[Japanese Journal of Water Treatment Biology Vol.43 No.1 43-49 2007]

Performance of Lab-Scale Membrane Bioreactor for Leachate from Go Cat Landfill in Ho Chi Minh City, Vietnam

NGUYEN NHU SANG[1*], SATOSHI SODA[1], KAZUNARI SEI[1], TOMONORI ISHIGAKI[2], LAM MINH TRIET[3], MICHIHIKO IKE[1], and MASANORI FUJITA[4]

[1] Division of Sustainable Energy and Environmental Engineering, Graduate School of Engineering, Osaka University/2-1 Yamada-oka, Suita, 565-0871, Japan
[2] Department of Environmental Solution Technology, Faculty of Science and Technology, Ryukoku University/1-5 Yokotani, Setaoe-cho, Otsu, 520-2194, Japan
[3] Department of Natural Resources and Environment of Ho Chi Minh City, Vietnam /63 Ly Tu Trong Street, District 1, Ho Chi Minh City, Vietnam
[4] Kochi National College of Technology/ 200-1, Monobe-Otsu, Nankoku, 783-8508, Japan

Abstract

This study examined characteristics of leachate from the Go Cat landfill in Ho Chi Minh City, Vietnam and the performance of a lab-scale bioreactor equipped with a microfiltration unit (membrane bioreactor; MBR) for leachate treatment. The COD concentrations of leachate were 39.6–59.8 g l^{-1} and 1.1–4.0 g l^{-1} in the dry season (Nov. 2003 – Apr. 2004) and the rainy season (May – Aug. 2004), respectively, indicating that intensive precipitation of the monsoon climate in summer promotes leachate generation and changes in its quality because of the enhanced degradation and increased dilution. The BOD/COD ratio over 0.68 through the year suggested that biological wastewater treatment processes are promising for leachate treatment. The MBR was operated for 90 days at volumetric loading rates of 1.9–4.2 g-COD l^{-1} d^{-1}. The microfiltration membrane kept the sludge concentration high in the MBR. The specific loading rate remained at 0.097–0.616 g-COD g-VSS^{-1} d^{-1} because of the high MLVSS concentration. The MBR showed high COD removal of 84–97% throughout the experimental period. Those results suggest that the effluent COD standard of 100 mg l^{-1} is probably achieved in the rainy season, but some post-treatment processes are needed, especially for the dry season.

Key words: landfill leachate, membrane bioreactor, Ho Chi Minh City

INTRODUCTION

Ho Chi Minh City (HCMC), with its population of over 6 million in 2004, is the most crowded city in Vietnam. The municipality manages about 5,000 tons d^{-1} of unclassified solid wastes containing about 60% biodegradable organic fraction, which are generated from residential and commercial areas[1)]. To accommodate rapid development of HCMC, several landfill sites have been constructed near the city. Leachate generated from such landfill sites is not always treated satisfactorily, although applicability of several treatment processes has been studied[2)]. One reason for difficulty in the treatment is that leachate characteristics depend greatly on precipitation. In HCMC, 80–85% of the precipitation at 1,800 mm year^{-1} usually occurs in the rainy season (May–Oct.)[1)]. Such landfill leachates in the monsoon climate should be studied intensively[3,4)]. However, characteristics of leachate in Vietnam have rarely been studied.

Leachate generated from young acidogenic landfills is characterized as having high concentrations of chemical oxygen demand (COD), biochemical oxygen demand (BOD), and several toxic/hazardous compounds. The high BOD/COD ratio in young landfill leachates requires biological treatment processes[5,6]. It is generally suitable to use a biological treatment process when the BOD/COD ratio is higher than 0.5[7]. Although several biological treatment processes have demonstrated high performance for leachate treatment, some problems have been detected depending on leachate characteristics such as flow rate variations and its complex composition. The membrane bioreactor (MBR) is a state-of-the-art technology for landfill leachate treatment to solve those problems[8-11]. The advantages of MBRs are their accumulation of large amounts of biomass, high volumetric loading rates (VLRs), and high effluent quality.

This study was intended to survey leachate characteristics of the Go Cat landfill in HCMC in the dry and rainy seasons and to evaluate a lab-scale MBR's leachate-treatment performance. Limitations of the MBR for leachate treatment in Vietnam were discussed on the basis of the national effluent standard for COD.

MATERIALS AND METHODS

Leachate sampling at the Go Cat landfill Go Cat landfill, at a distance of 15 km from the center of HCMC, is a young landfill that has been operated since 2001 by the City Environmental Company (CITENCO). This anaerobic open landfill has an area of 25 ha and a capacity for receiving 2,000 tons d^{-1} of commingled solid wastes[12]. A layer of high-density polyethylene material, which provides leakage prevention, covers the sloped sides and bottom of the dumping yards. The wastes are disposed and pressed every day in the yards. Vertical gas-collecting wells and leachate collection pipes were installed in the landfill.

Precipitation and average temperature in HCMC during Oct. 2003 – Nov. 2004 are shown in Fig. 1. The leachate samples were collected from the landfill in the dry season (Nov. 2003 – Apr. 2004) and the rainy season

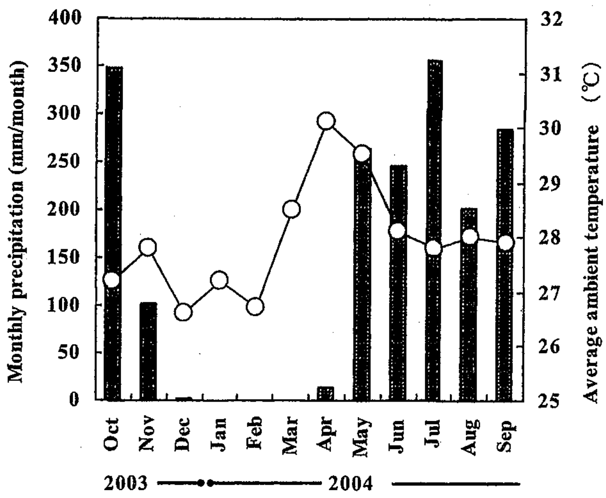

Fig. 1 Precipitation and average temperature in HCMC in Oct. 2003, Sep. 2004 (Statistical Office in HCMC, http://www.pso.hochiminhcity.gov.vn/). The precipitation (▩) and average temperature (–o–) are shown. Leachate generated from the Go Cat landfill was sampled in the dry season (Nov. 2003, Apr. 2004) and the rainy season (May, Aug. 2004).

(May – Aug. 2004). The samples were collected regularly in 20-liter plastic carboys from two ponds of the Go Cat landfill; they were subsequently transported to the laboratory. The samples were reserved in a refrigerator at 4°C and analyzed within two days. Table 1 shows the landfill leachate quality.

Laboratory-scale MBR A flow scheme of the lab-scale MBR, an Aerobic Digester W11 (Armfield Ltd., UK), is shown in Fig. 2. The apparatus comprises a 10-liter reactor vessel, a liquid feed pump, an air supply blower, and instruments for monitoring and controlling the process. The cylindrical inner wall, made from a porous plastic material with a pore size of 25 μm, has about 200 mm outside diameter and 300 mm height. This microfilter is responsible for retaining the suspended solids while allowing treated water to pass through to the outer, annular exit chamber. The pump delivers leachate to the reactor through a transparent lid. The transmembrane pressure (TMP) is monitored by the head loss of water inside and outside of the cylindrical wall. Air is supplied at a measured rate by the blower into the base of the reactor via a spider-arm dispenser, which

Table 1 Seasonal variations of leachate composition of Go Cat landfill

	Dry season				Rainy season			
Sampling date	Nov. 2003		Apr. 2004		May 2004		Aug. 2004	
Pond	Pond 1	Pond 2	Pond 1	Pond 2	Pond 1	Pond 2	Pond 1	Pond 2
pH	4.8	6.2	5.6	6.5	7.6	7.9	7.8	8.6
TDS (g l^{-1})	7.3	12.2	18.3	20.7	9.1	11.1	9.4	16.1
Hardness (g-$CaCO_3$ l^{-1})	5.8	9.7	5.7	8.1	1.5	1.9	0.6	1.5
SS (g l^{-1})	1.8	4.3	0.8	6.7	0.2	0.2	0.1	0.2
BOD (g l^{-1})	30.2	48.4	39.0	48.5	1.0	1.9	0.8	2.7
COD (g l^{-1})	39.6	59.8	50.6	57.3	1.4	2.7	1.1	4.0
BOD/COD	0.76	0.81	0.77	0.85	0.70	0.70	0.73	0.68
T-N (mg l^{-1})	560	900	980	1800	400	550	300	380
Org-N (mg l^{-1})	250	410	300	790	30	160	50	140
NH_4-N (mg l^{-1})	250	430	580	1550	370	390	230	320
NO_2-N (mg l^{-1})	0	2	0	2	0	2	0	2
NO_3-N (mg l^{-1})	0	5	0	5	0	5	0	5
T-P (mg l^{-1})	12.5	17.1	29.3	32.9	4.7	9.5	5.2	12.0

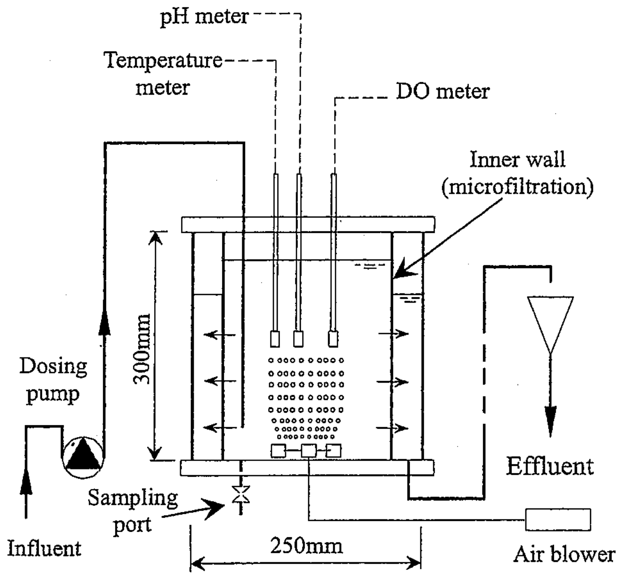

Fig. 2 Schematic diagram of the MBR for leachate treatment. The permeate is obtained as the process effluent through the inner cylindrical wall (microfiltration).

is designed to prevent blockage and to produce sufficient bubbling for stirring and reaction. The water volume inside the cylindrical membrane was maintained at 6.3–7.4 l. The permeate was discharged by gravity to a floor-standing tank.

Operational conditions of the MBR Seed sludge was sampled from a conventional activated sludge process in a wastewater treatment plant in HCMC. The sludge was cultivated in the MBR through a daily fill and draw operation with leachate of the initial COD concentration of 25–30 g l^{-1}. The start-up period was three weeks for obtaining COD removal greater than 70%.

The MBR trial was divided into three phases, Run 1, Run 2, and Run 3, each with a different sludge retention time (SRT) and VLR in the continuous treatment mode under ambient conditions. Table 2 presents experimental conditions for the three runs. In Run 1, COD removal and sludge production at VLR of 2.0 g-COD l^{-1} d^{-1} were evaluated without intentional sludge withdrawal from the MBR, except for measurement of the mixed liquor suspended solids (MLSS) concentration. In Runs 2 and 3, a certain amount of excess sludge was discharged intermittently from the bioreactor to maintain the predetermined SRT. After discharge of half of the sludge in the MBR at the end of Run 1, it was operated at VLR of 2.0 g-COD l^{-1} d^{-1} and SRT of 50 days in Run 2. The MBR was operated at various VLRs with SRT of 100 days in Run 3 with starting mixed liquor volatile suspended solids (MLVSS) concentration of 8.3 g l^{-1}. In Runs 1 and 2, the inflow rate was regulated depending on the influent COD concentration

Table 2 Experimental conditions for leachate treatment by MBR

	Run 1	Run 2	Run 3
Operation period	Days 0–48 (48 days)	Days 49–66 (18 days)	Days 67–90 (24 days)
SRT (day)	∞*1	50	100
Flow rate (l d^{-1})*2	0.4–1.5	0.9–1.7	2.5–3.5
Volumetric loading rate (g-COD l^{-1} d^{-1})	2.0	2.0	1.9–4.2
Specific loading rate (g-COD g-VSS^{-1} d^{-1})	0.097–0.44	0.231–0.328	0.209–0.616
Influent temperature (°C)	20–25	20–25	20–25
DO in bioreactor (mg l^{-1})	4–5	4–5	4–5
pH	6.5–8.5	6.5–8.5	6.5–8.5
KH_2PO_4 solution added to COD/P ratio	150	150	150

*1 Without sludge withdrawal, except for MLSS measurement
*2 The flow rate was regulated according to the influent COD concentration to maintain the predetermined VLR (see Fig. 3).

to maintain predetermined VLR values, as represented in Fig. 3.

The membrane module was taken from the bioreactor when TMP increased to 60–75 kPa; it was cleaned with tap water and then 0.5% NaOCl and 5% HCl solutions to remove membrane surface foulants. The membrane was washed once weekly in the first two weeks in Run 1, and 2–3 times a week thereafter.

Analytical methods The following parameters were measured using probe types: pH by 744 pH meter, Omega; dissolved oxygen (DO) and temperature by WTW Oxi 197 and total dissolved solids (TDS) by CDH-287-KIT, Omega. COD_{Cr}, BOD_5, MLSS, MLVSS, nitrate nitrogen (NO_3-N), nitrite nitrogen (NO_2-N), ammonium nitrogen (NH_4-N), organic nitrogen (Org-N), total Kjeldahl nitrogen (T-N), total phosphorus (T-P) and hardness were analyzed according to their respective standard methods[13].

RESULTS AND DISCUSSION

Leachate from Go Cat landfill in rainy and dry seasons Table 1 shows the leachate quality of Go Cat landfill in HCMC, Vietnam. Overall, the Go Cat landfill leachate, similar to young leachate of other open landfills in Vietnam, showed high organic matter contents, dark color and stench due to the digestion of the high biodegradable organic fraction in the municipal solid wastes. The leachate quality extremely depended on precipitation. Figure 1 shows that great precipitation occurs the rainy season in HCMC. Although the water balance in the landfill has not been exactly determined, the Go Cat landfill produces leachate of about 400 m^3 d^{-1} on average and much more in the rainy season[14]. The COD concentration in leachate dropped drastically from 39.6–59.8 g l^{-1} in the dry season to 1.1–4.0 g l^{-1} in the rainy season; the BOD value was also between 30.2–48.5 and 0.8–2.7 g l^{-1}. The BOD/COD ratio is an indicator of the proportion of biodegradable organic matter to total organic matter; it decreased slightly from 0.76–0.85 in the dry season to 0.68–0.73 in the rainy season, indicating enhanced biodegradation in the landfill in the rainy season.

The pH increased from 4.8–6.5 in the dry season to 7.6–8.6 during the rainy season, implying that the large precipitation in the rainy season dissolved alkaline components of the cover soil in the landfill into leachate. Major components of the nitrogenous compounds in leachate were NH_4-N and Org-N. The T-N and Org-N concentrations in the rainy season were apparently lower than those in the dry season. However, NH_4-N concentrations remained at the same level through the year, thereby enhancing ammonification of organic compounds in the rainy season. The NO_2-N and NO_3-N concentrations were negligible in the young leachate, suggesting that the nitrification process does not proceed greatly in the

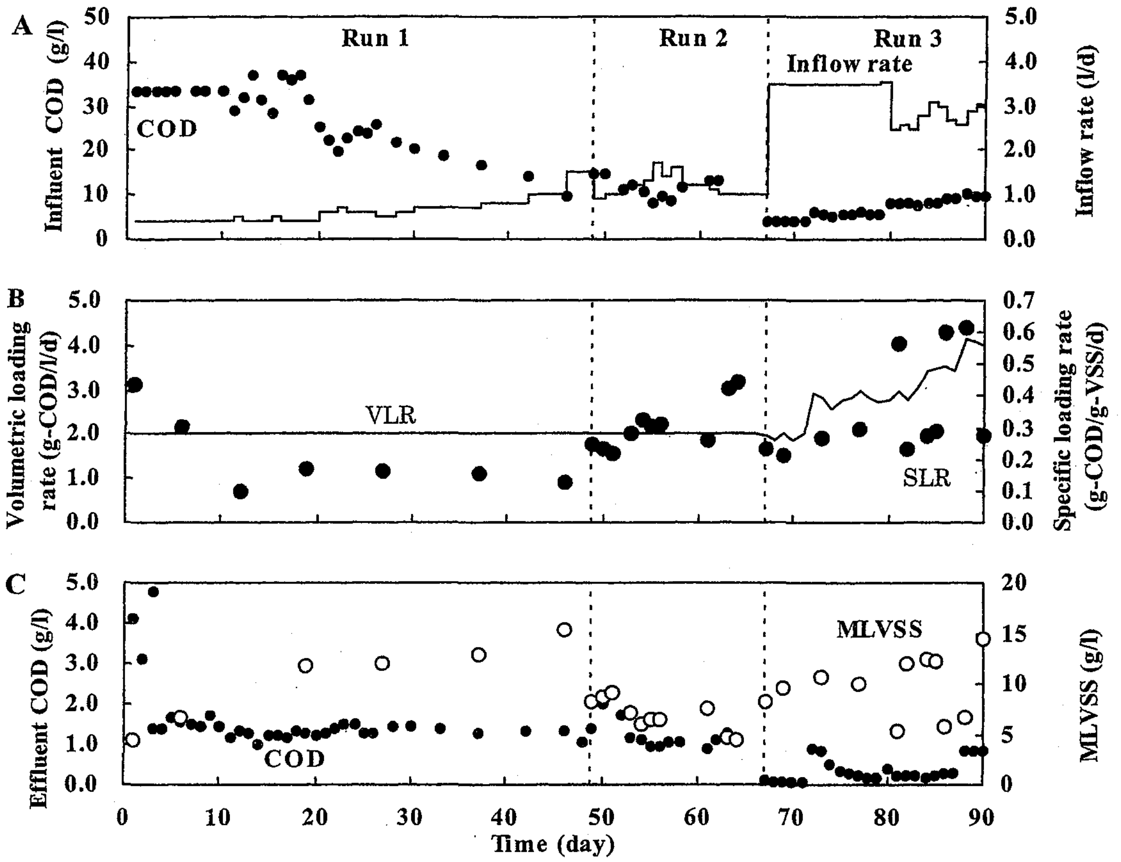

Fig. 3 Operational conditions and performance of the MBR for Go Cat landfill leachate treatment. The influent COD concentration (•) and the inflow rate (—) (A), the volumetric loading rate (—) and the specific loading rate (•) (B), and the effluent COD concentration (•) and the MLVSS concentration (○) (C) are shown.

anaerobic landfill. Total phosphorus concentrations also declined from 12.5–32.9 mg l^{-1} in the dry season to 4.7–12.0 mg l^{-1} in the rainy season. As a general rule, the optimal ratio of BOD:N:P is 100:5:1 to provide nutrients for biological processes[15]. Therefore, it is noteworthy that low nitrogen and phosphorus concentrations, especially the phosphorus concentration in the dry season, are an important limiting factor for subsequent aerobic biological treatment of leachate.

Although little information exists on the effect of the climate on the leachate composition and generation[3,4], Table 1 shows that intensive precipitation in summer of the monsoon climate promotes leachate generation and changes in its quality through enhanced degradation and increased dilution. It would be occasionally overloaded in practice because of the high discharges in the rainy season and high concentrations in the dry season if quantitative and qualitative variations of leachate were not incorporated into the design and operation of the leachate treatment process.

Performance of MBR for COD removal The lab-scale MBR was operated for treatment of Go Cat landfill leachate, which has BOD/COD ratios higher than 0.5. Phosphorus as KH_2PO_4 solution was added to leachate for retaining the COD/P ratio = 150. Operational conditions and the MBR performance are shown in Fig. 3. The inflow rate in Runs 1 and 2 was set as expressed in Fig. 3A to maintain the high predetermined VLR of 2.0 g-COD^{-1} l d^{-1}, whereas conventional activated sludge processes are usually applied at VLR of 0.4–0.8 g-COD l^{-1} d^{-1}.

In Run 1, the MBR was operated without intentional sludge withdrawal. According to variation of the influent COD concentration in a range of 35–9 g l^{-1} during 48 days, the inflow rate was regulated at 0.4–1.5 l d^{-1}. The MLVSS concentration increased from 4.6 g l^{-1} on day 0 to 15 g l^{-1} on day 46. After day 3, the effluent COD concentration remained at ca. 1–1.5 g l^{-1}. In Run 2, the MBR was controlled at SRT of 50 days. Because of the sludge withdrawal, the MLVSS concentration dropped from 8.2 g l^{-1} on day 49 to 4.5 g l^{-1} on day 64. The effluent COD concentration was 0.87–1.3 g l^{-1} during day 55–63. In Run 3, the MBR was operated at SRT of 100 days at various VLRs of 1.9–4.2 g l^{-1} d^{-1}, as shown in Fig. 3B. The influent COD concentrations were low between 4 and 10 g l^{-1}, whereas the inflow rate was kept very high in a range of 2.5–3.5 l d^{-1}. The MLVSS concentration increased from 8.3 g l^{-1} on day 67 to 14 g l^{-1} on day 90. The effluent COD concentration was 0.065–0.83 g l^{-1} in spite of the high VLR.

In all runs, the specific loading rate (0.097–0.616 g-COD g-VSS^{-1} d^{-1}) was kept as low as that of conventional activated sludge processes in spite of the high VLR because of the high MLVSS concentration that was maintained by the use of the membrane. High COD removal of 84–97% was also achieved, but the MBR performance was not always satisfactory for the national effluent standard type B as COD $\leq$100 mg l^{-1}. This standard is actually difficult to achieve by any typical wastewater treatment process alone, including MBR technology. Additionally, one of the reasons for difficulty to reach the standard might be the lack of nitrogen for biotreatment although phosphorus was added to leachate. Figure 4 shows a summary of the MBR performance with effects of the influent COD concentration and the inflow rate on the effluent COD concentration. If the influent COD concentration is comparable to that of leachate in the rainy season, i.e. less than about 4 g l^{-1}, it is possible to achieve the effluent COD standard at the high inflow rate of about 3.5 l d^{-1}. On the other hand, the effluent COD concentrations were much higher than the standard when the influent COD concentrations were higher than 4 g l^{-1}, even at low inflow rates. This result suggests that leachate treatment by MBRs in the rainy season would achieve the environmental standard more easily than that in the dry season if a reactor with sufficient volume were provided for preventing overflow.

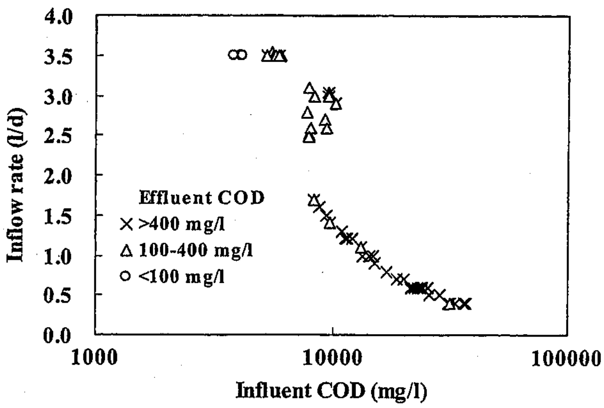

Fig. 4 Effects of the influent COD concentration and the inflow rate on the effluent COD concentration of the MBR treating Go Cat landfill leachate.

This study examined the potential uses and limitations of the MBR for leachate treatment on the basis of COD removal. One of the main limitations associated with the operation of MBRs is membrane fouling. Biofilms were formed on the surface of the membrane of the MBR. The effluent was filtrated not only by the membrane but also by the biofilm layer. The turbidity of the effluent gradually reduced with the biofilm formation (data not shown). The fouling and its consequences in terms of plant maintenance restrict the widespread application of MBRs for leachate treatment. Further studies of heavy metals, color components, and persistent organic pollutants in leachate are necessary. For constant compliance with environmental standards in Vietnam, especially in the dry season, some post-treatment processes such as coagulation, Fenton reactions, UV-TiO_2–H_2O_2 treatment[2], ultrafiltration, and nanofiltration should be pursued after adoption of MBR as a main treatment process. An important consideration is that degradation of organic pollutants by Fenton reactions and UV-TiO_2–H_2O_2 treatment under some operating conditions can generate toxic intermediates[2].

CONCLUSIONS

Intensive precipitation of the monsoon climate in summer exacerbates leachate generation from the Go Cat landfill and alters its quality because of the enhanced degradation and increased dilution. Results of leachate treatment tested using the lab-scale MBR suggest that the effluent COD standard in Vietnam would probably be achieved in the rainy season, but some post-treatment processes would be necessary, especially in the dry season.

ACKNOWLEDGEMENT

This work was partly supported by The Core University Program between Japan Society for the Promotion of Science (JSPS) and Vietnamese Academy of Science and Technology (VAST).

REFERENCES

1) **PCHCMC (People's Committee of Ho Chi Minh City)**: VIE/96/023 project, Technical reports for the HCMC environmental quality management strategy, Section 2, Part 2 and Part 10 (2002)
2) **Ishigaki, T., Tateda, M., Le Van Chieu, Cao The Ha, Pham Hung Viet, Ike, M., and Fujita, M.**: Field survey and advanced oxidation treatment of waste landfill leachate in Hanoi, Vietnam. J. Japan Soc. Wat. Environ., 25, 629–634 (2002) (in Japanese)
3) **Fan, H.-J., Shu, H.-Y., Yang, H.-S., and Chen, W.-C.**: Characteristics of landfill leachates in central Taiwan. Science of the Total Environment, 361, 25–37 (2006)
4) **Tränkler, J., Visvanathan, C., Kuruparan, P., and Tubtimthai, O.**: Influence of tropical seasonal variation on landfill leachate characteristics – Results from lysimeter studies. Waste. Manage., 25, 1313–1020 (2005)
5) **Inanc, B., Calli, B., and Saatci, A.**: Characterization and anaerobic treatment of sanitary landfill leachate in Istanbul. Wat. Sci. Technol., 41(3), 223–230 (2000)
6) **Timur, H., Ozturk, I., Altinbas, M., Arikan, O., and Tuyluoglu. B.S.**: Anaerobic treatability of leachate: a comparative evaluation for thee different reactor systems. Wat. Sci. Technol., 42(1–2), 287–292 (2000)
7) **Chain, E.S.K.**: Stability of organic matter in leachates. Wat. Res., 11, 225–232 (1977)
8) **Ahn, W.-Y., Kang, M.-S., Yim, S.-K., and Choi, K.-H.**: Advanced landfill leachate treatment using an integrated membrane process. Desalination, 149, 109–114 (2002)
9) **Robinson, A.H.**: Landfill leachate treatment. Membrane Technol., 6, 6–12 (2005)
10) **Tarnacki, K., Lyko, S., Wintgens, T., Melin, T., and Natau, F.**: Impact of extra-cellular polymeric substances on the filterability of activated sludge in membrane bioreactors for landfill leachate treatment. Desalination, 179, 181–190 (2005)
11) **Vasel, J.-L., Jupsin, H., and Annachhatre, A.P.**: Nitrogen removal during leachate treatment: comparison of simple and sophisticated systems. Wat. Sci. Technol., 50(6), 45–52 (2004)
12) **ODAP Newsletter**: No. 10 (2001)
13) **APHA, AWWA, WPCF**: Standard methods for the examination of water and wastewater, Washington, DC (1995)
14) **ODAP Newsletter**: No. 15 (2003)
15) **Metcalf & Eddy**: Wastewater Engineering – Treatment and Reuse, Chapter 8, 661–886 (2003)

(Submitted 2006. 9. 11)
(Accepted 2006. 12. 19)