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Intended process water management concept for the mechanical biological treatment of municipal solid waste

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Abstract: Accumulating operational experience in both aerobic and anaerobic mechanical biological waste treatment (MBT) makes it increasingly obvious that controlled water management would substantially reduce the cost of MBT and also enhance resource recovery of the organic and inorganic fraction. The MBT plant at Gescher, Germany, is used as an example in order to determine the quantity and composition of process water and leachates from intensive and subsequent rotting, pressing water from anaerobic digestion and scrubber water from acid exhaust air treatment, and hence prepare an MBT water balance. The potential of, requirements for and limits to internal process water reuse as well as the possibilities of resource recovery from scrubber water are also examined. Finally, an assimilated process water management concept with the purpose of an extensive reduction of wastewater quantity and freshwater demand is presented.

Key words: *mechanical biological waste treatment*; *process water*; *municipal solid waste*; *exhaust air treatment*; *intensive tunnel rotting*

1 Introduction

Unlike the output streams of treated waste and gaseous emissions, mechanical biological waste treatment (MBT) process water with high loads has so far received little attention from experts (Ibrahim 1998; Loll 2002; Böning and Doedens 2002; Schalk 2004; Wagner and Schalk 2004). This was certainly acceptable in the past for MBT installations with exclusively aerobic biological treatment since, due to high air change rates, they discharged large amounts of water with exhaust gas, leading to remarkable freshwater requirements (Fricke et al. 1997; Böning and Doedens 2002).

Because of its high energy efficiency and the production of biogas, the biological treatment of MBT is conducted more and more under anaerobic conditions. However, for optimum process conditions the waste must first be suspended in, or moistened with, a significant quantity of water: wet fermentation requires up to 0.6 m^3 and dry fermentation up to 0.4 m^3 for every ton of waste. In accordance with *Annexe 3 of the German Waste Storage Ordinance*, and especially to achieve the water content stipulated for the emplacement of treated waste, this water must be removed (AbfAblV 2001). Dewatering can be achieved mechanically after the anaerobic digestion or, to a limited degree, via biological drying during the subsequent aerobic stabilization.

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Against the background of new legal requirements in Germany like *Appendix 23 of the German Wastewater Ordinance* (AbwV 2004), thermal treatment of MBT exhaust gas is also required, even though, in sharp contrast, economical and ecological MBT operation should seek to severely reduce the quantity of exhaust gas (Stockinger 2004; Nieweler 2006). In general, water which is not taken out of the system with the exhaust gas must be removed as surplus water anyway, as the internal recycling of process water is limited by the accumulation of pollutants and salts.

Operational experience in Germany in both aerobic and anaerobic MBT makes it increasingly obvious that controlled water management would substantially reduce the cost of running MBT and also enhance resource recovery of the organic and inorganic fraction. It is assumed that, in the future, water management objectives will play a more essential role in the planning and operation of MBT, and hence the concept of MBT must adapt to them. Also, it has to be noted that the process water quality is determined in the same way as the quality of the output material, by the characteristics of the waste input and the installed processes, which is why individual pilot trials for water reuse or treatment are obligatory.

2 Fundamentals

2.1 Water flows and water balance

Böning (Böning and Doedens 2002; Böning 2006) summarized the origin of typical process water in MBT plants and presented a model for the calculation of water demand and consumption in relation to the installed biological process. Figure 1 shows the main water flows of MBT plants with encapsulated intensive tunnel rotting, subsequent rotting, and part stream anaerobic digestion, with the water input on the left side and the water output on the right side.

Some of the water flows are not only related to the single process, but also to the MBT installation itself, e.g. cleaning water, rainwater from the roof or operation surfaces, etc. Next to the water content of the waste input and output streams, the water demand for moisturisation or suspension and for the humidity of the exhaust air is the largest single process-related water flow.

Figure 2 shows examples of MBT water balances under the given process conditions for (a) intensive tunnel rotting with subsequent stabilization (IRSS) and (b) full stream anaerobic dry digestion with ensuing aerobic stabilisation (FAD). In the figure, RH is relative humidity, V_{STP} is the volume of gas under standard temperature and pressure, and DM, oDM and ΔoDM are dry matter, organic dry matter and degraded organic dry matter, respectively. For comparison, both input and output characteristics are standardized.

Due to the high humidity discharge via the warm exhaust gas, the water balance for IRSS (Figure 2(a)) leads to a water demand of 830 L for a ton of waste-input, and this has to be covered externally. For the balance calculation, it is assumed that the entire leachate can be reused for irrigation. However, extensive circulation will cause concentration, particularly with solid matter, and therefore will impair the operation (i.e., block the irrigation system) as well as the biological degradation (i.e., lead to inhibition and toxication).

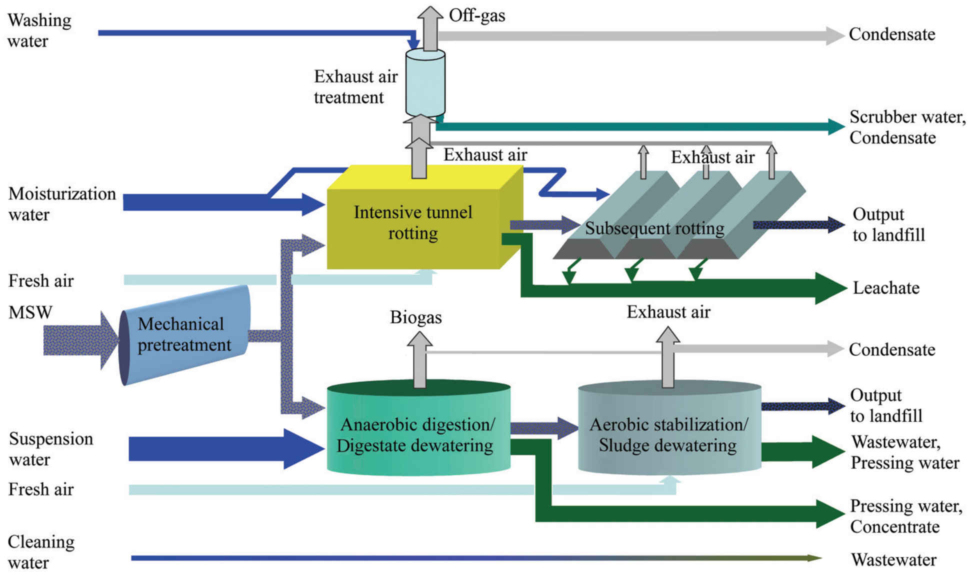

Figure 1 Main water flows of MBT

On the other hand, the water balance for FAD (Figure 2(b)) closes with a water surplus of approximately 350 L for a ton of waste-input. This could be reduced by increasing the recirculation rate, which is limited by the process water's high salt (i.e., NH_4^+, SO_4^{2-}) concentration, especially in the case of thermophilic operation (Böning 2006).

These MBT water balances show that there is water demand in the aerobic treatment, but, in order to avoid operation and process disturbances, process water must be replaced and therefore treated afterwards. For anaerobic digestion, surplus water must be reckoned. The amount of this surplus water is to a considerable extent determined by the process conditions (dry or wet fermentation) and the recycling rate of the process water (Weichgrebe et al. 2004). However, the required exhaust air treatment at MBT plants generally produces condensates and scrubber water. Moreover, in order to efficiently remove biological process-inhibiting compounds, MBT plants must be equipped with adequate sinks.

2.2 Composition and resources of process water

Table 1 provides a survey of different composition values of the individual process water streams and their loading ranges. The quality and quantity of MBT process water correspond to their origins. As shown in Figure 1, the process water flows can be differentiated into

(1) leachate from intensive rotting and/or subsequent rotting,

(2) process water and/or wastewater from anaerobic digestion,

(3) pressing water from digestate dewatering,

(4) condensates and/or scrubber water from the required exhaust treatment.

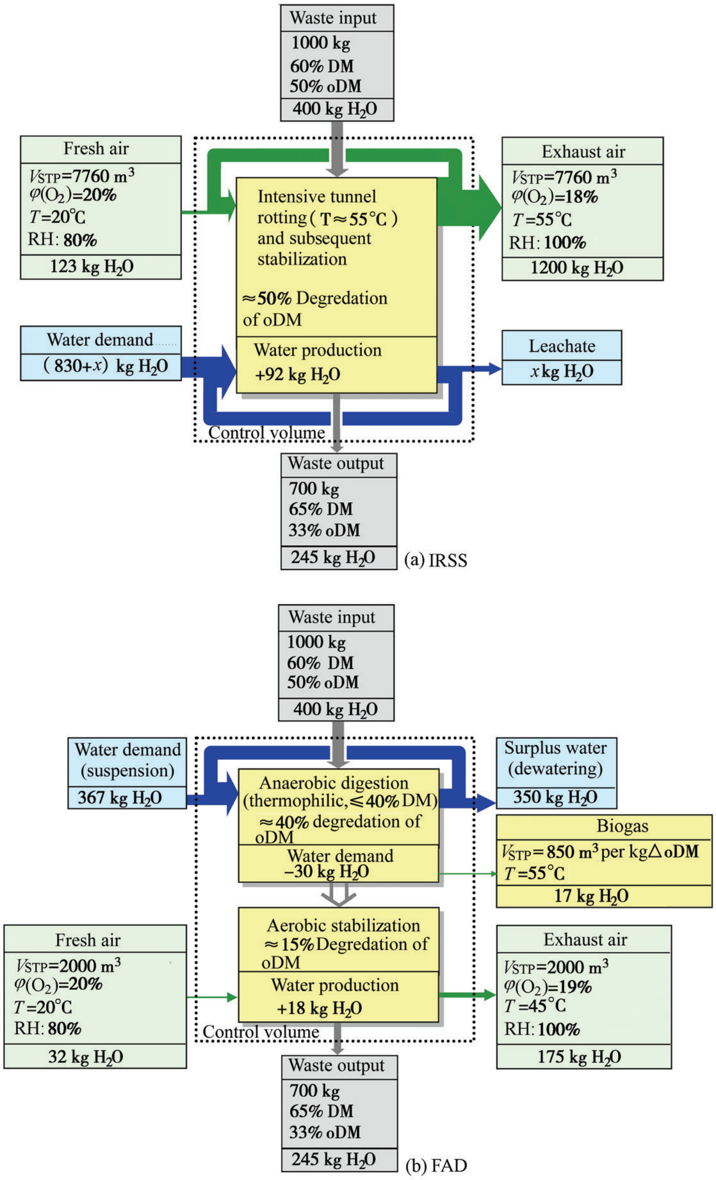

Figure 2 MBT water balances for MBT installations

The compiled parameters vary dramatically. Their concentration corresponds to the process balance occurring during the biological decomposition and to the exhaust air treatment. The optimum strategy of internal circulation, resource recovery or process water treatment can be selected for each stream based on the specific compositions (Krogmann and Woyczechowski 2000; Loll 2002; Fricke et al. 2005). Since the contaminant loads of leachate from the intensive tunnel rotting and the process water from the anaerobic digestion are to a considerable extent determined by the content of fine-dispersive and colloidal solid matter, preliminary process water treatment should contribute considerably to the decrease of these particular loads.

Table 1 Specific composition of MBT process water (data from authors as well as Ibrahim 1998; Böning and Doedens 2002; Böning 2006) mg/L

Parameters	Limiting values[1)] according to *Appendix 23 German WWD*, indirect-discharge	Leachate from intensive tunnel rotting	Leachate from subsequent rotting	Process water from anaerobic (dry) digestion	Pressing water from fermentation residues	Scrubber water from exhaust air scrubber
SS	[2)]	2000–10000	150–500	2000–10000	80–2000	33–700
COD	400[3)]	20000–70000	7500–17200	3500–33500	1100–7500	230–1200
BOD		10000–12500	2500–6200	800–2000	400–1600	n.n.[4)]
TN		2000–12000	1200–3200	1400–2500	1200–2900	40000-160000
TP		13–32	3.4–8.5	17–85	20–56	0.1–2.2
AOX	0.5	0.4–1	0.4–0.5	0.1–2.1	0.5–2	n.n.
Cu	0.5	0.2–3.1	0.2–1.2	0.2–4.8	0.06–0.22	n.n.
Zn	2	4.1–13.0	0.9–4.6	0.3–10	0.2–1	n.n.

[1)]extract; [2)]no numbers given; [3)]one of three alternative parameters; [4)]not measurable

3 Materials and methods

3.1 MBT plant at Gescher (MBTG) and anaerobic digestion plant at Gescher (ADPG)

Since December of 2000, the MBTG has been disposing of 115 000 tons per year of municipal solid waste produced in the rural district of Borken. Of this amount, 2% Fe-metals and 35% heat caloric value fraction are separated out in the mechanical treatment (pre-crushing, drum sieve with the grid size less than 80 mm and ballistic separator). The biological decomposition occurs in 26 intensive rotting tunnels (IR) for a maximum of 4 weeks, followed by 8 to 10 weeks of subsequent rotting (SR) in static piles. The depositable output thus amounts to approximately 34 500 tons per year.

For the treatment of exhaust air, one encapsulated biofilter (120 000 m^3/h) and three regenerative thermal oxidation plants (RTO, 88 000 m^3/h under standard condition) connected in series to acid exhaust air scrubbers (EAS) have been installed at the MBTG. Currently, the EAS are operated with nitric acid with a weight percent of 48%.

The wet ADPG (with the amount of SS less than 12%) has been in operation since November of 2004, treating an additional 15 000 tons per year of sewage sludge, bio-waste and green waste on the MBTG site. This plant uses two mesophilic digestion tanks (with a total volume of 940 m^3), hygienisation, two thermophilic digestion tanks (with a total volume of 2 000 m^3) and mechanical dewatering (sieve belt press).

3.2 Project objectives and approach

In accordance with our common project objectives, the following issues are examined, using MBTG as an example:

(1) quantity and composition of MBTG and ADPG process water and water balance,

(2) influence of mechanical pre-treatment and IR process control on process water quantity and composition,

(3) possibilities of resource recovery from scrubber water,

(4) potential of, requirements for and limits to internal process water re-use,

(5) option of wastewater discharge into landfill-leachate treatment plants and derivation of requirements.

Finally, an assimilated process water management concept is developed in order to extensively reduce the wastewater quantity and freshwater demand.

3.3 Lab-scale and pilot-scale equipment

For the investigation of the rotting processes, vessels with a volume of 100 L were operated at the INFA laboratory. The parameters are described in detail in Böning (2006).

In order to examine process water or pressing water utilization in the EAS, lab experiments were carried out, the first step of which were conducted as described in Böning et al. (2007). There followed a second step of pilot plant trials at MBTG. An acid EAS pilot plant container with the design parameters given in Table 2 was connected to the exhaust air system.

Table 2 Design parameters of the EAS pilot plant

Mass transfer zone				Sump tank		
Exhaust air flow rate (m^3/h)	Column diameter (mm)	Column height (mm)	Packing height (mm)	Diameter (mm)	Height (mm)	Operation volume (L)
530	392	1500	700	788	450	147

In addition to the pilot plant control device, we installed an online measuring device to determine the ammonia concentration in the raw gas and pure gas. This special sensor was developed by the GMBU Company in Jena and was provided to us for testing under the real conditions of MBT exhaust air treatment. The sensor was permanently but periodically fed with gas flow. It continuously and without any failures delivered ammonia values in a range from 6 mg/m^3 to 11 mg/m^3 for the raw gas and down to 1.5 mg/m^3 for the pure gas. As the sensor is sensitive to humidity, water traps were installed. Still, as mentioned above, the sensor proved to be highly reliable.

4. Results and discussion

4.1 Quantity and composition of process water and water balance

Since MBT plants were designed only for economically efficient operation, additional water flow meters had to be installed after the direct and the balance-determining water streams had been identified. Figure 3 presents the measured values of MBTG and ADPG. The water flows of both plants are at present coupled with the direct water input flows of drinking water and rainwater.

Provided that the change of water content in waste is insignificant during the treatment, the entire water input comprises rainwater (34.8%), drinking water (42%) and water input via the bio-waste and sewage sludge (23.3%), whereas the water output is made up of the overall losses via exhaust air (56.3%) from SR (-14.3%) and IR (-42%), the discharge of the wastewater to be treated (-42%) and other losses (1.8%).

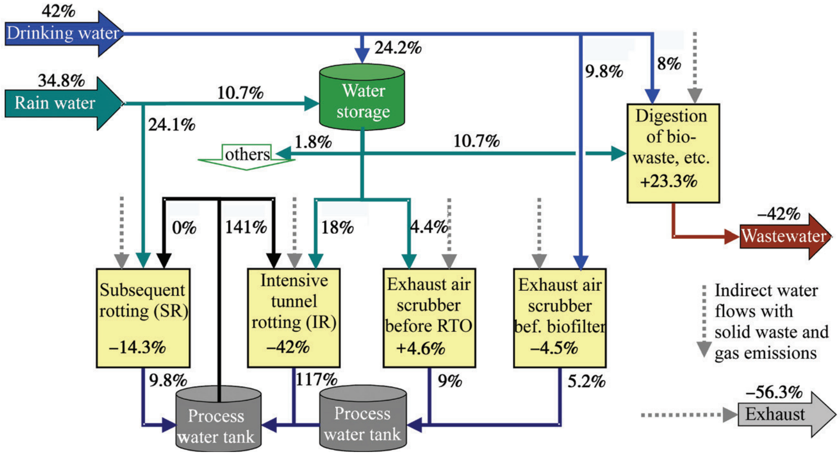

Figure 3 Percentage water balance of MBTG and ADPG at present

With the present installation, no surplus process water accumulates from IR. The generated leachate (117%) is collected at the bottom of the rotting tunnels, discharged in a process water tank, and reused, along with rainwater (18%), to irrigate the IR (141%). Due to the high solids content, however, this results in increasing deposits of solid matter in the shafts and in the process water tank, so that the process water must be exchanged from time to time supplementary to the cleaning of the entire process water system.

The static piles of SR are irrigated to a large extent (24.1%) with rainwater from the rainwater storage pond. The generated leachate (9.8%) is also discharged into the process water tank and used for IR irrigation.

For the removal of ammonia, the exhaust air from IR and some from SR is directed to acid EAS, in which condensate and scrubber water are generated. The surplus (9%, 5.2%) is collected in a separate process water tank and connected to the process water system for irrigation of IR, regardless of its high nitrogen content. For the project, this connection was terminated and the scrubber water disposed of separately.

Special attention is given to the pressing water of ADPG, since this currently represents the greatest volume flow (-42%) and must be disposed of at considerable cost.

The compositions of untreated IR leachate (L), pressing water (PrW) and scrubber water (SW) were analyzed, and the results correspond to the values given in Table 1. Additionally, the particle size distribution was determined, showing that the median size of leachate, pressing water and scrubber water was about 3 μm, 75 μm, 11 μm, respectively.

4.2 Internal re-use of process water and/or pressing water

4.2.1 Irrigation of IR and SR

To identify the specific influence of re-used water on biological decomposition by irrigation, parallel rotting experiments were run at a lab-scale plant for about 4 weeks. The total rotting volume is 100 L. The rotting temperature was measured online, and independent of the temperature the waste was mixed once after 2.5 weeks.

Initial results show that the biological decomposition of IR is not influenced by the different irrigation waters. Problems could occur, however, because of the eluate concentration of the output material. In particular, the TOC-eluate and NH_4N-eluate increase through irrigation with PrW rather than with drinking water. The usage of SW was observed to have a similar effect on TOC-eluate.

4.2.2 Usage of ADPG pressing water as scrubber water

In lab-scale experiments, the maximum ammonia absorption capacity of PrW in comparison to tap water (Böning et al. 2007) was determined first. Both measured absorption capacities were similar. From the chemico-physical point of view, PrW can be substituted for tap water in the EAS, but, because of its suspended solid content, it must still be examined to what extent pretreatment is necessary. Table 3 presents the analysis results of PrW parameters.

Table 3 Average values of relevant PrW parameters

PH	FS (mg/L)	Acid capacity (mmol/L)	COD (mg/L)	TOC (mg/L)	TIC (mg/L)	TKN (mg/L)	NH_4-N (mg/L)	NO_3-N (mg/L)	NO_2-N (mg/L)	H_2S (mg/L)
8.3	1430	124	3060	680	1590	1460	1495	5.7	0.1	1.3

A large reduction in filterable solids (FS), from 1 400 mg/L to 600 mg/L, could be achieved with only a simple process adjustment and installation. The two installed process water tanks (300 m^3 each) are in series connection. Moreover, in the first tank, the water inlet pipe end was laid downstream and a skimming wall was installed in front of the outlet, thus rendering the first tank a sedimentation tank.

The examined PrW contained H_2S with a concentration of 1.3 mg/L. With water submission of 10 m^3/d and an air flow rate of 2 300 000 m^3/d, the result is a corresponding load of 0.006 mg/m^3 and/or 0.5 g/h, which is much lower than the demanded toxicity limit value of 0.3 mg/m^3 and/or 15 g/h.

4.3 Utilization possibilities for scrubber water (SW)

In principle, there are several possible ways to utilize the SW. However, a concentration of approximately 7% to 8% N in the SW is an economic requirement for all applications. Eight percent N and 9% S in the scrubber sump correspond to a commercial ammonium sulphate solution of 40%, which is widely used in agriculture and from which, under favorable conditions, sales proceeds could be achieved. The analyzes of the examined SW show that the concentrations of those heavy metals that are restricted or the occurrence of which must be reported according to the *Fertilizer Regulation* (DüMV 2003) are below the limiting values at all times. This has to be verified for each application. If the content of harmful substances prevents agricultural utilization, or if the required N and S concentrations cannot be achieved, SW could alternatively be delivered to the cement industry. According to previous specifications of a cement factory, an ammonium-sulphate solution with approximately 7% N can be used directly for the NO_x-removal of fumes; however, the odour of SW could be the exclusion criterion. The proceeds reached are thus correspondingly smaller.

In order to establish a commercial product, the EAS process must be optimized. One eligible measure could be a more intense circulation of the SW, but one has to consider that a large amount of condensate is brought into the SW cycle via the almost vapor-saturated, warm exhaust from the rotting process. Currently, the EAS needs a daily input of fresh water of approximately 5 m^3, yet up to 10 m^3 of wastewater is produced per day, so 5 m^3 of condensate is generated per day. With more intensive circulation of SW, the exhaust amount increases, which stands in opposition to the SW, thus causing constant dilution and limiting the success of such a measure. Further options will be examined in a planned pilot operation with a semi-technical installation.

4.4 Intended process water management concept for MBTG

Figure 4 presents the developed water management concept for MBTG based on the investigation described above.

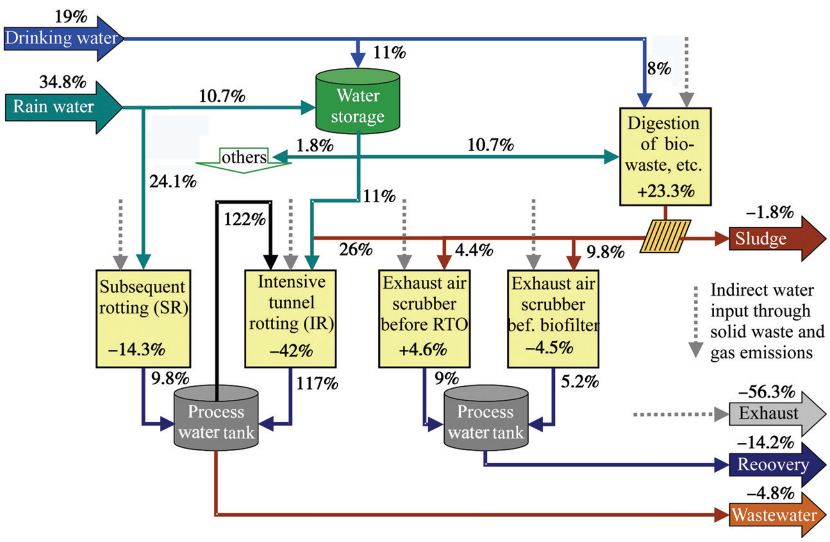

Figure 4 Assimilated water management concept for MBTG

In this concept, the consumption of external water (drinking water and rainwater) is considerably reduced, as is the amount of wastewater which has to be discharged and treated. Furthermore, this concept provides adequate sinks for those compounds which inhibit the biological process, for solids which disturb the process water, and for substances which reduce the quality of the recovered product.

In order to achieve optimum process conditions, such as the preparation of flocculants, the drinking water cannot be substituted in the ADPG. The PrW is freed from suspended solids by sedimention and, if necessary, by floatation, and completely re-used as a substitute for rainwater in the IR and EAS. Because of this, the SW is enriched with N and S in the EAS and could be delivered to agriculture or cement companies. To what extent this water has to be conditioned before recovery, for instance, by the addition of urea, will be examined under semi-technical conditions.

The concentrations of rotting and digestion processes are largely determined by the particulates of the process water. Sedimentation and floatation can also be used to reduce suspended solids in the recirculated process water. At present, options of wastewater discharge into landfill-leachate treatment plants and derivation of requirements are being scientifically investigated.

5 Conclusions

More attention should be given to process water emissions of MBT installations as they are highly polluted and their treatment is expensive. Through pilot projects, real treatment operational experience has been gained in both aerobic and anaerobic MBT in Germany. It is more and more obvious that controlled water management would substantially lessen the MBT running costs and also enhance the resource recovery of the organic and inorganic fractions.

Using the example of MBTG, we

(1) determined the quantity and composition of process water and leachates from intensive and subsequent rotting, pressing water from anaerobic digestion, and scrubber water from acid exhaust air treatment;

(2) prepared the MBT water balance;

(3) examined the potential of, requirements for and limits to internal process water re-use;

(4) investigated the possibilities of resource recovery from scrubber water;

(5) developed an assimilated process water management concept with the purpose of extensive reduction of wastewater quantity and freshwater demand.

The water input is mainly made up of rainwater, waste input and drinking water, whereas the water output comprises the amount of wastewater that needs to be treated, the discharge via exhaust air treatment and the overall losses of the rotting processes.

The aerobic biological decomposition is not influenced by the different irrigation waters. Problems could occur, however, due to the eluate concentration of the output material.

The maximum ammonia absorption capacity of pressing water is comparable to that of tap water. Thus, it can be used as scrubber water, as revealed by pilot plant trials. A large reduction of the filterable solids was achieved with simple process adjustments and installations. The scrubber water generated thus has potential as commercial fertilizer or alternatively as a NO_x-removal additive.

An intended process water management concept is being prepared in which wastewater quantity is reduced by a factor of eight and drinking water by a factor of two, and resource recovery is achieved.

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