Journal of Membrane Science and Research 7 (2021) 118-124

Journal of Membrane Science & Research

journal homepage: www.msrjournal.com

Research Paper

Full Scale Sanitary Landfill Leachate Treatment by MBR: Flat Sheet vs. Hollow Fiber Membrane

Hamit Tolu [1], Erol İren [1], Mahmut Altinbas [2,3,*]

[1] *Ozturk Enerji Corp., Kahramanmaras, Turkey*
[2] *Department of Environmental Engineering, Istanbul Technical University, 34469, Maslak, Istanbul, Turkey*
[3] *National Research Center of Membrane Technologies, Istanbul Technical University, 34469, Maslak, Istanbul, Turkey*

Article info

Received 2020-03-25
Revised 2020-06-24
Accepted 2020-07-04
Available online 2020-07-04

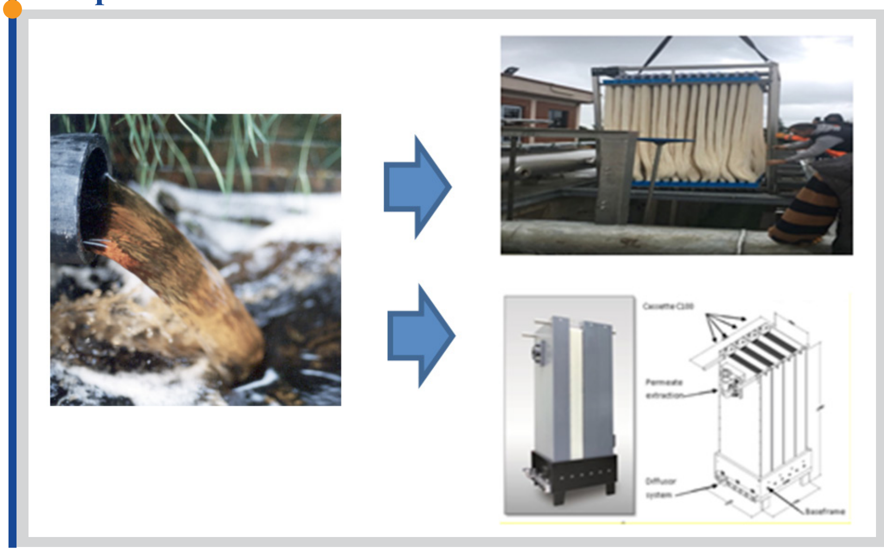
Keywords

Landfill leachate
MBR
Nanofiltration
Ultrafiltration

Highlights

- Submerged membranes are highly effective in leachate treatment
- Hollow fiber membrane is superior to landfill leachate than of flat sheet one
- Flat sheet membranes clogging earlier than hollow fiber ones

Graphical abstract



Abstract

The aim of this study was to find a cost-efficient leachate treatment system by comparing two MBR systems, flat sheet and hollow fiber. Data collected through continuous monitoring and laboratory analysis over the last two years has been evaluated in terms of treatment performance and economic analysis. MBR systems were found to be as effective and economical in terms of color, SS removal, and total treatment efficiency. It has been observed that the flat sheet membranes were clogged up in six weeks, while the hollow fiber membranes took 12–16 weeks to clog. Moreover, the hollow fiber module was less clogged and needed shorter washing times, resulting in lower amounts of chemical consumption. Hollow fiber membrane systems, compared to flat sheet membrane systems, have higher operational availability and lower maintenance costs. For the first time, the advantage of using submerged hollow fiber for the treatment of high-strength landfill leachate has been clearly demonstrated.

1. Introduction

As a result of industrialization and an increase in the welfare level, environmental problems are also increasing. Higher consumption habits that have enslaved all societies have brought about the consumption of natural resources as well as the generation of more waste, resulting in pollution and a decrease in natural resources by time the waste itself becomes a problem. The environmental problems caused by waste, the increase in the existing potential risks, the decrease in natural resources, as well as economic and other reasons make waste management important today. Therefore, the implementation of integrated waste management becomes a necessity. The integrated approach is reflected in national legislation on waste management. Integrated waste management is based on five main strategic principles: zero waste, waste reduction, resume, recycle, and recover [1].

Although there are many methods for the disposal of solid wastes, landfilling, one of the oldest methods, is the still most preferred today. However, this system inevitably produces wastewater (leachate). Leachate is highly polluted wastewater containing hazardous organic substances such as

* Corresponding author: altinbasm1@itu.edu.tr (M. Altinbas)

DOI: 10.22079/JMSR.2020.123563.1358

phthalates, phenols, pesticides, as well as inorganic hazardous substances such as heavy metals [2]. Leachate quantity and characterization vary considerably with age, landfill technology, location of the landfill site, composition of the stored waste, and the climate [3]. There are many chemical and biological treatment methods that can be used to treat leachate. Among these, membrane bioreactor (MBR) technology has gained great importance, especially in recent years, due to the fact that the required discharge standards are more easily achieved [4]. Although there are many advantages, the membrane clogging problems that are encountered during operation result in an increase in initial investment and operating costs of MBR systems [5].

The aim of this study was to reveal the potential of submerged membrane usage as MBR for sanitary landfill leachate. Also discussed were the advantages and disadvantages of leachate treatment of two different types of membranes, flat sheet and hollow fiber, considering treatment performance and economic analysis.

2. Material and methods

MunicipalThe municipal solid waste leachate treatment plant located at the landfill in Kürtül, Kahramanmaraş, is the first treatment plant in Turkey to use MBR systems where membranes are submerged. Öztürk Energy Corporation was awarded a contract in 2013 to build, operate, and transfer an integrated waste handling, recycling, landfill, and energy generation facility. The plant was commissioned in late 2016 and has been operating since then with continuous enhancements.

Around 630 tons of mixed household waste is collected daily and brought to the sorting plant where recyclables like PET, metals, other plastics, and an organic fraction of the waste is sorted out. The organic fraction is fed into anaerobic digesters; recyclables are sold, and the remaining waste is sent to the landfill. The humidity of the waste is measured slightly above 50% prior to landfilling. The residual waste is an input to the deposition area; landfill gas and leachate are the outputs. Landfill gas and biogas are converted to electricity by four CHP units with a total capacity of 4.8 MWe. The leachate is collected at leachate pools (lagoons) prior to transfer to the treatment plant.

In order to maintain a variable flow rate, two lagoons with a total storage capacity of 7,000 m^3 are installed as buffers. Retention time at the lagoons is around 43 days, which causes a reduction of COD levels. The treatment plant was built step by step, where the first stage had a capacity of 100 m^3/day, finally reaching a capacity of 300 m^3/day. The process calculations were designed according to the data mentioned above.

2.1. Treatment plant

The flow diagram of the full-scale plant treatment is given in Figure 1 and the photograph of full scale treatment plant is given in Figure 2.

Two different types of submerged membrane bioreactors were used in the treatment plant. At first, a flat sheet membrane was used, but over time capacity declined and operating and maintenance costs increased. Afterwards, hollow fiber membrane modules were installed at the same location, working in parallel with the flat sheet membranes. The plant continued to operate with two different membrane modules for a long time. Thus, in this study, two different modules could be compared in leachate treatment. The membranes used in the treatment plant were as in Figures 3 and 4. The total surface areas of the modules of hollow fiber and flat sheet membranes were 825 m^2 and 520 m^2, respectively.

Four sets of Nano filtration membrane pipes and X-flow hollow fiber membranes were used. The discharge point was a dry creek near the facility. There was no sewer infrastructure close to the treatment plant.

2.2. Analytical Methods

COD (SM5220 B), BOD (SM 5210 B), SS (SM 2540 D), TKN (SM 4500-Norg B), TP (SM 4500-P B,E), and Color (2120D–F) were measured according to Standard Methods [6].

3. Results and discussion

3.1. Leachate characterization

The leachate is generated partly from decomposition of waste after landfilling, partly from liquid waste carried to the landfill (such as half-filled water bottles) and partly due to rain collected at the landfill surface. General characteristics of landfill leachate worldwide are summarized in Table 1. The typical characteristics of the leachate differ widely according to the age of the landfill [7]. As can be observed in Table 1, COD concentrations higher than 10,000 mg/L are classified as young landfill leachate.

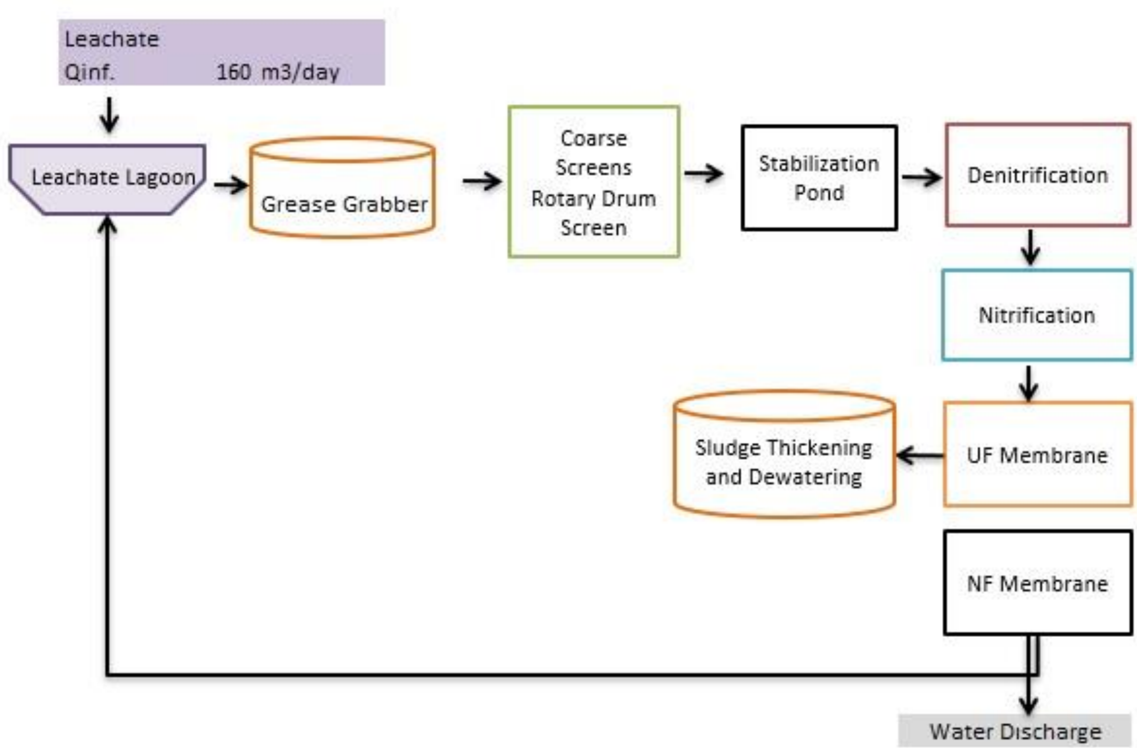


Fig. 1. Treatment plant flow diagrams.

Fig. 2. Treatment plant overview.

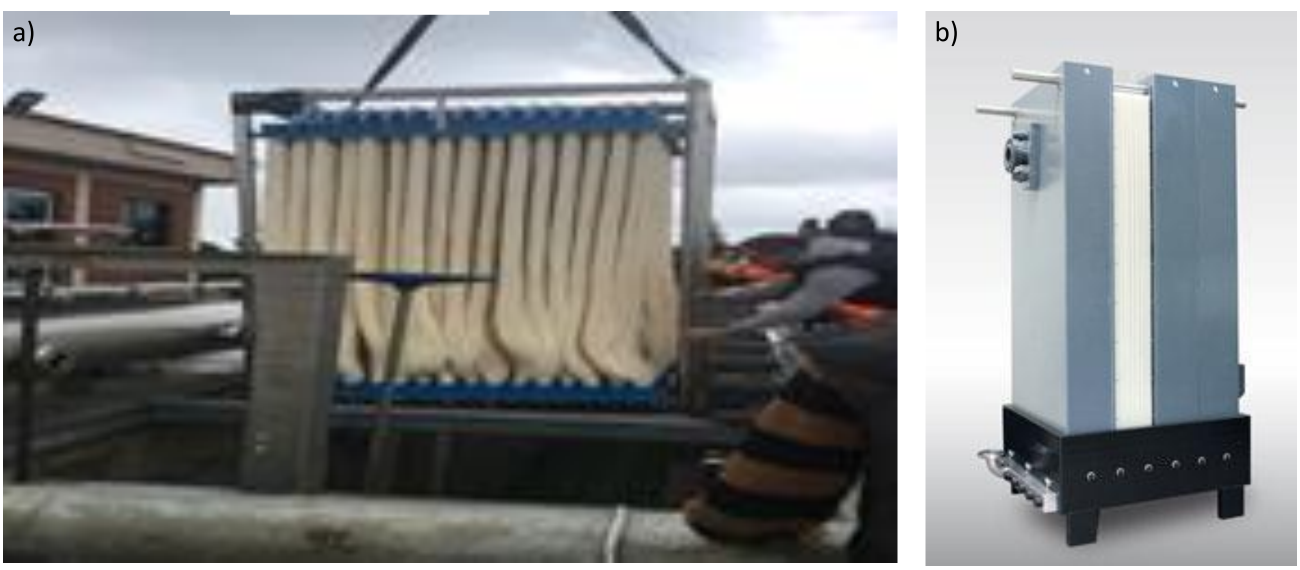


Fig. 3. UF membranes: **(**a) Hollow fiber – MEMSİS, (b) Flat sheet – MDN.

Fig. 4. NF membrane.

Table 1
General characteristics of landfill leachate.

Country and Place	Status	pH	COD	BOD_5	BOD_5/COD ratio	SS	TKN	TP	Ref.
Generic	Young	< 6.5	>10000	10000–25000				100–300	[8, 9]
	Intermediate	6.5-7.5	4000-10000	1000–4000				10–100	[8, 9]
	Old	> 7.5	<4000	< 50				< 10	[8, 9]
Nigeria, Lagos		8.1	7700	109	0.14	271	500	42	[10]
Canada, Toronto	-	7.1	12971		0.60				[11]
South Korea, Kyungj		7.3	24000	10800	0.45	2400	1766	31	[12]
Denmark, ESØ	-	6.9	624	90	0.12		411	3	[13]
China, Guangdong		7.9	5436				1489		[14]
India, Gazipur	-		27200						[15]
Bangladesh, Matuail	-	9.2	2900	1650	0.30		2130		[16]
Turkey, K.Maraş		-	9000	6000		1000	2000	20	This study
Discharge Standards, Turkey	Composite sample (24 hrs.)		500	-		100	15	1	[17]
	Grab Sample (2 hrs.)		700	-		200	20	2	[17]

* Water Pollution Control Regulation (WPCR) published in the official gazette No. 25687 dated 31 December 2004 and entered into force Table 20.6.

Kahramanmaraş landfill started accepting waste in 2013. It is therefore reasonable to categorize it as a young landfill. The amount of leachate measured at the site during this year fluctuated between 160 m^3/day and 110 m^3/day. This difference could be expressed by changing the precipitation regime and the amount of leachate evaporation in the field. The average pollution concentration of the leachate, together with the discharge standards according to water pollution control regulations in Turkey, are given in Table 1. The time-dependent COD change in the concentration of incoming wastewater is given in Figure 5. COD concentration increased with the decreasing precipitation rate in summer months. In autumn and winter, COD concentration decreased with increasing rainfall.

3.1. Treatment performance

About one year after the plant was commissioned, stabilization was reached in the treatment process. Operational enhancement and higher MLSS levels (close to 10,000) were the two major changes from 2018 to 2019. These changes can also be observed in the COD values after UF and NF membranes (Figure 6).

The results of the treatment plant can be seen in Table 2. The leachate, which has a young character, is treated in high yields in terms of discharge parameters, then reduced to desired levels.

According to the findings obtained by examining the data, treatment efficiencies on the basis of parameters were above 90 percent (Figure 7). The appearances of samples are given in Figure 8.

The treatment performances of two different modules are given in Table 3 for comparison. There were no significant differences in treatment performance between the two modules. The flux values of the hollow fiber and flat sheet membranes were also very close to each other, 8.5 L/m^2.h.

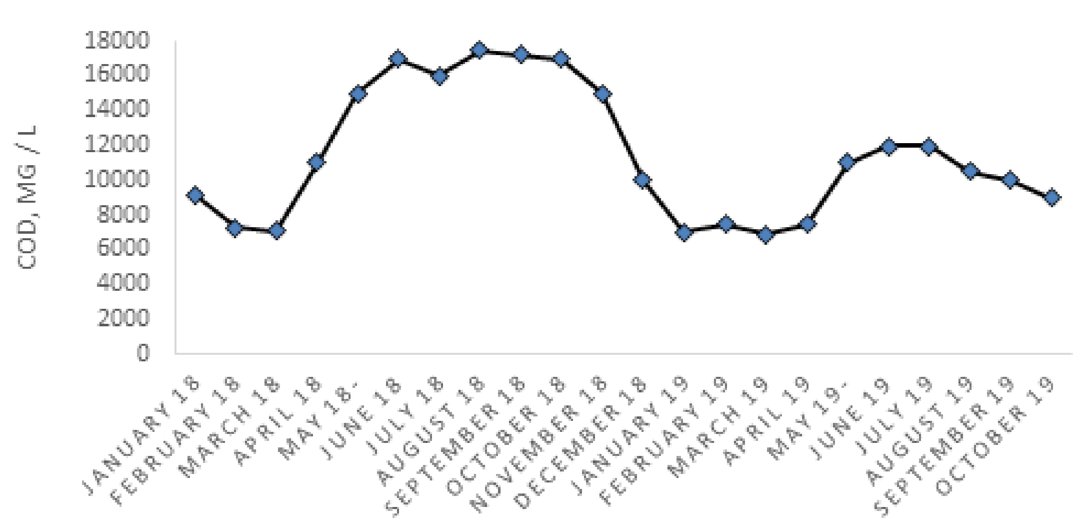


Fig. 5. COD concentrations of raw leachate change (2018-2019).

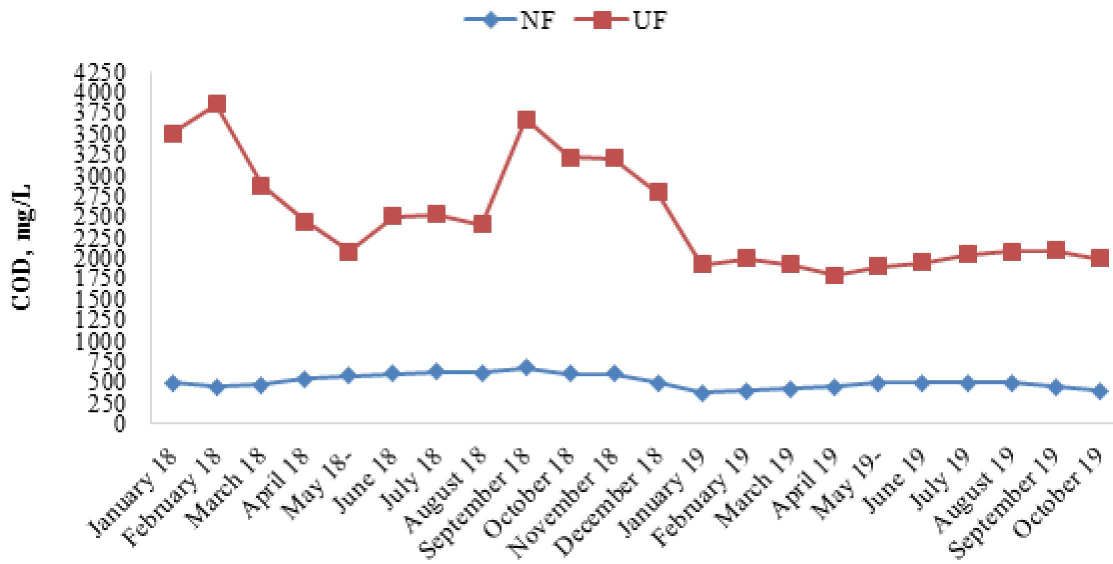


Fig. 6. UF-NF output COD values (2018-2019).

Table 2
Parameter based efficiency of the whole treatment plant.

Parameters	(mg/L)Units		(mg/L)	Treatment Efficiency (%)
	Lagoon	**UF Effluent**	**NF Effluent**	
BOD_5 (mg/L)	6000	225	100	98,3
COD (mg/L)	9000	5001979	512	94,3
SS (mg/L)	1000	100	80	90
TNTKN (mg/L)	1000	150	15	98,5
TP (mg/L)	20	2,5	1	95
Color (Pt-Co)	8800	1080	175	98

Table 3
Treatment performance of two different modules.

Parameters	Lagoon	Hollow Fiber Effluent	Flat Sheet Effluent
COD (mg/L)	9000	1367 ± 128	1396 ± 120
SS (mg/L)	1000	58 ± 2,2	64 ± 5,5
TKN (mg/L)	1000	103 ± 3,5	103 ± 3,0
TP (mg/L)	20	3,6 ± 0,5	3,6 ± 0,5

3.2. Comparison of two MBR systems

Some results obtained from field experience in the comparison of MBR systems are presented in Table 4.

The most significant advantage of hollow fiber membranes over flat sheet membranes was the membrane cleaning times. Therefore, less chemical consumption and shorter maintenance times were experienced. Clogging of membrane surfaces was observed more frequently due to the lack of homogeneous ventilation and backwashing of flat sheet membranes. Considering these time differences, the more suitable hollow fiber membrane for leachate treatment was observed in flow and operation. CAPEX and OPEX comparisons of the two MBR modules at the Kahramanmaraş landfill site are given in Tables 5 and 6.

MBRs are frequently preferred in cases of small footprints: treated water can be reused or have strict discharge standards. In addition to these important features, it provides an advantage in leachate treatment with biomass retention in biological nitrogen removal. In addition, membrane location and external support mechanisms are added to increase performance [18]. However, the common problem of all membrane systems is frequent fouling. This limits the maximum permeate flux that can be obtained and increases the cleaning period, thus leading to more frequent membrane replacement [19]. External cross-flow is performed in all large-scale leachate treatments, while internal applications are very rare. However, internal applications are more feasible in terms of economic and practical applications [20]. In this study, this situation was clearly demonstrated, and a comparison of submerged flat sheet and hollow fiber was made. This comparison was also carried out by revealing treatment performance and cleaning frequency [21]. Leachate characteristic changing with landfill age has a great influence on purification performance [22]. Most of the time, MBR may be sufficient for young leachate. At BOD/COD ratios higher than 0.3, MBR can be used as the most effective system [23]. These conditions provided the desired conditions for determining the membrane location and type in our study.

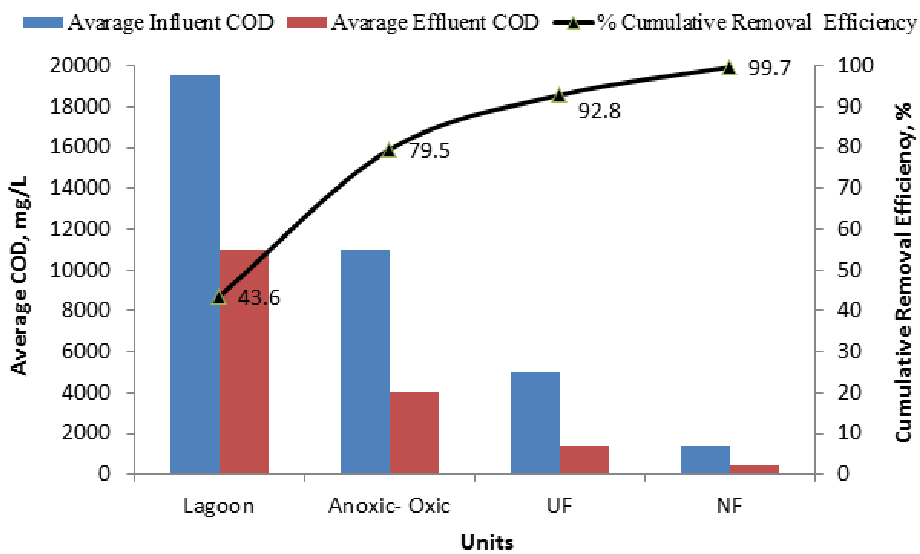


Fig. 7. COD Removal Efficiencies of total leachate treatment plant.

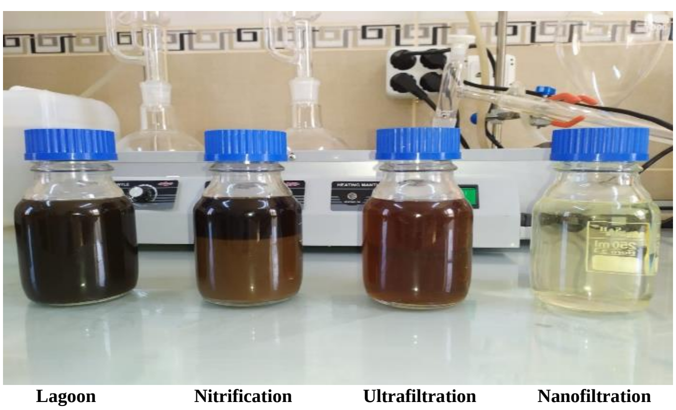


Fig. 8. Samples from each treatment process units.

Table 4
Comparison of flat sheet and thin hollow fiber membrane.

Comparative situation	Flat Sheet	Hollow Fiber
Air used for cleaning	0,42 m³ air / m² hrs	0,2-0,3 m³ air / m² hrs
Stripping with air	Only the surface was stripped with air and this situation caused loss of efficiency	Since the fibers move freely in the water, the stripping with air provides cleaning of the membranes as a result of turbulence caused by the movement of the fibers in the water and collision of the membranes.
Back wash	Fast plugging. Because backwashing characteristics were not good, backwashing cannot be done completely. They must be taken out of the pool for washing	The fibers were suitable for backwashing
Membrane area	Membrane area to fit the membrane tank varied from 180-220 m².	They were more advantageous. There were 350 m² fiber membranes per m² membrane tank.

Table 5
CAPEX and OPEX comparison of two different MBR modules at Kahramanmaraş Landfill site.

Cost Items	Flat Sheet	Hollow Fiber
CAPEX related		
Space requirement Per m^2 membrane	5x	2x
Local production	N/A	Available
Delivery times	10-14 weeks	2-4 weeks when locally sourced
Module cost (per m^2)	2.5x	x
OPEX related		
Yearly - per m^3 leachate	3x	x

Table 6
Detailed OPEX comparison.

<table>
<tr><th colspan="2">Operations</th><th>Flat Sheet</th><th>Hollow Fiber</th></tr>
<tr><td colspan="2">Maintenance Cleaning (CIP) period</td><td>Every week (1 hr.)</td><td>Every week (1hr.)</td></tr>
<tr><td colspan="2">Chemical Cleaning period</td><td>Every 4 week (24 hr.)</td><td>Every 12 week (48 hr.)</td></tr>
<tr><td colspan="2">Yearly total unoperational time (hr.)</td><td>364</td><td>260</td></tr>
<tr><td colspan="2">Yearly active operation time (hr.)</td><td>8396</td><td>8500</td></tr>
<tr><td rowspan="6">complete cycle</td><td>Filtration (sec.)</td><td>510</td><td>540</td></tr>
<tr><td>Relaxation (sec.)</td><td>30</td><td rowspan="2">8</td></tr>
<tr><td>Deaeration (sec.)</td><td rowspan="2">40</td></tr>
<tr><td>Back Wash (sec.)</td><td rowspan="2">40</td></tr>
<tr><td>Relaxation (sec.)</td><td>30</td></tr>
<tr><td>Switch time (sec.)</td><td>10</td><td>10</td></tr>
<tr><td colspan="2">Cycle period (sec.)</td><td>620</td><td>588</td></tr>
<tr><td colspan="2">Filtration time / cycle time ratio</td><td>82,26%</td><td>91,84%</td></tr>
<tr><td colspan="2">Yearly active filtration time (hr.)</td><td>6906</td><td>7806</td></tr>
<tr><td colspan="2">Yearly active filtration time (day)</td><td>288</td><td>325</td></tr>
<tr><td colspan="2">Total availability ratio</td><td>78,84%</td><td>89,11%</td></tr>
</table>

4. Conclusions

Leachate is one of the most difficult substances to treat in terms of wastewater characterization. Membrane bioreactor systems used in the treatment of these waters are very successful. In terms of treatment costs, the most important cost item of conventional membrane bioreactor systems is electricity consumption. In this study, two different membrane types, flat sheet and hollow fiber, were used, and it was concluded that submerged membranes used in the treatment of leachate were efficient. Hollow fiber membrane systems, compared to flat sheet membrane systems, have higher operational availability and lower maintenance costs. When investment expenditures are compared, it is clear that hollow fiber membrane modules are much more favorable.

Acknowledgements

We would like to thank to ÖZTÜRK ENERJİ Corp. laboratory and facility employees for their support during the studies.

References

[1] A.U. Zaman, Measuring waste management performance using the 'Zero Waste Index': the case of Adelaide, Australia, J. Clean. Prod. 66 (2014) 407- 419, doi:10.1016/j.jclepro.2013.10.032.

[2] M. Z. Justin and M. Zupančič, Combined purification and reuse of landfill leachate by constructed wetland and irrigation of grass and willows, Desalination 246 (2009) 157-168, doi:10.1016/j.desal.2008.03.049.

[3] T.G. Bulc, Long term performance of a constructed wetland for landfill leachate treatment, Ecol. Eng. 26 (2006). 365-374, doi:10.1016/j.ecoleng.2006.01.003.

[4] B. X. Thanh, C. Visvanathan, M. Spérandio and R.B. Aim, Fouling characterization in aerobic granulation coupled baffled membrane separation unit, J. Membrane Sci. 318 (2008) 334-339.

[5] A. Drews, J. Mante, V. Iversen, M. Vocks, B. Lesjean and M. Kraume, Impact of ambient conditions on SMP elimination and rejection in MBRs, Water Res. 41 (2007) 3850-3858, doi:10.1016/j.watres.2007.05.046.

[6] APHA, Standard methods for the examination of water and waste water, 21st edn. American Public Health Association, Washington, DC, 2005, ISBN:0875530478 9780875530475.

[7] S. Renou, J.G. Givaudan, S. Poulain, F. Dirassouyan and P. Moulin, Landfill leachate treatment: Review and opportunity, J. Hazard. Mater. 150 (2008) 468-493, doi:10.1016/j.jhazmat.2007.09.077.

[8] S. Mishra, D. Tiwary and A. Ohri, Leachate characterization and evaluation of leachate pollution potential of urban municipal landfill sites, Int. J. Environ. Waste Manage. 21 (2018) 217-230, doi:10.1504/IJEWM.2018.093431.

[9] A. Amokrane, C. Comel, J. Veron, Landfill leachates pretreatment by coagulation-flocculation, Water Res. 31 (1997) 2775-2782, doi:10.1016/S0043-1354(97)00147-4.

[10] A.O. Aderemi, A.V. Oriaku, G.A. Adewumi and A.A. Otitoloju, Assessment of groundwater contamination by leachate near a municipal solid waste landfill, Afr. J. Environ. Sci. Technol., 5 (2011) 933-940, doi: 10.5897/AJEST11.272.

[11] M.D. Armstrong and R.K. Rowe, (1999, October). Effect of landfill operations on the quality of municipal solid waste leachate. In Proc. 3rd Int. Landfill Symp., Cagliari (pp. 81-88).

[12] J. H. Im, H.J. Woo, M.W. Choi, K.B. Han and C.W. Kim, Simultaneous organic and nitrogen removal from municipal landfill leachate using an anaerobic-aerobic system, Water Res. 35 (2001) 2403-2410, doi:10.1016/S0043-1354(00)00519-4.

[13] P. Kjeldsen and M. Christophersen, Composition of leachate from old landfills in Denmark, Waste Manage. Res. 19 (2001) 249-256, doi:10.1177/0734242X0101900306.

[14] D. Zhou, Y. Li, Y. Zhang, C. Zhang, X., Li, Z. Chen, ... and M. Kamon, Column test-based optimization of the permeable reactive barrier (PRB) technique for remediating groundwater contaminated by landfill leachates, J. Contam. Hydrol. 168 (2014) 1-16, doi:10.1016/j.jconhyd.2014.09.003.

[15] S. Mor, K. Ravindra, A. De Visscher, R.P. Dahiya and A. Chandra, Municipal solid waste characterization and its assessment for potential methane generation: a case study, Sci. Total Environ. 371 (2006) 1-10, doi:10.1016/j.scitotenv.2006.04.014.

[16] K. Mahmud, D. Hossain and S. Shams, Different treatment strategies for highly polluted landfill leachate in developing countries, Waste Manage 32 (2012) 2096-2105, doi:10.1016/j.wasman.2011.10.026.

[16[17] WPCR, Su Kirliliği Kontrol Yönetmeliği,, Turkish Official Gazette, date: 31.12.2004 No: 25687.

[18] L. Huang and D.J. Lee, Membrane bioreactor: A mini review on recent R&D works, Bioresource Technol. 194 (2015) 383-388, doi:10.1016/j.biortech.2015.07.013.

[19] J. Tsilogeorgis, A. Zouboulis, P. Samaras and D. Zamboulis, Application of membrane sequencing batch reactor for landfill leachate, Desalination 221 (2008) 483-493, 10.1016/j.desal.2007.01.109.

[20] M. Rizkallah, M.El-Fadeh, P.E. Saikaly, G.M. Ayoub, N. Darwiche and J. Hashisho, Hollow-fiber membrane bioreactor for the treatment of high-strength landfill leachate, Waste Manage. Res., 31 (2013) 1041-1051, doi:10.1177/0734242X13497075.

[21] J. Hashisho, M. El-Fadel, M. Al-Hindi, D. Salam and I. Alameddine, Hollow fiber vs. flat sheet MBR for the treatment of high strength stabilized landfill leachate, Waste Manage. 55 (2016) 249-256, doi:10.1016/j.wasman.2015.12.016.

[22] W. Yang, N. Cicek and J. Ilg, State-of-the-art of membrane bioreactors: worldwide research and commercial application in North America, J. Membrane Sci., 270 (2006) 201-211, doi:10.1016/j.memsci.2005.07.010.

[23] H. Alvarez-Vazquez, B. Jeffersen and S.J. Judd, Membrane bioreactors vs conventional biological treatment of landfill leachate: a brief review, J. Chem. Technol. Biot. 79 (2004) 1043-1049, doi.org/10.1002/jctb.1072.