Experience in the Operation of Mechanical-Biological Waste Treatment Plants
– Report by the Operator of a German MBT Plant (Hannover) –

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Abstract

In the Hannover region, non-recyclable waste generated is either subjected to mechanical-biological treatment (being utilised as a high-calorific fraction following material-flow-specific treatment) or undergoes direct thermal use. After having been in operation for six years, many parts of the mechanical-biological treatment (MBT) plant in Hannover have undergone technical and cost-effectiveness optimisation. The key areas involved were personnel-related operational organisation, the separating out of heavy materials prior to fermentation, the production of (and energy recovery from) fermentation gas, and the exhaust air treatment facility. The energy produced from fermentation gas (i.e. electricity and heat) helps to ensure that the waste treatment plants in Hannover are almost completely energy-self-sufficient, that considerable quantities of power can be fed into the public grid on a commercial basis, and that only small quantities of electricity have to be bought in from outside to cover the shortfall. Additionally, energy efficiency was investigated and a carbon audit performed for Hannover’s MBT plant in association with various methods of treatment for the high-calorific fraction.
1. Introduction

The Hannover region is home to 1.1 million inhabitants in an area covering around 2,300 km². aha (Zweckverband Abfallwirtschaft Region Hannover) is the public provider of waste disposal services. It carries out kerbside collection of refuse and recyclable materials as well as running various waste collection centres, composting facilities, a mechanical-biological treatment (MBT) plant and three landfill sites. In 2010, around 330,000 Mg of residual waste was generated in the region. Once it has been optimally sorted by origin, calorific value and distance to be transported, this waste is fed into various treatment facilities. Additional plant capacity is available in several external refuse incineration plants and aha's own MBT plant for non-recyclable waste.

The MBT plant in Hannover is approved for an annual capacity of 200,000 Mg. The mechanical waste treatment (MT) facility has been in operation since the year 2000, and the biological waste treatment (BT) facility installed downstream from it has been running since 2005. The BT facility is operated as a dry mesophilic fermentation unit based on the VAL-ORGa system, with subsequent aeration and closed-system maturation. There have been several publications about the waste concept employed by the MBT plant in Hannover [3, 4].

The various processes that the Region Hannover authority pursues in treating non-recyclable waste are outlined below. The procedural approach adopted for the MBT plant in Hannover is described, along with experience gained in its operation, and the energy audit and information on energy efficiency are presented.

2. Material flow management

In recent years the focus with regard to the plant's operation has increasingly been on material-flow-optimised quantity control, the quality of high-calorific fractions with a view to their further utilisation, and transport optimisation.
The merger of the City of Hannover with local authorities in the surrounding area to form the Region Hannover authority with effect from 1 January 2003 has meant that various agreements on incineration have been adopted by this new body. Within these arrangements, wide supply corridors have been agreed; these enable transport to be optimised, thus allowing fairly substantial cost savings to be made. In this connection, optimised supply arrangements with another public provider of waste disposal services have also been entered into. This involved the contractually agreed points of supply being exchanged, thus reducing the required transport distance by around 320,000 km/a. In Hannover, the MBT plant and the refuse incineration plant (RIP) owned by E.ON Energy from Waste Hannover are directly adjacent to each other. Figure 2 shows an aerial view of the waste treatment centre in Hannover run by aha, which consists of a biowaste composting facility, the MBT plant and (in the foreground) the RIP.

Additionally, in recent years the demand for high-calorific fractions of different grades has grown. This is of particular interest, especially in view of the disposal costs involved. Even if contracts that have been in place for many years do not allow for amendment at short notice, the potential expected within this sector is fairly substantial. The generation of high-calorific fractions will, in the future, be of increasing importance for the processes applied at an MBT plant.

We see additional potential in the biological treatment of low-calorific fractions. This is facilitated by the fact that biowaste fermentation facilities are being built to an increasing extent. In this sector too, however, new process technologies such as the generation of biologically stabilized material will influence the trend towards combining the treatment of residual waste with an MBT plant or energy recovery.
3. Hannover MBT plant – procedural approach

The waste entering the MBT plant in Hannover is chiefly domestic refuse and domestic-refuse-like commercial waste. The flow chart in Figure 3 illustrates the process involved: collection vehicles unload the non-recyclable waste into shallow bunkers. From there, grabber excavators are used to place the waste in shredders, where it is broken down. Harmful substances are removed. Magnetic separators extract usable ferrous metals. Screening drums separate the coarse fraction (containing any residual paper, wood or plastic) from the fine-particle fraction, which contains the organic material (most of which is suitable for rotting down). The mesh size used for screening is 60 mm. Within the MT facility, four largely identical processing lines are operated concurrently. The high-calorific coarse fraction is compacted into containers and disposed of in E.ON’s refuse incineration plant located nearby. Fine screening (</> 15 mm) and subsequent air classification of the > 15 mm fraction aid in the processing of fine materials prior to fermentation. These processes remove from the < 60 mm fraction the inert heavy materials – stones, glass and mineral content – that are unsuitable for fermentation (around 20 % of the input into the BT facility). These materials are then fed directly into the maturation process.

Biological treatment involves three stages: fermentation, aeration and maturation. The main components of the system are schematically illustrated in Figure 4. The lightweight fraction resulting from air classification enters the fermentation process. In the event that the MT or BT facility are – owing to scheduled maintenance work or operational restriction caused by malfunction – unable to process any waste, an intermediate hopper belt and a shallow bunker can receive one day’s input of fine material (around 400 Mg).

Anaerobic fermentation takes place in the mesophilic temperature range (35-42 °C) and the material spends a nominal period of about 20 days in the fermenters. The digestate then undergoes a three-stage dehydration process before being sent for aeration. The waste is then aerobically rotted down in table windrows, during the course of which it is suction-ventilated and automatically turned once a week. The resulting deposit is transported by truck to a landfill 30 km away. Waste air treatment comprises three acid scrubbers and four RTO lines with a total capacity of 122,000 m³/h.
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The MBT plant in Hannover is operated in three daily shifts from Monday to Friday. Waste is received during the day – between 6 a.m. and 10 p.m. – and the machinery has a running time of 12 to 14 hours. Maintenance work takes place during the night shift.

Figure 4: Process flow chart for biological waste treatment facility

4. Operational experience

The mechanical waste treatment (MT) facility was put into service in the year 2000, since which time its operation has been largely free of malfunction. The convenient redundant design and configuration of the two processing lines is a contributory factor in this, as it allows operation to continue at 60 % capacity or more even when repairs are being undertaken.

The manufacturer of the biological waste treatment (BT) facility commenced operation in 2005, but was not able to successfully complete the trial operation period by the end of 2006. The large number of technical difficulties encountered prompted aha to terminate its contract with the manufacturer in February 2007, since when it has operated the facility itself.

In 2008, the optimisation potential of Hannover’s MBT plant was systematically analysed and assessed. A sensitivity analysis was carried out with the assistance of external technical consultants, and this provided the technical and economic basis for selecting and implementing optimisation measures.
These measures were pursued with the following aims:

- To ensure compliance with the terms of approval (adherence to the German 30th Ordinance Implementing the Federal Emission Control Act and German Landfill Ordinance);
- To increase throughput and availability;
- To boost cost-effectiveness.

Each of these measures was evaluated with regard to personnel costs, expenditure saved (e.g. external waste treatment), costs of repair, upkeep and maintenance, capital costs and operating-consumables costs. The balance of the product costs was viewed in relation to throughput. Only if a measure resulted in a lowering of operational costs was it pursued further. The financial impact on throughput and treatment costs was calculated. All planned measures were completed in 2010, so that falling operational costs confirm that the key optimisation measures are already proving successful.

The Hannover MBT plant is in a process of ongoing refinement, with various projects aimed at optimizing its management and costs continually being pursued alongside day-to-day operations.

4.1. Operational organisation

During the first years of its operation, the plant was run in two shifts from 6 a.m. to 10 p.m. However, it became evident that machine downtime caused by plannable maintenance was taking up too much available productive time. Malfunctions causing plant downtime were, in some cases, not remedied until the following day shift – which, again, had a detrimental impact on production time.

In response, a new work-time model was put in place involving the introduction of an additional night-time maintenance shift. This enabled necessary maintenance and repair work to be deferred to non-productive times, which increased plant availability during the day. This maintenance night shift was, to a considerable extent, also able to replace the outside companies that had previously been employed on an as-needed basis.

Switching to three-shift operation resulted in an increase in the MBT plant’s annual throughput performance. As it no longer needs to be shut off on a daily basis, the increased availability leads to a lowering of incineration costs and thus, in turn, of specific treatment costs.

Furthermore, special training programmes were carried out to ensure that all MBT plant personnel are qualified to work in production shifts. Previously, employee shift schedules were fairly rigid: drivers, for example, did not work within the plant, and night shift staff carried out only maintenance and cleaning operations. The aim of these skills-upgrading measures is to ensure – by adding qualified drivers and cleaning staff to the night shift – that, if waste treatment operations are shut down during the day, it is possible to make up for lost time at night. Overall, this allows far more flexible personnel allocation and plant operation.

4.2. Separation of heavy materials

The fine material undergoes mechanical treatment in order to separate out what is termed the heavy fraction – containing stones, broken glass and mineral components – from the screened fine-particle fraction (< 60 mm). These heavier materials are not suitable for fermentation, and increase the risk that downstream assemblies will be worn by abrasion. The risk of sedimentation in the fermenters must also be prevented.
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The ballistic separators provided by the manufacturers had proved prone to malfunction ever since the fine-particle treatment unit came online and, for a time, even seemed to be the source of the production bottleneck in the MBT plant (for full details, see [4]). The annual costs for parts subject to wear, downtime and personnel deployment required just for the operation of this section of the plant were considerable.

The ballistic separators were dismantled in 2009 and replaced by a two-stage process involving fine screening and simple separation of heavy materials. This consisted of a screening drum of 15 mm mesh size in combination with an air classifier installed downstream for the 15-60 mm fraction. The material < 15 mm and the lightweight fraction following impact separation and air classification are then fed into the fermentation process (approximately 80 % of the mass flow). The heavy fraction, which is added to the digestate prior to entering the table windrows (for maturation), is suitable as structural material for the maturation process. Experience has shown that this technology has considerably increased the plant’s operational reliability.

4.3. Biological waste management

The biological treatment facility is designed for a daily input of 400 Mg. Input fluctuations of +/- 25 % or more in the fermentation process may cause biological reactions to be inhibited. Upstream interim storage of the waste is therefore necessary. In addition, increasing the carbonate buffer zone (by adding sludge waste from paper manufacturing, for example) may help to prevent microbiological inhibition. The operational parameters given in the operating manual must be adhered to, and the fermentation process is monitored by means of twice-weekly laboratory analysis of the input and output.

Loss-free circulation of the fermentation gas ensures that the fermenters are mixed thoroughly. The 320 input jets are subject to regular measurements and checks to ensure proper mixing. It has thus far been possible to remove sediment deposits at the edges of the fermenters using single high-pressure injections. According to the manufacturers, the fermenters are due for their first inspection ten years after being put into service.

Biogas yield depends on the quantity of the waste supplied (which fluctuates seasonally), and its composition. The manufacturers state the target biogas yield for the Hannover MBT plant as being 12 million N cbm/a. In fact, the gas yield is considerably higher (currently standing at around 15 million N cbm/a).

4.4. Gas processing and utilisation

At the ‘Deponie Hannover’ landfill site, the fermentation gas from the MBT plant and landfill gas from a disused landfill are mixed before undergoing purification and utilisation. Availability of landfill gas is fairly constant at around 600-800 m³/h. As no fresh waste is added (Hannover’s landfill site having been closed in 2005), the methane levels in the landfill gas are, at 40-45 %, relatively low. The amount of producible gas has decreased by some 10 % each year since 2005.

Figure 5 shows the typical sawtooth curve depicting the amount of energy recovered from landfill gas and biogas over a week, averaged from the 15-minute values obtained over a year. 1,000 kW is equivalent to about 200 m³/h of gas.

The fermentation gas contains about 56 % methane on average. The quantity of gas produced in the gas space of the fermenters is strongly dependent on the volume of waste input: at the Hannover MBT plant, fresh waste is added over a period of about 12 to 14 hours daily.
from Monday to Friday. The quantities of fermentation gas reach their minimum (around 500 m³/h) on Monday mornings, increasing to their daily maximum by midnight. Depending on the waste input, this daily peak – which rises to a weekly maximum on Friday evening or thereabouts – lies between 2,000 and 3,500 m³/h. Over the weekend, the quantities of gas fall back down.

![Figure 5: Average weekly cycle for energy obtained from landfill gas and fermentation gas (as thermal output in kW)](image)

The mixed gas first enters a compressor station before undergoing processing. It is initially dehydrated in a cold dryer with a capacity of 3,600 m³/h. Two connected activated-carbon filters are used to adsorb siloxane and hydrogen sulphide. The gas then passes through a gas storage tank with a capacity of 1,500 m³. This tank serves less as a bulk storage facility (buffer capacity around 30 minutes) and more as a mixed storage tank. Without a storage tank, the fact that landfill gas and the considerably more calorific fermentation gas mixed only to a very small extent (despite sharing a pipeline some 500 m long) would have proven a problem for the engines of the cogeneration unit. The performance of the unit’s engines is dependent on the gas’s calorific value, and the engines struggle to keep up with the oscillation in the calorific value of the two gas types. The gas storage tank evens out fluctuations in pressure and calorific value within the gas grid, and improves the cogeneration unit’s operational reliability.

Behind the gas storage tank, some 500 m³/h of processed gas from the MBT plant’s exhaust air treatment facility is diverted off as fuel gas. The remaining gas (12.5 million Nm³ in 2010) is converted to electricity in cogeneration units, which have an electrical and thermal output of around 3.8 MW. Here, the gas is used to generate electrical current that is fed into both the site’s own grid and the public grid, and district heating for the hot-water and heating requirements of the Hannover landfill site.
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Figure 6 shows the average weekly cycle for on-site electricity production from landfill and fermentation gas in the cogeneration units, power consumption by the Hannover landfill site, the amount of electricity fed into the public grid, and the quantity that needs to be bought in. The lack of new waste input at weekends leads to a drop in gas production (and, in turn, in electricity production), with the level at its minimum on Monday mornings. Throughout the week, power consumption can be met by internal production. The surplus electricity produced can be commercially marketed to the public grid. Only on Mondays does a shortfall regularly occur, which makes it necessary to purchase electricity provided by the external grid operator. On the other days of the week, any cogeneration unit downtime must be made up for. As meeting this shortfall generates relatively high costs, it is being considered whether the waste input should be evened out.

![Average active electronical power](image)

Figure 6: Average weekly cycle for in-house electricity production, electricity consumption, the quantity of electricity fed into the grid and the resulting purchase to cover the shortfall

4.5. Use of ferrous hydroxide sludge to precipitate sulphur

Biogas combustion places certain demands on emissions in exhaust air. The emissions thresholds for boilers, gas flares and cogeneration unit exhaust gas are set as follows by Germany's Federal Emission Control Act (BImSchV) and Clean Air Act (TA Luft): sulphur dioxide in flue gas < 310 or 350 mg/Nm³ dry flue gas, which is equivalent to hydrogen sulphide (H₂S) levels < 780 or 885 mg/Nm³, in relation to 50% CH₄ in fermentation gas. An H₂S threshold for cogeneration unit engines is also stipulated. This can be met only by using activated carbon.

The H₂S concentrations in the untreated raw gas from the fermenters are around 1,200 mg/Nm³. For emissions control reasons, therefore, the gas needs to be desulphurised. The sulphur can be precipitated out by adding trivalent iron, which is reduced to divalent iron under anaerobic conditions. This is precipitated to iron sulphide (FeS, FeS₂), a poorly soluble compound that remains within the deposit.
Initially, an industrially produced iron powder (containing around 36 % iron) was used for precipitating the sulphur, which was added immediately before fermentation at a ratio of 4-5 kg/Mg of waste. Concern about imminent price increases drove the search for a substitute. This led to trials being conducted on the use of iron hydroxide sludge (IHS) derived from drinking-water treatment (iron content 16-42 %; [5]). IHS has proven highly effective. Moreover, considerable cost-saving effects are achieved, as IHS is available in large amounts and the only costs involved are those of extraction and transport.

Since 2009, IHS has been added on an ongoing basis to the waste in the mixing pumps immediately prior to fermentation. The thixotropic consistency of IHS can on occasions be problematic in that, despite being in a highly compact state when extracted, the sludge is stackable only to a limited extent after being transported.

4.6. Exhaust air treatment plant

The exhaust air treatment plant consists of acid scrubbers for separating out ammonia and a regenerative thermal oxidation (RTO) facility, which involves combusting the exhaust gas at around 850 °C. The RTO at the Hannover MBT plant has four lines with a total capacity of 122,000 m³/h.

Stainless-steel components of the RTO’s mixing chambers were being increasingly affected by corrosion damage. The mixing chambers are charged with raw gas (exhaust air from the maturation process) and the ‘pure gas’ flowing from the combustion chamber. Temperatures there average around 80 °C, reaching a maximum of 100 °C. The mixing chambers come into contact with a gas mixture containing ammonia (NH₃), hydrogen chloride (HCl), hydrogen fluoride (HF), hydrogen sulphide (H₂S), hydrogen bromide (HBr), sulphuric acid (H₂SO₄), chlorine (Cl), methane (CH₄), nitrous oxide (N₂O) and a high concentration of total carbon.

In order to elucidate the corrosion mechanism, complex investigations were conducted that take particular account of microbiological factors and were designed to provide insights into how this corrosion can be prevented or at least slowed down in the future [1].

The corrosion phenomena are local rust damage caused by pitting corrosion of 1.4571 grade stainless steel. Because of its high resistance to corrosion, this grade is widely used in plant construction for the chemical and pharmaceutical industry. Other components of the mixing chambers, the support rings and the support structures of the ceramic blocks consist of 1.4462 grade stainless steel and show no signs of corrosion.

The study revealed that the 1.4571 grade stainless steel used in the RTO is not suitable for permanent contact with solutions that have high levels of chloride. 1.4462 grade stainless steel, which is also used for a number of components, is significantly better protected from the damaging influence of chloride, although this is not the case under the high temperatures present. Only 1.4410 grade steel is sufficiently resistant to chloride at the temperatures found in the RTO. 1.4469 grade steel can also be recommended here.

Trials are currently underway using different materials and coatings in order to find the technically optimal and most cost-effective material under real-life operational conditions.

5. Energy balance and energy efficiency

The mechanical-biological and thermal processes involved in the treatment of residual waste have been compared in a study with specific reference to the energy efficiency and CO₂ emissions of the MBT plant in Hannover [2]. Net primary target energy was chosen as the framework for this audit. After deduction of all in-house consumption (gas, electricity)
and additional energy (such as diesel), only the excess energy that is effectively used is incorporated into the energy efficiency calculation with regard to the amount of residual waste treated (see Fig. 7).

**Figure 7:** Calculating energy efficiency and carbon credit from net primary target energy


This model investigation involved taking the high-calorific fraction generated in the MBT plant and feeding it into different recovery facilities (RIP, RDF power plant). In these plants, the influence of different energy recovery solutions was investigated (see Table 1: conversion into electricity only; electricity and district-heating generation; steam generation only). The actual net energy levels utilised were used to calculate the resulting amount of CO₂ emissions that were saved and disclosed as carbon credit. These three forms of energy – electricity, heat and steam – differ with respect to their CO₂ rating. For this reason, the degree of energy efficiency does not allow direct conclusions to be made concerning the level of carbon credit earned unless the form of energy used is known. High energy efficiency predominantly based on heat recovery (option 2) may therefore result in lower levels of carbon credit than are obtained with conversion into power only (option 1).

**Table 1:** Energy efficiency and CO₂ credit for the Hannover MBT plant and power plant combination of processes with different approaches to energy recovery

<table>
<thead>
<tr>
<th>Option</th>
<th>Energy efficiency</th>
<th>Carbon credit Mg CO₂/a</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 MBT + RIP (power)</td>
<td>18%</td>
<td>89,000</td>
</tr>
<tr>
<td>2 MBT + RIP (power + heat)</td>
<td>30%</td>
<td>63,700</td>
</tr>
<tr>
<td>3 MBT + RDF power plant (power)</td>
<td>28%</td>
<td>130,000</td>
</tr>
<tr>
<td>4 MBA + RDF power plant (steam)</td>
<td>50%</td>
<td>85,500</td>
</tr>
</tbody>
</table>

Eco-auditing does not clearly favour or disfavour any one of the processes. The energy efficiency of a combination of MBT and incineration depends not only on site-specific external conditions but chiefly on the way in which the high-calorific fraction is utilised. The energy efficiency of an MBT plant can be positively influenced by material flow management, biogas yield, individual energy needs and energy use in cogeneration units. The energy efficiency of a refuse incineration plant depends on the quality of energy conversion (i.e. which type of turbine), the form of energy (i.e. power, heat or steam) and its utilisation (i.e. the consumer structure at the site in question).

All processes investigated yield carbon credit owing to their positive target energy levels. The amount of credit earned depends on the type of energy that was generated (power, district heating or steam) and on the substituted primary energy (standard fuels in a regional energy mix). Within the context of the overall eco audit, high energy efficiency in the utilisation of the high-calorific fraction results in the MBT plant procedure having advantages over the others in terms of the greenhouse effect.

Further approaches to optimising the MBT plant with the aim of improving the level of energy efficiency and carbon credit obtained include exhaust air management (RTO: higher availability, reduced energy consumption), the efficiency of the cogeneration unit (increased efficiency factor, greater power generation, higher energy recovery on site) and energy consumption management (such as reducing power consumption).

6. Outlook

This report shows that the optimisation potential for an MBT plant is high, manageable and promising. Owing to the increasing demands placed on material flows, MBT plants will continue to be used for pretreatment. The treatment of biogenic residues is an addition to the diverse range of processes that treatment plants offer. The production of, and energy recovery from, biogas is of great importance. The ability to be energy self-sufficient at the Hannover site in terms of both power and heat, as achieved by converting gas into electricity in a cogeneration unit, will be further optimised.

In the light of these developments, it is a basic requirement that the plants already in use be flexible. This fact has been recognised in Hannover and will define the future course we take.

7. Bibliography


