Waste Manage Res 1999 17· 520–526
Printed in UK – all rights reserved


Waste Management & Research
ISSN 0734–242X

# Full-scale experiences with mechanical–biological pretreatment of municipal solid waste and landfilling

Dierk von Felde Dipl-Ing
Heiko Doedens Prof Dr-Ing habil
Institute of Sanitary Engineering and Waste Management, ISAH, University of Hanover, Hanover, Germany

In Lower Saxony three full-scale plants for the mechanical–biological pretreatment (MBP) of residual municipal solid waste (RMSW) prior to landfilling are now in operation. The three plants support a wide range of mechanical and encapsulated biological process techniques. In addition to biological degradation, pretreatment allows mechanical separation of iron fractions and refuse derived fuel (RDF). This causes a strong reduction in the need for landfill sites and hence lowers landfill emissions. To describe the efficiency of biological stabilization of RMSW several chemical-physical or biological methods for analysing solid matter or eluate can be used. On the one hand, chemical–physical methods determine a large portion of the total organic carbon (TOC) of pretreated wastes, but often do not allow a differentiation between mobile (with respect to degradable) and immobile (with respect to non-degradable) portions. On the other hand biological parameters explain only a small portion of the TOC, but are well suited devices for qualitative evaluation of landfill reactions and emissions. First results from separate landfill compartments show lower hydraulic permeability, higher landfilling density, lower organic and nitrogen concentrations in leachate of landfilled MBP wastes compared to untreated wastes. An acid phase with high organic leachate concentrations does not occur. This will create new requirements for landfilling techniques.

**Keywords** – biological; landfilling; landfill gas; leachate; mechanical; municipal solid waste; pretreatment; waste analysis

**Corresponding author:** Dirk von Felde, Institute of Sanitary Engineering and Waste Management, ISAH, University of Hanover, Welfengarten 1, D-30167, Hanover, Germany.
Email: dierk.vonfelde@isah.uni-hannover.de

## Introduction

In spite of increasing efforts made to collect recoverable and non-recoverable waste separately a considerable quantity of residual waste is left for final depositing in sanitary landfills. The German 'TA Siedlungsabfall', (technical instruction for utilization, treatment and other disposal of municipal solid wastes), has demanded higher standards to be achieved by May 1994 or June 2005 at the latest. The landfilling of waste without pretreatment will not be permitted any longer. To minimize gaseous emissions and leachate it will be required to reduce the organic fraction to less than 5% dry weight (DW). Only thermal treatment can be recommended to accomplish this goal.

In Austria the landfill order requires a net caloric value of $H_u$ = 6000 KJ $kg^{-1}$ DW for biological pretreated wastes. This is equal to a level of volatile solids (VS) between 30 and 35% DW. Such an organic content cannot be achieved by biological treatment alone. Additionally, the mechanical separation of fractions rich in organic matter like RDF is necessary.

Further to the legislation on thermal treatment of residual wastes the government of Lower Saxony is also trying to establish additional techniques for waste pretreatment. It is funding three full-scale demonstration plants for the MBP of residual waste in association with the Institute of Sanitary Engineering and Waste Management (ISAH), at the University of Hanover. The scientific guidance includes:

- planning, building and process optimizing of all three plants;
- investigations into landfilling properties and emissions of pretreated residual waste;
- investigation of fractions consisting of iron and RDF separated from the residual waste during the process;
- investigation of gaseous emissions during the process;
- developing methods to describe biological stabilization of residual waste after mechanical and biological treatment.

## Mechanical–biological pretreatment of RMSW in three full-scale plants in Lower Saxony

Together all plants have a capacity of 160 000 t $y^{-1}$. A wide variety of technical solutions for MBP is covered by the three plants in Lüneburg, Bassum and Friesland/Wittmund (see Table 1).

### Plant 1

Mechanical processing with separation of fractions consisting of disturbing materials, iron and RDF (material >100 mm) followed by 16 weeks of composting in a closed system with outgoing air treatment through air washer and biological filter (see Fig. 1).

### Plant 2

Mechanical processing with separation of fractions consisting of disturbing materials, iron and RDF (>80 mm) and anaerobic treatment of fractions <40 mm followed by 8 weeks of composting in a closed system.

### Plant 3

Mechanical processing with separation of fractions consisting of disturbing material, iron and RDF followed by 2 weeks of composting in a closed system with outgoing air treatment

Table 1. Characterization of the three process technological concepts for MBP in Lower Saxony

| Capacity | MBP Lüneburg 37.500 t/a | MBP Bassum 65.000 t/a | MBP Friesland/Wittmund 61.000 t/a |
|---|---|---|---|
| Components of the mechanical treatment | Sorting<br>Two step shredding<br>Magnet<br>Screening<br>Homogenization<br>Addition of water | Identical | Identical |
| Sorted out fractions | RDF<br>Ferrous metals<br>Disturbing compounds<br>Hazardous compounds | Identical | Identical |
| Type of biological treatment | Aerobic, active aeration | Main stream aerobic, active aeration<br>Partial stream (fraction <40 mm) 20 days one-stage anaerobic treatment | Aerobic<br>1. Intensive composting active aeration<br>2. Open composting with different processing variants, partly passive aeration |
| Encapsulation | Whole process encapsulated (112 days) | Whole process encapsulated (56 days) | Intensive composting encapsulated (14 days)<br>Open composting on landfill (210 days) |
| Outgoing air treatment | Air Washer + Biofilter | Identical | Identical |
| Start of operation | 4/1996 | 9/1997 | Identical |

t/a=tons/annum.

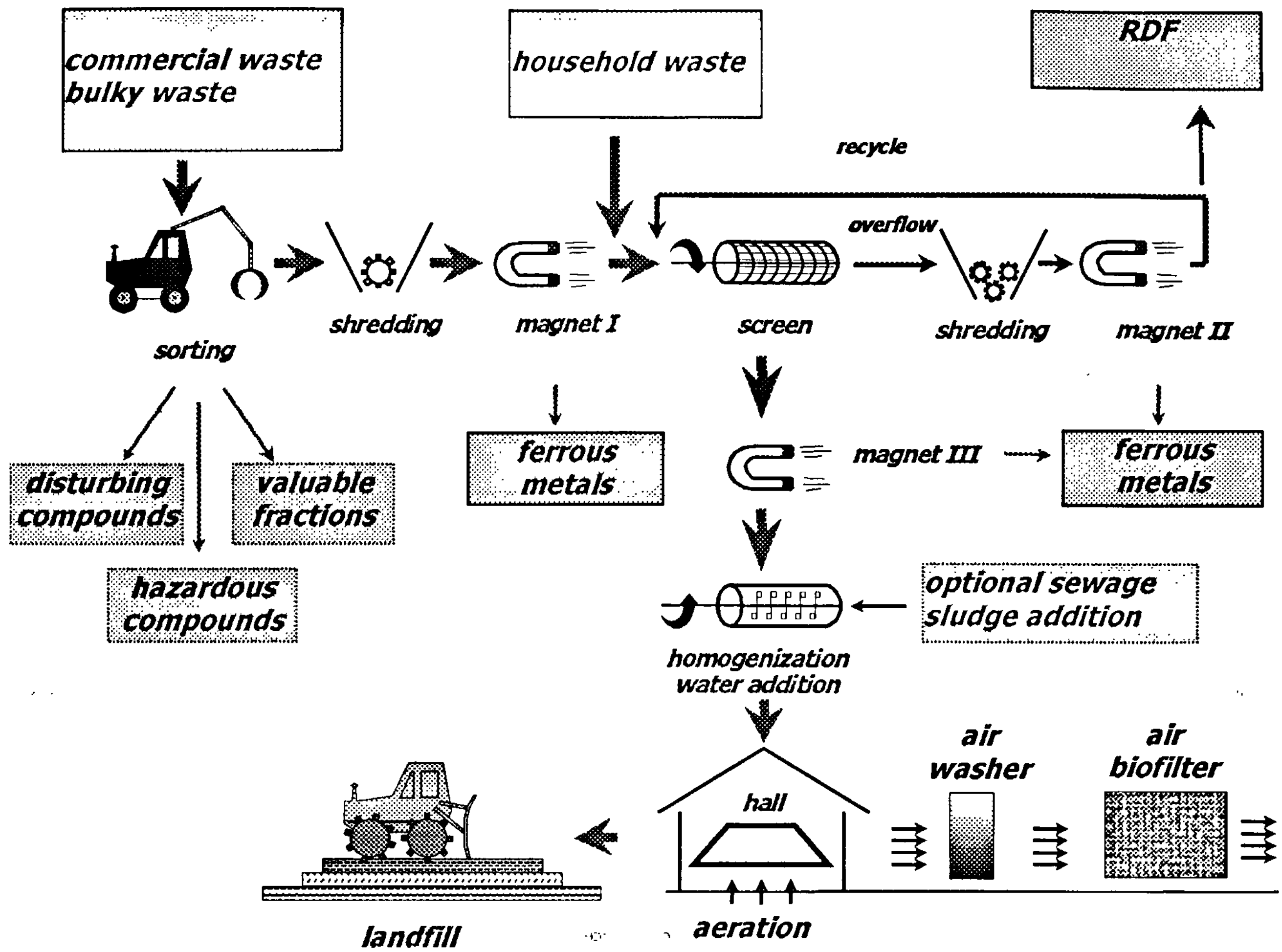


Fig. 1. Diagrammatic view of the operation process at the MBP plant in Lüneburg (Von Felde & Doedens 1997).

in biological filters and 7 months of after treatment in openo composting on the landfill with different processing alternatives.

The pretreated wastes are landfilled in separate landfill compartments to enable an evaluation of gaseous and leachate emissions of MBP wastes.

## Methods to describe stabilization of residual waste after MBP

To characterize mechanical and biological treated residual waste, chemical, physical and biological methods for solid matter (see Table 2), as well as eluate can be used. In own examinations beside volatile solids biological activities of solid matter were measured in the Sapromat, in a laboratory composting device and anaerobic gas production tests.

Eluate investigations measured parameters according to German 'TA Siedlungsabfall' as well as humic acids, 5-day biological oxygen demand ($BOD_5$), nitrogen components and different methods for toxicity determination. A detailed description and discussion of the methods is given by Laga (1984), Doedens, Von Felde, Grieße, Bröker, Bülow 1995), Brüggert *et al.* (1996), Von Felde (1996) and Von Felde & Doedens (1997).

The real biological emission potential of landfilled MBP waste cannot be determined on the basis of the standardized observation time of 4 days in the Sapromat. To achieve this goal, longer periods of observation or long-term anaerobic tests are better suited.

## Results of MBP in full-scale plants

Investigations show an evident decrease of biological activity in solid matter between 90 and 98% (see Fig. 2). The recommended values (respiration activity $AT_4$ = 5 $mgO_2\ g^{-1}$ DW, anaerobic gas production $GB_{21}$ = 20 l $kg^{-1}$ $DW^{-1}$) (Von Felde 1996) can be achieved during treatment time in the biological process step (Doedens *et al.* 1997). Gas production of MBP waste is an important parameter to estimate gaseous landfill emissions. It decreases over 90% from 150 to 250 l $kg^{-1}$ DW to below 20 l $kg^{-1}$ DW after MBP. Taking into account the mass degradation during MBP

Table 2. Comparison of different stabilization criteria for the description of mechanical-biologically pretreated residual waste (Dach *et al.* 1996; Müller *et al.* 1996; Von Felde 1996)

| | Biological methods | | | Chemical-physical method |
|---|---|---|---|---|
| Parameters | Respiration activity $O_2$-need in 7 d $AT_4$ | Respiration activity $O_2$-need in 7 d $BSB_7$ | Anaerobic gas production in 21 d, $GB_{21}$ | Organic substance Volatile solids VS |
| Methods | Sapromat (LAGA M10, modified) | Composting in laboratory reactors of ISAH | DIN 38414, S8 modified | DIN 38414, S3 modified |
| Sample Storage | Use fresh material or freeze material at −18 °C | ←Identical | ←Idendical | Dry |
| Pretreatment | shredding <10 mm disturbing material (stone, metal) calculated as not reactive | ←Identical | ←Identical | Shredding <1 mm |
| Sample size | 40 g | 7000−12000 g | 300–700 g | 10–30 g |
| Water content of samples | water content 40–50% WW or 60–70% of the water capacity | ←Identical | Original water content | Dry |
| Number of parallel tests | 3 | 1 | 4–6 | 3 |
| Temperature | 20 °C | 50 °C | 35 °C | 550 °C |
| Time for pretreatment | 0.5 d for shredding | ←Identical | ←Identical | 2 d for drying and shredding |
| Time for analysis | f. $AT_4$ 4d variable | f. $BSB_7$ 7d variable | f. $GB_{22}$ 21d variable | 1 to 4 h |
| Result | $mgO_2/(gDW{*}4d)$ | $mgO_2/(gDW{*}7d)$ | $Nl/(kgDW{*}21d)$ | %DW |
| Converted TOC-portion[1] | 1–2% | ca. 10% | ca. 10% | 100%×X[2] |

Assumption for pretreated waste: [1]TOC=150–250 mg $Cg^{-1}$ DW; $AT_4$=1.5 to 2.5 mg $Cg^{-1}$ DW; $BSB_7$=10 to 12 mg $Cg^{-1}$ DW, $GB_{21}$=10 to 12 mg $Cg^{-1}$ DW, volatile solids=25 to 40% DW; [2]possibly incorrect results through non-biotic influences.

in a range from 40 to 60% by sorting out RDF, ferrous metals and disturbing compounds as well as by biological degradation, the emission degradation is even higher.

Volatile solids, limited by TA Siedlungsabfall to 5% DW exceed this limit and range from 30 to 45% DW after 16 weeks of MBP. The wide range of results in untreated and treated wastes prevents evaluation of efficiency of biological treatment (Fig. 3).

Eluates of wastes are made for the qualitative characterization of mobility of waste components during the liquid phase. They present a potential landfill emission, even if the values of the concentrations measured in eluates cannot be compared directly to leachate concentrations because conditions of standardized elution differ strongly from conditions of real landfilling.

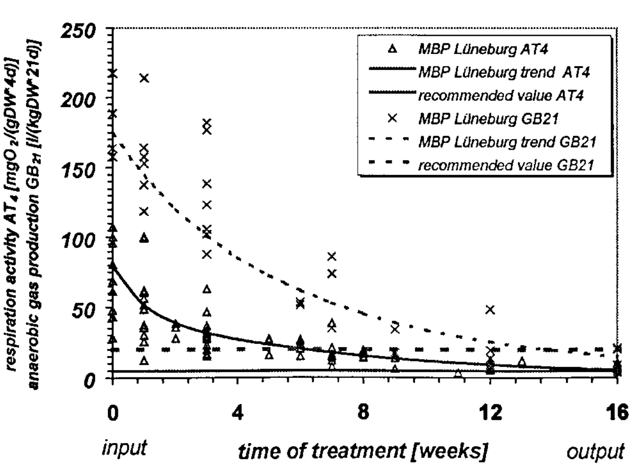


Fig. 2. Respiration activity and anaerobic gas production during the period of treatment.

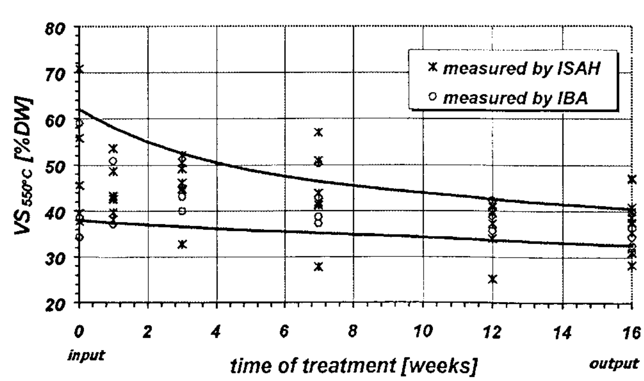


Fig. 3. Volatile solids during the period of treatment of materials at the MBP plant in Lüneburg.

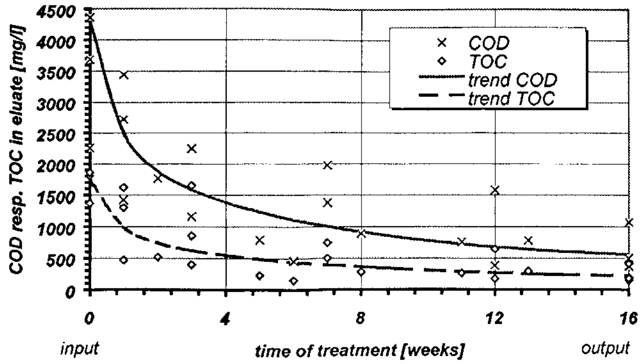


Fig. 4. Chemical oxygen demand and TOC in eluate during the period of treatment of materials at the MBP plant in Lüneburg (Von Felde 1998).

Both TOC and COD (chemical oxygen demand) concentrations in eluates decrease more than 85% during biological treatment (see Fig. 4). The average TOC-concentration after 100 days of treatment is below 300 mg $l^{-1}$. In treated wastes about 60% of TOC consists of non-biodegradable humic acids (Von Felde 1998) (Fig. 5). With the exception of TOC all requirements set by the 'TA Siedlungsabfall' (i.e. for heavy metals, organic compounds etc.) are met.

The results in Fig. 6 show a good correlation between biological parameters in solid matter and TOC. This means that in contrast to VS, biological parameters are well suited to describe a potential landfill emission.

Volatile solids of MBP material range from 30 to 40% and do not meet the requirements set by the 'TA Siedlungsabfall'. There is only a poor correlation between VS and organic components in eluate. Thus VS, in contrast to respiration activity and anaerobic gas production, is not a viable measure for the qualitative assessment of potential landfill emissions (Von Felde & Doedens 1997).

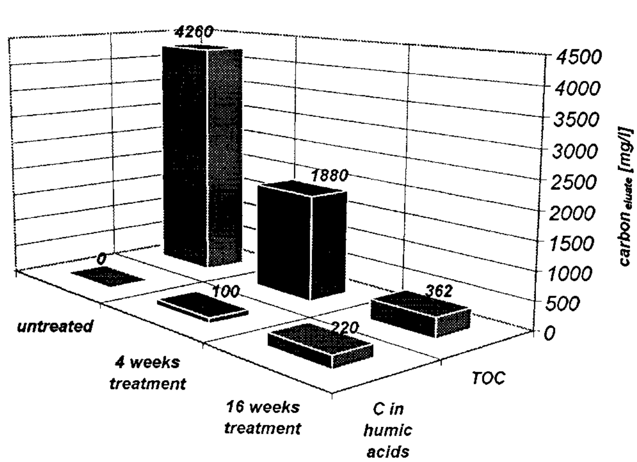


Fig. 5. Total organic carbon and carbon in humic acids during the period of treatment of materials at the MBP plant in Lüneburg.

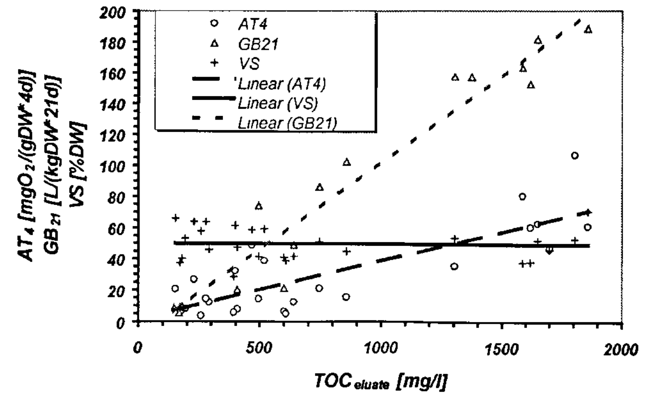


Fig. 6. Correlation between TOC concentrations in eluates, according to DEV S4 and respiration activity, anaerobic gas production and volatile solids of materials at the MBP plant in Lüneburg (Von Felde 1998).

## Landfill properties of MBP wastes

Owing to the larger homogeneity and smaller grain size of MBP wastes, compared with untreated wastes, a higher landfill density and lower gas and hydraulic permeability (Fig. 7) in the range of $K_f = 10^{-7}$ to $10^{-9}$ m $s^{-1}$ can be achieved (Bidlingmaier & Scheelhaase 1997, Von Felde & Doedens 1997).

For gas drainage two main characteristics working against each other determine the distance of gas drains: the low gas production potential and the high waste density causing low gas permeability of the pretreated material. It is to be expected, that the low gas production will prevent an economical energetic use of landfill gas (LFG) from MBP landfills. Thus either flaring or alternative techniques of LFG disposal will be applicable if gas drainage is necessary at all, otherwise methane oxidation at the landfill surface should prevent intolerable LFG emissions.

Initial investigations on landfill behaviour of MBP material were carried out at the MBP plant in Lüneburg. The landfill compartment with an area of 0.5 ha has been in operation since the summer of 1997. To avoid any damage of

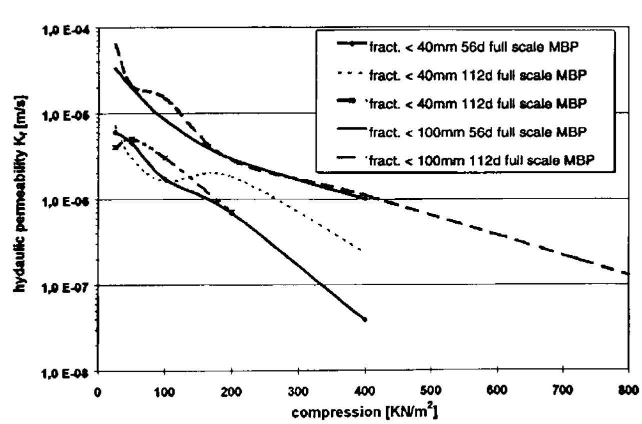


Fig. 7. Hydraulic permeability in relation to compression applied to material at the MBP plant in Lüneburg (Von Felde & Doedens 1997).

Table 3. Characterization of leachate from a full-scale MBP landfill in Lüneburg, laboratory landfill simulation and untreated waste compared with German legislative limits (own results; Ehrig 1980; ATV 1988; Theilen 1995; Leikam & Stegmann 1997)

| Parameter | MBP Lüneburg start phase of landfilling | DSR laboratory scale landfilling of MBP waste start phase | Untreated waste acid start phase | Untreated waste methane phase | German legislative limits* |
|---|---|---|---|---|---|
| pH | 7.5 | 7.0 to 7.5 | 4.5 to 7.5 | 7.5 to 9 | – |
| COD | 700 to 1.600 | 2000 to 2400 | 6000 to 60000 | 500 to 4500 | 200 |
| TOC | 300 to 650 | – | 2000 to 30000 | 200 to 2000 | 67 |
| $BOD_5$ | 1 to 55 | 100 to 1100 | 4000 to 40000 | 20 to 550 | 20 |
| COD to $BOD_5$ | 20 to 150 | 2 to 20 | 2 | 15 to 20 | – |
| TKN | 10 to 37 | – | 1350 | Identical | – |
| $NH_4$-N | 0 to 27 | 90 to 130 | 750 | Identical | – |
| $NO_3$-N | 15 to 66 | – | – | – | – |
| $NO_2$-N | 0.1 to 1.7 | – | – | – | 2 |
| $N_{inorganic}$ | 16 to 75 | – | 750 | Identical | 70 |
| total N | 35 to 140 | 200 to 250 | 1350 | Identical | – |
| COD to total N | 4.6 to 8.7 | 10 | 8 to 12 | 2 to 3 | – |
| AOX | 0.1 to 0.9 | – | 0.3 to 3.4 | Identical | 0.5 |

*. Limits for direct discharge of leachates according to German legislature: N° 51. 'Anhang Abwasser Verordnnag'.

the base sealing system landfilled material is left uncompacted. The thickness of MBP waste is about 2.5 to 3 m. The conditions are still aerobic, and methane concentrations are below 1 Vol.%.

Analysis of leachate from MBP landfill compartments at the Lüneburg plant in Table 3 and Fig. 8 show COD concentrations in the range of 700 to 1600 mg $l^{-1}$. A wide COD to $BOD_5$ ratio demonstrates the inertization by MBP. An acid phase, characterized by high organic concentrations with high biodegradable portions (of a narrow COD to $BOD_5$ ratio), does not occur. Inorganic nitrogen, $BOD_5$, Nitrite and absorbable organic halogenic compounds (AOX) concentrations are at the German legislative limit for direct discharge. But COD concentrations that clearly exceed the German limits demonstrate the necessity for treatment of leachate from MBP landfills. The wide COD to $BOD_5$ ratio and low nitrogen concentrations show that biological treatment plants used for leachate treatment at MSW landfills will not affect an optimal solution for treating leachate from MBP landfills. The low portion of biodegradable organic compounds will surely create new requirements on leachate treatment.

Several laboratory scale investigations were carried out in Germany to estimate landfill reactions in short-term experiments. (Höring & Ehrig 1997; Leikam & Stegmann 1997). By scaling up the results the authors sought to estimate the time necessary for aftercare of gaseous and liquid emissions. These times range from 50 to 340 years compared with times of aftercare of untreated wastes of 120 to 440 years. This would mean that the effect of inertization by MBP is not as high as expected. Our own investigations show that the initial COD, $BOD_5$ and nitrogen concentrations in leachate of full-scale MBP material landfilling are lower than in laboratory tests. This may mean that the period of leachate-emissions aftercare could be much shorter than estimated. At this point further full-scale investigations in combination with new calibration of landfill simulation tests are absolutely necessary.

One important aspect for shortening the period of aftercare is the possibility of accelerating landfill reactions at the time of landfilling and during the period of aftercare. When a highly efficient base sealing is achieved, it would be logical to use the period where the seal is functioning well to minimize the emission potential by leaching. This could be affected by treating a large portion of the mobile, biodegradable fractions of waste – instead of rapidly covering the waste and minimizing actual emission. In this case the

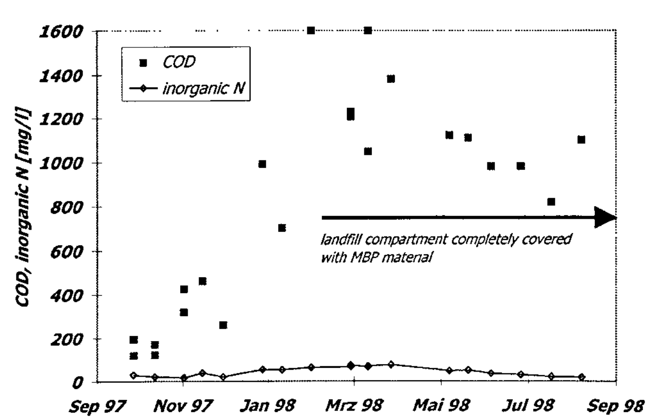


Fig. 8. Leachate concentrations of full-scale landfilling for MBP wastes at the Lüneburg plant.

remaining emission potential is reduced and left to a future date when the sealing is no longer functioning.

## Conclusions

All technological concepts in the three full-scale MBP demonstration plants for residual waste in Lower Saxony illustrate the state of the art of MBP in Germany today. They include mechanical treatment devices that allow a specific treatment of different waste components by sorting out RDF, ferrous metals, disturbing compounds and biodegradable fractions. An air treatment system is necessary for each recovery method. The concepts substantially differ in the kind of biological treatment they offer.

Relative organic contents between 30 and 40% DW clearly exceed the legislative requirements of 5% DW for sanitary landfill class II in Germany.

The biological activity, measured as respiration activity in a Sapromat machine, decreases with full-scale aerobic treatment by over 95% to values of around 5 mg $O_2$ $g^{-1}$ DW. The anaerobic gas production decreases by over 98% to values of around 4 to 9 l $kg^{-1}$ DW. Analysis of eluates from the mechanical-biologically treated material shows that, with the exception of TOC, all requirements for class II landfills according to the standards set by the 'TA Siedlungsabfall' are met.

Volatile solids do not correlate with the organic load of the eluates. Thus VS are not an appropriate parameter for evaluation of potential landfill emission. Respiration activities measured in a Sapromat machine, as well as anaerobic gas production show a good correlation to the organic load of eluates. Therefore, these parameters are at least well suited devices for the qualitative evaluation of landfill emissions.

Soil-mechanical properties (especially low gas and hydraulic permeability) low levels of gas production and quality of leachates with low organic and nitrogen load, and small quantities of biodegradable compounds will all create new requirements for the design of leachate and gas drainage and treatment. This is the subject of current investigations.

## References


Doedens, H., Von Felde, D., Grieße, A., Bröker, E., Bülow, W. (1995) Biologische Vorbehandlung vor der Ablagerung. Zwischenbericht des Instituts für Siedlungswasserwirtschaft und Abfalltechnik der Universität Hannover, Hannover, Germany.

Atv (1988) Arbeitsbericht der ATV-Arbeitsgruppe 7.2.26 Sickerwässer aus Abfalldeponien. Bad Honnel, Germany: ATV.

Bidlingmaier, W., Scheelhaase, T. (1997) *Geomechanical Evaluation Of Mechanical-biological Pretreated Waste*. Sardinia 1997, 5th International Landfill Symposium. Vol. I, S495–512. Cagliari, Italy: Environmental Sanitary Engineering Centre CISA.

Brüggert, B., Bülow, W., Kallert, U., Müller, U., Müller, W., Rospunt, B., Schappler-Scheele, Suhlmann, J. (1996) Zwischenbericht des Nds. Landesamtes f. Ökologie. Untersuchung einer biologischen Restabfallvorbehandlungsstufe. Hildesheim, Germany: NLO.

Dach, J., Danhamer, H. & Jager, J. (1996) Ergebnisse eines Laborvergleiches zur Harmonisierung des Gärtests für feste Siedlungsabfälle. *Waste Reports* **4**.

Doedens, H., Von Felde, D., Ketelsen, K., Bröker, E., Giebel, B. (1997) "Wissenschaftliche Begleitung der drei großtechnischen Anlagen zur mechanisch-biologischen Vorbehandlung von Restabfällen in Niedersachsen', Statusbericht, Hannover, Germany.

Ehrig, H.J. (1980) Beitrag zum quantitativen und qualitativen Wasserhaushalt von Mülldeponien, 2. erweiterte Auflage, veröff. des Inst. *Für Stadtbauwesen der TU Braunschweig, H.* **26**, 1980.

Höring, K., & Ehrig (1997) Langfristige Emissionen aus Ablagerungen mechanisch-biologisch vorbehandelter Abfälle; %. Münsteraner Abfallwirtschaftstage, Labor für Abfallwirtschaft, Siedlungswasserwirtschaft, Umweltchemie der Fachhochschule Münster.

Laga (1984) Qualitätskriterien und Anwendungsempfehlungen für Kompost aus Müll und Müll/Klärschlamm, Länderarbeitsgemeinschaft Abfall, 10/1984.

Leikam & Stegmann (1997) *Mechanical, Biological Pretreatment of Residual Municipal Solid Waste and The Landfill Behaviour of Pretreated Waste*. Sardinia 1997, 5th International Landfill Symposium, Vol. I, S. 463–474. Cagliari, Italy: Environmental Sanitary Engineering Centre CISA,

Theilen (1995) Behandlung von Sickerwässern aus Siedlungsabfalldeponien, Veröff. d. Inst. für Siedlungswasserwirtschaft und Abfalltechnik der Universität Hannover, Germany. 1995.

Von Felde, D. (1996) Alternativen zum Glühverlust; Vortrag auf den 1. Niedersächsischen Abfalltagen, veröffentlicht in Heft 95 der Veröffentlichungen des Inst. für Siedlungswasserwirtschaft u. Abfalltechnik der Universität Hannover, Hannover, Germany. 1996.

Von Felde, D. (1998) Untersuchungsergebnisse der niedersächsischen Demonstrationsanlagen, Vortrag auf den 2. Niedersächsischen Abfalltagen, Oldenburg, Germany.

Von Felde, D., Doedens, H. (1997) *Mechanical–biological Pretreatment: Results Of Full Scale Plants*. Sardinia 1997, 5th International Landfill Symposium. Vol. I, S. 531–542. Cagliari, Italy: Environmental Sanitary Engineering Centre CISA.