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Biodegradability of leachates from Chinese and German municipal solid waste*

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Abstract: The quantitative and qualitative composition of Chinese municipal solid waste (MSW) differs significantly from German waste. The focus of this paper is on whether these differences also lead to dissimilar qualities of leachates during storage or landfilling. Leachates ingredients determine the appropriate treatment technique. MSW compositions of the two cities Guilin (China) and Essen (Germany), each with approx. 600000 inhabitants, are used to simulate Chinese and German MSW types. A sequencing batch reactor (SBR) is used, combining aerobic and anaerobic reaction principles, to test the biodegradability of leachates. Leachates are tested for temperature, pH-value, redox potentials, and oxygen concentration. Chemical oxygen demand (COD) values are determined. Within 8 h, the biodegradation rates for both kinds of leachates are more than 90%. Due to the high organic content of Chinese waste, the degradation rate for Guilin MSW leachate is even higher, up to 97%. The effluent from SBR technique is suitable for direct discharge into bodies of water.

Key words: Leachate, Biodegradability, Sequencing batch reactor
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INTRODUCTION

The composition of municipal solid wastes (MSWs) depends on industrialization, culture, waste management, and local conditions. Due to the composition of wastes, during storage or disposal of MSW, wastewater is separated and is polluted by organic materials, heavy metals, and other toxic substances. The amount of leachate depends on the initial water content of the MSW, and on the storage or disposal conditions such as temperature, humidity, and ventilation.

The water content of MSW often leads to problems regarding the application of waste treatment techniques like incineration or landfilling. In incineration plants, MSW is usually stored in a concrete bunker where leachate containing chlorinated hydrocarbons penetrates the concrete bottom. Special leachate treatment facilities must be installed on MSW landfill sites to avoid the contamination of ground water by organic and inorganic pollutants.

Suitable aerobic/anaerobic biodegradation of leachates could be advantageous due to easy operation, low costs, and reduced maintenance.

To investigate the differences between leachates from Chinese and German MSW, and to test the practicability of biological wastewater treatment by sequencing batch reactor (SBR), the compositions of MSW from Guilin (China) and Essen (Germany) were chosen as examples for the simulation. Both cities have approx. 600 000 inhabitants, and their average waste compositions have been determined (Selic *et al*., 2006) as summarized below.

SBR processes were investigated for biological treatment of different types of wastewater, like municipal wastewater (Irvine *et al*., 1983), hazardous wastewater (Herzbrunn *et al*., 1985), leachate from older and younger landfill sites (Manoharan *et al*., 1992; Kulikowska and Klimiuk, 2003; Klimiuk and

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Kulikowska, 2005; Zhou *et al*., 2006), and industrial wastewater e.g. from textile processing industry (Hemmi *et al*., 1999). An authoritative survey of the state-of-the-art in SBR technology was given by Wilderer *et al*.(1997).

MATERIALS AND METHODS

MSW compositions of Guilin and Essen

The average composition of MSW from Guilin and Essen was determined by a sorting analysis of fresh delivered waste in a standardized procedure (Selic *et al*., 2006; Herbell *et al*., 2006) and in accordance with German ordinance LAGA PN 98 (Länderarbeitsgemeinschaft Abfall, 1998).

In this procedure, samples of fresh delivered waste were premixed by opening each waste bag and shoveling. The mixed wastes were distributed on a clean surface to one layer coverage. After screening of the area in squares of 1 m^2, 25% of the fields were randomly chosen. The waste in these fields was sorted manually into the following 13 fractions: metals, hard plastics, textiles/shoes, wood, composites (mixed materials), paper/cardboard, pampers/cellulose, glass/mineral/porcelain, plastic foils, ash/sand, organics (kitchen and green waste), fine material, electronics.

Wastes too small for manual sorting (<40 mm) were classified as fine material and collected with a brush and dustpan.

All fractions were weighed and their mass fraction was calculated in percent.

Additionally, the water content of each fraction was determined in accordance with the German regulation DIN 18121 (Deutsches Institut für Normung e.V., 1998). The results are listed in Table 1.

Further sieve analysis of the fine material from Guilin yielded mainly ash/sand (67.15%) and organics (32.84%). Fine material from Essen is a mixture of many fractions with a high organic fraction content.

The large differences between Guilin and Essen wastes are obvious. The average waste composition for Essen was comprised of approx. 25% paper/cardboard and approx. 12% plastics. The average waste composition for Guilin waste was comprised of only approx. 2.5% paper/cardboard and approx. 8% plastics (hard plastic+plastic foils).

Table 1 Aerage MSW composition and water content in the Cities Guilin and Essen

Fraction	Guilin, China		Essen, Germany	
	Average mass (%)	Water content (%)	Average mass (%)	Water content (%)
Electronics	–	–	0.74	0.00
Metals	0.25	7.01	2.56	5.00
Hard plastics	1.27	6.11	5.05	13.46
Textiles/shoes	3.44	52.57	4.42	24.56
Wood	1.40	27.87	0.69	7.97
Composites	1.43	22.12	4.06	26.84
Paper/cardboard	2.46	31.09	25.74	20.63
Pampers/cellulose	5.48	60.07	13.86	49.14
Glass/mineral/porcelain	4.01	4.93	6.24	5.00
Plastic foils	6.76	49.29	7.23	21.85
Ash/sand	6.11	5.24	0.21	0.00
Fine material <40 mm	26.21	32.23	7.73	56.60
Organics	41.47	74.41	21.49	77.27

The lower percentage of plastics and paper/cardboard in Chinese wastes is mainly caused by the private collecting and trading with those valuable fractions. In Germany, as MSW is the property of the municipality, private trading of wastes is not allowed.

Due to Chinese culture, the organic content of Guilin waste, which averaged 51% (41.47% organics +8.56% organics <40 mm), is twice that of organic waste in Essen, Germany.

Definitely, the high proportion of ash/sand which averages 23% (6.11% ash/sand+17.5% ash/sand <40 mm) in Guilin can be explained. It is caused by the so-called cooking stones filled with coal, which are widely used in Chinese cities for cooking or heating. After burning, these cooking stones mainly consist of sand and some ash that can be easily crushed into fine material.

Leachate preparation

According to the sorting analysis mentioned above, leachates from Essen and Guilin MSW, respectively, were simulated by using the known waste compositions and water contents. One kilogram waste was prepared for each city by using dried waste fractions. The dry mass of the fractions was calculated by:

$$\text{Dry mass (g)}=1000\text{ g}\times\text{average mass (\%)}/100\times[100-\text{water content (\%)}]/100.$$

Only for the organic fraction fresh compounds were used. The fine material fraction from Guilin was divided into ash/sand and organics, based on the results of the sieve analysis. For Essen's fine material fraction a greater amount of the originally collected fine material during the sorting analysis was dried in advance until constant weight.

Finally, according to the specific water content of the fractions, water was added to the mixture. The weighed portions of the fractions are listed in Table 2.

Table 2 Weighed portion (g) for each fraction

Fraction	Guilin	Essen
Electronics	–	7.4
Metals	2.3	24.3
Hard plastics	11.9	43.7
Textiles/shoes	16.3	33.3
Wood	10.1	6.3
Composites	11.1	29.7
Paper/cardboard	17.0	204.2
Pampers/cellulose	21.9	70.5
Glass/mineral/porcelain	38.1	59.3
Plastic foils	34.3	56.5
Ash/sand	223.7	2.1
Fine material <40 mm	0.0	33.5
Organics	500.3 (fresh)	214.9 (fresh)
Water	113.0	214.3

Five liters of water were added to each MSW composition and homogenized for 3 d using vibrating machines. For further treatment in an SBR the mixture was filtered using a 200 μm metal sieve.

Sequencing batch reactor (SBR)

The sequencing batch process is a variation of the activated sludge process. The construction and functions of this type of reactor are illustrated in Fig.1.

The main characteristics are a discontinuous loading with wastewater, and a temporary separation of anaerobic and aerobic treatment phases. In the aeration phase, dissolved oxygen is supplied to the aerobic environment in order to supply necessary energy for the bacteria, while under anaerobic conditions necessary energy is provided via a complex chain of redox reactions.

After periodical treatment the sludge is separated

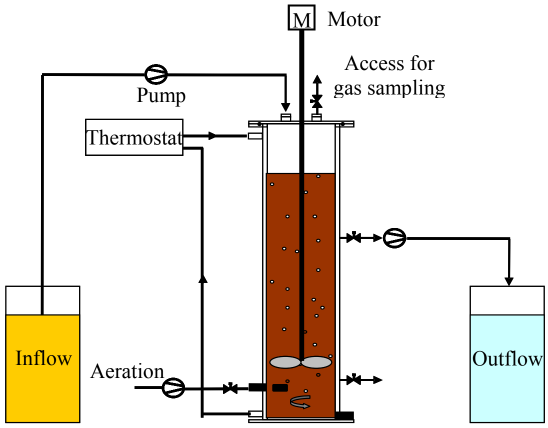

Fig.1 Scheme of lab scaled SBR (10 L)

from the liquid by settling, and the clear overflow can be drawn off. A new cycle can be started with the next batch of wastewater.

The advantage of this reactor type is that it is space-saving. Aerobic and anaerobic treatment takes place in one container. Co-cultures of anaerobic and aerobic organisms in sequential redox environments can be used for the treatment of refractory chemical oxygen demand (COD).

Experiments

Two reactors of uniform size and shape were set up to compare the degradation processes of Guilin and Essen wastewater in parallel. The reactors were filled with 7.2 L activated sludge (2 g/L volatile suspended solids) from a German leachate treatment plant operating at 35 °C. The SBR was run at a steady state for 14 d before starting the experiments. During degradation process, sensors in the reactors collected online pH-values, temperatures, redox potentials, and oxygen concentrations. Fig.2 shows the characteristic curves of the degradation processes.

The curves show the change between anaerobic and aerobic phases. Temperature inside the reactors was 35 °C, to which the microorganisms were adapted. During the processes, the pH-value varied slightly between 7.0 and 7.4. The oxygen demand was zero during the filling and anaerobic phase, increases in the aerobic phase due to aeration and decreases in the following anaerobic phase due to bacterial oxygen consumption. The redox potential increases in the aerobic phase due to oxidation processes and decreases in the anaerobic phase.

The sequencing phases of one cycle are dependent on time as shown in Fig.3 which consists of a filling phase, alternating anaerobic and aerobic phases, settling phase, discharging phase, and a resting phase.

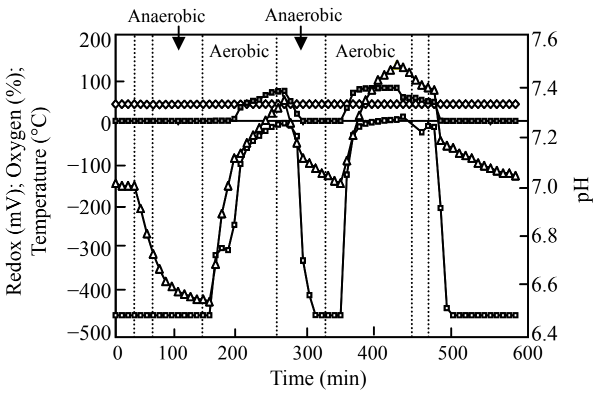

Fig.2 Temperature, oxygen concentration, redox potential and pH-value during the degradation processes in an SBR
Δ: pH; □: Redox; ◘: Oxygen; ◇: Temperature

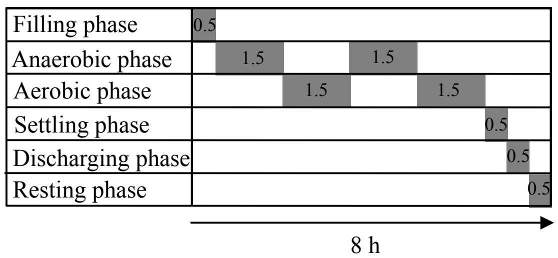

Fig.3 Sequencing phases of one cycle

Five cycles over 5 d were carried out. Prepared wastewater was diluted 1:4 for each cycle of 8 h and 1 L was added to the reactors via a pump at the inflow. At the end of each cycle, 1 L of outflow was removed.

A sample of each outflow was prepared for analysis by centrifugation (2000 r/min) and filtration (45 nm-poresize membrane).

ANALYSIS AND RESULTS

To investigate whether the degradation in the SBR was successful, the COD for each cycle outflow was determined and compared with the COD from the inflow. The comparison was used to calculate the degradation rate.

The nitrogen concentrations of ammonium, nitrite, and nitrate were determined to control the degradation process of potentially existing nitrogen compounds.

Phosphor is partly responsible for the eutrophication of waterbodies. Therefore, the total phosphor concentration of the inflow was controlled.

All determination methods accorded with German DIN regulations. The results are listed in Tables 3~6.

The total phosphor concentration of the inflow was 2.5 mg/L in Essen wastewater and 6.2 mg/L in Guilin wastewater.

Table 3 COD values from inflow and outflow samples and calculated degradation rates

City	Inflow (mg O_2/L)		Cycle				
			1	2	3	4	5
Essen	1089	Outflow (mg O_2/L)	65.40	71.80	85.35	88.95	94.70
		Degradation rate (%)	93.99	93.41	92.16	91.83	91.30
Guilin	1606	Outflow (mg O_2/L)	50.00	56.10	50.60	53.20	55.00
		Degradation rate (%)	96.89	96.51	96.85	96.69	96.58

Table 4 Ammonium nitrogen concentrations from inflow and outflow samples and calculated degradation rates

City	Inflow (mg/L)		Cycle				
			1	2	3	4	5
Essen	0.93	Outflow (mg/L)	0.03	0.04	0.04	0.08	0.06
		Degradation rate (%)	96.77	95.70	95.70	91.40	93.55
Guilin	2.16	Outflow (mg/L)	0.04	0.07	0.03	0.07	0.07
		Degradation rate (%)	98.15	96.76	98.61	96.76	96.76

Table 5 Nitrite nitrogen concentration of the inflow and outflow from Essen and Guilin of each cycle

City	Inflow (mg/L)	Outflow (mg/L)				
		1	2	3	4	5
Essen	0.20	0.01	0.02	0.01	0.01	0.01
Guilin	0.34	0.01	0.01	0.01	0.00	0.01

Table 6 Nitrate nitrogen concentration of the inflow and outflow from Essen and Guilin of each cycle

City	Inflow (mg/L)	Outflow (mg/L)				
		1	2	3	4	5
Essen	4.16	3.39	3.39	2.96	3.74	3.35
Guilin	1.27	1.89	2.61	2.49	2.12	2.24

Phosphor elimination in the SBR does not take place, therefore the phosphor concentration in the outflow was not analysed.

CONCLUSION

Comparison of Chinese and German leachates from MSW after treatment with an SBR for simulation of Guilin and Essen wastewater was successful. The characteristics of the different waste compositions are reflected in the wastewater. The high amount of organic material in Guilin waste leads to a COD value more than 50% higher and an ammonium concentration two times higher than that in Essen wastewater. The higher phosphor concentration in simulated Guilin wastewater is probably based on the higher content of fertilized fruits and vegetables.

Biodegradation of both simulated wastewaters was satisfactory. This is shown by the high COD and ammonium degradation rates of more than 90% (Tables 3 and 4). The degradation process for Guilin wastewater was more effective than that for Essen wastewater. Within the same time the COD of Guilin outflow is lower than that of Essen, although the COD of the Guilin inflow is higher. This is reflected in the higher average sludge removal loading rates, being 276 mg COD/(g SS·d) for Essen wastewater and 431 mg COD/(g SS·d) for Guilin wastewater. Fig.4 shows the COD of the outflow samples from both reactors after each cycle.

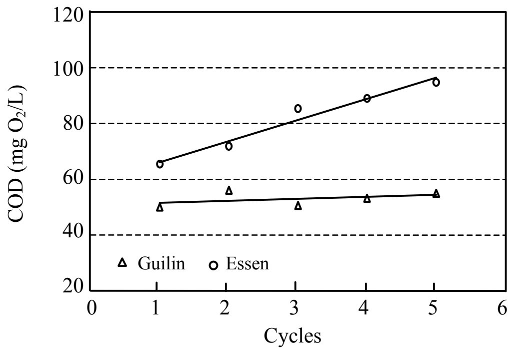

Fig.4 COD of each outflow from Guilin and Essen

The curves indicate a different trend. While the COD of Guilin wastewater keeps constant, the COD of Essen wastewater increases with the number of cycles. This effect is significant for accumulation of non-biodegradable compounds in the reactor. The high amount of paper/cardboard and pampers/Cellulose in Essen waste provides an explanation for this trend. Cellulose from theses products only shows low biodegradability.

For laboratory simulation of the organic fraction of waste, only plants have been used. Additionally, in order to prepare a young leachate, the waste was allowed to remain only 3 d in water. Therefore less plant protein degradation to ammonium took place, resulting in low ammonium, nitrite, and nitrate nitrogen concentrations.

The experiments proved that biological treatment of the examined wastewater via SBR is an efficient process, easy to operate and involves low costs. On the basis of the determined data, the effluent of both reactors can be discharged directly into waterbodies even under the control of German environmental protection limits (Koss and Trapp, 2003).

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