Journal of Water Sustainability, Volume 5, Issue 3, September 2015, 75-83

Removal of UV Quenching Substances in Landfill Leachate with Open Channel Reverse Osmosis Membrane Technologies

D. Lei, D. P. Xu, F. Li*

Chong qing San feng Science and Technology Co., Ltd, Chong qing 400084, China

ABSTRACT

Sequencing batch reactor (SBR) is one of the widely applied biological approaches for landfill leachate treatment. The SBR process is most effective in treating young leachate, which mainly consists of volatile fatty acids. However, the SBR process has limitations in treating methanogenic phase leachate. Humic substances are the predominant organic substances in methanogenic leachate. Humic substances are not readily biodegradable (Poblete et al., 2011), and pass through the biological treatment processes, appearing in the SBR effluent. The SBR effluent is often discharged or transported to the publically owned treatment works (POTWs). To avoid of the formation of disinfection by-products (DBPs) caused by chlorine disinfection, ultra-violet (UV) disinfection has recently been adopted for the disinfection of the effluent of POTWs. Humic substances and fulvic acid-like materials were found to contribute to the majority of UV light quenching fractions which consequently interfere the disinfection process at POTWs where UV light is applied (Zhao et al. 2013). This study reports the findings of a full-scale one-stage open channel reverse osmosis plant treating landfill leachate SBR effluent in east coast of USA to reduce the UV quenching substances. The results presented in this study indicate that open channel reverse osmosis membrane is able to significantly reduce the UV quenching substances in the landfill leachate SBR effluent. The open channel RO membrane has achieved satisfactory water quality, process stability and membrane flux results. Open channel RO polishing after biological treatment has been demonstrated as an effective technology for landfill leachate treatment.

Keywords: Landfill leachate; leachate treatment; reverse osmosis; open channel module; open channel reverse osmosis; leachate permeate; leachate concentrate

1. INTRODUCTION

Landfill leachate wastewater is heavily loaded with organic and inorganic contaminants, representing major risk to natural water resources (Christensen et al., 1992). The treatment of landfill leachate from Municipal Solid Waste (MSW) is very complex when stringent discharge limits are required, as the quality and quantity of MSW landfill leachate vary with the climatic conditions and the age of the landfill (Li et al., 2009).

Leachate is often pre-treated through an on-site sequencing batch reactor (SBR). SBR effluent is then often discharged or transported to the publicly owned treatment works (POTWs) for further treatment with mixed municipal wastewater. SBR treatment is effective for the removal of easily bio-degradable organic substance, but less efficiencies in treating humic substances, derived from cellulose and lignin with high molecular weight and fulvic acid-like

**Corresponding to*: Fangyue_l@yahoo.com

DOI: 10.11912/jws.2015.5.3.75-83

materials with medium to high molecular weight (Cossu, et al., 2007). The majority of bio-refractory humic substances and fulvic acid-like materials will pass through the SBR process and enter into the POTWs.

Li and Deng (2012) reported that the bio-refractory humic substances in a leachate treatment plant through co-treatment of landfill leachate and sewage are typically transformed into trihalomethanes, which were substantially higher than the trihalomethanes formation during chlorination of the effluent of POTWs without landfill leachate addition. To avoid of the formation of disinfection by-products (DBPs) caused by chlorine disinfection, many POTWs are applying ultra-violet (UV) disinfection to the plant effluent. Humic substances and fulvic acid-like materials were found to be the most prevalent UV light quenching fractions which consequently interfere with disinfection process at POTWs where UV light is applied (Zhao et al. 2013). Zhao et al. (2013) reported that a wastewater containing 5% biologically pre-treated leachate is able to block 65-80% of UV_{254} light, making the UV disinfection in the POTWs ineffective. This number increases up to 98% for untreated young leachate (Zhao et al. 2013). Lower UV transmittance requires additional UV disinfection equipment, increased energy consumption, and increased lamp maintenance. For efficient UV disinfection the UV_{254} transmittance should be greater than 60-65% (Basu et al., 2007). High rejection open channel reverse osmosis membranes, which retain both organic and inorganic contaminants at a high rejection rate (Peters, 1998; Peters, 2001), have demonstrated to be a more efficient means for biologically pre-treated landfill leachate. In this study, a full-scale one-stage open channel reverse osmosis plant, delivered by ROCHEM UF Systeme GmbH, was installed at a landfill leachate treatment plant in the east coast of USA.

2. MATERIALS AND METHODS

A simplified flow diagram of the leachate treatment system is shown in Fig. 1. The existing biological pre-treatment process at the landfill is a SBR process. The SBR process has a HRT of 5 days and a SRT of approximately 30-35 days. The single SBR process effectively removes ammonia, biological oxygen demand and phosphorus. However, the SBR process effluent maintained a UV transmittance of effectively 0%, failing to meet POTW discharge limits, and demonstrating and inability to eliminate the large amount of non-biodegradable organic substances, necessitating the application of polishing reverse osmosis systems to complement and support the major process (Li et al., 2009).

A full-scale single-stage open channel reverse osmosis plant, delivered by ROCHEM UF System GmbH, was installed at a landfill leachate treatment plant in the east coast of USA. Two parallel RO skids with a treatment capacity of 17 m^3/h each were installed on-site to treat the effluent from the SBR leachate treatment plant. Each skid was equipped with sixty ROCHEM Open channel Reverse Osmosis membrane modules. The RO membrane module, developed by ROCHEM in 2002, combines the advantages of both disc tube (DT) module and the spiral wound module to treat wastewater with high potential of both biological fouling and chemical scaling. Identical to DT module, open channel RO module is one meter in length and 0.202 meters in diameter. Similar to the spiral wound module, the membrane envelopes are manufactured from two flat membranes, between which an internal fabric fleece is used for permeate drainage. The membrane envelops are set apart by feed side spacers, creating open channels. The feed spacers (Fig. 2) used in the open channel RO modules consist of two types of filaments with different diameters. The thick filaments, are parallel to the channel axis and the thin filaments are lying in the cross direction. The thick filaments have direct contact with the membrane envelops and the thin filaments do not touch the membrane surface, allowing small particles to pass through on either side. This allows the open channel RO module to treat wastewaters containing high dissolved solids and high turbidity with excellent resistance to scaling and fouling. Suspended particulates deposited on the membrane surface can easily be flushed away during routine cleanings in the opened channel.

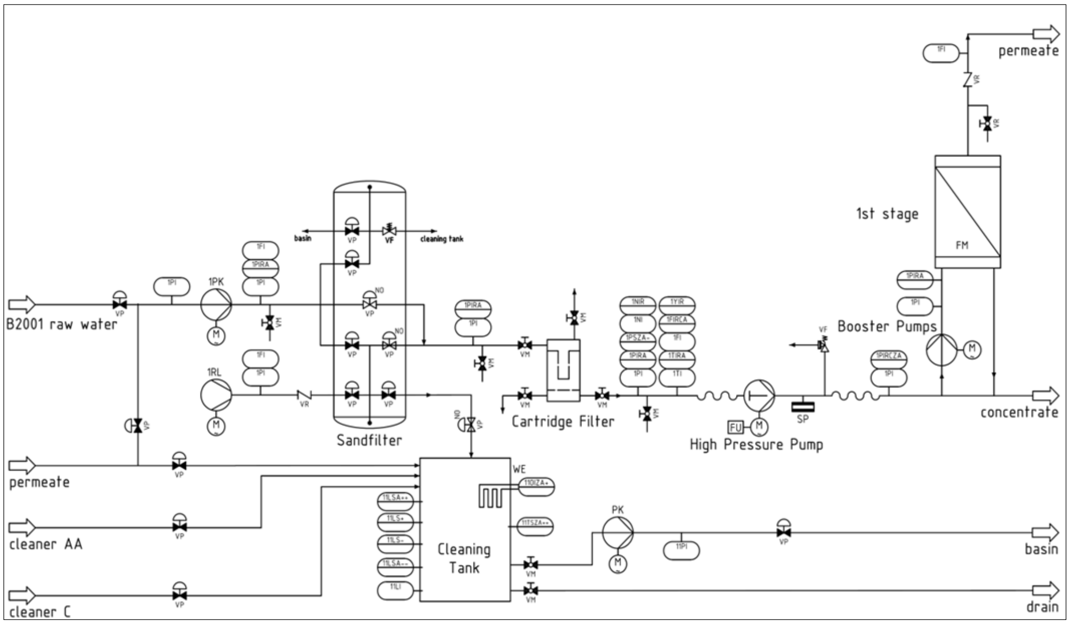

Figure 1 Simplified leachate treatment system process flow diagram

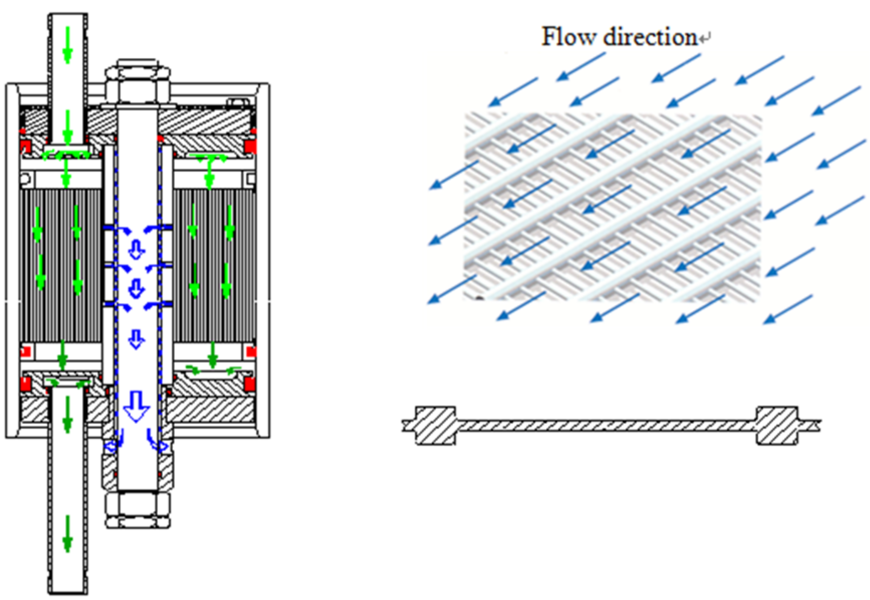

Figure 2 Schematic drawing of the ROCHEM's Open channel (ST) module and Open channel module Spacer

One RO membrane module has a total membrane area of 25.0 m^2, which is three times higher than the membrane area applied in one DT module. Due to this fact, the productivity of one open channel RO module is three times higher than that of one DT module. Therefore, to achieve same permeate flow rate, less membrane modules and less space are required and the large amount of hydraulic discs, O-rings, tensions rods, end flanges and joining flanges used in DT modules are not needed. Open channel RO modules have the same dimensions as DT modules, which enables the existing DT reverse osmosis system to be exchanged by open channel RO modules easily.

Before entering into the RO skids, SBR effluent is treated by a sand filter for removal of suspended solids larger than 50 µm. SBR effluent treated by the media filter, is dosed with sulphuric acid (98%) to maintain a pH value of 6.0-6.5, which is applied to increase the solubility of inorganic salts. By maintaining a pH value of 6.0-6.5 the chemical oxygen demand (COD) and ammonium rejection rates across the membrane are improved. Acidic conditions shift the equilibrium of ammonia from the gas to the liquid phase, improving removal of ammonium from the leachate. Acid conditions enhance the electrostatic attraction between the humic substances and the membrane surface, improving COD rejection from the leachate across the membrane (Chan et al., 2006). Acidified SBR effluent is passed through cartridge for further removal of the suspended solids greater than 10 µm. A feed and bleed system was installed for the RO leachate treatment skids. The leachate treatment system was operated at a constant flux rate. Over the operating time, the feed pressure was regulated to compensate the fluctuation of the temperature and salinity of the feed water and the decline in permeate flux with time.

The ROCHEM RO skids generates two waste streams: permeate and concentrate. The concentrate contains the majority of the soluble particles in the leachate and has a final liquid volume approximately 20% of the influent. Concentrate is shipped offsite to a large POTW capable of handling the poor water quality. The permeate is liquid volume is approximately 80% of the system flow rate, and is discharged to the local POTW by a sewer main pipeline.

3. RESULTS AND DISCUSSIONS

3.1 Treatment efficiency of the leachate SBR process

Analyses of major parameters in the SBR effluent and RO feed including pH, Temperature, Conductivity, UV transmittance, TSS, COD, BOD, $NH4^+$-N, TKN, Ortho-Phosphate, FOG, Chloride, and metals were analyzed on a daily to weekly basis and the results are summarized in Table 1. Based on the observed pH, COD value and landfill age, the average landfill leachate was in the methanogenic phase. At this phase, the composition of leachate is characterized by relatively low BOD values and low ratios of BOD/COD. Nitrogen remains at a relatively high level (Stegmann et al., 2005). Low biodegradability of the leachate indicates that humic substances, derived from cellulose and lignin, with high molecular weight, and fulvic acid-like materials, with medium to high molecular weight, are predominant organic substances.

It was observed that pH decreased from 9 to 7.84 during the SBR process. No significant reduction of leachate electrical conductivity and chloride in the activated sludge process was observed in the present study (Table 1). The reduction rate of COD by the SBR was 77.32% of the total COD. This is significantly more effective than the 34.0% COD reduction rate reported in leachate SBR processes by

Zhao et al. (2012). The BOD and ammonia nitrogen concentrations in the leachate were reduced from the 603 mg/L and 2610 mg/L in raw leachate to 13.5 mg/L and 6.92 mg/L in the SBR effluent, respectively. Operating results of the SBR process demonstrate effective treatment of biodegradable organic substances, heavy metals and ammonia. The SBR process was not efficient in the removal of non-biodegradable organic substances (Table 1). These results confirm the necessity of reverse osmosis technologies to complement and support the SBR process (Li et al., 2009).

Table 1 Characteristics of raw leachate and SBR effluent

Parameter	Unit	Raw leachate	SBR effluent	Discharge limit
pH	-	9.0	7.84	5.5 - 9.0
Temperature	ºC	31	33.25	< 40
Conductivity	µS/cm	20000	20262	-
UV transmittance	%	0%	0%	60-65%
TSS	mg/L	147	52.91	600
COD	mg/L	5830	1321.8	-
BOD	mg/L	603	13.5	400
NH_4^+–N	mg/L	2610	6.92	-
TKN	mg/L	-	75.3(62.8 lb/d*)	60 lb/d
Ortho-Phosphate	mg/L	25	4.25	-
FOG	mg/L	148	9.23	100
Chloride	mg/L	4750	3608.8	-
Aluminum	mg/L	1.5	0.27	-
Arsenic	mg/L	1.18	1.39 (1.1159 lb/d*)	1.65 lb/d
Cadmium	mg/L	0.15	0.01	0.1
Chromium	mg/L	0.29	0.17	1.0
Copper	mg/L	0.047	<0.01	0.55
Lead	mg/L	0.047	0.01	0.14
Nickel	mg/L	0.14	0.14	0.6
Silver	mg/L	0.033	<0.003	0.1
Zinc	mg/L	0.77	0.03	3.76
Mercury	mg/L	0.0004	<0.0003	0.002

*Feed rate (lb/d) = dosage (mg/L) × flow rate (mgd) × 8.34l b/gal

The UV_{254} transmittance of the leachate treated in the SBR was consistently 0%. Zhao et al. (2013) reported that humic substances (HA and FA) > 1 kDa were the major UV quenching substances in landfill leachate. The SBR system was able to remove 42.6% COD at the organic fraction of less than 1 kDa and has little effect on the removal of the organic fraction > 1 kDa, indicating that activated sludge is not effective for the removal of the UV quenching substances (Zhao et al. 2012).

3.2 Treatment efficiency of RO process

Various studies have proven that the organic rejection of reverse osmosis membrane can reach up to 98% (Baumgarten and Seyfried, 1996; Linde et al., 1995; Peters, 1998). The use of reverse osmosis membranes after biological pre-treatment has demonstrated to be a very promising and effective method for the removal of the UV quenching substances. Although landfill leachate discharging standard for inorganic salts is not clearly defined in many countries around the world, inorganic components have negative impacts on the environment due to the fact that introducing salts and inorganic components to the natural water cycle, even at very low concentrations, can lead to bioaccumulation in ecological system. As an example, traditional biological treatment processes do not efficiently remove chloride from wastewater streams. However, waste streams discharging to natural systems in Spain and Italy are regulated at chloride concentrations of 2000 mg/L and 1200 mg/L, respectively (Li, 2013); requiring heavy metals removal by a process such as reverse osmosis.

The pH value of the RO permeate in this study ranged from 6.24-7.91 with an average value of 7.6. The ROCHEM RO skids were able to achieve a chloride rejection rate of 94.1%. The overall salts rejection, indicated by the electrical conductivity was 86.2% across the RO membrane (Fig. 3). Lower salt rejection rate is assumed to be caused by the lower trans-membrane operating pressure (TMP) (around 30-40 bars) during the observation period. As most of the bio-degradable organic substances were degraded by the SBR pre-treatment step, organic bio-fouling was reduced across the membrane. Therefore the TMP, required to generate the desired membrane flux was approximately 30% lower than that of the pure RO leachate treatment system (without biological pre-treatment). Low TMP results in low energy consumption of the RO system.

The open channel RO systems demonstrated excellent COD and BOD_5 rejection rates of 97.3% and 99.67%, respectively. The high organic rejection rate achieved by the RO skids resulted in UV transmittance of the RO permeate between 63% and 83.5%, with an average value of 74.25% (Fig. 4). TKN rejection rate of 97.0% was achieved, which war far below the required discharging limit. The treatment efficiency in terms of the major parameters of the RO skids is summarized in Table 2.

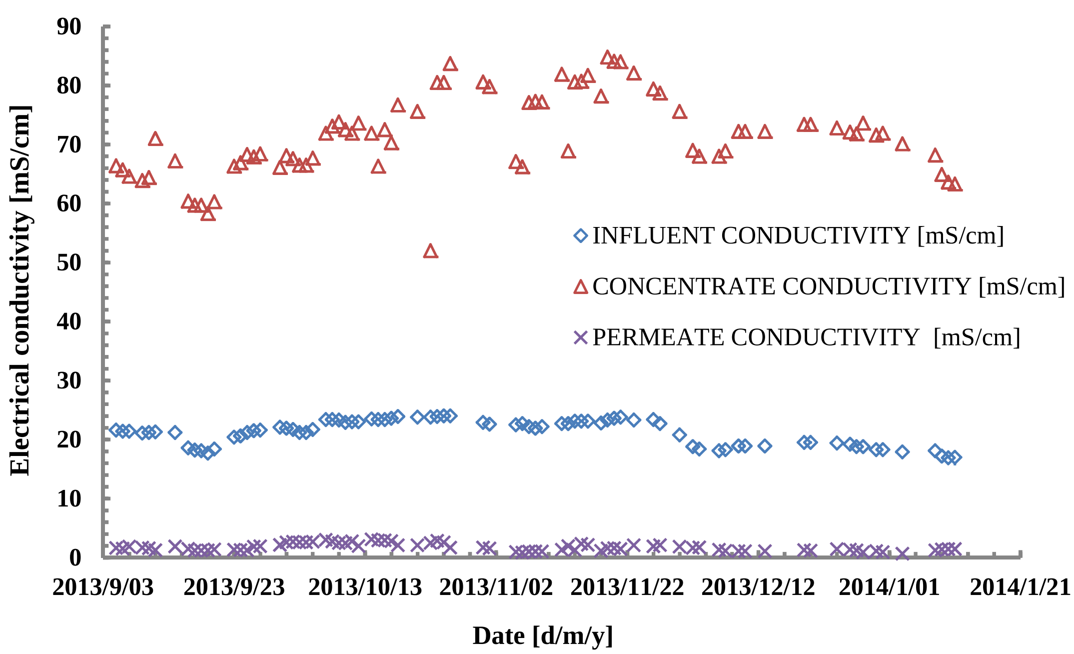

Figure 3 Electrical conductivity in influent (SBR effluent), concentrate and RO permeate

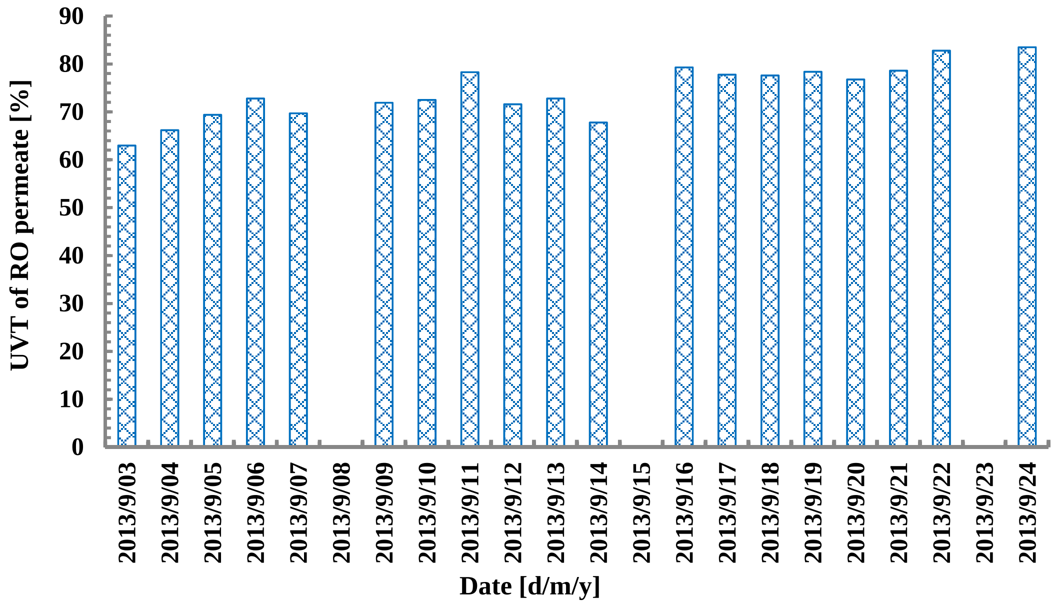

Figure 4 UV transmittance of the RO permeate

Table 2 Characteristics of SBR effluent and RO effluent

Parameter	Unit	SBR effluent	RO permeate	Discharge limit
pH	-	7.84	7.60	5.5 - 9.0
Temperature	ºC	33.25	31.83	< 40
Conductivity	μS/cm	20262	2.797.5	-
UV transmittance	%	0%	74.25%	60-65%
TSS	mg/L	52.91	<4	600
COD	mg/L	1321.8	35.57	-
BOD	mg/L	13.5	<2	400
NH_4^+–N	mg/L	6.92	3.64	-
TKN	mg/L	75.3(62.8 lb/d)	5.50 (4.6 lb/d)	60 lb/d
Ortho-Phosphate	mg/L	4.25	0.04	-
FOG (fat oil and grease)	mg/L	9.23	<5	100
Chloride	mg/L	3608.8	211.95	-
Aluminum	mg/L	0.27	<0.2	-
Arsenic	mg/L	1.39 (1.1159 lb/d)	<1.0 (0.834 lb/d)	1.65 lb/d
Cadmium	mg/L	0.01	<0.01	0.1
Chromium	mg/L	0.17	0.52	1.0
Copper	mg/L	<0.01	<0.01	0.55
Lead	mg/L	0.01	<0.01	0.14
Nickel	mg/L	0.14	<0.01	0.6
Silver	mg/L	<0.003	<0.003	0.1
Zinc	mg/L	0.03	<0.003	3.76
Mercury	mg/L	<0.0003	<0.0002	0.002

The permeate flux varied between 7-10 L/(m^2·h) after around 150 hours continuous operation during this study. The initial trans- membrane pressure difference was 25 bars, which increased to around 45 bars before membrane cleaning. After every cycle of 150 h of continuous operation, the permeate flux in the raw water stage decreased to around 7 L/(m^2·h), indicating the occurrence of membrane fouling. Alkaline agent and acid agent were applied at a TMP of 5 bars to the modules for membrane cleaning. After cleaning the membrane effectively, a negligible drop in the permeate flux was observed. A total recovery rate of the RO skids varied between 75% and 80%. Around 20-25% concentrate was generated.

4. SUMMARY AND CONCLUSION

In this study, landfill leachate at a landfill in east coast of USA is treated onsite by a traditional SBR system followed by a single-stage reverse osmosis (RO) system. The following conclusions can be drawn from the results of the study period:

- Biological treatment alone is effective for the removal of bio-degradable organic substances but not effective for the removal of the bio-refractory organic substances which quench UV transmittance.
- Biological pre-treatment was not able to successfully improve the UV transmittance to the levels required for UV disinfection at the POTWs.
- This study demonstrates that the ROCHEM RO system is able to efficiently reduce the UV quenching substances in the landfill leachate below the level interfering UV disinfection by the downstream POTWs.
- This study demonstrates that the ROCHEM RO system is able to achieve satisfactory water quality, process stability and membrane flux. RO polishing after the biological treatment can be regarded as an effective technique for landfill leachate treatment.

ACKNOWLEDGEMENT

The first author would like to acknowledge Ms. Amanda Taylor from ROCHEM Membrane Systems, Inc. for proofreading this paper.

REFERENCES

Basu, S., Page, J. and Wei, I.W. (2007). UV disinfection of treated wastewater effluent: influence of color, reactivation and regrowth of coliform bacteria. *Environmental Engineer: Applied Research and Practice*, 4(Fall), 32-38.

Baumgarten, G. and Seyfried, C. F. (1996). Experiences and new developments in biological pre-treatment and physical post treatment of landfill leachate. *Water Science and Technology*, 34(7-8), 445-453.

Chan, G., Chang, J., Kurniawan, T. A., Fu, C. X., Jiang, H. and Je, Y. (2006). Removal of non-biodegradable compounds from stabilized leachate using VSEPRO membrane filtration. *Desalination*, 202(1-3), 310-317.

Christensen, T. H., Cossu, R. and Stegmann, R. (1992). *Landfilling of Waste： Leach*ate. The Chemical Rubber Company Press, Boca Raton, USA.

Cossu, R., Polcaro, A. M., Lavagnolo, M. C. and Palmas, S. (2007). Treatment of MSW Landfill Leachate by electrochemical oxidation. Paper presented at the 11th International Waste Management and Landfill Symposium, 1–5 Oct, Cagliari, Italy.

Li, F., Wichmann, K. and Heine, W. (2009). Treatment of the methanogenic landfill leachate with thin open channel reverse osmosis membrane modules. *Waste Management*, 29(2), 960-964.

Li, F. (2013). *Development of open channel membrane modules for landfill leachate treatment*. Proceedings Sardinia 2013, 14th International Waste Management and Landfill Symposium, 30 September-4 October 2013, Italy.

Li, N. and Deng, Y. (2012). Formation of Trihalomethanes (THMs) during Chlorination of Landfill Leachate. *International Journal of Environmental Pollution and Remediation*, 1(1), 7-12.

Linde, K., Jönssone, A. and Wimmerstedt, R. (1995). Treatment of three types of landfill leachate with reverse osmosis. *Desalination*, 101(1), 21-30.

Peters, T. A. (1998). Purification of landfill leachate with membrane filtration. *Filtration and Separation*, 35(1), 33-36.

Peters, T. A. (2001), High advanced open channel membrane desalination. *Desalination*, 134(1-3), 213-219.

Poblete, R., Otal, E., Vilches, L.F., Vale, J., Fernández-Pereira, C. (2011). Photocatalytic degradation of humic acids and landfill leachate using a solid industrial by-product containing TiO2 and Fe. *Applied Catalysis B: Environmental*, 102(1-2), 172-179.

Stegmann, R., Heyer, K. U., and Cossu R. (2005). *Leachate Treatment*. Tenth International Lanfill Symposium Proceedings, 3-7 October, Sardiniai，Italy.

Zhao, R., Novak, J.T., Goldsmith, C.D. (2012). Evaluation of on-site biological treatment for landfill leachates and its impact: a size distribution study. *Water Research*, 46(12), 3837-3848.

Zhao, R., Gupta, A., Novak, J.T., Goldsmith, C.D., Driskill, N. (2013). Characterization and treatment of organic constituents in landfill leachates that influence the UV disinfection in the publicly owned treatment works (POTWs). *Journal of Hazardous Materials*, 258-259(6), 1-9.