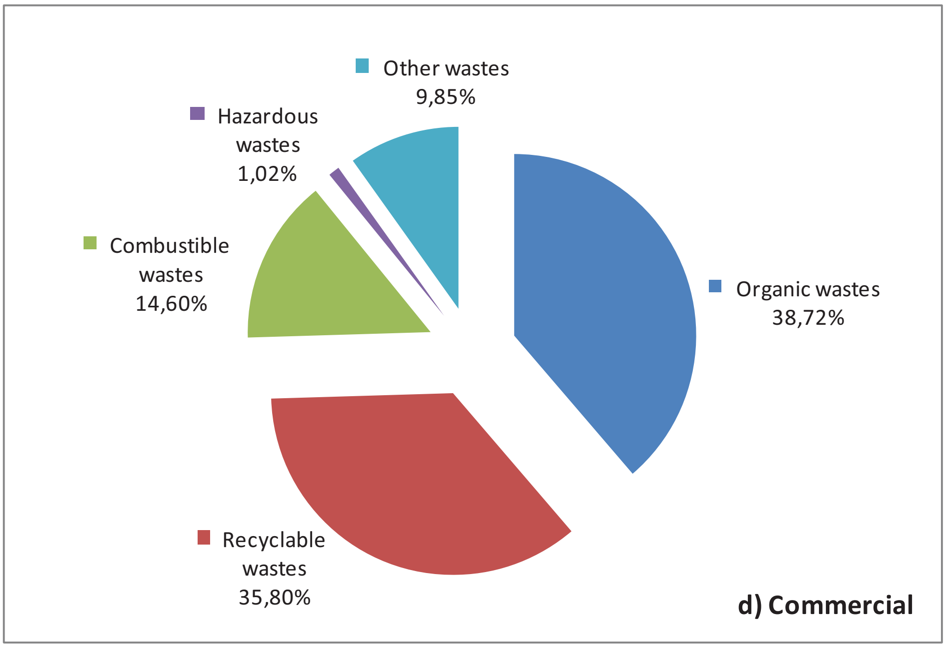


Figure 4 Average MSW compositions for Kocaeli in winter

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.

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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).

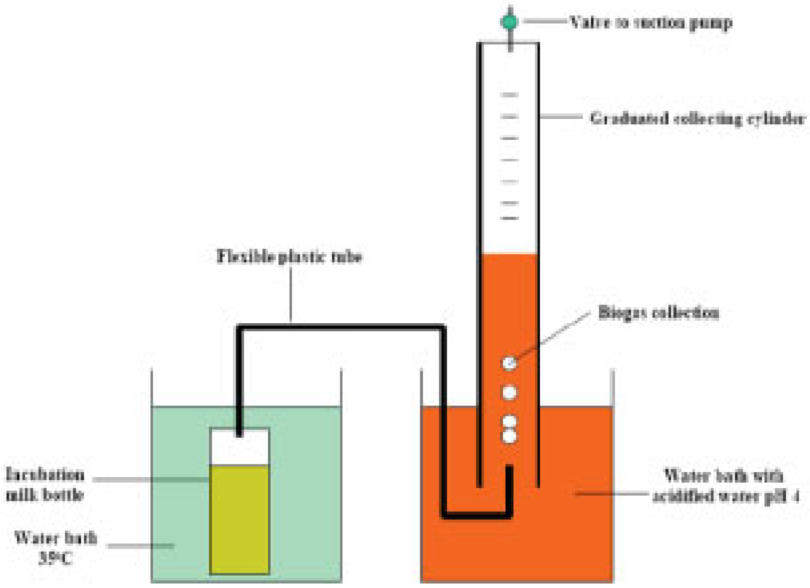

Figure 1: Schematic of BM100 method set up

<u>Dynamic Respiration Rate (DR4)</u>

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.

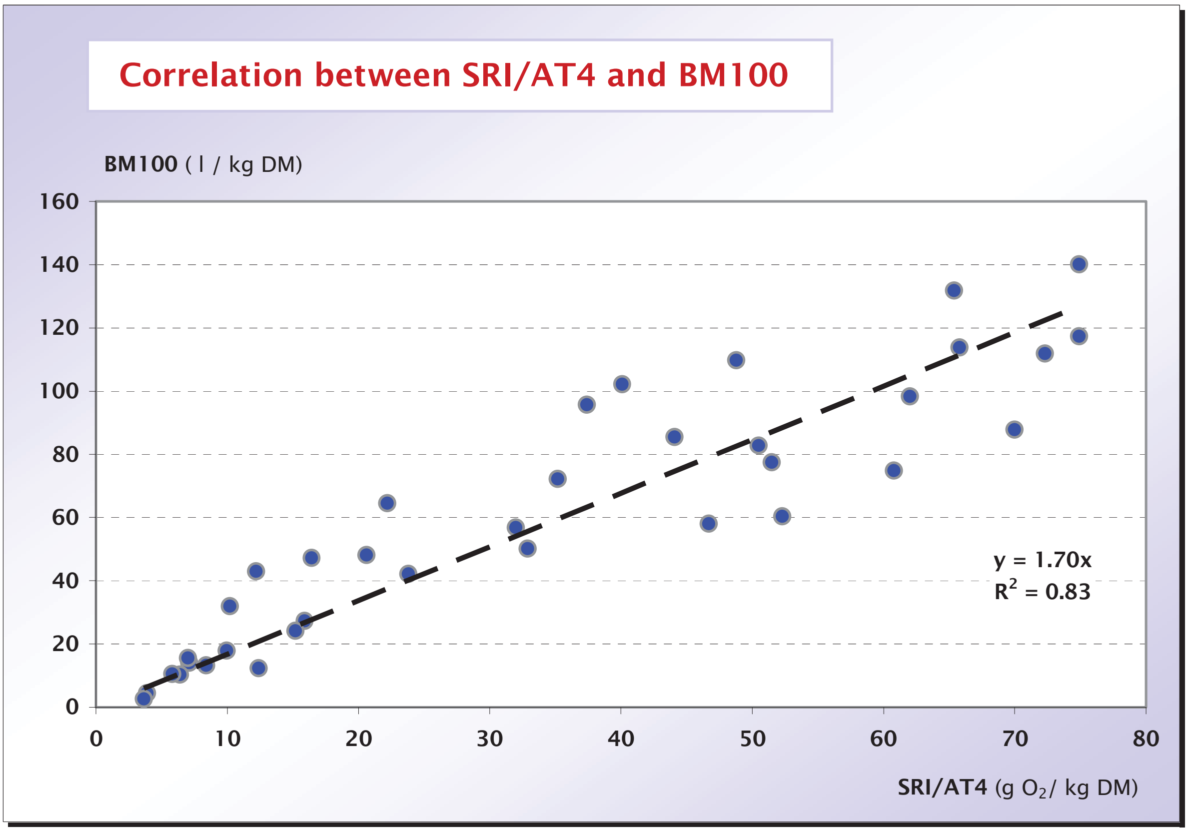

Figure 5: Correlation between SRI/AT4 and BM100

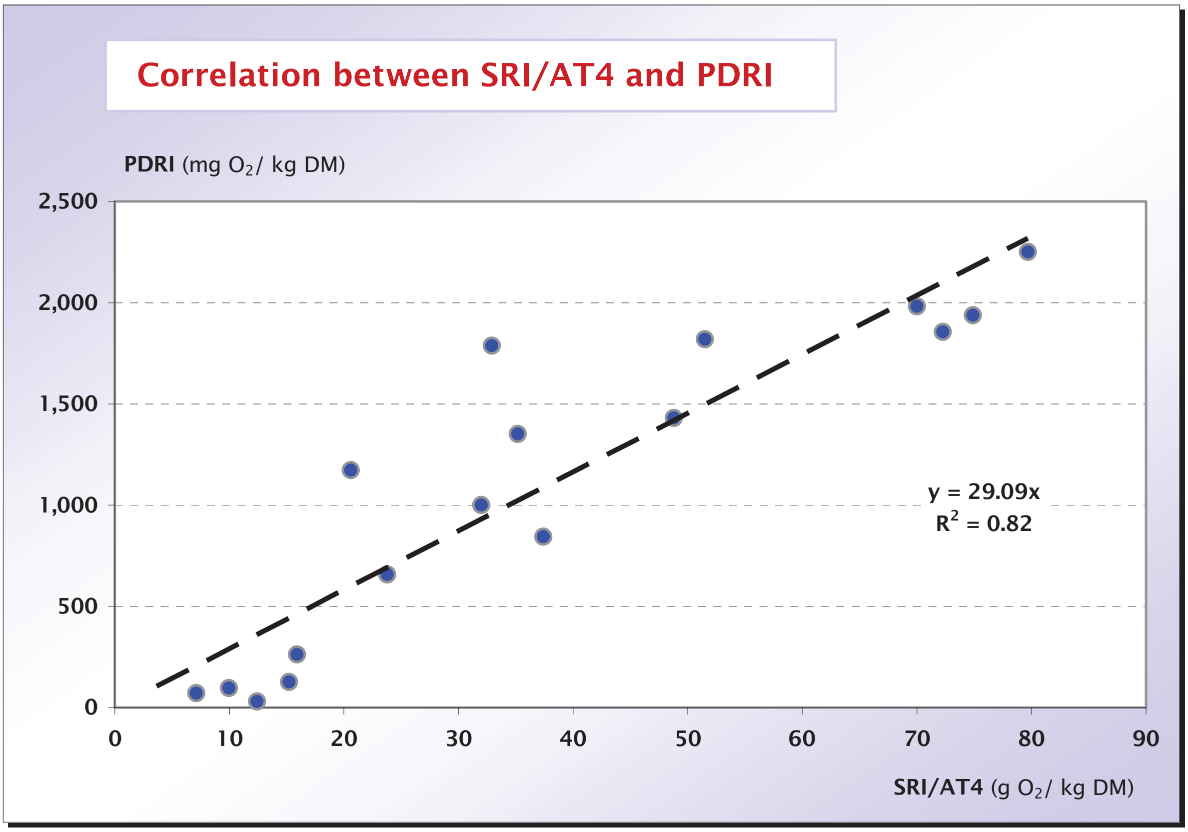

Figure 6: Correlation between SRI/AT4 and PDRI

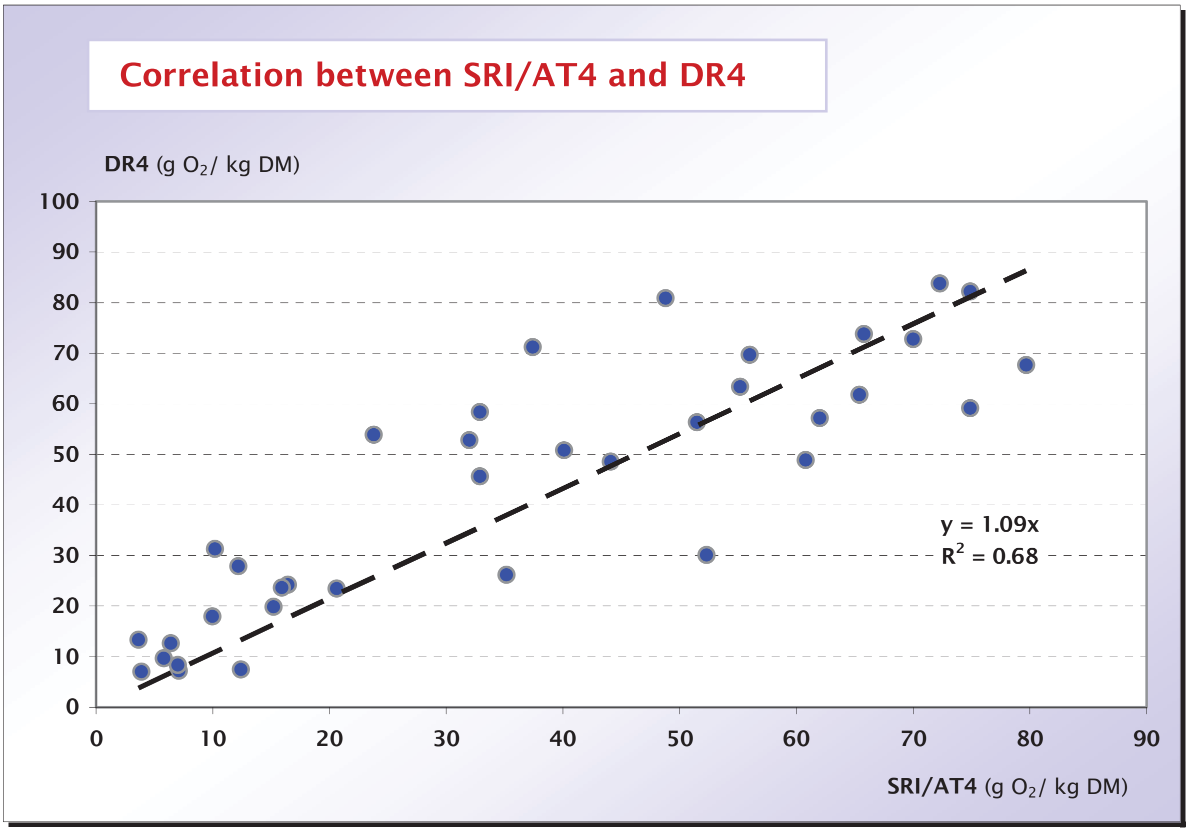

Figure 7: Correlation between SRI/AT4 and DR4

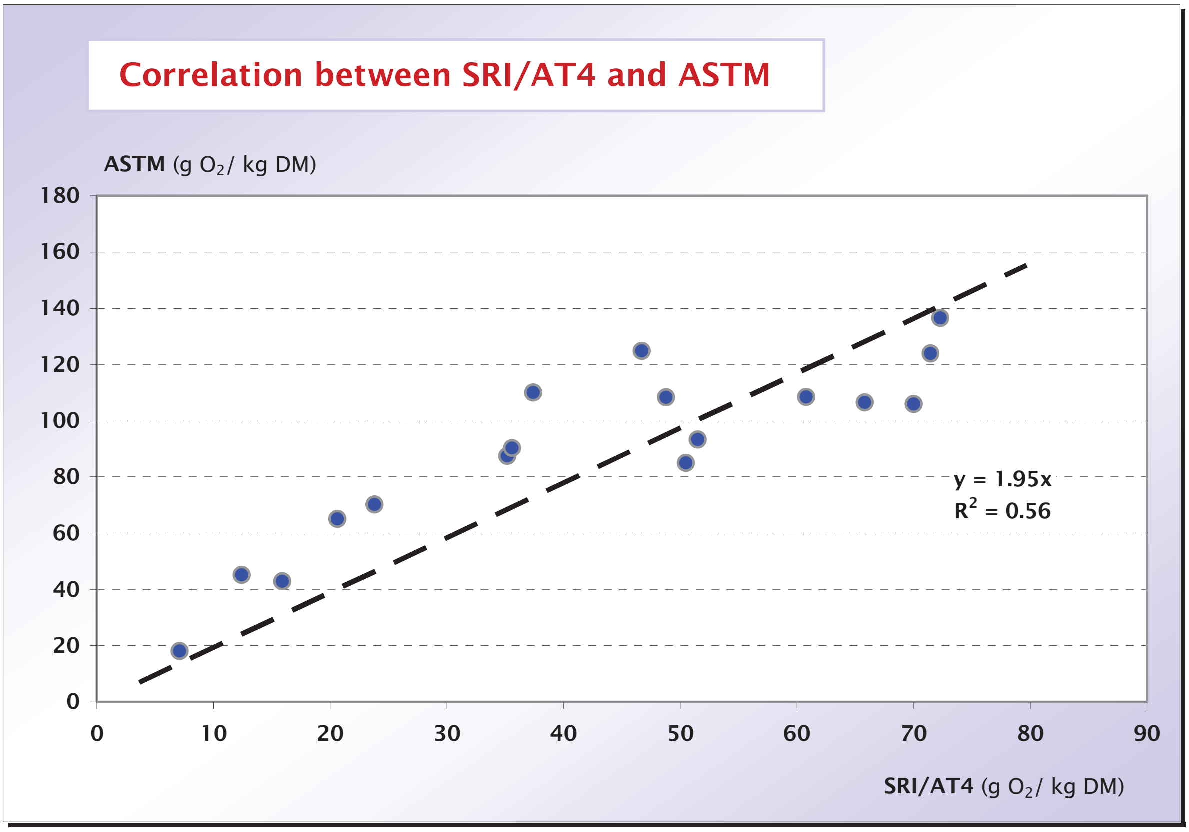

Figure 8: Correlation between SRI/AT4 and ASTM

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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:

$$|Z_{1,2}| = \sqrt{(G_m + 2G_i)^2 + (1/\pi \bullet f \bullet C_1)^2} \quad (1)$$

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.

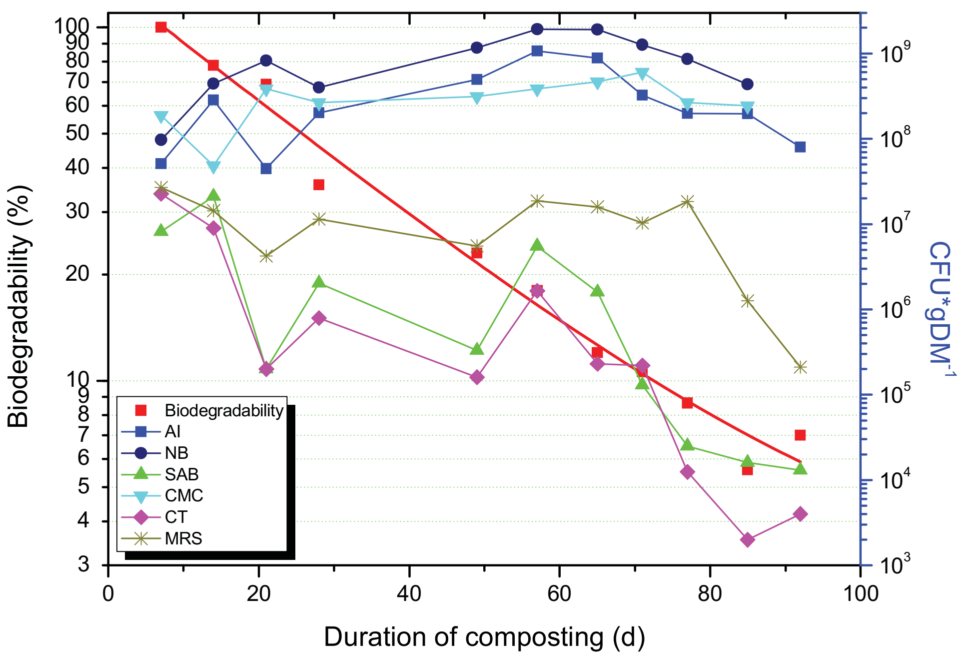

Figure 1: example for Germ count biodegradability (RA_4) AI – Actinomycetes, NB – total germ count, SAB - Fungi, CMC – Cellolytic MO´s, CT – Arthrobacter, MRS – Lactobacillales.

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.

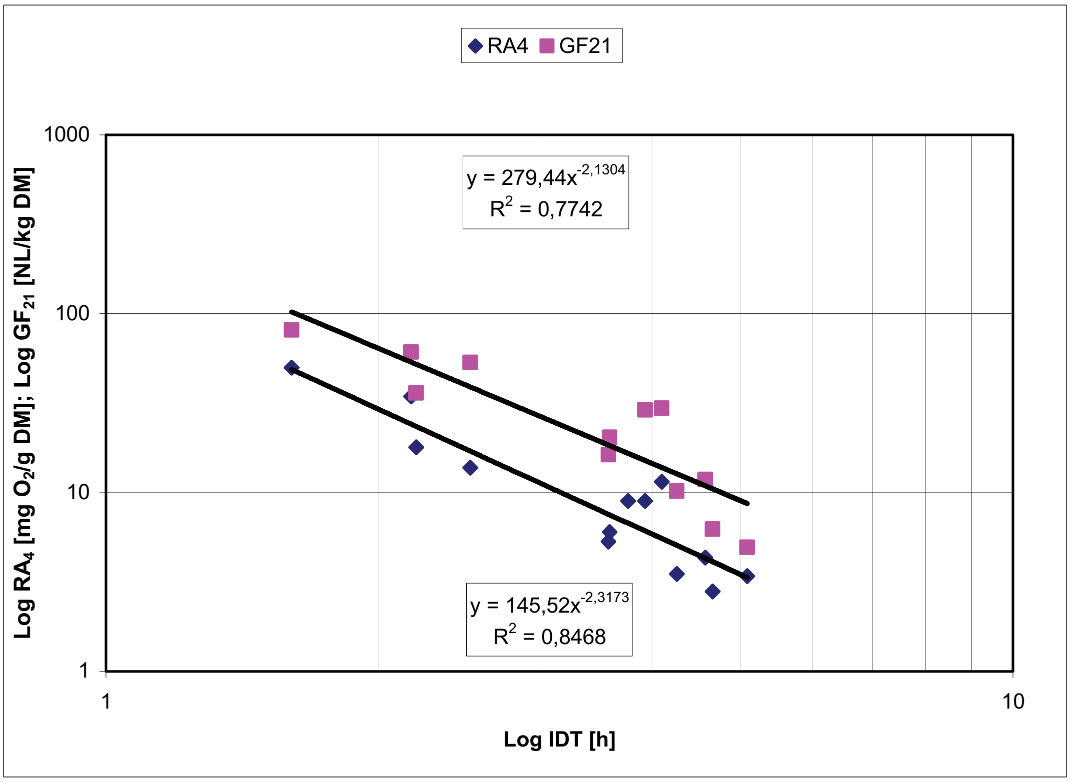

Figure 2: IDT in correlation with RA_4 and GF_{21} (organic waste). Growth media for total germ count used.

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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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 r² 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 r² 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.

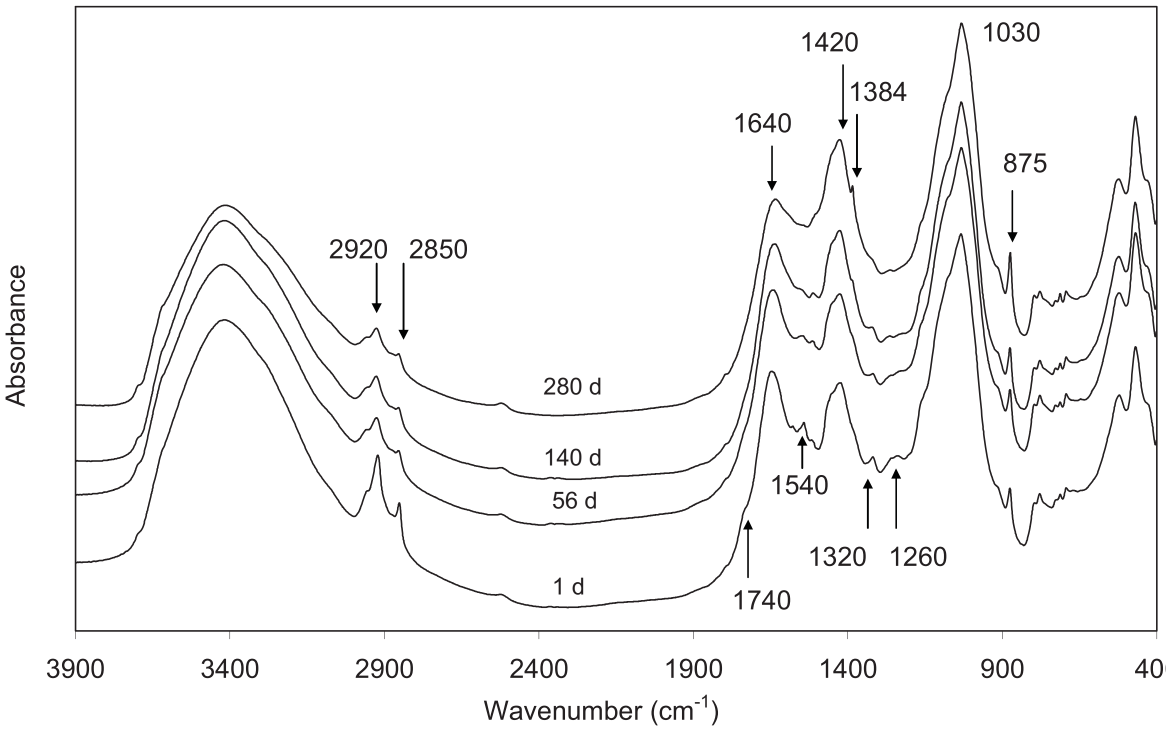

Figure 1 Development of infrared spectra during decomposition of municipal solid waste

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.

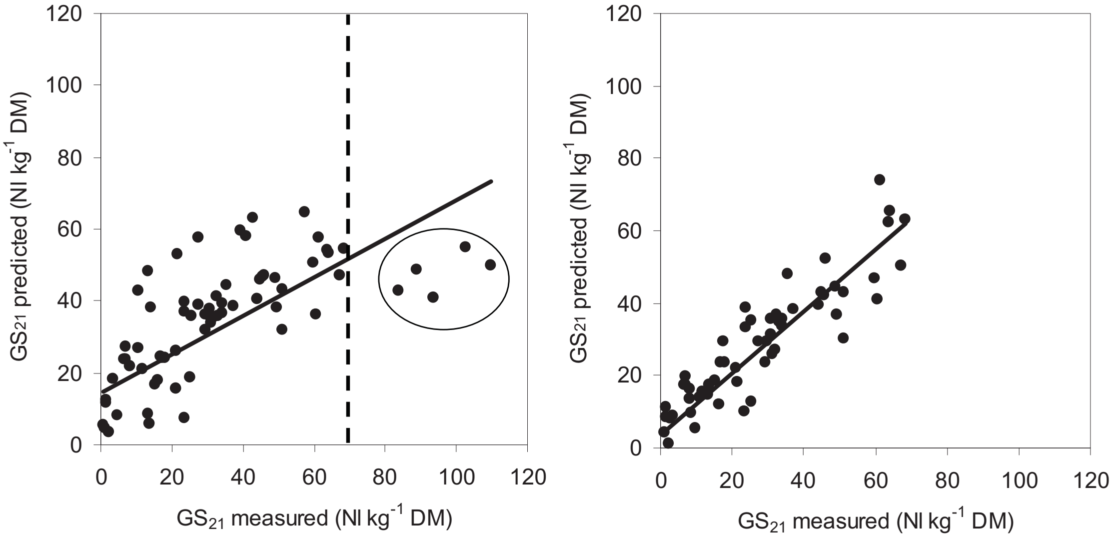

Figure 2 PLS-R model for gas generation sum (a) 0-120 Nl kg^{-1} DM and (b) 0-70 Nl kg^{-1} DM

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.

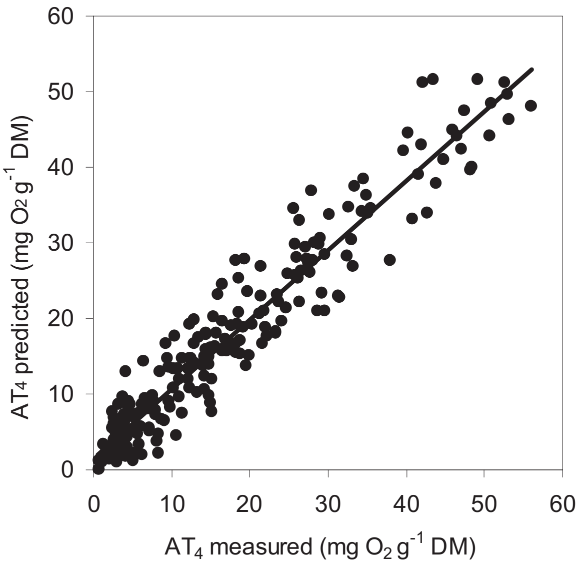

Figure 3 PLS-R model for respiration activity

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.

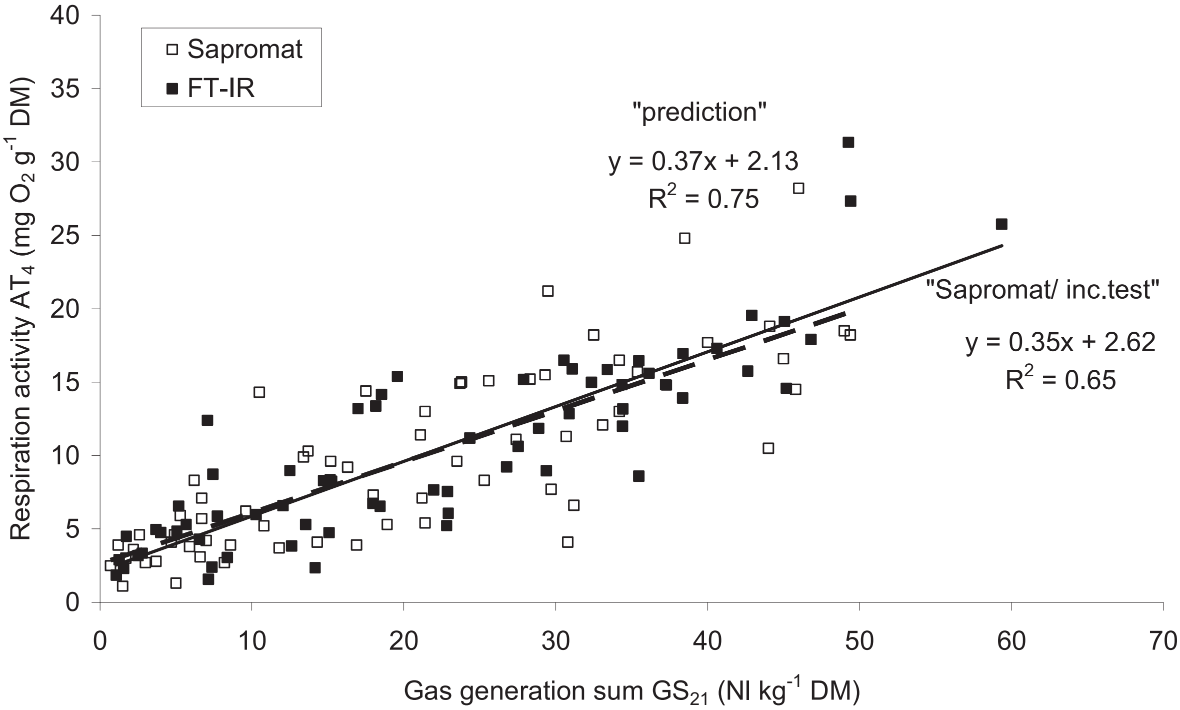

Figure 4 Correlation of respiration activity and gas generation sum by "Sapromat" and "incubation test" resp. predicted by the PLS-R models.

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.

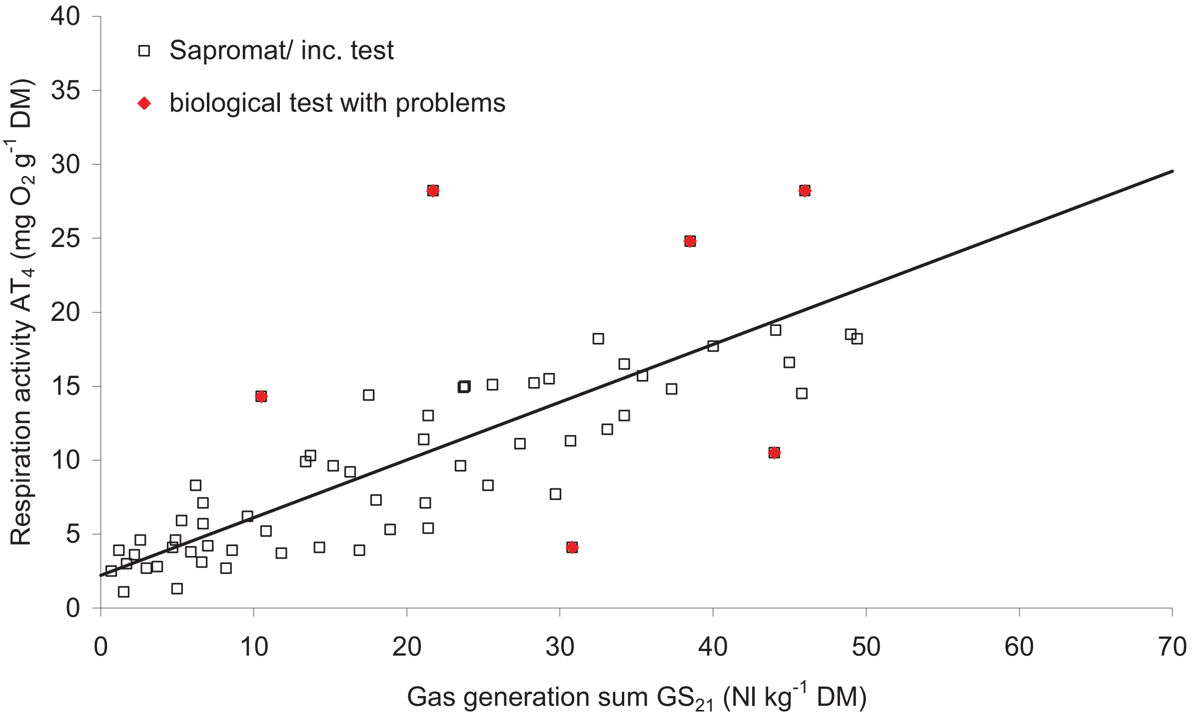

Figure 5 Correlation between gas generation sum (GS_{21}) and respiration activity (AT_4); samples with problems during the biological test are marked

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}).

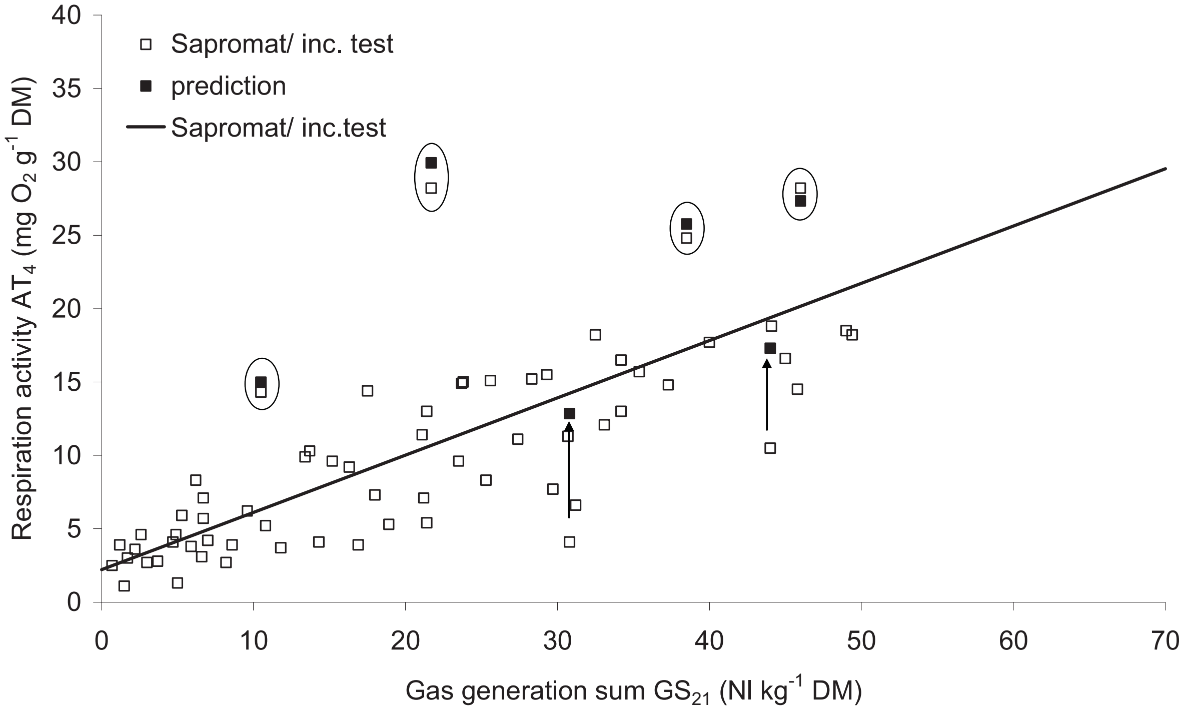

Figure 6 Prediction of the respiration activity of the sample set showing problems during the biological test

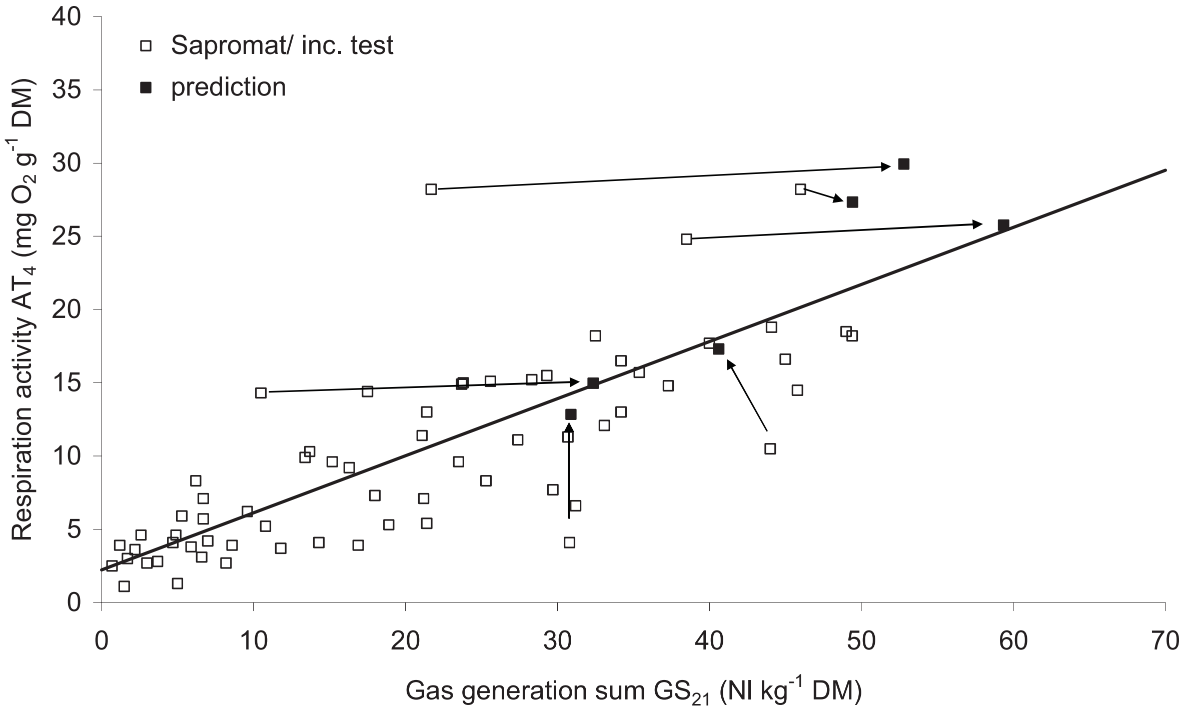

Figure 7 Recalculation of the sample set using prediction models for AT_4 and GS_{21}

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.

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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.

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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.

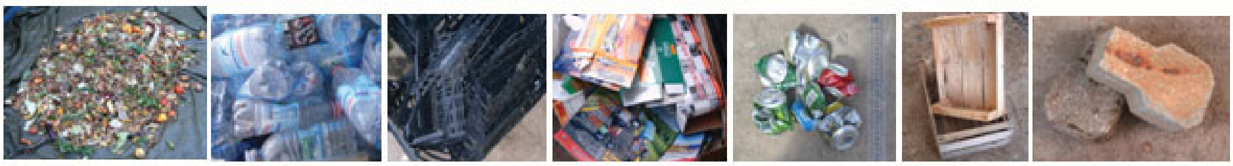

Figure 2 Waste fractions

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.

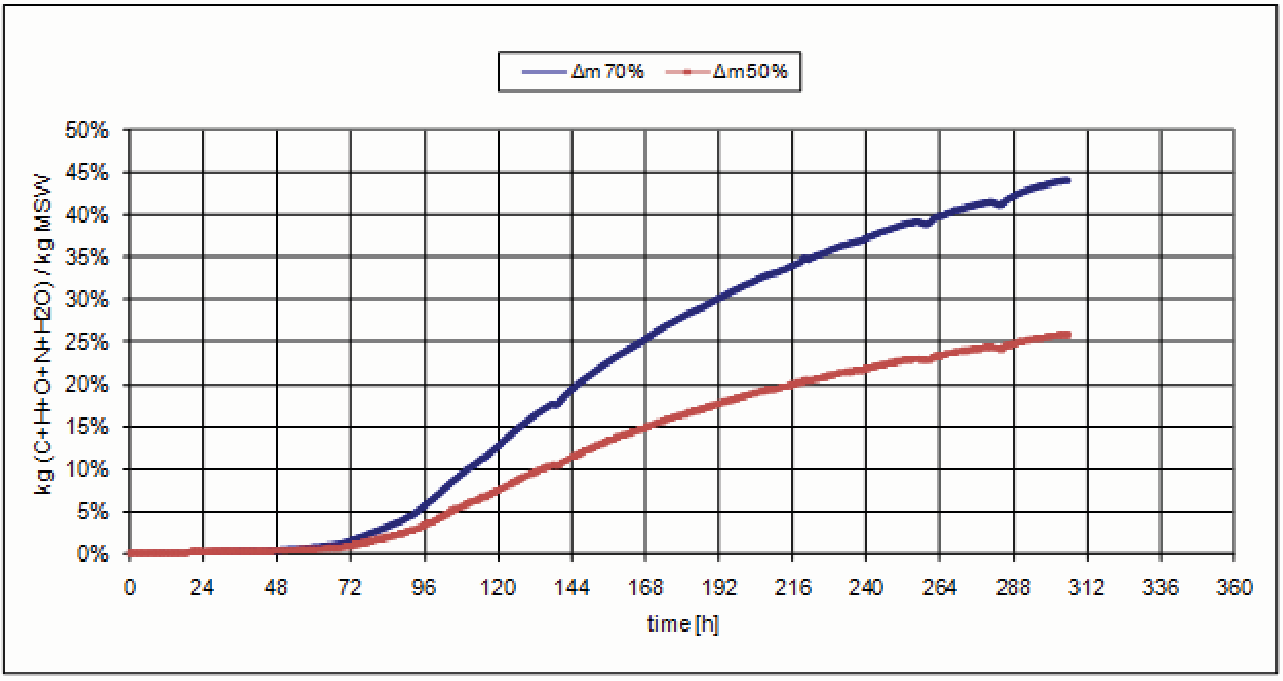

Figure 3 Mass loss dynamics during the bio-drying runs

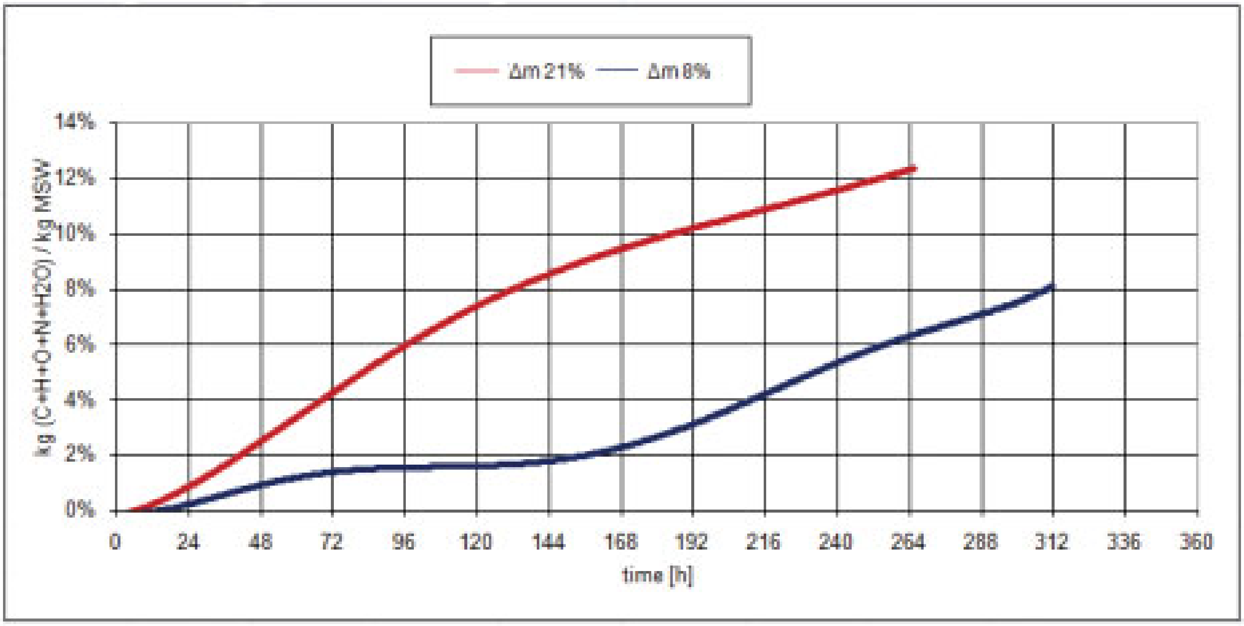

Figure 4 Mass loss dynamics during the bio-drying runs

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.

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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.

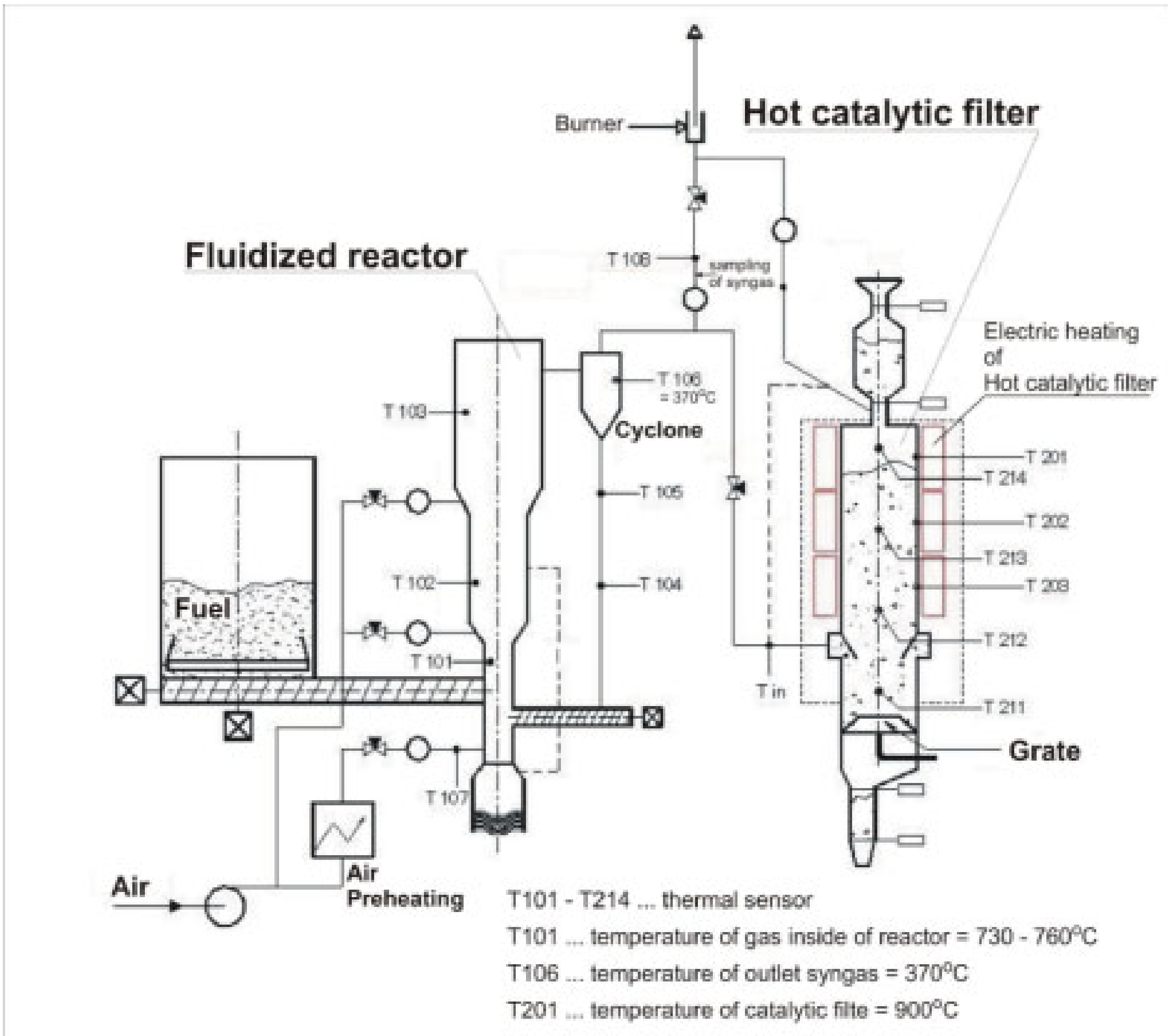

Figure 1 Gasifier Biofluid 100 - General view and simplified technological scheme

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.

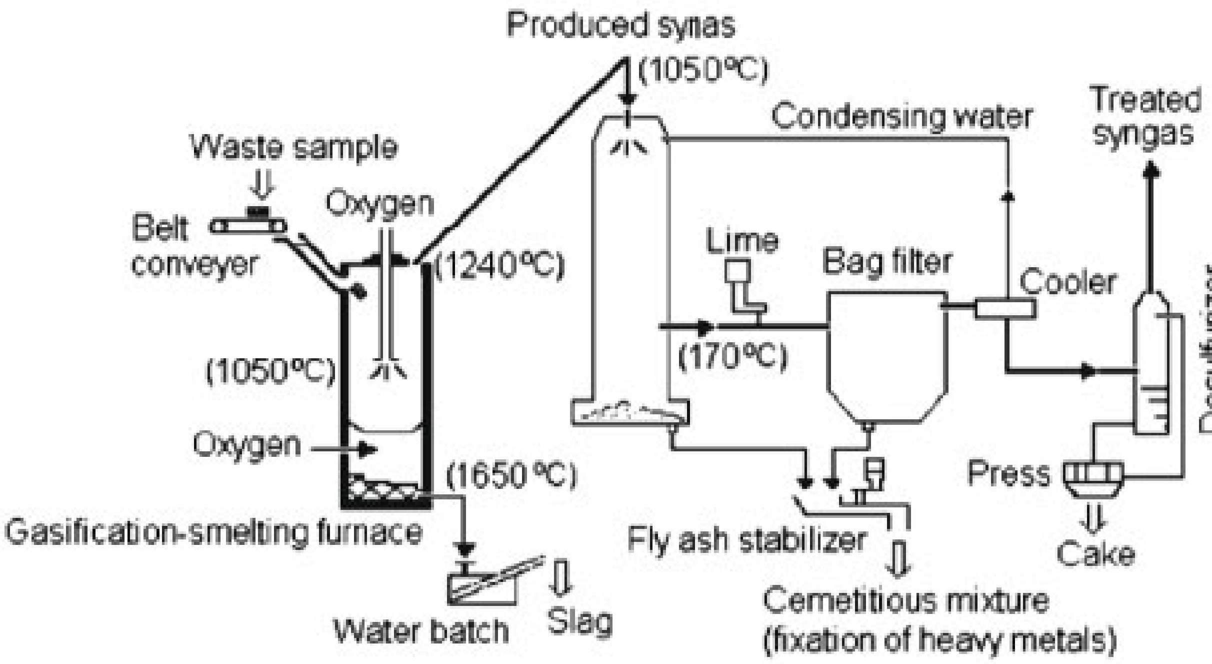

Figure 2 Scheme of the furnace incorporating a gasification unit with a smelting unit

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.

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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 / м^3**	**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.

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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 on-line 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.

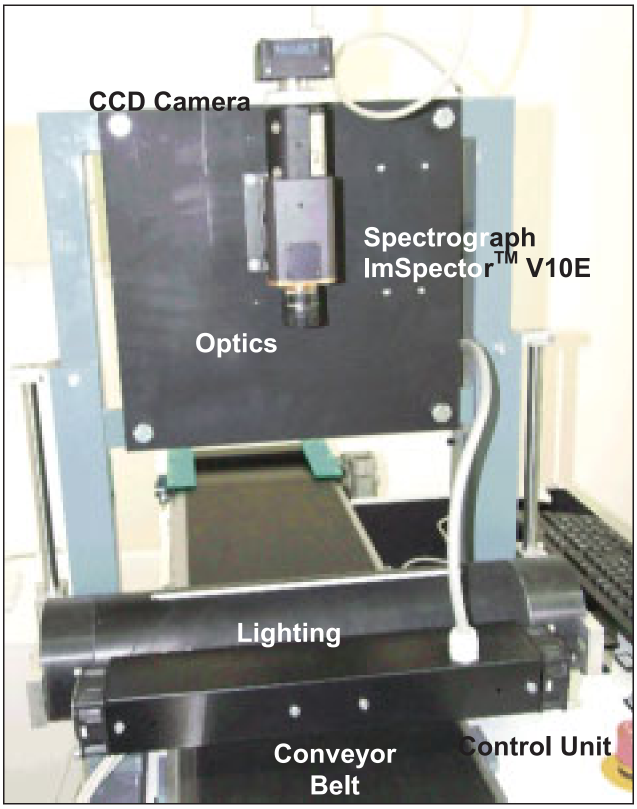


Figure 1 Spectral scanner architecture utilised to acquire compost samples spectra.

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.

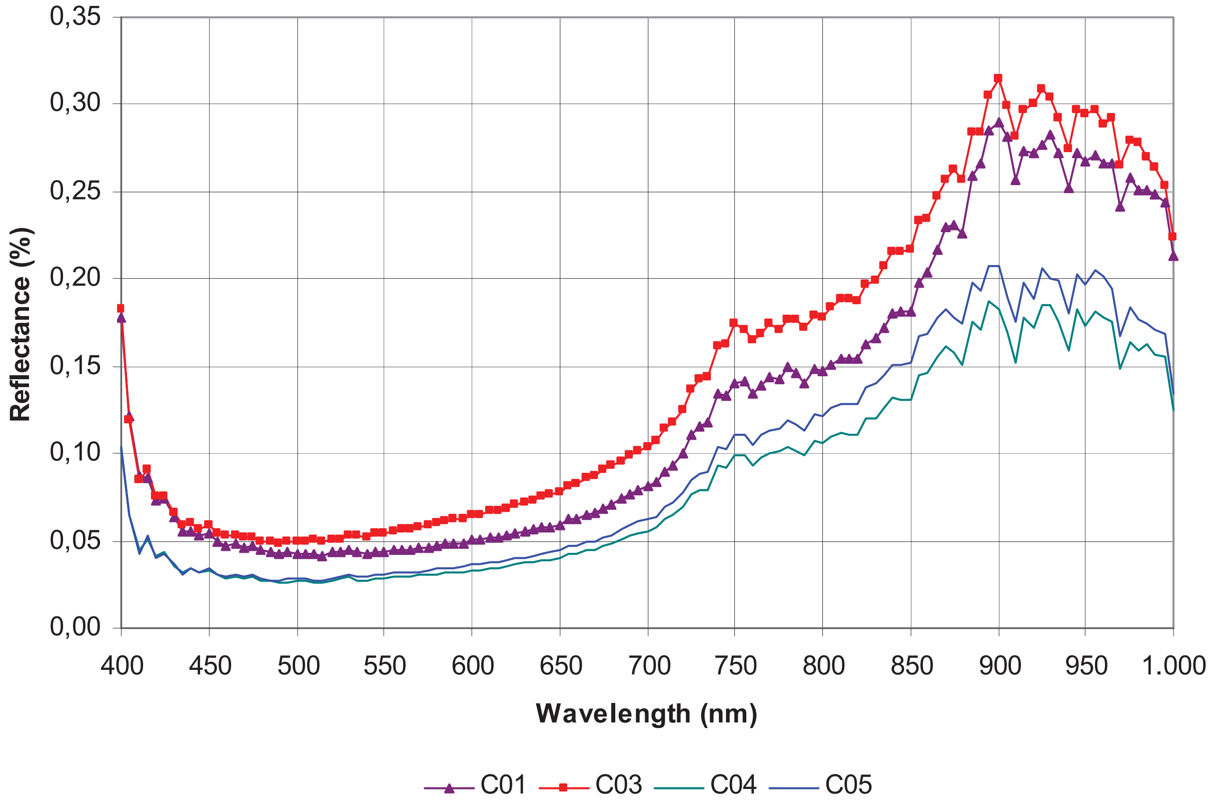


Figure 2 *Average reflectance spectra in the VIS-NIR field (400-1000 nm) of the different compost samples, as resulting by different processing (Sample C01: aged 120 days without enzyme blending. Sample C03: aged 300 days with enzyme blending. Sample C04: short curing with enzyme blending. Sample C05: 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).

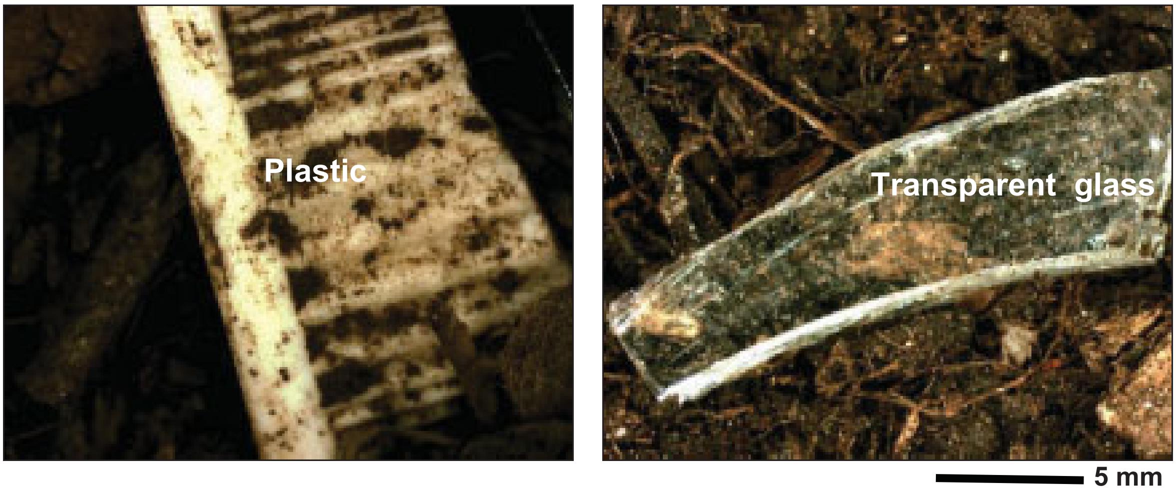


Figure 3 Examples of contaminants as detected in sample C03.

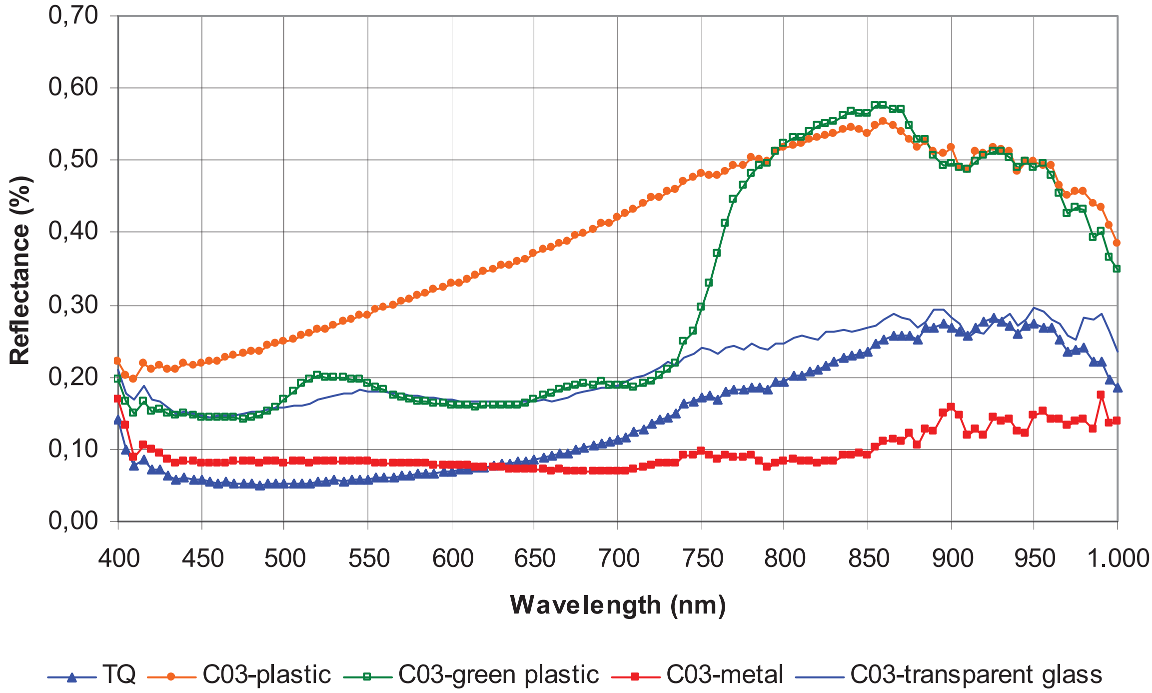


Figure 4 Average reflectance spectra in the VIS-NIR field (400-1000 nm) of different contaminants (plastics, glass and metal fractions,) as shown in Figure 3, and of the compost matrix, as detected in sample C03.

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.

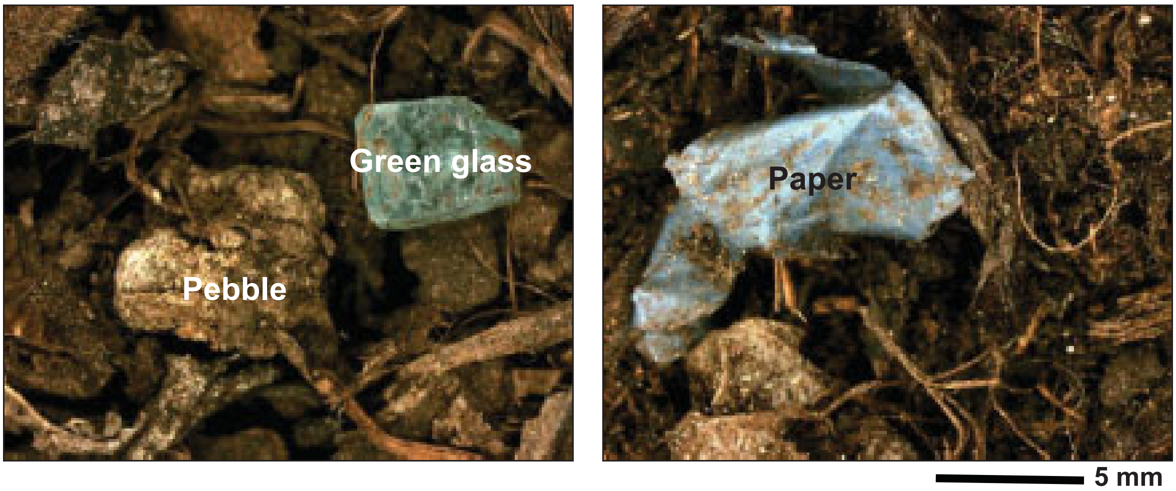


Figure 5 *Examples of contaminants as detected in sample C05.*

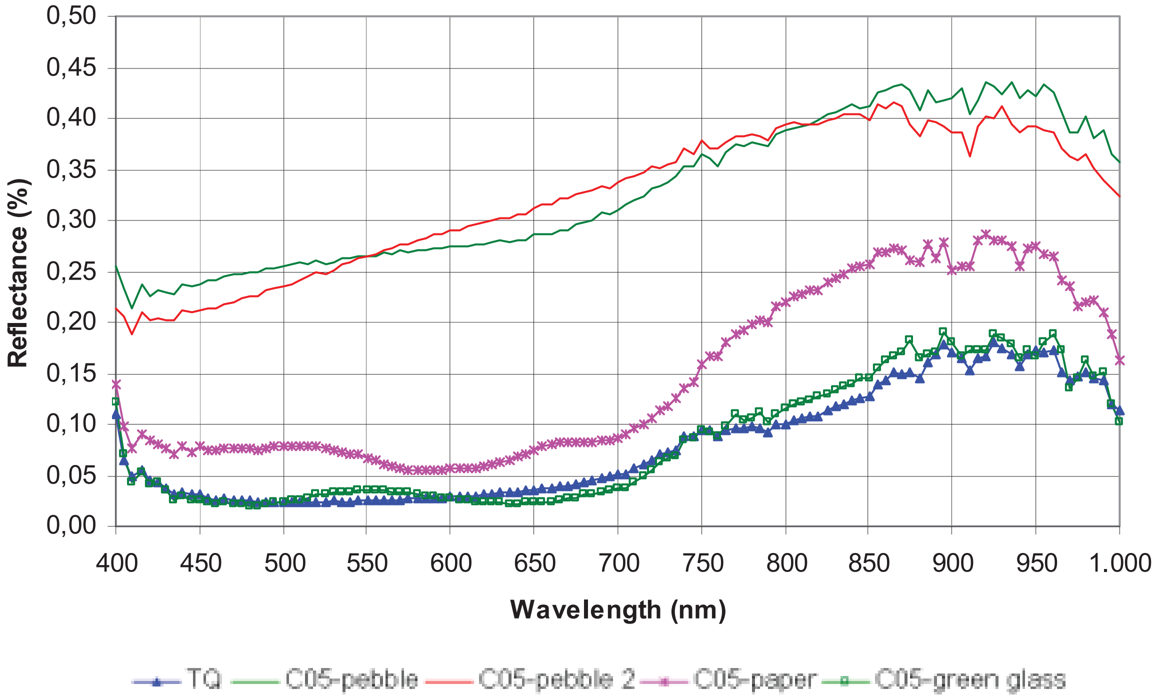
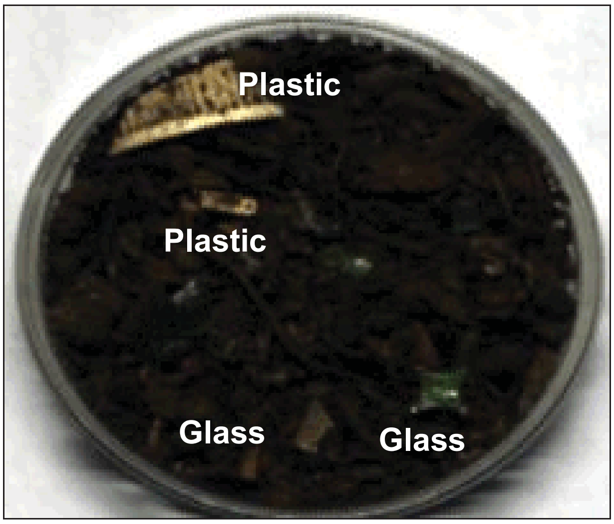


Figure 6 *Average reflectance spectra in the VIS-NIR field (400-1000 nm) of different contaminants (pebbles, paper and metal fractions) as shown in Figure 5, and of the compost matrix, as detected in sample C05.*

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***pproach* (HPCIA) allows to perform a full identification of contaminants and their topologi-



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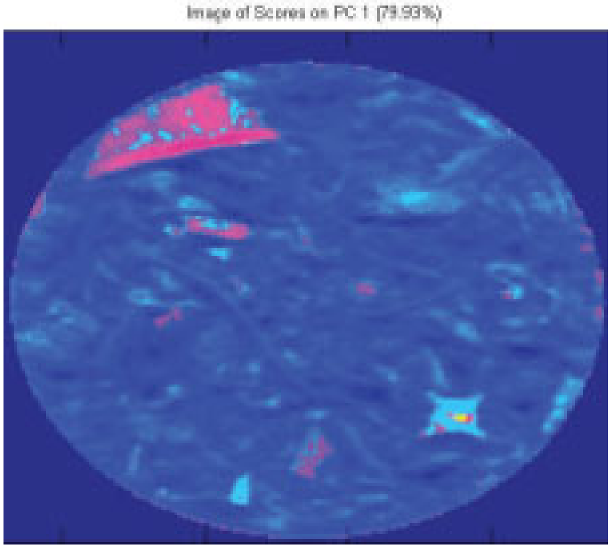

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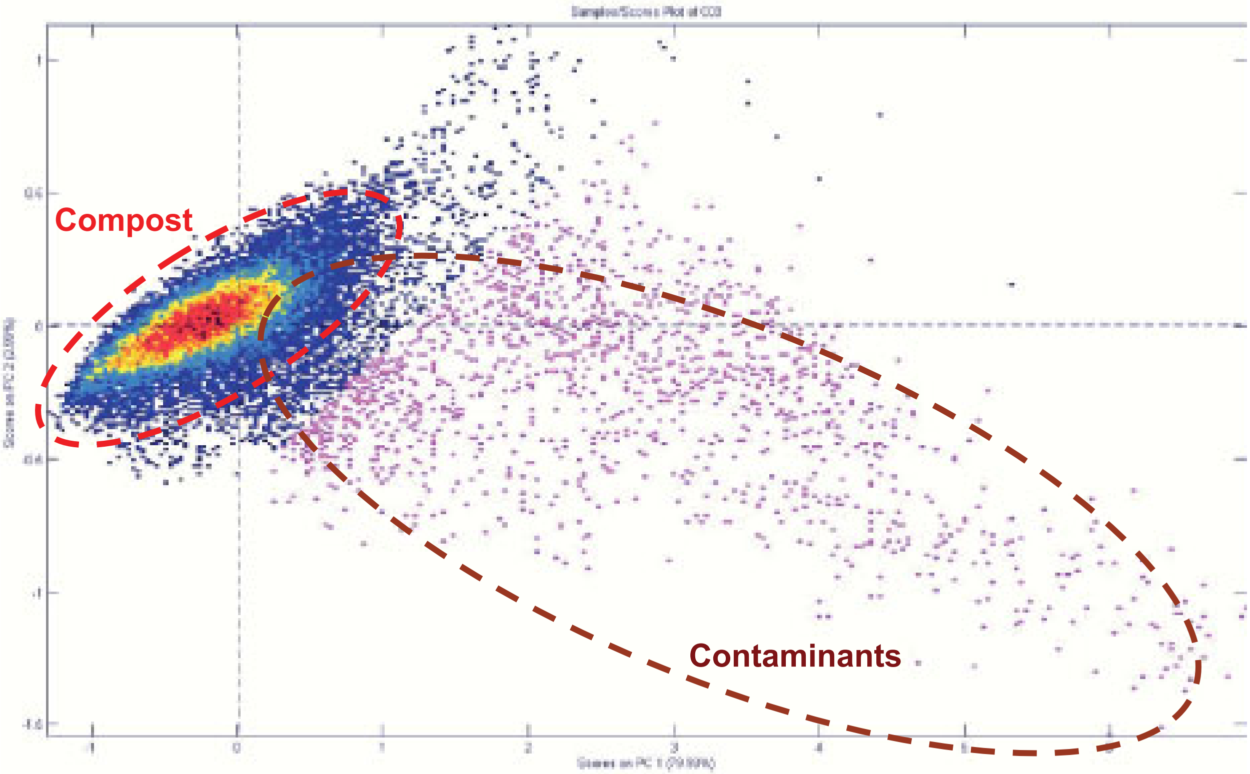

7c

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.*

cal assessment in the investigated hyperspectral image field (Figure 7).

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

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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).

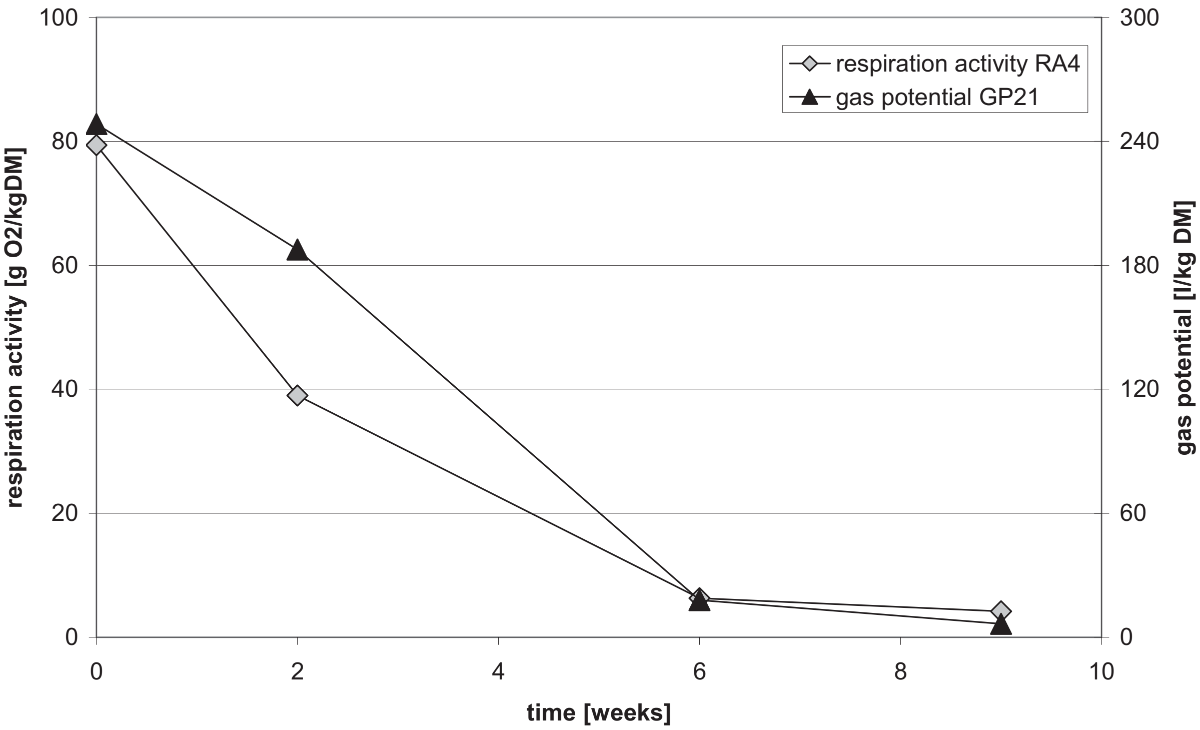

Figure 1 Progress of the respiration activity RA4 and the gas potential GP21 of the investigated materials over a 9 week rotting period.

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.

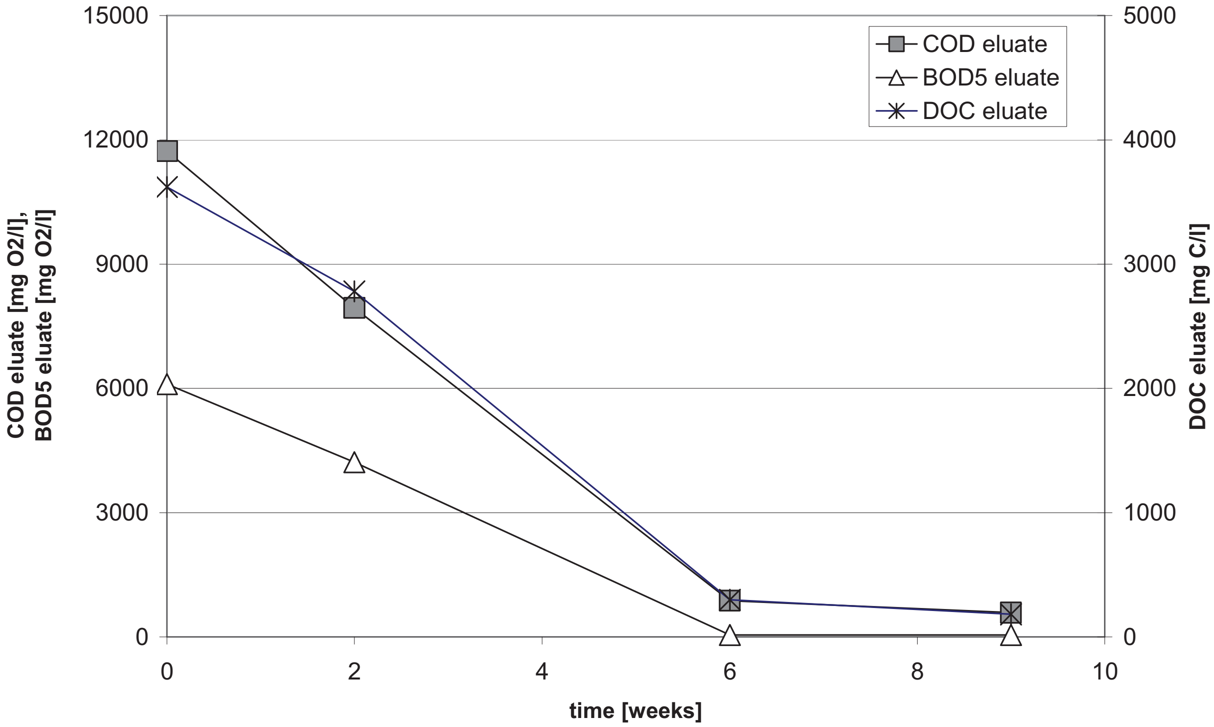

Figure 2 *Progress of the DOC, COD and BOD5 content in the eluate of the investigated MBA materials*

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.

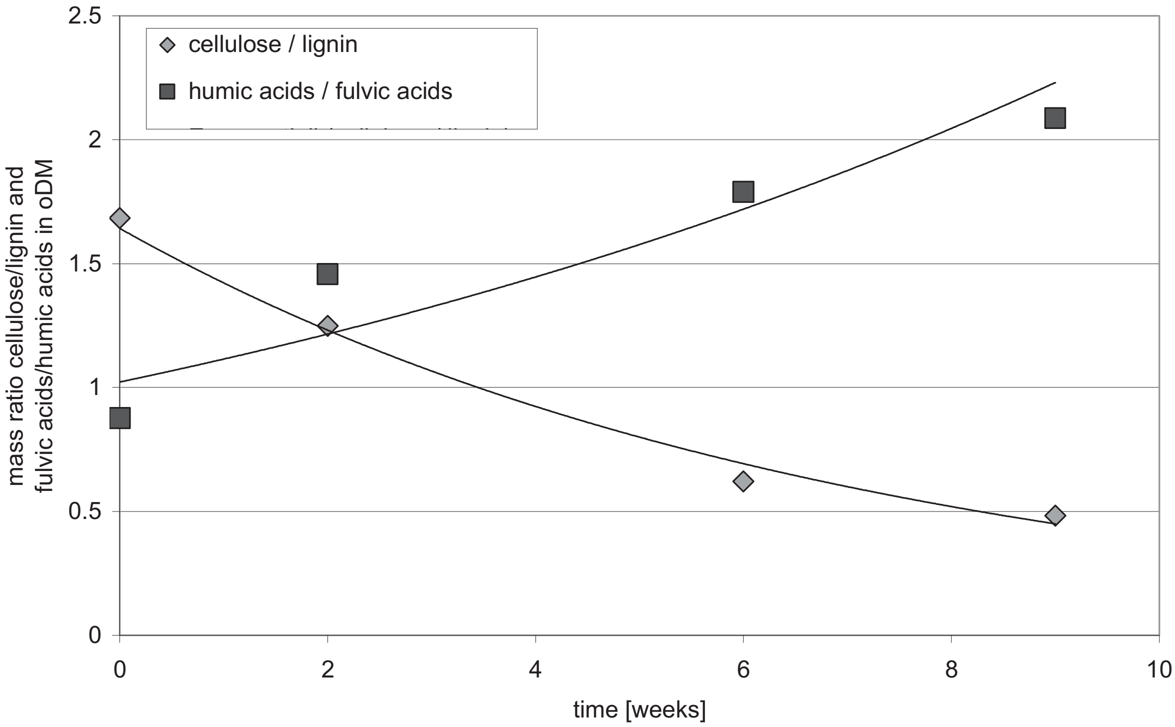

Figure 3 Change in the mass ratio of cellulose and lignin as well as fulvic acids and humic acids in the organic dry matter of residual waste during aerobic treatment

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.

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Gesamtkonzept für die Aufbereitung von Ersatzbrennstoffen (EBS)

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Overall concepts 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 Effiziente Ersatzbrennstoff Aufbereitung

1.1 Einleitung

Für eine wirtschaftliche Ersatzbrennstoff Aufbereitung sind passendes Input-Material sowie effiziente und leistungsstarke technische Aggregate wie Zerkleinerungs-, Trenn- und Fördertechnologie notwendig. Wichtige Aspekte sind hierbei u.a. hohe Verfügbarkeit, einfache Wartung und Bedienung sowie ein geringer Energiebedarf.

1.2 Ersatzbrennstoff Aufbereitung mit der Lindner-Recyclingtech GmbH

Seit Jahrzehnten bietet die Lindner-Recyclingtech GmbH innovative und erfolgsbewährte Lösungen aus einer Hand – Forschung, Entwicklung, Konstruktion, Planung und Produktion moderner Zerkleinerungstechnik (Einwellen-Vor- und -Nachzerkleinerung) für die Abfallaufbereitung, ganzheitliche Systeme zur Herstellung von Ersatzbrennstoffen mit zugehöriger Steuerungstechnik, Separierungs- und Abscheidetechnik sowie Förderanlagen im Baukastensystem.

Mit mehr als 100 weltweit installierten EBS-Aufbereitungsanlagen zählt die Lindner-Recyclingtech GmbH zu den Spezialisten in diesem Bereich. Das Unternehmen bietet effiziente und kompakte EBS-Anlagen, die in einem speziellen Baukastensystem mit ausgereiften und erprobten Einzelkomponenten realisiert werden. Durch dieses ergibt sich maximale Flexibilität auf engstem Raum sowie einfache spätere Erweiterbarkeit. Die LINDNER EBS-Kompaktanlage besteht aus Vorzerkleinerung, Förder- und Trenntechnik, Nachzerkleinerung sowie einem innovativen Steuerungs- und Diagnosesystem. Mit diesem modularen System kann aus Inputmaterial wie z.B. Haus-, Gewerbe- und Industriemüll ein Outputgranulat von kleiner 25 mm mit bis zu 25 Tonnen Durchsatz pro Stunde erzielt werden.

1.3 Auszug aus den Referenzen der Lindner-Recyclingtech GmbH

Die Lindner-Recyclingtech GmbH hat zahlreiche Ersatzbrennstoff Produktionslinien mit dem Schwerpunkt Zementindustrie und Entsorgungsbetriebe installiert. Namhafte Zementhersteller wie z.B. Lafarge, Holcim Group (Ecorec), Cemex, Heidelberg Cement, Wietersdorfer & Peggauer etc. wie auch namhafte Ersatzbrennstoffzulieferer wie z.B. Remondis, SITA, Veolia, Alba, ThermoTeam, Zuser, ASA, Saubermacher etc. zählen zu den unzähligen zufriedenen Kunden.

Die Aggregate der Lindner-Recyclingtech GmbH (Vorzerkleinerer JUPITER 3200 und zwei Nachzerkleinerer POWER KOMET 2800) sind auf der Tagungs-Exkursion zur MBA Südniedersachsen im Einsatz zu sehen. Bei der MBA Südniedersachsen wurde in der Zerkleinerung zuerst ein reißendes System eingesetzt – dieses wurde aber nach massiven Problemen durch das nun installierte schneidende System der Lindner-Recyclingtech GmbH ersetzt.

2 Die Einzelkomponenten der EBS-Kompaktanlage der Lindner-Recyclingtech GmbH

2.1 Die Vorzerkleinerung

Der langsamlaufende Einwellen-Vorzerkleinerer JUPITER ist mit einem revolutionierenden Schneidsystem ausgestattet, das Abfall auf eine definierte Korngröße bringt. Dadurch können die nachgeschalteten Anlagenkomponenten wie z.B. Fe-, Ne-, NIR-Abscheidung, Siebung, Windsichtung und Nachzerkleinerung effizienter und störungsfrei arbeiten und es ergeben sich geringer Ausfallszeiten. Weiteres Feature ist der sichelförmige Nachdrücker, der auch leichtes Material problemlos zum Rotor drückt und somit zu hohen Durchsatzleistungen führt.

Trotz des abrasiven Inputmaterials erreicht man mit dem schneidenden System sehr wirtschaftliche Standzeiten und ist in der Lage Fremdkörper zu zerkleinern. Sollte jedoch ein massiver Störstoff in den Schneidraum gelangen, kommt es aufgrund der innovativen Rutschkupplung zu keinem massiven Maschinenschaden. Der Störstoff kann durch die patentierte nach innen öffnende Störstoffklappe entnommen werden, wodurch der Trichter nicht entleert werden muss. Dieser Vorgang dauert lediglich wenige Minuten, was eine hohe Verfügbarkeit des Zerkleinerers ermöglicht. Praxiserfahrungen zeigen, dass eine Störstoffentnahme z.B. bei Hausmüll maximal ein- bis zweimal pro Schicht notwendig ist. Aufgrund der einfachen Entnahme kommt es zu keiner teuren Entsorgung von kontaminiertem Material, sondern lediglich zu einer direkten Entsorgung des Störstoffes.

Der JUPITER (seit 6 Jahren am Markt) wird vorwiegend für die Vorzerkleinerung von unbehandelten Materialien mit Störstoffen (wie z.B. Haus-, Industrie- und Gewerbemüll – Durchsatz von bis zu 50 t/h) eingesetzt.

Abbildung 1: Langsamlaufender Vorzerkleinerer JUPITER der Lindner-Recyclingtech GmbH

2.2 Die Förder- und Trenntechnik

Das mit einem Selbstreinigungssystem ausgestattet und von 0 – 32 Grad einstellbare Knickförderband (beides von LINDNER entwickelt) erlaubt ein direktes Aufstellen der Shredder am Betriebsboden. Dadurch wird ein minimaler Wartungs- und Reinigungsaufwand des Abförderbandes gewährleistet.

Mit dem beim Innovations- und Forschungspreis prämierten „Schwerstoffabscheider HFS 1200“ konnte ein modernes und leistungsstarkes Aggregat mit geringem Energiebedarf zum Schutz der Nachzerkleinerung entwickelt werden. Dieser sondert Störstoffe wie z.B. Steine, Keramik, etc. aus dem Abfall aus und schützt somit den Nachzerkleinerer, wodurch den Abfallaufbereitern kostspielige Reparaturen und teure Anlagenstillstände erspart bleiben. Durch die kompakte Bauweise kann das Aggregat sehr einfach als Inline-Komponente im Materialhauptstrom zwischen Vor- und Nachzerkleinerung integriert werden.

Abbildung 2: Der prämierte Schwerstoffabscheider HFS 1200 der Lindner-Recyclingtech GmbH

2.3 Die Nachzerkleinerung

Der neu entwickelte, beim Innovations- und Forschungspreis zweitplatzierte, Nachzerkleinerer POWER KOMET besticht durch ökonomische und ökologische Spitzenwerte. Herausragendes Merkmal ist wie beim JUPITER das außergewöhnliche Antriebkonzept mit Schwungmassen. Mit diesem in dieser Branche bisher eher unüblichen Konzept wird eine von unabhängigen Experten bestätigte Energieeinsparung von mindestens 20 - 30 % gegenüber herkömmlichen Antriebssystemen erreicht. Durch diese Energieeinsparungen und weitere Vorteile ergeben sich für den POWER KOMET relativ kurze Amortisationszeiten.

Der POWER KOMET ist in der Lage das vorzerkleinerte störstofffreie Inputmaterial auf eine Korngröße von bis zu 15 mm zu zerkleinern. Das innovative Siebkonzept ermöglicht ein rasches Wechseln der Siebe, wodurch Korngrößen von 10 – 100 mm erreicht werden können. Mit dem POWER KOMET 2800 sind Durchsatzleistungen von bis zu 12 – 15 t/h bei einem Endgranulat von 25 mm möglich.

2.4 Das Steuerungskonzept

Ebenso innovativ ist das neuartige Steuerungskonzept über Industrie PC und Touch Panel. Dieses bietet neben Diagnosesystemen auch Online-Unterstützung bei der Wartung. Dadurch ist eine schnelle Serviceunterstützung durch Fernwartung möglich, was wiederum eine Steigerung der Verfügbarkeit gewährt. Mittels dieses Systems können wichtige Parameter zur Anlagenoptimierung erfasst und ausgewertet werden.

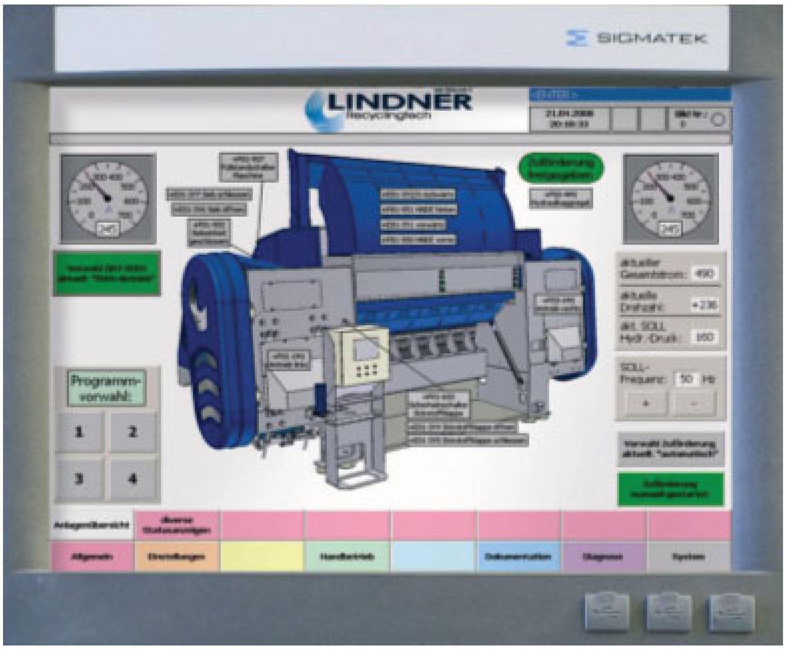

Abbildung 3: Diagnosesysteme und Online Unterstützung der Lindner-Recyclingtech GmbH

3 Die Anforderungen des Marktes

Die Lindner-Recyclingtech GmbH hat es sich zur obersten Priorität gesetzt ihren Kunden effiziente und leistungsstarke Aggregate zu liefern. Mit hausinterner F&E Abteilung sowie Fertigung kann auf Kundenwünsche und Marktanforderungen rasch und effizient reagiert werden. Dies spiegelt sich v.a. im hohen Pionier- und Innovationsgeist des Unternehmens wider. Gemeinsam mit namhaften externen Institutionen wird geforscht und entwickelt, um dem Kunden den entscheidenden Vorteil zu bieten. Das Unternehmen ist auf Service- und Bedienungsfreundlichkeit sowie weltweite Verfügbarkeit ausgerichtet. Es wird auf Stabilität, Robustheit und höchste Verfügbarkeit der Aggregate gesetzt, wodurch die laufenden Kosten minimal bleiben. Wesentlich für den Betrieb von Zerkleinerungsmaschinen sind der sparsame Energieeinsatz sowie die Minimierung der Stillstandszeiten.

Das von LINDNER eingesetzte innovative energiesparende Antriebskonzept mit Schwungmassen ist nahezu wartungsfrei. Aufgrund des elastischen Riemenantriebes kommt es zu keiner Belastung der Antriebskomponenten und somit zu hoher Lebensdauer sowie hoher Verfügbarkeit. Das Prinzip der Schwungmassen im Antrieb wurde bereits im 15. Jahrhundert von Leonardo da Vinci erkannt. LINDNER schaffte es, diese alte Technik in technologisch zukunftsweisender Form für die effiziente Aufbereitung von Abfällen erneut nutzbar zu machen. Dieses Antriebskonzept bietet folgende Vorteile: Im Teillastbereich wird Energie durch die Schwungmassen gespeichert. Diese steht dann im Spitzenlastbereich zur Verfügung, wodurch wesentlich höhere Spitzen (das bis zu fünffache der Nennlast) abgedeckt werden können. Dadurch kann die Antriebsleistung gegenüber herkömmlichen Antrieben um ca. 20 % niedriger ausgelegt werden z.B. statt 250 kW werden nur 200 kW eingesetzt.

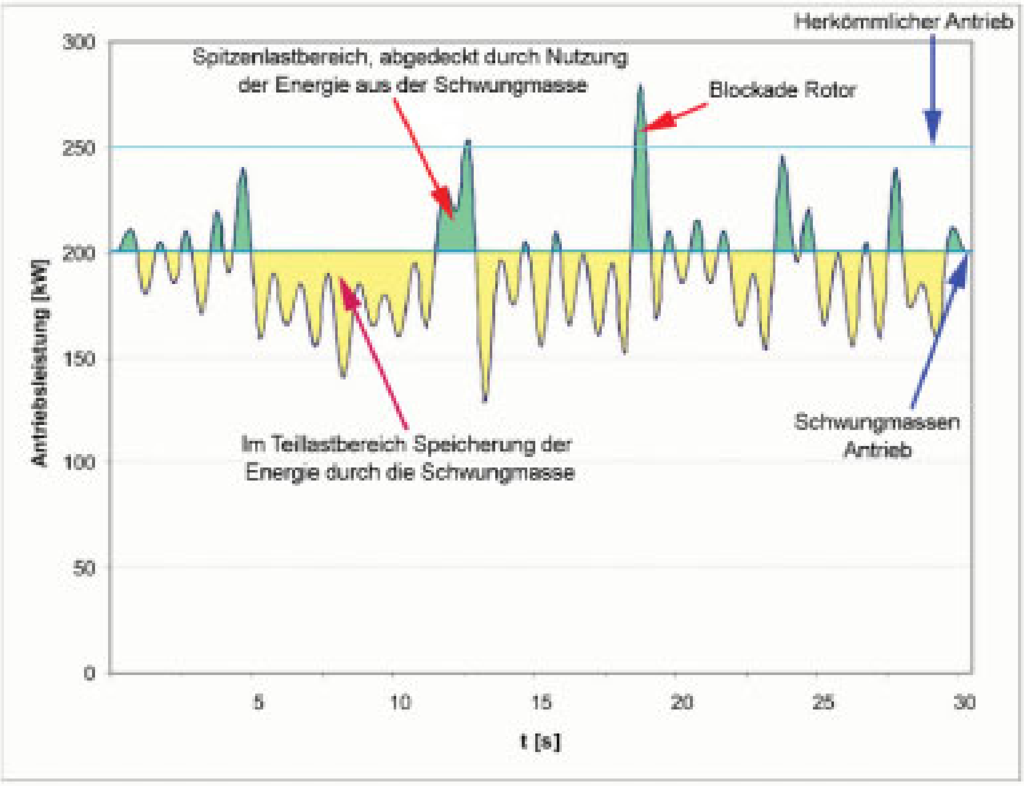

Abbildung 4: Shredderantrieb mit hoher Schwungmasse

Abbildung 5: Innovatives Antriebskonzept mit Schwungmassen von LINDNER

Um die Wartungsarbeiten zu vereinfachen und schneller zu gestalten, wurde eine optimale Zugänglichkeit zum Schneidsystem entwickelt. Die Siebe sind durch das neue Klemmsystem einfach und schnell auszutauschen.

Die Schutzhauben des POWER KOMET aus glasfaserverstärkten Kunststoffen sind nicht nur optisch ansprechend, sie tragen außerdem zu einer Reduktion der Betriebsgeräusche bei und erleichtern durch einen stark vereinfachten Zugang zur Antriebseinheit die notwendigen Instandhaltungsarbeiten.

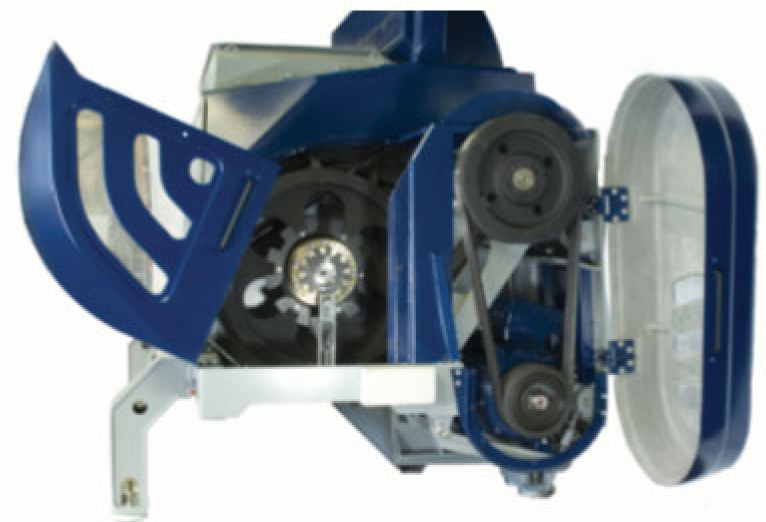

Abbildung 6: Wartungsfreundlichkeit, leichte Zugänglichkeit zum Antrieb und rasches Service durch den modernen Kunststoffschutz der Lindner-Recyclingtech GmbH

Das Baukastensystem der Lindner-Recyclingtech GmbH bietet neben der kompakten und flexiblen Aufstellung auch die Möglichkeit einer einfachen späteren Erweiterung. Dieses System inkludiert neben den Zerkleinerungsmaschinen auch die Anlagen und die Anlagenkomponenten. Dadurch liefert dieses durchgängige Konzept eine reduzierte Lagerhaltung, erleichterte Wartung sowie einfache Bedienung und Einschulung. Aufgrund dieses modularen Systems, das in einem ähnlichen Grundaufbau der Aggregate resultiert, ist es möglich durch die Einschulung bzw. Bedienung auf eine Maschine, auf die restlichen Maschinen umzumünzen.

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