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An overview on techniques and regulations of mechanical-biological pre-treatment of municipal solid waste*

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ABSTRACT

Landfilling of municipal solid waste (MSW) causes significant problems from the production of landfill gas (LFG) and highly polluted leachate over long periods of time. These emissions have to be controlled, treated and sustainable reduced during the aftercare phase, incurring significant costs. Therefore, the overall waste management strategy in Europe is towards reducing landfilling and promoting energy recovery from MSW. However, as thermal treatment capacities are currently limited and incineration plants rely on large waste input quantities (> 150,000 $t \cdot a^{-1}$), mechanical-biological pre-treatment (MBP) of waste was implemented as an alternative in different EU countries. By means of a combination of mechanical pre-treatment and subsequent biological treatment, the emissions potential of the residual MSW can be significantly reduced under controlled conditions. As a result, MBP can be seen as an integral part of modern waste management concepts, including the mandatory separation of the high caloric fraction to be used as a fuel and for the production of biologically stabilised waste for landfilling. In order to improve the overall energy balance, modern MBP plants often include anaerobic treatment as the biological process component, hence increasing the efficiency of energy recovery from MSW.

INTRODUCTION

The overall strategy for waste management in Europe is towards more material and energy recovery from waste and less landfilling. The EU has, via the Landfill Directive (Council Directive 1999/31/EC), set targets for reducing the biologically degradable waste fraction going to landfill. This reduction will be implemented in three steps. Based on statistical data on waste composition for the year 1995, member countries must meet the following targets for the reduction of biodegradable MSW for landfilling: 25% by 2006 (5 years after implementation of the EU Landfill Directive into national law (deadline 7/2001)), 50% by 2009 and 65% by 2016 where there are some exceptions, e.g. longer time limits for the implementation in the new EU member states (Council of the European Union 1999).

In Austria, target values for mechanical-biological pre-treatment (MBP) of MSW as a prerequisite for land-filling have already been in place since the beginning of 2005. In Germany, the implementation of the Landfill Directive indirectly stipulates that, as of June 1st 2005, only thermally or mechanically-biologically pre-treated MSW can be landfilled (German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety 2001a). A selection of German limit values for waste going to landfill is presented in Table 1. In addition, off-gas emission limit values (see Table 2) from in-house treatment facilities (waste delivery, mechanical and biological treatment) have been set (30. BImSchV, German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety 2001b).

In Germany, MBP is seen more as a transient solution in order to fill up landfills that have a base liner already installed or have made other investments, since depreciation costs for the investment have to be paid anyway. There is no great incentive, if at all, for the construction of new MBP landfills in Germany. Apart from the problems of landfill acceptance by the public, costs for new landfills in combination with pre-treatment will be high (comparable to MSW incineration). The German government has set a target that as of 2020, no more landfilling will take place in Germany. This should be achieved by a complete recovery (energy or material recycling) of the MSW (German Environmental Protection Agency 2003).

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Table 1. Allocation criteria for landfills for mechanically and biologically treated waste [Ordinance on Environmentally Compatible Storage of Waste from Human Settlements, Annex 2; German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (2001a)].

No.	Parameter	Allocation value
1.	Strength [1)]	
2.	Organic component of dry residue in original substance [2)], determined as TOC	≤18 % by weight
3.	Extractable lipophile substances in original substance	≤0.8 % by weight
4.	Eluate criteria	
4.01.	pH value	5.5-13.0
4.02.	Conductance	≤50,000 μS/cm
4.03.	DOC	≤300 mg/l
4.04.	Phenols	≤50 mg/l
4.05.	Arsenic	≤0.5 mg/l
4.06.	Lead	≤1 mg/l
4.07.	Cadmium	≤0.1 mg/l
4.08.	Chromium(VI)	≤0.1 mg/l
4.09.	Copper	≤5 mg/l
4.10.	Nickel	≤1 mg/l
4.11.	Mercury	≤0.02 mg/l
4.12.	Zinc	≤5 mg/l
4.13.	Fluoride	≤25 mg/l
4.14.	Ammonium-N	≤200 mg/l
4.15.	Cyanide, easily released	≤0.5 mg/l
4.16.	AOX	≤1.5 mg/l
4.17.	Water-soluble component (evaporation residue)	≤6% by weight
5.	Biological degradability of dry residue in original substance	
	determined as respiration index (RI_4) *or*	≤5 mg O_2/g dry weight[3)]
	determined as gas-formation potential (GP_{21})	≤20 ml/g dry weight[4)]
6.	Gross calorific value (H_0)[2)]	≤6,000 kJ/kg

1) The strength is to be determined in accordance with Annex 4, No. 3.1.4. of the Ordinance on Environmentally Compatible Storage of Waste from Human Settlements.

2) 2 may be applied in equivalence to 6.

3) mg O_2 with respect to dry weight.

4) Standard litre of gas with respect to dry weight.

Table 2. German standards in accordance with the 30th Ordinance to the Federal Immission Control Act [30. BImSchV] and the Technical Instructions on Air Quality Control [TA Air] (German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, 2001b).

Parameter	Target Values Clean Gas		
Sample	½ h – mean	Daily mean	Monthly mean
TOC	40 mg · m^{-3}	20 mg · m^{-3}	55 g · Mg^{-1}
Nitrous oxide (N_2O)	1)	1)	100 g · Mg^{-1}
Ammonia (NH_3)	30 mg · m^{-3} (TA air)		1)
Dust	30 mg · m^{-3}	10 mg · m^{-3}	1)
Dioxins / Furans	0.1 ng · m^{-3} [2)]		
Odour (OU)[4)]	500 OU · m^{-3} (single measurement)[3)]		

1) No target value.

2) For any sample.

3) Average of a single sampling campaign.

4) Odour (OU) units measured in an olfactometer.

LEGAL REQUIREMENTS FOR THE OPERATION OF MECHANICAL-BIOLOGICAL PRE-TREATMENT PLANTS AND FOR THE LANDFILLING OF MBP WASTE

Ordinance on Environmentally Compatible Storage of Waste from Human Settlements and on Biological Waste-Treatment Facilities (Waste Disposal Regulation – AbfAblV)

The Waste Disposal Regulation (German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety 2001a) dated February 20th 2001 defines the allocation criteria for the composition of MSW before being landfilled and regulates the operating mode of landfills. According to the latter, MBP landfills must meet the requirements of Class 2 Landfills (e.g. the existence of a qualified base sealing system, including plastic liner and mineral layer, and the installation of a qualified surface sealing after the end of waste deposition) and the waste must comply with the allocation criteria stipulated in Appendix 2 of the regulation (Table 1).

Critical limit values for MBP waste are, among others, the gross calorific value (H_u), total organic carbon (in the solid material) (TOC_{solid}) and dissolved organic carbon (in the eluate) (DOC_{eluate}). However, during analyses of the target value parameters, compliance is still achieved if, in one of four analyses, the limit value is exceeded but is below 7000 KJ · kg^{-1} (H_u), 21% (TOC_{solid}) and 600 mg · l^{-1} (DOC_{eluate}). The evaluation of the results of the declaration analyses (i.e. when the waste is landfilled) is similar: the regulations are also met when 80% of the measured values are below 7000 KJ · kg^{-1} (H_u), 21% (TOC_{solid}) and 600 mg · l^{-1} (DOC_{eluate}), and when 50% of the values from the previous 12 months are below 6000 KJ · kg^{-1} (H_u), 18% (TOC_{solid}) and 300 mg · l^{-1} (DOC_{eluate}). Along with this, either the H_u or the TOC_{solid} limit must be met (German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety 2001a).

30th Ordinance for the Implementation of the Clean Air Act (30th BImSchV)

The 30th BImSchV dated February 20th 2002 (German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety 2001b) governs the construction and operation of MBP plants. Paragraphs 4 and 5 require complete enclosure of the plants including exhaust air collection and treatment. However, Paragraph 16 stipulates that the authorities involved are authorised to allow open post-rotting without exhaust air collection and treatment for multi-stage biological treatment when:

- the respiration index of the waste intended for post-rotting is < 20 mg O_2 · g^{-1} DW (DW = Dry Weight); and
- further operational measures are implemented to limit harmful environmental effects.

With regards to ammonia, no limit value is defined in the 30th BImSchV. Therefore, the target value of 30 mg · m^{-3}, as prescribed in the Technical Instructions on Air Quality Control (TA Air, German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety 2002) applies. The unloading process, as well as the mechanical-biological pre-treatment step, have to be practised in-house in Germany. This means that all buildings must be ventilated and the off-gases captured and treated.

Off-gas from the unloading and mechanical pre-treatment area can generally be treated in biofilters which may be combined with an acid scrubber for NH_3 removal. The off-gas emanating from aerobic biological treatment, especially during the intensive rotting phase, has relatively high nitrogen and carbon concentrations so that thermal treatment (e.g. regenerative thermal oxidation (RTO) for the removal of the organic compounds and probably an acid scrubber for the reduction of NH_3 compounds may be necessary in most cases (see also Doedens 2001). The off-gas treatment contributes significantly to the costs of the entire MSW pre-treatment process.

MECHANICAL AND BIOLOGICAL TREATMENT OF MUNICIPAL SOLID WASTE

Why is a reduction in the landfilling of biodegradable organics implemented in the EU Landfill Directive and what are the main advantages of applying mechanical-biological pre-treatment? The main emissions (leachate and biogas) are greatly influenced by biological processes taking place in the landfill. When MSW is landfilled without pre-treatment, emissions arise during landfill operations and continue after closure. Depending on waste composition, climatic conditions, etc., these constitute approximately 150 m^3 biogas/Mg MSW (based on dry weight) and 5m^3 · ha^{-1} · d^{-1} of highly polluted leachate (Ehrig and Stegmann 1992; Stegmann 1996), as an approximation for a high compacted landfill in Central Europe at an annual precipitation rate of 750 mm.

Ehrig (1996) investigated the gas production from MSW in laboratory scale experiments. The results showed a range from 128 to 271 m^3 · ton^{-1}, based on dry MSW. Robinson (2005) investigated numerous large landfills worldwide respecting their leachates. They can be characterised by very high concentrations of ammonia-nitrogen, almost always in excess of 1000 mg · l^{-1}, often up to 2000 or 3000 mg · l^{-1}, and sometimes higher. The chemical oxygen demand (COD) values are generally between 2000 and 8000 mg · l^{-1}, although measured biological oxygen demand (BOD_5) values are much lower – usually below 1000 mg · l^{-1}.

Due to biological degradation processes, significant settling of the landfill surface takes place in the range of 20-25% of the landfill height, which may damage structures such as surface liners, gas extraction and leachate collection systems. The leachate produced has to be collected and treated at a high cost over many decades (Christensen et al. 1992). The biogas pro-duced must be extracted and flared or can be used as an energy source. By undertaking MBP, processes which normally take long periods of time (decades) to complete in a landfill are shortened to several months. The emissions potential of the waste is reduced to a great extent during pre-treatment so that, compared to non- pretreated waste, a significant reduction in emissions occurs. The production of “compost” to be applied in agriculture or horticul-ture is not the aim of mechanical-biological pre-treatment, because the content of heavy metals and other harmful or interfering substances is generally too high (Leikam and Stegmann 1996).

MBP AS A PART OF WASTE MANAGEMENT CONCEPTS

General considerations

Although extensive waste prevention and recycling is practised, there is still a considerable quantity of residual waste left which is not or cannot be reused. Also, even if packaging material and biowaste were collected separately, only a certain percentage of these compounds (±80% (packages) and ± 50% (biowastes) of the total potential) is actually recovered (German Environmental Protection Agency 2007). As a result, the residual waste still contains significant amounts of plastics and organics.

Within a waste management concept, mechanical-biological pre-treatment is applied to pre-treat residual MSW either prior to landfilling or for the conditioning before subsequent thermal recovery. The first option includes the mechanical separation of the high calorific value fraction (refuse-derived fuel, RDF) before biological treatment (see Figure 1) whereas for the latter the complete MSW is biologically treated. The RDF can be used for energy production in a variety of plants (e.g. cement kilns, coal power plants) (see also Thomé-Kozmiensky 2004).

In principle, aerobic and anaerobic biological processes can be applied for the biological treatment step, but they have to be adapted to the target values to be reached and the composition of the residual waste.

Many different concepts for mechanical-biological pre-treatment are in operation. Figure 2 (Ketelsen et al. 2005) gives an overview of different technologies in operation in Germany, Austria and Italy. The question of which system is the most optimum cannot be answered since each process has its own advantages and disadvantages.

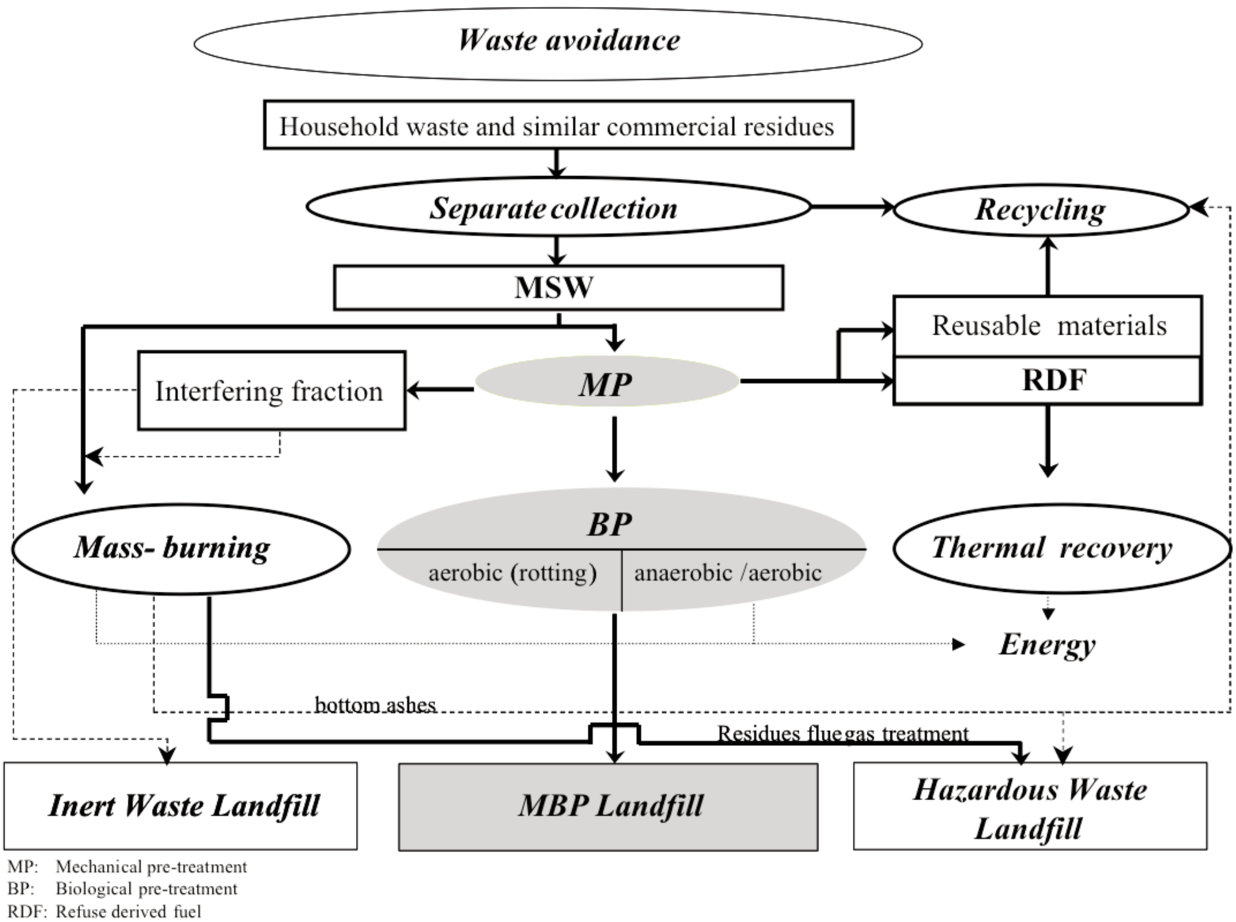


Figure 1. General concept of municipal solid waste managment.

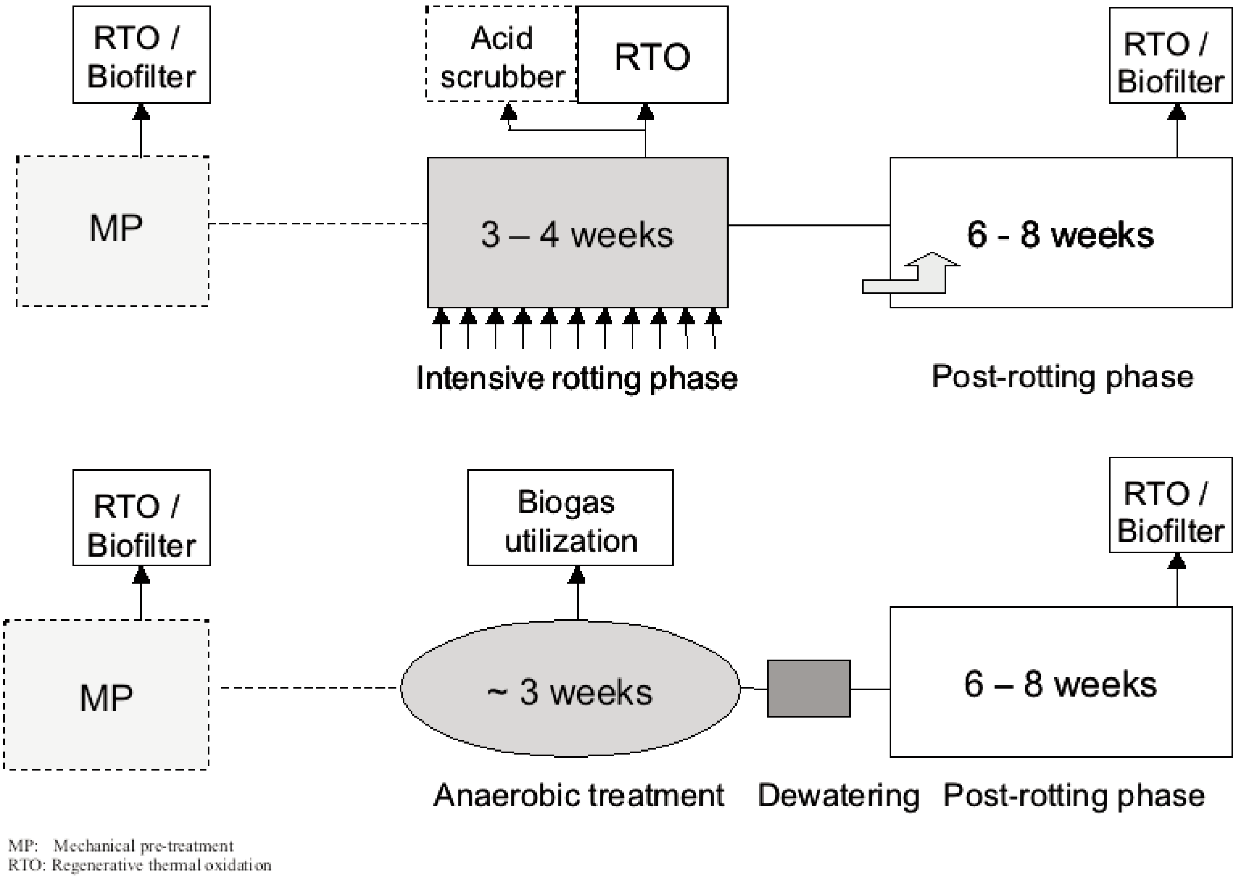


Figure 2. Overview of different technologies for mechanical-biological pre-treatment (Ketelsen et al. 2005).

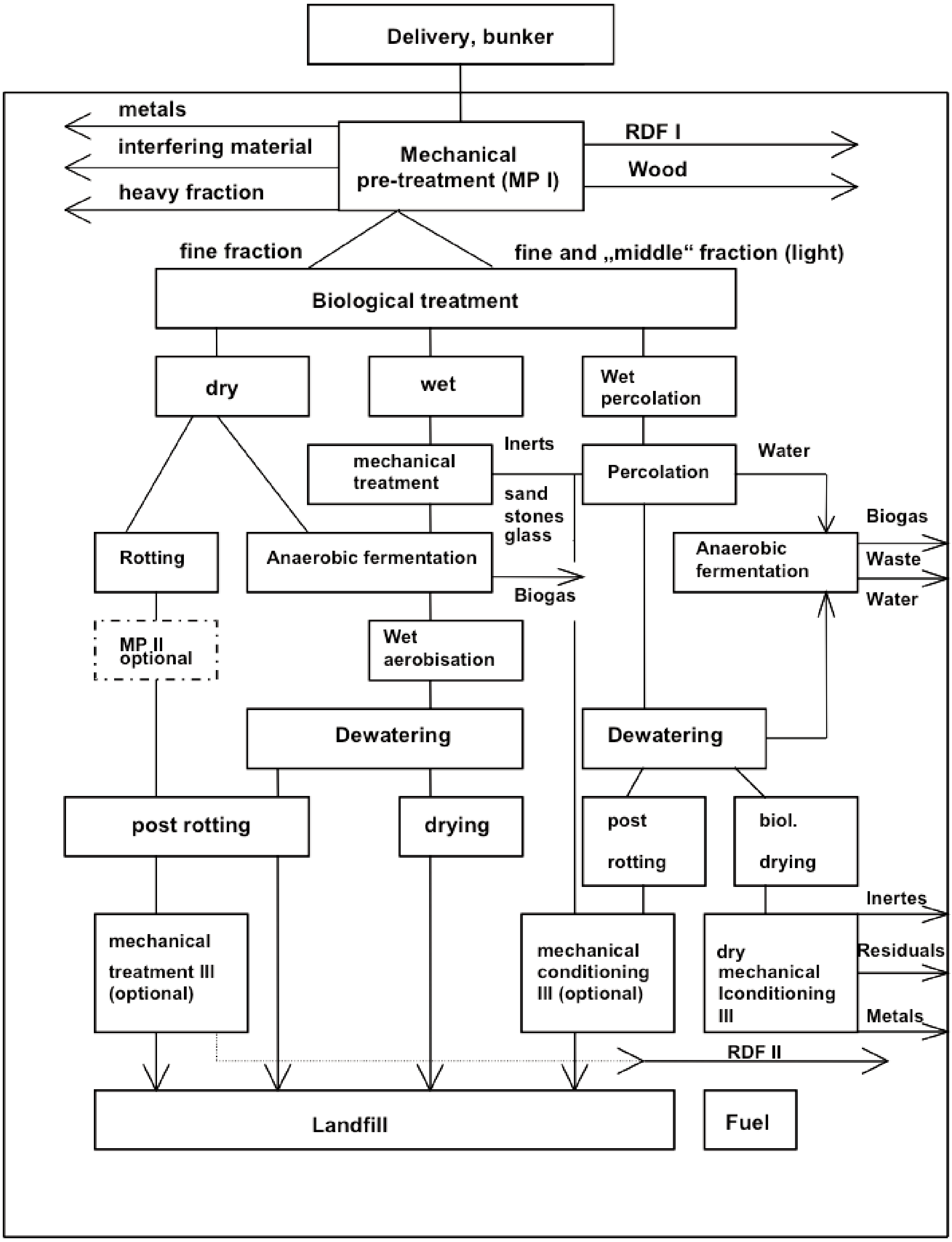
MBP concepts including aerobic biological treatment

During aerobic treatment, mechanical pre-treatment is necessary to separate out the RDF fraction. Bulky, interfering materials and metals must also be removed in order to protect the machines, which include conveyer belts and turning machines, during the succeeding treatment steps. In addition, the moisture content has to be adjusted while retaining a sufficient material structure in the waste to allow adequate air distribution. During the operation of aerobic processes, a great emphasis must be placed on adequate water content and sufficient air supply. Mechanical post-treatment is easier or not even necessary when aerobic processes are used. If the water content is inappropriate for landfilling, it must be adjusted.

During aerobic biological pre-treatment, high odour concentrations are emitted during the initial intensive rotting phase (see also Doedens 2001). As a consequence, in Germany, this step has to be undertaken in an enclosed system with forced aeration and off-gas treatment. The post-rotting or curing phase (at least 6–8 weeks) must be operated in-house or under a roof, depending on the degree of maturation reached during the intensive rotting step. In total, a rotting period of about 12–16 weeks or even longer is necessary to meet the German target values (see Figure 3). More details about the biological treatment step are presented elsewhere (Fricke et al. 2001; Leikam and Stegmann 1997).

MBP concepts including anaerobic biological treatment

If anaerobic treatment is undertaken, pre-treatment is more extensive and stringent. In addition to the removal of the RDF fraction, preferably small particle sizes, with no stones, sand or metal pieces, or other interfering materials (e.g. wood) should be present during anaerobic dry and wet fermentation. This is in order to avoid problems during transport and anaerobic fermentation of the waste. For example, an elevated sand content will cause sand to settle in an anaerobic wet fermentation reactor, and with the time, this material will take on a concrete-like consistency. Sand in a dry fermentation process can result



RDF: Refuse derived fuel
MP: Mechanical pre-treatment

Figure 3. Mechanical-biological treatment concepts for municipal solid waste: aerobic and anaerobic treatment including off-gas emission control (detention times may be longer depending on waste properties and technology used).

in an increased abrasion of the pumps. When a wet fermentation process is used, light fractions may float on the surface of the substrate in the anaerobic tank and, together with other material, may form a sludge blanket.

Mechanical pre-treatment therefore serves as an appropriate conditioning step for the substrate followed by the anaerobic process, which is a standard technology. The problem of odorous off-gas is only relevant for the pre- and post-treatment stages,

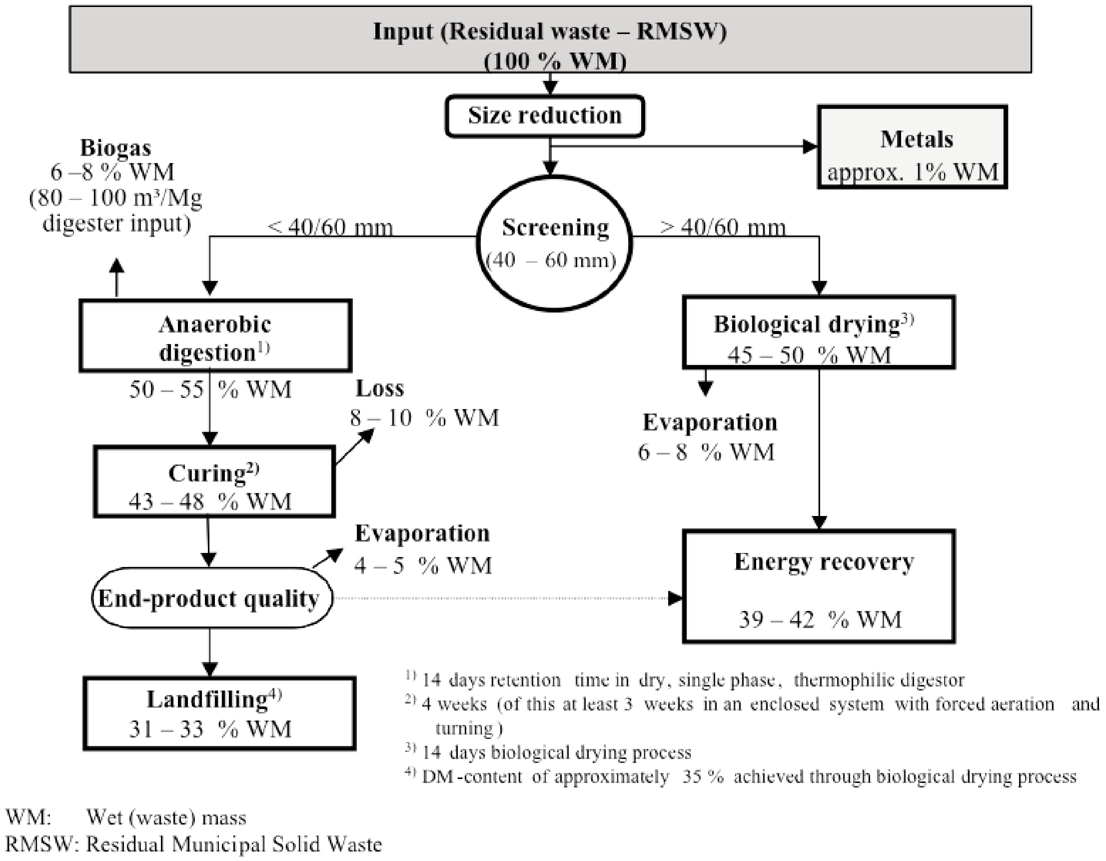


Figure 4. Mass balance for a MBP process (Müller et al. 2001).

since during anaerobic treatment, only biogas is produced which is used for energy production. Figure 4 shows an example a MBP process mass balance.

After an intensive mechanical pre-treatment (removal of RDF, metals, sand etc.), including shredding and in many cases water addition, anaerobic biological treatment is often used in Germany. Anaerobic pre-treatment may have several advantages over aerobic treatment, e.g. energy savings (no aeration) and energy gain from biogas production, as well as less odorous off-gas production. As a result, the removal of odours and other compounds (see Table 2) is less costly. Anaerobic fermentation should always be combined with a post-rotting step, since not all organic substances (e.g. lignin-containing components) can be degraded under anaerobic conditions to the degree required by the German regulations (see Table 1). In addition, since the compounds are in a reduced stage, they should be converted into their oxidised form.

The anaerobic treatment step, which is the alternative to the intensive rotting step, takes about 3 weeks to complete, while the post-rotting (curing) step takes at least another 6-8 weeks (see also Figure 3).

New MBP concepts

MBP using the percolation process

The percolation process is another option for mechanical-biological pre-treatment. In this case, after the removal of the RDF fraction and bulky substances, the waste is placed in a drum where water is added under anaerobic conditions, and the water/waste mixture is slowly mixed. Over a detention period of about 7-10 days, organic acids and CO_2 are mainly produced. The liquid phase is separated from the solids and subjected to treatment in a high organic content anaerobic reactor where biogas is produced. Solids are separated from the digested liquid which is returned back to the percolation reactor. The solid phase is dewatered and aerobically treated in order to meet the German limit values (Table 1). Figure 5 shows the general set-up of this process which is practised in Germany and Austria at full-scale (Fricke et al. 2004).

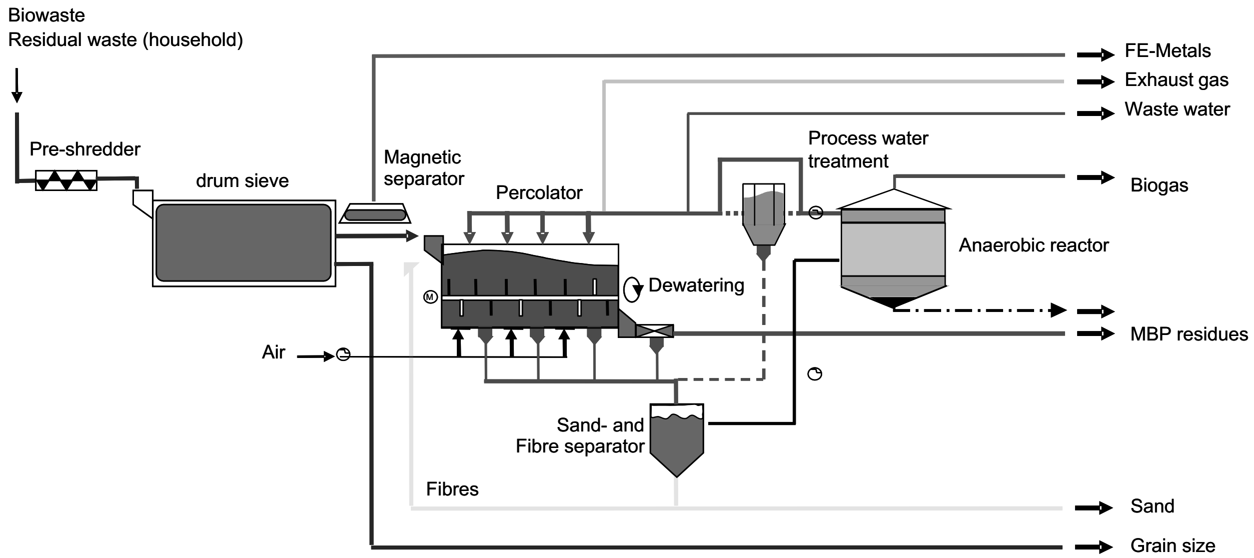


Figure 5. Concept of the "ISKA" percolator with subsequent anaerobic treatment (Fricke et al. 2004).

MBP using the anaerobic/aerobic treatment concept in the liquid phase

A new concept is proposed whereby, after the anaerobic treatment step in the liquid phase, an aerobic post-treatment of the effluent from the anaerobic reactor (also in the liquid phase) is implemented (Heerenklage and Stegmann 2005). When anaerobic processes are used, a dewatering and perhaps a drying step of the digested material are usually necessary. The post-rotting phase has to be undertaken in order to meet the limit values presented in Table 1. These values cannot be met if only anaerobic treatment takes place. If after a wet anaerobic fermentation step a wet aerobic step follows (see Figure 6), a dewatering and drying step only may be sufficient (Heerenklage and Stegmann 2003, 2005). In this case, the wet biological oxidation step may replace the post-rotting step.

Haase Energietechnik AG in Neumünster, Germany, implemented the new treatment concept at full-scale, applying an annual throughput of 146,000 Mg (120,000 Mg · a^{-1} residual waste and 26,000 Mg · a^{-1} sewage sludge) (Kahn 2004). According to Martens (2005), the concept of *fermentation + aeration in the liquid phase* offers the following advantages:

- Closed process where the substrate can be pumped.
- Process-air treatment facility requires less space compared to plants with entire aerobic biological treatment.
- Physical drying using biogas as an energy source is independent of biodegradation; process is easier to control than biological drying (rotting).
- Less space required.
- Reduced energy consumption.

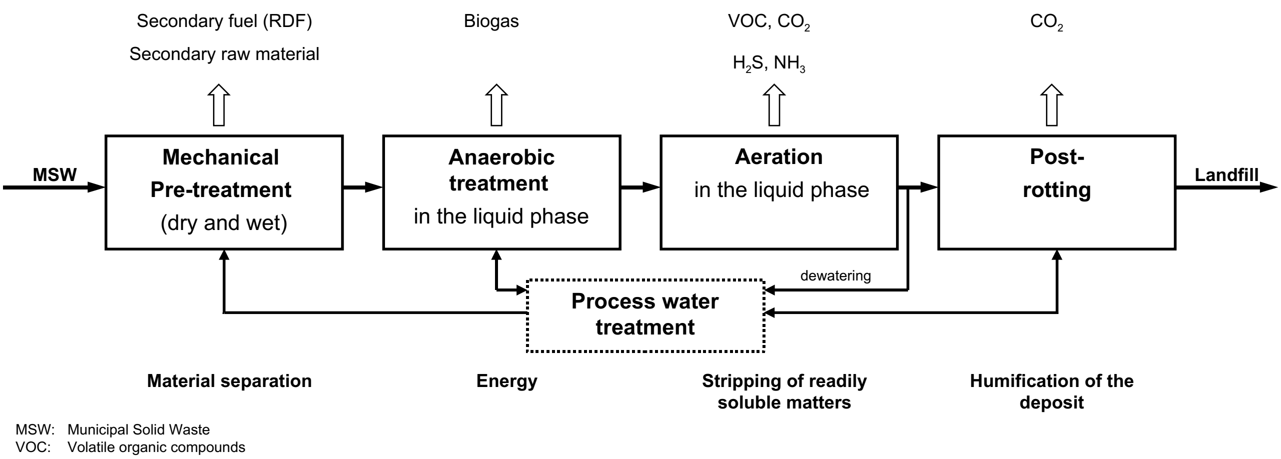


Figure 6. Concept of the anaerobic treatment of the mechanically pre-treated MSW with subsequent aeration in the liquid phase.

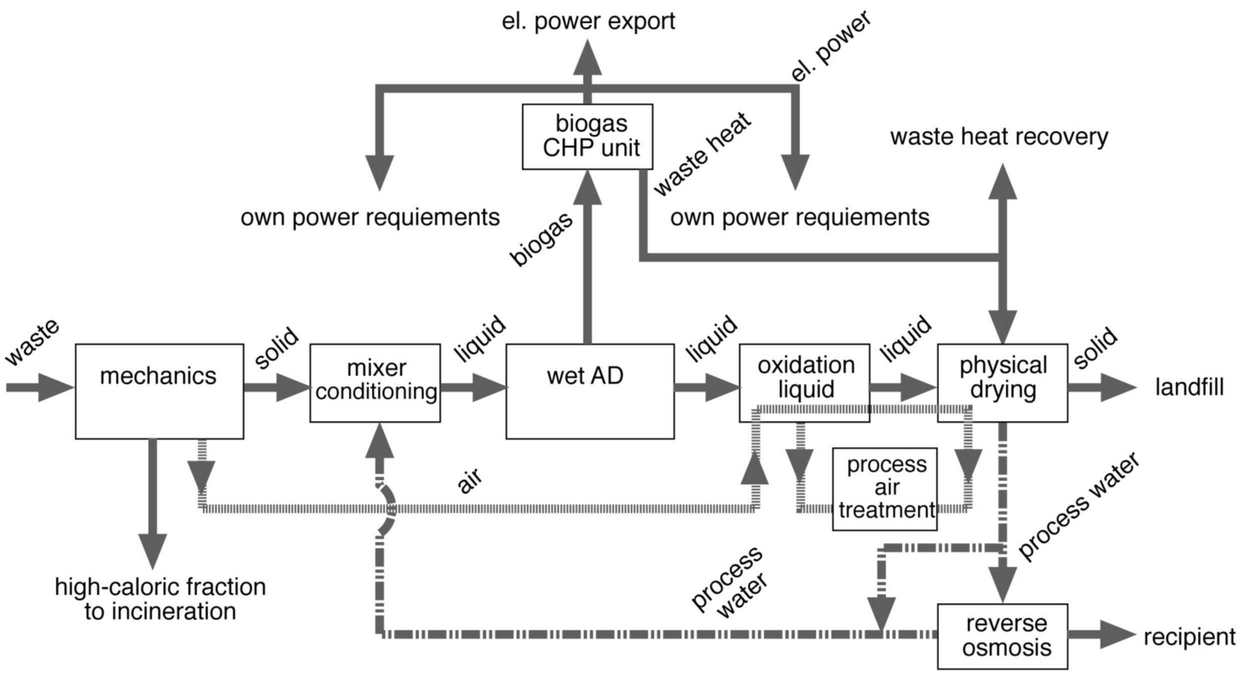


Figure 7. Plant concept of the Haase Energietechnik AG for mechanical-biological pre-treatment of residual waste (Martens 2005).

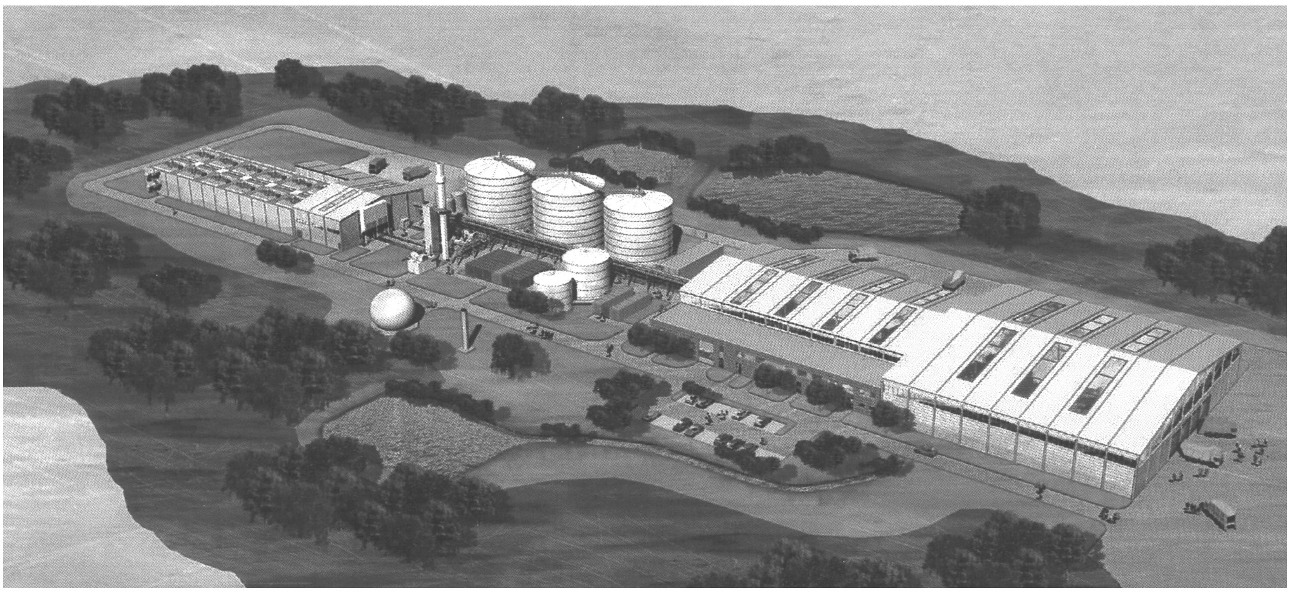


Figure 8. Model of the mechanical-biological pre-treatment plant in Lübeck (Martens 2005).

The entire plant concept of the Haase Energietechnik AG is shown in Figures 7 and 8. At first, the waste to be treated is separated in the mechanical pre-treatment stage (screening and sorting) for the following fractions: iron, non-ferrous metals and glass, as well as the RDF fraction consisting mainly of plastic and paper. Thus, approximately 41% (w/w) related to the plant input is RDF and subject to thermal utilisation. The fraction with a grain size of d < 60/80 mm (d = diameter) is blended in, in order to adjust it to the required water content. Subsequently, the remaining light fraction (plastic) and the high-density solids (e.g. sand, stones and glass) are separated from each other in the separator. The fraction rich in organic substances is supplied to the two-stage fermentation plant at a dry matter content of approximately 10% (w/w). In a combined heat and power plant, the biogas produced (approximately 11.3 MW · a^{-1}) is converted into electrical and thermal energy. Part of the electrical energy (11.5 MWh · a^{-1}) may be supplied to the electrical power supply system. After the fermentation stage, the material is led to an aeration stage which is also in the liquid phase, in order to biologically convert the residual organic substances and to systematically remove volatile gaseous components. These include ammonia, hydrogen sulphide and dissolved organic carbon, which are then treated in a waste air treatment plant. Thereafter, the treated waste material is dewatered and, if necessary, can be led to a post-rotting stage. Finally, the material poor in emissions (approximately 33% (w/w) related to the plant input) is landfilled (Kahn 2004).

LANDFILLING OF MBP MATERIAL

To describe the emissions behaviour of biologically pre-treated residual waste, landfill simulation experiments in the laboratory were carried out (Stegmann 1997). By choosing appropriate ambient conditions, an enhanced biological degradation process was achieved. The emissions and the emissions potential of the waste samples, as represented by gas quality and production as well as leachate concentrations and loads, were determined within a reasonable period of time. Table 3 presents a summary of the results of the landfill simulation reactors (LSR), which show that the emissions regarding organics and nitrogen as well as the gas production were all reduced by approximately 80–90%. Due to mechanical-biological pre-treatment of the MSW, the landfill characteristics achieved with this waste (MBP material) would also be significantly different from raw MSW in the following ways:

- The separation of the high calorific value fraction (e.g. plastics, paper, wood) means MBP material has a low structural material content.
- Active gas extraction would not be necessary since the gas formation potential is low; however, the residual amount of gas produced would need to be biologically oxidised before leaving the landfill (Lechner and Humer 2001).
- By adjusting the waste properties (e.g. water content) and using appropriate landfilling techniques, the MBP material would have a high density ($\rho \pm 1.5$ t · m^{-3} wet weight) which may result in low permeability ($k_f \pm 10^{-8}$ m/s) and savings in landfill volume.
- The mechanical stability of the landfill would be affected by the water content of the waste material and the way the landfill is operated. If for instance the pore gas pressure or the pore water pressure is too high, landfill stability may be reduced (see also Stegmann and Heyer 2001, 2002).

Full scale experiences are necessary before a final conclusion can be made. Due to the complex procedures of MBP waste landfilling required in Germany (e.g. landfilling of MBP waste during rainfall should be avoided (German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety 2001a) other options may be advantageous. A proposal for the construction and operation of bale landfills has been made already back in 1993 (Stegmann 1993). This type of landfill is especially suitable for mechanically-biologically treated wastes (see also Stegmann et al. 2005) as the relatively homogenous MBP material is compacted to high density bales and subsequently installed (stacked) under a roofing at the MBP landfill.

DISCUSSION AND CONCLUSIONS

Meeting the German or Austrian criteria for mechanical-biological treatment of MSW prior to landfilling means, that sophisticated treatment technologies need to be applied. As a result, this process can be costly. However, MBP processes offer a number of advantages such as flexibility (in terms of the desired output characteristic, e.g. MBP material for Landfilling or secondary fuel for energy recovery), the production of biogas and the effective separation of recyclables

Table 3. Effects of MBP on landfill emissions (results from laboratory scale tests) (Stegmann and Heyer 2001).

Emission	Raw Waste	MBP-Waste	Reduction
COD [mg · kg^{-1} TS]	25,000-40,000	1,000-3,000	90%
Total Nitrogen [mg · kg^{-1} TS]	1,500-3,000	150-300	90%
Gas production GP_{21} [mg · kg^{-1} TS]	150-200	0-20	90%

COD: Chemical Oxygen Demand.
TS: Total Solids.
GP21: Gas Production in 21 days.

(like metals, plastics, etc.). The question from a scientific point of view is whether the set standards – which consist of the target values for the pre-treated waste (Table 1 and 2), the air emission standards for the off-gases from the biological treatment plants (Table 3) and the landfilling criteria as described in the Waste Disposal Regulation – are appropriate.

Regarding the set quality criteria for the pre-treated waste, the authors are of the opinion that these values are generally acceptable. It is also necessary to achieve a separation of the high calorific value fraction from the incoming waste in order to use the energy potential of this fraction (mainly paper, cardboard, plastic). To achieve this, the calorific value of the pre-treated waste is limited to lower than or equal to 6000 $kJ \cdot kg^{-1}$ (Table 1). Once landfilled, the pre-treated waste should have a relatively low leachate and gas emissions potential. The set standards describing the respiration activity and the gas production potential to achieve this are therefore acceptable.

The maximum DOC in the eluate ($< 300\ mg \cdot l^{-1}$) is appropriate as it represents the amount of humic acids to a great extent. This was actually very recently approved by the German government but tightened to a value $< 250\ mg \cdot l^{-1}$ for the first 1.5 years after the waste disposal regulation came into force. Only recently (December 2006) the limit value has been adapted to $< 300\ mg \cdot l^{-1}$. Regarding the analysis procedures for the target values, as seen in Table 1 and 2, the existing procedures do not guarantee the same results, independent of the laboratory performing the test. In this regard an additional demand for standardization can be identified.

Another question arises regarding the air emission standards that have to be met after treatment of the off-gas from the different stages of MBP treatment. In Germany, these standards are not required for composting plants where separately collected kitchen and yard waste is treated. During MBP, the organic limits which have to be met in the off-gas are only achievable by applying thermal treatment. Whether the high costs associated with this highly sophisticated treatment method is proportional to what is achieved for the environment is questionable. By the installation of bioscrubber/biofilter mainly the residual methane in the off-gas may not be reduced (Doedens 2001) – in contrast to thermal treatment – whereas most of the other parameters listed in 30th Ordinance to the Federal Immission Control Act might be kept. However, against the background of the current discussion on climate change and climate protection it is very unlikely that the strict requirements for MBP will be reduced.

In general, there are two possible approaches for biological treatment. Either:

- achieve a high level of biological stability as set by e.g. the German and Austrian governments, or
- biologically stabilize the waste only to a very limited degree prior to Landfilling (this approach would not meet the German and Austrian legal stipulations).

The latter case can be categorised as a measure for the acceleration of the anaerobic processes once this partly-stabilised waste is landfilled. Due to the reduction in easily degradable organic compounds, the methanogenic phase can be reached relatively quickly so that the landfill can be operated as a bioreactor landfill, supported by means of leachate recirculation if necessary. If this concept is applied, landfill gas will still be produced (the amount depends on the degree of stabilisation) and has to be extracted, and should be energetically used. Leachate of a quality produced from the methanogenic phase will also be produced. The final cap should be placed on the landfill when the biological processes have nearly come to an end (low gas production). Both concepts may be applied depending on the goals that are to be achieved and on the regulations to be met. The German and Austrian approach is more vigorous, and in the opinion of the authors, the preferred option for the future.

New MBP plants will mandatory feature a possibility for energy recovery from MSW, i.e. including an anaerobic biological treatment process. Furthermore it seems to be likely that existing MBP plants with aerobic biological treatment will be gradually reconditioned. In the long term MBP prior to Landfilling might be gradually reduced in favour of the production of secondary fuels for energy recovery. However, this will strongly depend on the future development of the market for substitute fuel but in the same time would widely correspond with the German government's target of avoiding Landfilling from 2020 on.

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