ELSEVIER

Desalination 222 (2008) 128–134

DESALINATION

www.elsevier.com/locate/desal

The application of hybrid system UASB reactor-RO in landfill leachate treatment

Jolanta Bohdziewicz[a], Anna Kwarciak[b]*

[a]*Silesian University of Technology, Institute of Water and Wastewater Engineering, ul. Konarskiego 18, 44-100 Gliwice, Poland*
[b]*Technical University of Czestochowa, Institute of Environmental Engineering, ul. Brzeźnicka 60, 42-200 Częstochowa, Poland*
Tel. +48 343250-917; Fax +48 34325-04-61; email: akwarciak@is.pcz.czest.pl

Received 20 December 2006; accepted 7 January 2007

Abstract

The aim of the paper was to study landfill leachate treatment efficiency during fermentation process in UASB reactor and post-treatment in RO process. In the first step of experiment, the granular sludge was acclimatized to treatment with high loaded synthetic wastewater. Next, the optimal concentration of raw leachate in synthetic wastewater was determined (5% v/v–40% v/v). At this stage, UASB reactor was operated at hydraulic retention time (HRT) of 7 days and organic loading rate (OLR) of 0.6 kg COD $\times$ $m^{-3} d^{-1}$. While the optimal concentration of raw leachate in synthetic wastewater (20% v/v) was determined, the HRT was shortened from 7 to 2 days with a increase of OLR from 0.6 to 2.0 kg COD $\times$ $m^{-3} d^{-1}$. The HRT (3 days) and OLR 1.3 kg COD $\times$ $m^{-3} d^{-1}$ were taken as the optimum fermentation process parameters. Under such designed conditions COD removal achieved value of 76%. The concentration of COD, BOD, ammonia nitrogen, chloride concentration in effluent was kept on the level of 960 mg $O_2 \times dm^{-3}$, 245 mg $O_2 \times dm^{-3}$, 196 mg $NH_4^+ \times dm^{-3}$ and 2350 mg $Cl^- \times dm^{-3}$ respectively. Due to poor quality of UASB effluent, wastewater was put into the post-treatment process. In RO process COD, BOD, chloride, ammonia nitrogen parameters were removed in 95.4%, 90.2%, 85.4% and 88.7% respectively.

Keywords: Landfill leachate; UASB reactor; Hydraulic retention time; Organic loading rate; Reverse osmosis

1. Introduction

Landfill has been the most economical and environmentally acceptable method for the disposal of solid waste throughout the world. Up to 95% of solid waste generated worldwide is currently disposed in landfills [1–3]. After landfilling, the solid waste, undergoes physico-chemical and biological changes. Municipal solid waste (MSW) produces leachate and gas emissions during decomposition process [4,5]. Landfill leachate is a wastewater, formed in a result of percolation of

*Corresponding author.

Presented at the conference on Desalination and the Environment. Sponsored by the European Desalination Society and Center for Research and Technology Hellas (CERTH), Sani Resort, Halkidiki, Greece, April 22–25, 2007.

doi:10.1016/j.desal.0000.00.000

rainwater and moisture through waste in a landfill. The composition of leachate depends on: landfill age, quality and quantity of solid waste, biological and chemical processes occurring in the landfill and the amount of precipitation and percolation of rainwater [2].

When the landfill is a few years old the dominated fermentation phase is acidogenic and the leachate generated is generally referred as "young". In that case, COD and BOD reaches very high concentrations. The ratio of BOD/COD is higher than 0.7 and pH is low due to the high concentrations VFA_s. Landfill grater than 10 years old are generally in the methanogenic phase and the leachate generated is referred to as "old". During the methanogenic phase, bacterias are degrading the VF-acids and reduce the organic strength of leachate, leading to the pH value higher than 7. In "old" leachate BOD decreases faster than COD and the radio BOD/COD is stabilized on the level less than 0.2 [2,4]. Leachate is a mixture of organic and inorganic compounds and many of them have a hazardous impact on the environment. Additionally, landfill leachate is a mixture of pathogenic microorganism. The presence of pathogens in leachate have been confirmed mainly as thermotolerant bacteria and fecal *Streptococcus*. Other pathogens found in leachate are *Salmonela, Diplococcus pneumoniae* [5]. Leachate management and treatment is very important standard operation in landfilling process [6].

Leachate treatment methods can be classified as:

- physico-chemical (chemical precipitation, activated carbon adsorption, membrane filtration, ion exchange etc.).
- biological (aerobic or anaerobic conditions).

Usually a combinations of physical, chemical and biological methods for landfill leachate treatment, is more efficient than using one of these methods separate [6–9]. Biological treatment process is mainly the first stage in combination with additional physical–chemical process. The major biological treatment processes can be comprises of aerobic process like activated sludge (AC), sequencing batch reactor (SBR) and anaerobic process like upflow anaerobic sludge blanker reactor (UASB), anaerobic filters (AF) etc.

However, anaerobic treatment methods are more suitable for concentrated leachate streams, they are offering lower operating costs, the emission of biogas, and low sludge production [6].

Anaerobic treatment of leachate is similar to the anaerobic processes occurring inside municipal waste landfills. The most common anaerobic treatment is the methanogenic fermentation where the organic matter is completely degraded to mainly methane and carbon dioxide. Anaerobic treatment process is used mainly for young landfill leachate, which BOD_5 and BOD_5/COD ratio is very high [2]. However, Kettunen, et al. [10] performed the treatment with UASB reactor were municipal landfill leachate was having COD higher than 800 mg $\times$ dm^{-3} and the BOD/COD radio was higher than 0.3.

Anaerobic processes of landfill leachate in UASB reactor allow complete removal of COD from 65 to 76% and BOD_5 removal beyond 90% [11].

2. Materials and methods

2.1. Leachate analysis

The municipal landfill considered in this work is located close to the urban area of the city Czestochowa (Southern Poland) at Sobuczyna. This is an old landfill and leachate generated in, had relatively low BOD_5 values and low BOD/COD ratio. Since 1987, on Sobuczyna landfill, municipal and non-hazardous industrial wastes are deposited. Currently landfill leachate are accumulating in special tanks, and part of them are cleaning by reverse osmosis. Overflow leachate are treating in municipal mechanico-biological wastewater treatment plant. The main characteristic of the raw leachate used during experiment are shown in Table 1.

Table 1
Characteristics of landfill leachate from Sobuczyna

Parameter	Value
COD, mg $O_2 \times dm^{-3}$	3500–4200
BOD_5, mg $O_2 \times dm^{-3}$	380–420
pH	8.2–8.4
Alkalinity mg $CaCO_3 \times dm^{-3}$	4900–5200
Chloride mg $Cl^- \times dm^{-3}$	1800–2500
Ammonia nitrogen, mg $NH_4^+ \times dm^{-3}$	890–994
VFA, mg $CH_3COOH \times dm^{-3}$	500–900

2.2. Synthetic wastewater

The value of COD in synthetic wastewater use in treatment process was in the range of 3950–4100 mg $O_2 \times L^{-1}$. Chemical composition of synthetic wastewater, which was prepared according to PN-72/C-04550, was:

– mineral component I-K_2HPO_4 (6 g $\times$ dm^{-3})
– mineral component II-$CaCl_2 \times 7H_2O$ (0.6 g $\times$ dm^{-3}), KH_2PO_4 (6 g $\times$ dm^{-3}), NaCl (12 g $\times$ dm^{-3}) $MgSO_4 \times 7H_2O$ (2.6 g $\times$ dm^{-3}), NH_4Cl (6 g $\times$ dm^{-3})
– glucose (3.75 g $\times$ dm^{-3})
– sodium hydrogen carbonate (4.0 g $\times$ dm^{-3}).

2.3. Analytical methods

Landfill leachate, effluent from the UASB reactor and permeate from RO process were sampled periodically for pH value, alkalinity, COD, BOD_5, ammonia nitrogen, volatile fatty acids (VFA) and chloride analyses. Chemical oxidation demand (COD) was analyzed using colorimetric tests on HACH-DR 4000 photometer. Biochemical oxidation demand in five days (BOD_5) was measured with an OxiTop respirometer. The alkalinity and chloride were measured according to standard method [12].

The pH value was determined with a pH-meter Cole Parmenr. Ammonia nitrogen and VFA were determined with the distillation method on Büchi 323-Distillation Unit.

Biogas yield (Y) was calculated according to the following formula:

$$Y = \frac{V_b}{a} [dm^3 \times g^{-1} \text{ COD}_{\text{removed}}]$$

where
V_b, biogas production per day [$dm^3 \times d^{-1}$].
a, COD removal per day [$g \times d^{-1}$].

2.4. Reactor UASB

In the experiment an upflow anaerobic sludge blanket bioreactor (UASB) was used. The UASB reactor have cylindrical shape with total volume of 5 L (Fig. 1). The reactor tank was made from plexiglass. The reactor was filled up with anaerobic granular sludge at the concentrations of 10 g $\times$ dm^{-3}. The produced biogas was collecting in calibrated glass cylinders which were filled with acidified aqua deioned water.

2.5. Reverse osmosis unit

The effluent from anaerobic bioreactor was post-treatment using reverse osmosis. The RO process was carried out on laboratory scale membrane test unit illustrated in Fig. 2. The specification of the RO membranes is given in Table 2.

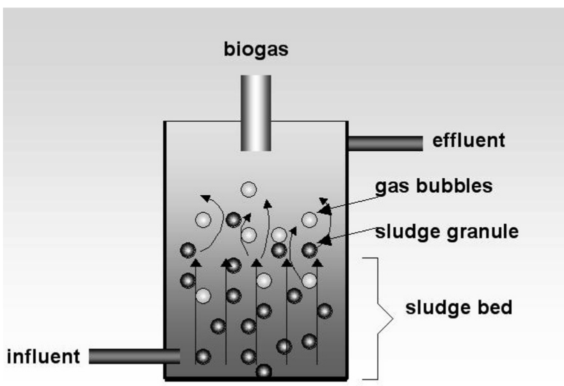

Fig. 1. The upflow anaerobic sludge blanket bioreactor (UASB).

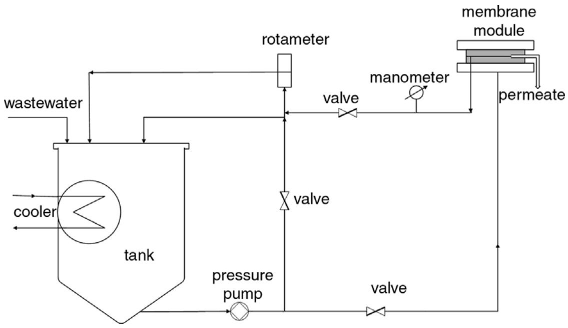

Fig. 2. Laboratory scale membrane test unit.

3. Results and discussion

3.1. Start-up UASB reactor and determining of landfill leachate concentration in synthetic wastewater

The start-up of anaerobic reactor is difficult to due because of low biodegradability of leachate and the presence of toxic compounds. That is why the start-up of the UASB reactor and acclimation were carried out in two steps. In the first step the anaerobic granular sludge was acclimated to treatment with high concentration of synthetic wastewater. UASB reactor was operated at organic loading rate (OLR) at 0.6 kg COD $m^3 \times dm^{-3}$ and hydraulic retention time (HRT) at 7 days. At the end of the 30-day period, effluent COD achieved value of 200 mg $O_2 \times dm^{-3}$. The COD removal efficiencies was about 95%. Since that moment, the landfill leachate was mixed with synthetic wastewater in the 8% proportions were precipitation of landfill leachate was increasing from 5, 10, 15, 20, 25, 30, 35 to 40% (v/v).

A higher COD removal over 90% was maintained with leachate addition of 5% (v/v). Under total content of landfill leachate in synthetic wastewater on 20% level, COD removal efficiency was 70%. COD concentration was 1200 mg $O_2 \times dm^{-3}$ and quality of effluent was the highest.

Gradual decreasing of organic removals was observed when leachate percentage increased too (Fig. 3). When the content of landfill leachate in synthetic wastewater was 40%, COD removal efficiency decreased to the level of 49%.

3.2. HRT and OLR determining

In the second phase of research, most advantageous parameters of landfill leachate anaerobic treatment was estimated. These parameters were: hydraulic retention time and organic loading rate. The HRT was shortened from 7 to 2 days, with a increase of OLR from 0.6 to 2.0 kg COD $\times m^{-3}$ d^{-1}. Therefore, every time a mixture of landfill leachate with synthetic wastewater (having constant, previously estimated optimum

Table 2
Specification of RO unit

Parameter	Membrane "Osmonics" Inc., type SEPA CF – HP, RO-DS3SE
Pressure, MPa	Max 4.0
pH, range	1–11
Temperature, °C (max)	90
Sodium rejection, %	C = 0.2% NaCl R_{NaCl} = 98.9
Membrane material	Polyamide

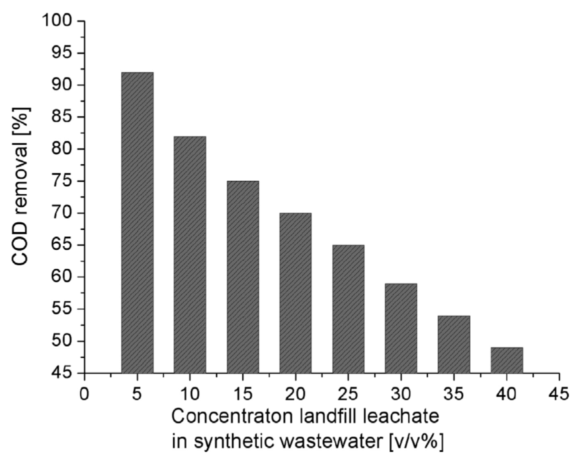

Fig. 3. Relationship between amount of landfill leachate in synthetic wastewater and COD removal efficiency.

Table 3
Influence of HRT on investigated parameters in anaerobic process

Parameter	HRT [d]			
	7	5	3	2
Effluent COD, mg $O_2 \times dm^{-3}$	1200	1080	960	1280
COD removal, %	70	73	76	68
OLR, kg COD $m^3 \times dm^{-3}$	0.6	0.8	1.3	2.0
Redox potential, mV	–420	–425	–380	–360
Biogas production per day, cm^3	1000	1500	2600	3100
Biogas yield, dm^3 biogas $\times g^{-1}$ $COD_{removed}$	0.50	0.50	0.52	0.52
VFA, mg $CH_3COOH \times dm^{-3}$	380	420	480	510

composition — 20% v/v) was put into the reactor. During the process, at HRT value equaled to 7 days, the COD removal efficiency was on 70% level. Shortening of HRT from 7 to 5 days caused an increase OLR from 0.6 kg COD $\times m^{-3} d^{-1}$ to 0.8 kg COD $\times m^{-3} d^{-1}$ and increase of COD removal by 3%. Therefore, COD concentration of effluent was 1080 mg $O_2 \times dm^{-3}$. Additionally, a 30% increase of daily biogas production (1500 cm^3) in comparison with 7 days HRT process (1000 cm^3) was observed.

Shortening HRT to 3 days, caused increase OLR to 1.3 kg COD $\times m^{-3} d^{-1}$. With that balanced parameters, a 76% HRT decrease was achieved, which is equaled to 960 mg $O_2 \times dm^{-3}$ in effluent. Also, the daily biogas production increased almost 2 times (2600 cm^3) in comparison to anaerobic treatment with HRT of 5 days. During the co-treatment process with landfill leachate and synthetic wastewater that had 2 days retention time, the quality of effluent changed for the worst. The HRT was approximately 1280 mg $O_2 \times dm^{-3}$. COD removal efficiency decreased from 76% to 68%.

Additional parameter that was monitored during the fermentation process was biogas yield (Table 3).

Dependence of COD removal and biogas production to HRT — Fig. 4.

At HRT equaled to 7 and 5 days, the biogas yield was on the same level approximately 0.50 dm^3 biogas $\times g^{-1}$ $COD_{removed}$. At the HRT equaled to 3 and 2 days, the biogas yield was approximately 0.52 dm^3 biogas $\times g^{-1}$ $COD_{removed}$.

3.3. Post-treatment process — reverse osmosis

In the final part of the experiment the RO process was used in order to post-treating effluent from UASB reactor. This stage was started with determination of transport properties of the membranes by finding the dependence of volume deionized water flux on transmembrane pressure. Pressure range used in the study varied from 1.0

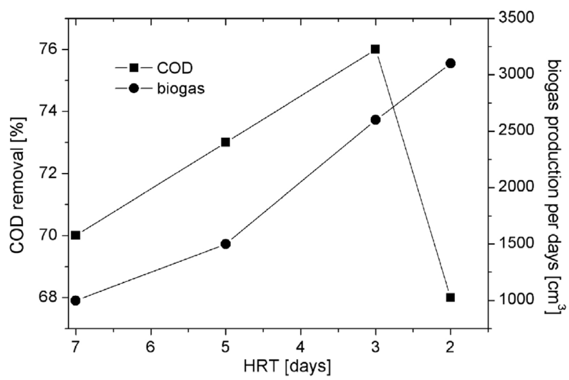

Fig. 4. Relationship between efficiency COD removal, biogas production per day and hydraulic retention time.

Table 4
Effectiveness of wastewater treatment in the system combining anaerobic process and reverse osmosis

Parameter	Raw wastewater	Wastewater after anaerobic process		Wastewater after RO process		Permissible standards [13]
		Concentration	Retention *R* (%)	Concentration	Retention *R* (%)	
COD[a]	4000	960	76	44	95.4	125
H	8.4	8.1	–	9.26	–	6.5–9.0
Ammonia nitrogen[a]	280	196	30	22	88.7	10
BOD_5[a]	1350	245	81.8	24	90.2	30
Chloride[a]	2500	2350	6	215	85.4	1000

[a]Concentration, $mg \times dm^{-3}$.

to 3.0 MPa. It was observed that in all cases, the water flux increased with increasing transmembrane pressure. Volume water flux achieved value of 8.9×10^{-5} $m^3 \times m^{-2}$ at transmembrane pressure equaled to 2.0 MPa and linear flow velocity 2 m/s. The post-treatment process was carried out for these parameters.

The volume permeate flux value after 14 h of RO-process was decreased to 2.9×10^{-5} $m^3 \times m^{-2}$ and was lower in relation to deionized water flux equaled to 67.6%.

The efficiency of membrane process and anaerobic process were shown in Table 4.

The COD removal efficiency with RO process was very high and achieved value of 95.4%. RO process allowed also to remove BOD, chloride, ammonia nitrogen by 90.2%, 85.4% and 88.7% respectively.

However, a high concentration of ammonia (22 mg $NH_4^+ \times dm^{-3}$) and pH value in permeate from RO process was observed. Because of high concentration of that ammonia, permeate can not to be discharged into natural water without additional treatment process.

4. Conclusion

- The investigations showed, that the hybrid system anaerobic process — reverse osmosis, did not reach a sufficient level which enable it to use in landfill leachate process.
- COD, BOD, ammonia nitrogen, chloride concentrations in permeate after RO was kept 44 mg $O_2 \times dm^{-3}$, 24 mg $O_2 \times dm^{-3}$, 22 mg $NH_4^+ \times dm^{-3}$ and 215 mg $Cl^- \times dm^{-3}$ respectively.
- A addition of ammonia stripping process to hybrid system UASB reactor-RO in landfill leachate treatment is suggested.

Acknowledgement

The study was supported by the Polish Ministry of Science and Higher Education (grant no. T09D 078 30).

References

[1] D.P. Komilis, R.K. Ham and Stegmann, The effect of municipal solid waste pretreatment on landfill behavior: a literature review, Waste Manag. Res., 17 (1999) 10–19.
[2] J. Surmacz-Gorska, Degradation of organic compounds in municipal landfill leachate, Publisher of Environmental Engineering Committee of Polish Academy of Sciences, Lublin, 2001.
[3] M. El-Fadel and N. Findikakis, Environmental impacts of solid waste landfiling, J. Environ. Manag., 50 (1997) 1–25.

[4] T. Kurniawan, Lo Wai-hung and G. Chan, Physico-chemical treatments for removal of recalcitrant contaminiants from landfill leachate, J. Hazar. Mater., B129 (2006) 80–100.

[5] K. Haarstad and T. Maehlum, Important aspects of long-term production and treatment of municipal solid waste leachate, Waste Manag. Res., 17 (1999) 470–477.

[6] K.J. Kennedy and E.M. Lentz, Treatment of landfill leachate using sequencing batch and continuous flow upflow anaerobic sludge blanket (UASB) reactors, Water Res., 34 (14) (2000) 3640–3656.

[7] J. Berrueta, A. Gutierres and G. Fueyo, Anaerobic treatment of leachates in a pilot-scale UASB: strategy of start-up, J. Chem. Technol. Biotechnol., 67 (1996) 302–314.

[8] L. Chiang, J. Chang and C. Cung, Electrochemical oxidation combined with physical-chemical pretreatment processes for the treatment of refractory landfill leachate, Environ. Eng. Sci., 18 (2001) 369–378.

[9] H.D. Robinson and M.J. Barr, Aerobic biological treatment of landfill leachates, Waste Manag. Res., 17 (1999) 478–486.

[10] R.H. Kettunen and J.A. Rintala, Performance of an on-site UASB reactor treating leachate at low temperature, Water Res., 36 (1998) 537–546.

[11] J. Szyc, Municipal landfill leachate, Science Publishers:Gabriel Borowski, Warsaw, Poland, 2003.

[12] APHA, Standard Methods for Water and Wastewater Examination, 17th edn., Amer. Public Health Assoc., Washington, DC, 1992.

[13] Regulation of the Ministry of Environmental Protection, Natural Resources an Forestry, dated 8 July 2003, on the classification of water and conditions the sewage discharged to waters and soil should satisfy, J. Law No. 168, item 1763.