MECHANICAL BIOLOGICAL PRETREATMENT OF MUNICIPAL SOLID WASTE

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1. INTRODUCTION

The overall strategy of waste management in Europe is towards more material and energy recovery from waste and less landfilling. The European Union (EU) has via the Landfill Directive set targets for reducing the biologically degradable waste fraction going to landfills. This reduction will be implemented in three steps. Based on statistical data on waste composition of the year 1995 each member country has the following targets on reduction of biodegradable MSW: 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. (Anonymous 1999)

In Austria target values for mechanical biological pretreatment of MSW as a prerequisite for landfilling are already in power from the beginning of 2005. In Germany the implementation of the Landfill Directive prescribes indirectly that from June, 1st 2005 only thermally or mechanically-biologically pretreated MSW can be landfilled (Anonymous 2000). A selection of German limit values for waste going to landfills are presented in Table 1. In addition, also off-gas emission limit values (see Table 2) from the in-house treatment facilities (waste delivery, mechanical and biological treatment) are set (30. BImSchV, Anonymous 2001).

Table 1. Selection of target values for the landfilling of mechanically-biologically pretreated municipal solid waste (MSW) in Germany

Parameter	*target value*
respiration activity[1)] *(RA_4)* resp.	*≤ 5 mg O_2/g dry mass*
gas formation potential[2)]*l (GF_{21})*	*≤ 20 N ml/g dry mass*
TOC_{eluat}[3)]	*≤ 250 mg/l*
TOC_{solid}	*≤18 Mass-%*
gross calorific value	≤6000 kJ/kg

1) by means of bacteria in 4 day dependent on the amount of substrate available (indirect method to measure the biodegradable fraction of the waste sample

2) gas formation potential (GF_{21}): Gas formation of the waste sample in 21 days

3) TOC in the eluate produced in an aelution test (1:10 solid/liquid ration and 24 hours shaking)

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In Germany the mechanical biological pretreatment is seen more as a transient solution in order to fill up landfills that have already installed a base liner and/or made other investments so that depreciation costs for the investment have to be paid anyway. There is not a great potential – if there is one – for the construction of new landfills for MBP-waste in Germany. Apart from the problems of landfill acceptance by the public the costs for the new landfill in combination with pretreatment will be high (comparable with MSW incineration). The German government has the target that from 2020 there will be no landfilling in Germany anymore.

2. MECHANICAL AND BIOLOGICAL TREATMENT OF MUNICIPAL SOLID WASTE (MSW)

Why is the reduction of the landfilling of biodegradable organics implemented in the EU-directive and what are the main achievements, when practising mechanical biological pretreatment (MBP)?

The main emissions (leachate and biogas) are to a very high degree influenced by the biological processes in the landfill. When municipal solid waste (MSW) is landfilled without pretreatment, emissions occur during and after the landfill operation depending on waste composition, climatic conditions, etc. in the form of approximately 150 m^3 biogas/Mg MSW and $5 m^3/ha*d$ highly polluted leachate. Due to biological degradation processes significant settling of the landfill surface takes place in the range of 20-25% of the height of the landfill, which may damage f.e. surface liners, gas extraction and leachate collection systems. The leachate produced has to be collected and treated with great technical expenditure over many decades (Christensen et al., 1992). The biogas produced has to be extracted and flared or used as an energy source.

Practising the mechanical-biological waste pretreatment (MBP), processes taking place in the landfill over long periods of time (decades) will be shortened to several months. The emission potential of the waste will be reduced to a large extent during pretreatment so that, compared to unpretreated waste, significantly reduced emissions occur. It is not the aim of mechanical-biological pretreatment to produce "compost" to be applied in agriculture or horticulture because the content of heavy metals and other harmful or disturbing substances is in general too high (Leikam and Stegmann, 1996).

3. MECHANICAL-BIOLOGICAL PRE-TREATMENT AS PART OF WASTE MANAGEMENT CONCEPTS

Although extensive waste prevention and recycling is practised there is still a considerable quantity of residual waste left, which is not resp. cannot be reused. Also if both the packaging material and the biowaste are separately collected, only a certain percentage of these compounds (± 50% of the total potential) is actually recovered. As a result the waste composition may not change essentially.

Within a waste management concept mechanical biological pre-treatment is applied to pretreat the residual MSW prior to landfilling. This includes the mechanical separation of the high calorific value fraction (refuse derived fuel, RDF) before the biological treatment (see Fig. 1). The RDF is used for energy production in a variety of plants (f.e. kilns, coal, power plants). (see also Thomé-Kozmiensky, 2004)

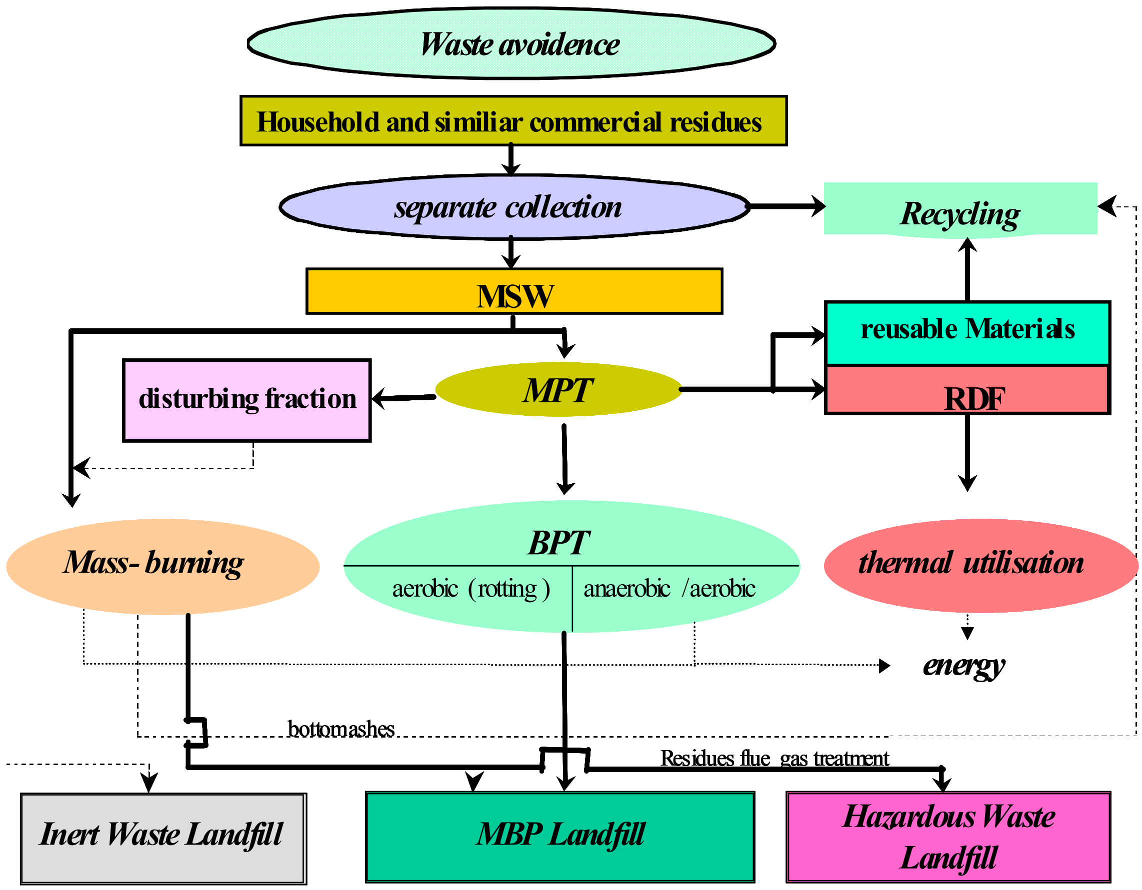
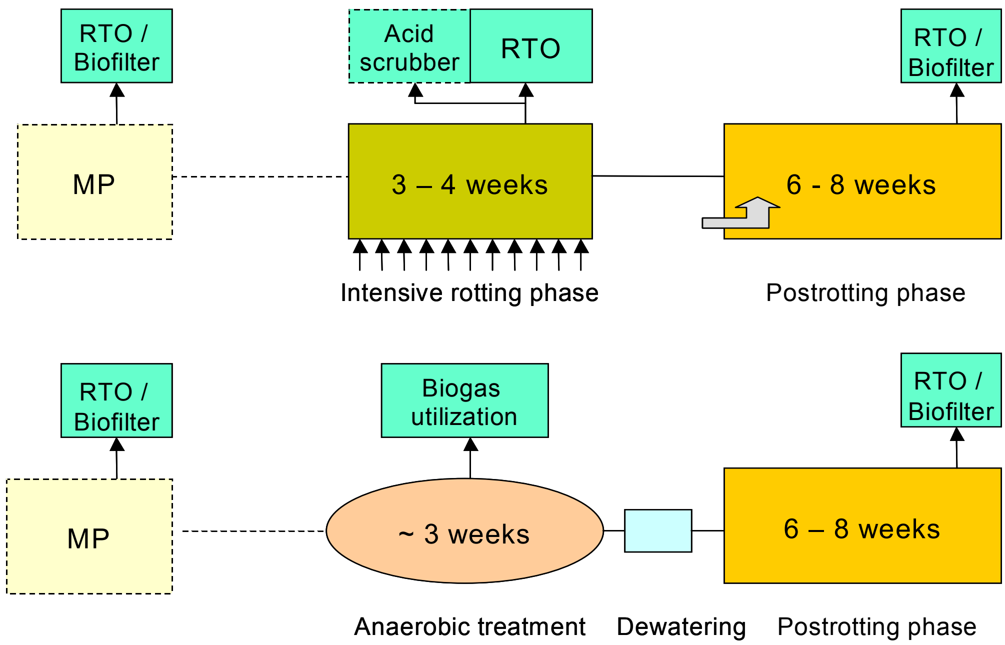


Figure 1. General Concept of Municipal Solid Waste Management

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. By the aerobic biological pre-treatment high odour concentrations emit during the initial intensive rotting phase.(see also Doedens, 2001). As a consequence it has to be practised in Germany in enclosed systems with a forced air aeration system and off-gas treatment. The postrotting or curing phase (at least 6-8 weeks) has to be operated in-house or under a roof dependent 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 also Fig. 2). More details about the biological treatment step are presented elsewhere (Fricke et al., 2001, Leikam and Stegmann, 1997).

After an intensive mechanical pretreatment (removal or RDF, metals, sand etc.) including shredding and in many cases water addition more often the anaerobic biological treatment is used in Germany. The anaerobic pretreatment may have several advantages compared to aerobic treatment, e.g. saving energy (no aeration) as well as gaining energy 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 milieu conditions to the degree required by German regulations (see Table 1). In addition, the compounds are in a reduced stage and should be converted into the oxidised form.



RTO: regenerative thermal oxidation

Figure 2. Mechanical-biological treatment concepts for municipal solid waste: aerobic and anaerobic treatment including off-gas emission control (detention times may even be longer due to waste properties and technology used).

For the anaerobic treatment step, which "substitutes" the intensive rotting step, about 3 weeks and for the past-rotting (curing) step at least another 6-8 weeks are necessary (see also Fig. 2).

There are many different concepts for mechanical biological pretreatment in operation. Figure 3 (Ketelsen, et. al., 2005) gives an overview of different technologies in operation in Germany and probably elsewhere. The question which kind of system is the optimum cannot be answered since there are always advantages and disadvantages of the process.

During aerobic treatment the mechanical pretreatment is mainly necessary to separate out the RDF-fraction. Bulky disturbing material as well as metals have also to be removed in order to protect the machines during the following treatment steps as there are conveyer belts, turning machines etc.. In addition the moisture content has to be adjusted and there should be sufficient structure material in the waste allowing adequate air distribution. When aerobic processes are operated great emphasis has to be put on the adequate water content and a sufficient air supply. Mechanical post treatment is easier resp. not necessary when the aerobic processes are used. If the water content is not appropriate for landfilling it has to be adjusted.

If anaerobic treatment is practised pretreatment has to be more extensive. In addition to the removal of the RDF anaerobic dry and wet fermentation requires preferably small particle sizes, no stones, sand and no metal pieces resp. other disturbing materials (f.e. wood). The pretreatment has to be very intensive in order to avoid problems during transport and anaerobic fermentation of the waste. F.e. elevated sand content will settle in an anaerobic wet fermentation reactor and with the time this material will become a concrete like consistence. Sand in dry fermentation results beyond others in increased abrasion in the pumps. When the 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. Once the mechanical pretreatment serves for an appropriate conditioning for the substrate, then the anaerobic process is standard technology. The odorous off-gas problematic is only relevant for the pre- and post treatment, since during anaerobic treatment only biogas is produced which is used for energy production. Fig. 4 shows as an example a mass balance of MBP-process.

As a new concept, 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 proposed. An aerobic curing phase of the dewatered sludge may be necessary in order to achieve the target values (Heerenklage and Stegmann, 2004).

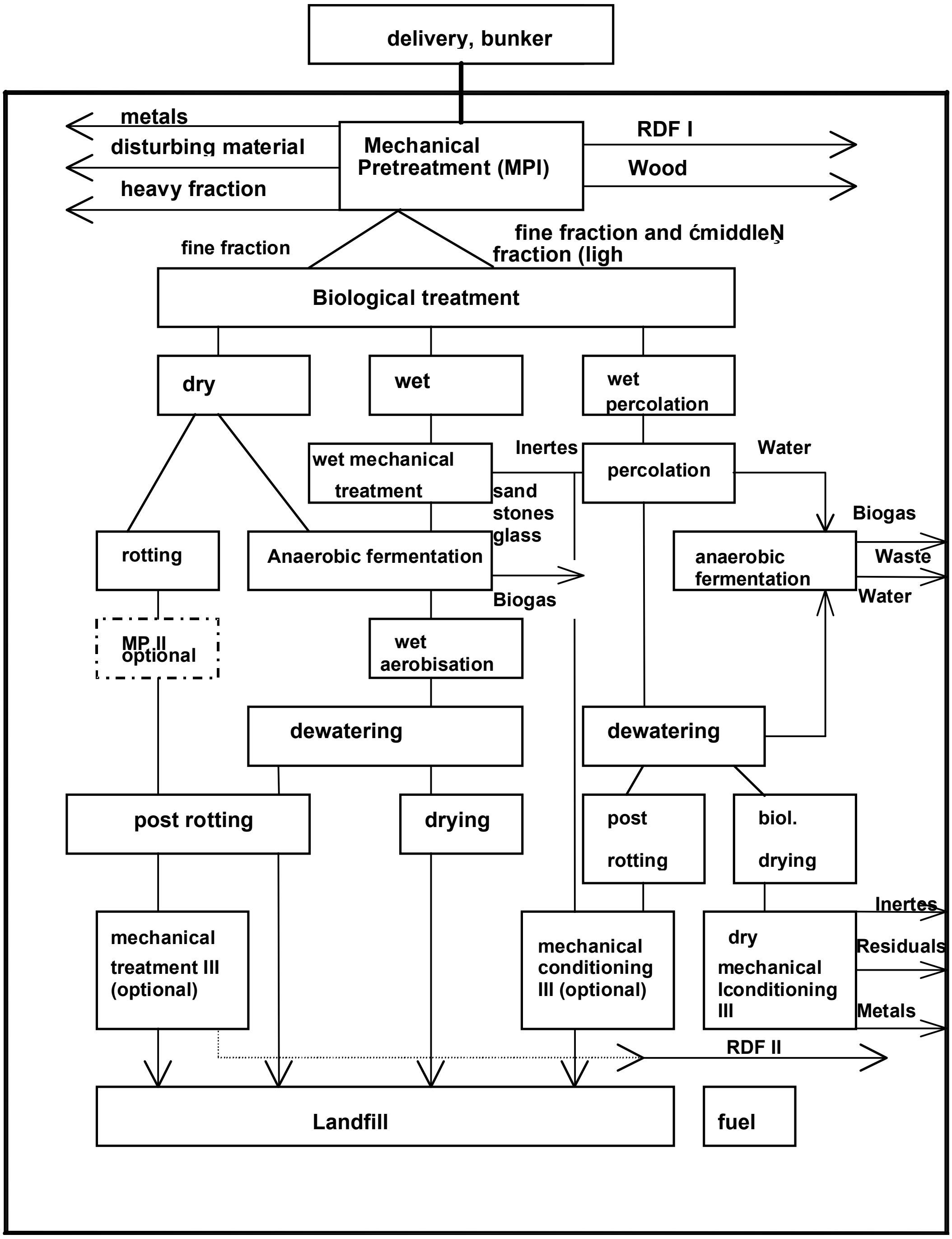


Figure 3. Overview of different technologies for mechanical biological pretreatment (Ketelsen et. al., 2005)

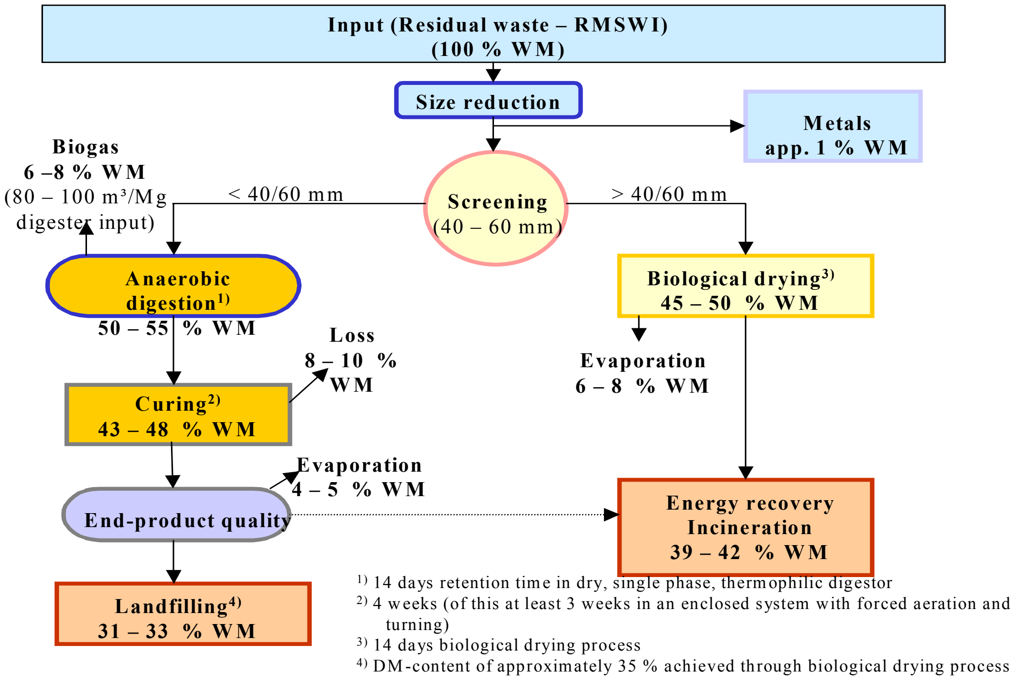


Figure 4. Mass balance of Mechanical-Biological Treatment (MBP) process (Müller et. al., 2001)

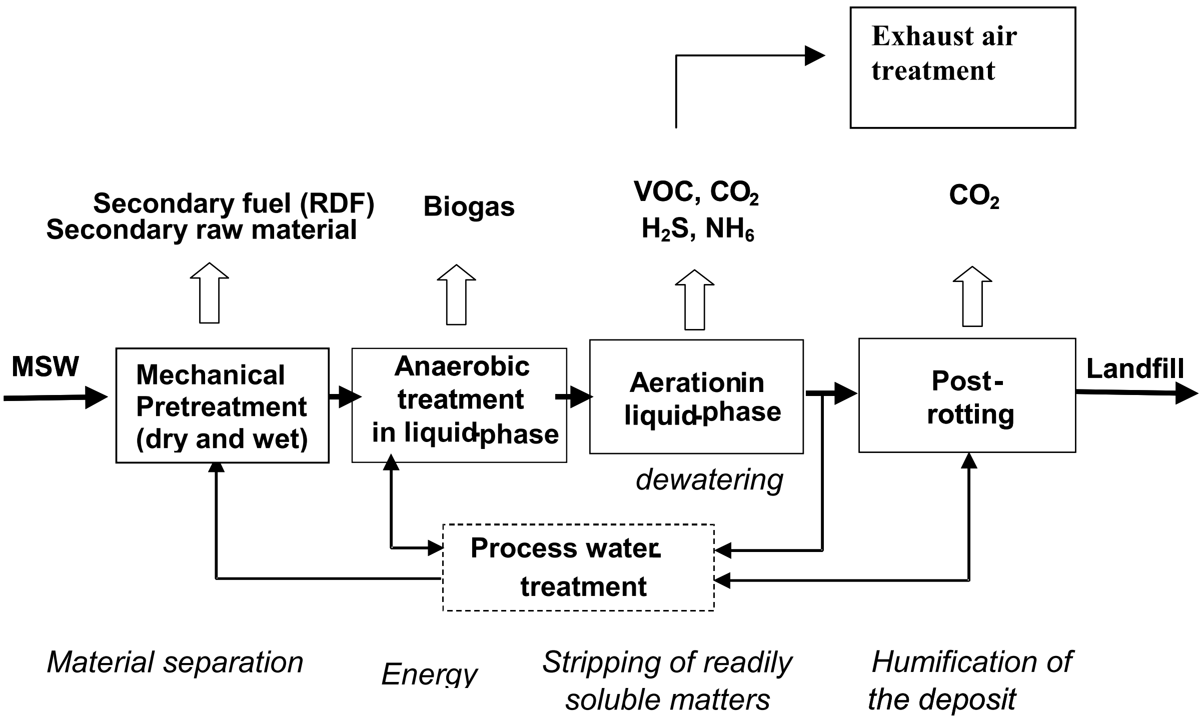


Figure 5. Concept of the anaerobic treatment of the mechanically pretreated Municipal Solid Waste (MSW) with subsequent Aeration in the Liquid Phase.

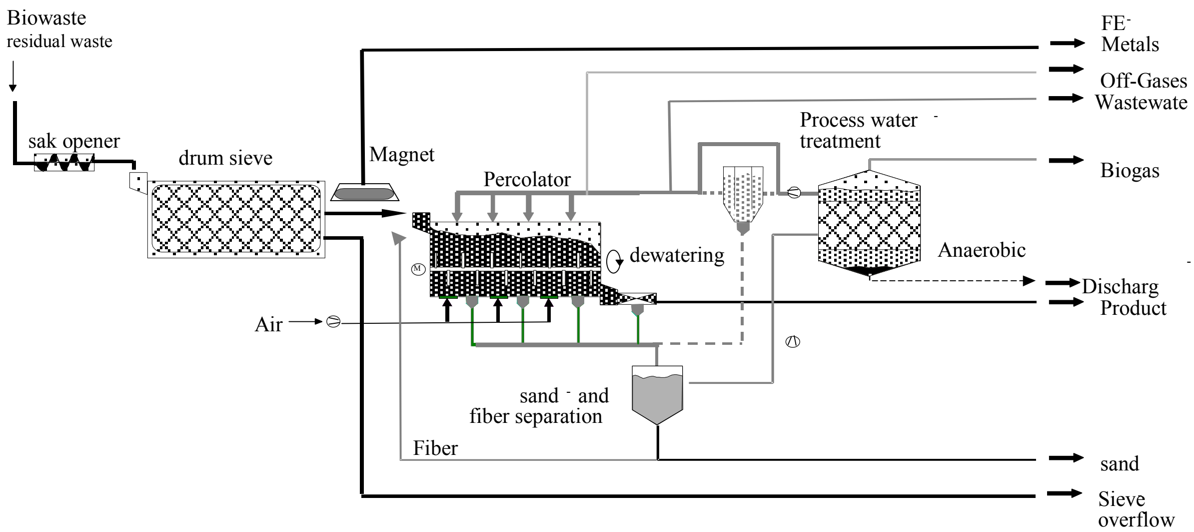


Figure 6. Concept of the "ISKA" Percolator with subsequent anaerobic treatment (Fricke et al., 2004)

When anaerobic processes are used, a dewatering and perhaps a drying step of the digested material will be in general necessary. The post rotting phase has to be practised in order to meet the limit values presented in Table 1. These values cannot be met if only an anaerobic treatment takes place. If after a wet anaerobic fermentation step also a wet aerobic step follows (see Fig. 5) only a dewatering and drying step may be sufficient. (Heerenklage and Stegmann, 2005). The wet biological oxidation step replaces the post composting step.

The percolation process is another option for the mechanical biological pretreatment. In this case after the removal of the RDF and bulky substances the waste is subjected to a drum, where under anaerobic conditions water is added and the water / waste mixture is steadily slowly mixed. During a detention time of about 7-10 days mostly organic acids and CO_2 are produced. The liquid phase is separated from the solids and subjected to an anaerobic highly organic reactor where biogas is produced. The digested liquid is dewatered and to a high extent recirculated into the percolation reactor. The solid phase is dewatered and aerobically treated in order to meet the German limit values (Table 1). Figure 6 shows the general set up of this process which is practised f.e. in Germany and Australia in full scale (Fricke et al., 2004).

4. OFFGAS TREATMENT

The unloading, as well as the mechanical and biological pretreatment have to be practised in-house in Germany. This means, that all buildings have to be ventilated and the off-gases have to be captured and treated. Due to the German off-gas emission standards (30. BImSchV (Anonymous, 2001)) the treated off-gas from the whole plant has to meet target values that are presented in Table 2.

Table 2. German target values for off-gases from MBP-Plants after 30. BimSchV (Anonymous, 2001)

Parameters	**Target values clean gas**		
Sample	½ h - mean	Daily mean	Monthly mean
TOC	40 mg/m³	20 mg/m³	55 g/Mg
Nitrous oxide (N_2O)	-	-	100 g/Mg
Ammonia (NH_3)	30 mg/m³ (TA air)		-
Dust	30 mg/m³	10 mg/m³	-
Dioxins / Furans	0.1 ng/m³		
Odor	500 OU/m³ (single measurement)		

OU: odour units as measured in a olfactometer

Off-gas from the unloading and mechanical pretreatment area in general can be treated in biofilters which may be combined with an acid scrubber for NH_3-removal. The off-gas from the aerobic biological treatment, especially from the intensive rotting phase, has in general relatively high nitrogen and carbon concentrations so that a thermal treatment (f.e. 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-pretreatment process.

5. LANDFILLING OF MECHANICALLY-BIOLOGICALLY PRETREATED MBP

To describe the emission behaviour of biologically pre-treated residual waste, landfill simulation experiments in the laboratory have been carried out. (Stegmann, 1997). By choosing appropriate milieu conditions, an enhanced biological degradation process is achieved. By these means, the emission and the emission potential of the waste samples represented by gas quality and production as well as leachate concentrations and loads can be determined within reasonable periods 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 can be reduced by approximately 80 - 90 %.

Due to mechanical-biological pre-treatment of the MSW also the landfilling characteristics are significantly different from raw MSW.

- Due to the separation of the fraction rich in calorific value (f.e. plastics, paper, wood) it has low contents in structural material
- Since the gas formation potential is low, an active gas extraction will not be necessary; however, the residual amounts of produced gas need to be biologically oxidised before leaving the landfill (Lechner and Humer, 2001).
- Using appropriate waste properties (f.e. water content) and landfilling techniques the MBP material can be disposed off at a high density ($\gamma \pm$ 1,5t / m³ wet weight) which may result in a low permeability (kf $\pm 10^{-8}$ m/s). If this will actually happen ha to be verified under full scale landfilling conditions.
- The stability of the landfill may be affected by the water content of the waste material at placement and the way of landfill operation. If for instance the pore gas pressure or/and the pore water pressure is too high landfill stability may be reduced (see also Stegmann and Heyer, 2001 and 2002). Again in this regard full scale experiences are necessary for a final conclusion

Table 3. Effects of mechanical-biological pre-treatment (MBP) on landfill emissions (Results from laboratory scale tests) (Stegmann and Heyer, 2001)

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

TS: Total Solids
GB_{21}: Gas production in 21 days

Due to the complex landfilling procedure of the MBP-waste – as required in Germany (f.e. landfilling of MBP-waste during rainfall should be avoided),(Anonymus, 2000) other options may be advantageous. The author has made a proposal for the construction and operation of bale landfills (Stegmann,1993). This type of landfill is especially suitable for mechanically-biologically treated wastes. (see also Heyer and Stegmann, 2005)

6. DISCUSSION AND CONCLUSIONS

Meeting the German resp. Austrian Criteria for mechanical biological treatment of MSW prior to landfilling means that sophisticated technologies have to be applied. As a result this process is costly. The question is also from a scientific point of view whether the set standards as there are the target values for the pretreated waste (see Table 1), the air emission standards for the off-gases from the biological treatment plants (Table 2) and the landfilling criteria as described in the Waste Disposal Ordinance are appropriate.

Regarding the set quality criteria for the pretreated waste, the author is of the opinion that these values are in general acceptable. It is necessary to achieve a separation of the high calorific value fraction from the incoming waste also in order to use the energy potential of this fraction (mainly paper, cardboard, plastic). In order to achieve this, the calorific value of the pretreated waste is limited to be lower or equal than 6000 kJ/kg (see Table 1).

The pretreated waste once it is landfilled should result in a relatively low leachate and gas emission potential. In order to achieve this, the set standards describing the respiration activity respectively the gas production potential are acceptable. The question is whether the COD in the eluate $\leq$250 mg/l is appropriate, since this value is in many cases too difficult to achieve. As a result the detention time in the biological treatment plant has to be in some cases significantly prolonged which is associated with increasing costs. In the opinion of the author the COD in the eluate represents to a high degree humic acids. Respecting this, in the opinion of the author probably a value of $\leq$ 300mg COD/l may also be acceptable.

Regarding the measuring of the target values as mentioned in Table 1 there is still not a precise procedure available, that guarantees the same results independent on the laboratory doing the test.

A question arises also regarding the air emission standards that have to be met after treatment of the off-gas from the different sections of MBP-treatment plants. In Germany these standards are not required for composting plants where separately collected kitchen and yard waste is treated. Regarding the organic parameter that have to be met, in the off-gas, this is only achievable after thermal treatment of the off-gases. The question is whether the high costs associated with this highly sophisticated treatment is in good relation to what is achieved for the environment. Compared to the utilisation of a bioscrubber/biofilter combination instead of a thermal treatment mainly residual methane in the off gas may not be reduced (see also Doedens, 2001 and 2002).
There are in general two approaches for the biological treatment:

- Achieving high biological stability as set f.e. by the German and Austrian Government
- Reduce the degree of biological stabilisation only to a certain degree

In the latter case this pretreatment is more a measure for the acceleration of the anaerobic processes once this partly stabilised waste is landfilled. Due to the reduced easy degradable organic content in the waste the methanogenic phase is reached relatively fast, so that the landfill can be run as a bioreactor landfill probably supported by means of leachate recirculation, where necessary.

When 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, that has the quality of leachate from the methanorganic phase, will be produced. The final cap should be put in place, when the biological processes have come nearly 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 approach is more consequent and in the opinion of the author the preferred option in highly economical developed countries.

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