Original Article

Performance evaluation of membrane bioreactor for treating industrial wastewater: A case study in Isfahan Mourchekhurt industrial estate

Mohammad Mehdi Amin[1,2], Mahnaz Heidari[2], Seyyed Ali Reza Momeni[3], Hamide Ebrahimi[2,4]

[1]Environment Research Center, Research Institute for Primordial Prevention of Non-communicable disease, Isfahan University of Medical Sciences, Isfahan, Iran, [2]Department of Environmental Health Engineering, School of Health, Isfahan University of Medical Sciences, Isfahan, Iran, [3]Department of Environment, Isfahan Industrial Estates, Isfahan, Iran, [4]Student Research Committee, Isfahan University of Medical Sciences, Isfahan, Iran

Address for correspondence:
Eng. Hamide Ebrahimi,
Department of Environmental Health Engineering, School of Health, Isfahan University of Medical Sciences, Hezar-Jerib Ave., Isfahan, Iran.
E-mail: ebrahimi.h940@yahoo.com

ABSTRACT

Aims: The aim of this study was to evaluate a membrane bioreactor (MBR) system for optimization effluent quality by feeding of the influent (raw wastewater and anaerobic reactor effluent) in Isfahan - Mourchekurt Industrial Estate Centralized Wastewater Treatment Plant.

Materials and Methods: The MBR was equipped with two flat sheets membrane with 0.2 μm pore size, were operated in parallel style and feed simultaneously with raw industrial wastewater (MBR1) and anaerobic reactor effluent (MBR2). The average organic loading rates in two reactors were 1.37 and 0.52 (kg chemical oxygen demand [COD]/m^3.day), respectively. All analyses were implemented according to the standard methods procedure.

Results: The average concentration of COD was lower than 100 mg/L and 50 mg/L in both reactor effluent, respectively, and it was <30 mg/L for biological oxygen demand (BOD_5) in both reactors. In addition, the average turbidity, COD, BOD_5 and total suspended solid removal were higher than 92%. In both reactors effluent, average microbial indicators contamination were >1000 MPN/100 mL for MBR1 and these were <1000 MPN/100 mL for MBR2. During the operation flux reduction in MBR1 was more than MBR2.

Conclusion: The MBR technology was used to treat the combined industrial wastewater was efficient, and its effluent can be perfectly used for water reuse. The MBR performance was improved by applying an anaerobic pretreatment unit.

Key words: Combined industrial wastewater, membrane bioreactor, raw wastewater, reuse

INTRODUCTION

Nowadays, the shortage of fresh water is a critical problem in most of the countries. Insufficient treatment before the release of industrial wastewater and the discharge of hazardous compounds with potential toxicities can contaminate aquatic ecosystems.[1,2] In the last decade, water resources

Access this article online

Quick Response Code:

Website: www.ijehe.org

DOI: 10.4103/2277-9183.190638

This article may be cited as: Amin MM, Heidari M, Momeni SA, Ebrahimi H. Performance evaluation of membrane bioreactor for treating industrial wastewater: A case study in Isfahan Mourchekhurt industrial estate. Int J Env Health Eng 2016;5:12.

management has become one of the important operational and environmental topics. Wastewater treatment and reuse are effective for sustainable industrial development plans.[3] A qualified treated wastewater is water that is not only low in organic or mineral contaminants, but also free from biological organisms. Therefore, treatment processes that are cost efficient and effective in removing a wide range of pollutants are required. The utilization of membrane bioreactors (MBRs) is one of very promising technology.[4] During the last years, MBRs were extensively used for industrial wastewater treatment because of their high removal efficiencies.[5,6] The membrane filtration coupled with the activated sludge treatment allows biodegradation of the organic substance and removal of the suspended solids.[7,8] High-quality permeate can be recovered and reuse.[1] The pore diameter of the microfiltration membranes is in the range between 0.01 and 0.1 μm so that particulates and bacteria can be kept out of permeate.[3] There are some features related to the MBR process that turns it into the "best available" technology. Use of membranes provides a better disinfection capability, compactness and offers greater operating flexibility, allowing a constant quality of the treated wastewater during flow/load variations. The sludge preserved in the reactor can operate as an absorbent.[9] In these systems membrane filtration units are used instead of the secondary clarifiers in traditional activated sludge systems.[10] Worldwide >5000 MBR plants are under operation.[5] Limitations inherent to MBR processes are the cost of membranes, the operative costs related to fouling and their higher energy consumption when compared to traditional wastewater treatment plants.[11]

Several studies have investigated evaluation of MBRs systems for treating several types of industrial wastewaters such as: Mineral oil,[6] pharmaceutical,[9] tannery,[10] dairy,[11,12] combined sanitary and industrial,[13] high strength synthetic,[14] oil contaminated wastewater,[15] and winery wastewater.[16] In this studies, organic material removal efficiency was obtained >82%.[6,8,9,12-16]

In previous study, the MBR was used for treating decentralized industrial wastewaters in separate industries but in our investigation, MBR was used for treating combined industrial wastewaters (referred to material and method, wastewater characteristic).

The aim of this study was the main purpose of this work was to study and compare the treatment of two different wastewaters, raw wastewater and anaerobic reactor effluent in different characteristics, by using a pilot scale MBR. The membrane modules were used as submerged configuration, which is directly placed in the mixed liquor. Lower energy consumption and less hard cleaning procedures are distinguished advantages of submerged MBRs.[17]

MATERIALS AND METHODS

Reactors and membrane specifications

Figure 1 shows the schematic of the experimental setup. Two pilot-scale plexiglass reactors, with working effective volume of 60 L were used in this study for each module, which they were equipped with six flat sheets submerged membranes and the effective filtration area 0.26 m^2. The membrane basic characteristics are shown in Table 1. A peristaltic pump was used for withdrawing permeates from the filter module. The permeate pump was operated in an alternation suction mode with a cycle of 8 min on and 90 s off; during off time, tow air blowers, cleaned the surface of the membrane. When flux was decreased to 25-30% of the initial flux, the membranes were cleaned by tap water. The diffuser aeration was located under the membranes on the floor of the reactor. Wastewater was saved in a separate tank, and an electrical valve fed each reactor. Reactors were operated for 62 days at flux of 20 $Lm^{-2}\ h^{-1}$ in the beginning of the study. The sludge from the Mourchekurt Industrial Estate Centralized Wastewater Treatment Plant (MIEWWTP) aeration tanks was added to the reactors as seed.

Wastewater characteristic

The used wastewater was sampled from a centralized industrial wastewater treatment plant located in the MIE, on 50 km - North-West of Isfahan, center of Iran. The available capacity of the treatment plant was about 2000 m^3/day, and the ratio of sanitary/industrial wastewater was 50%. In the MIE, main industries were: As food and dairy, textile, paper, metal and electrical industries. In the industrial estate, after industrial wastewaters were achieved to the standards, it was discharged to the sewer and combined with sanitary wastewater. In MIEWWTP, after screening and grit removal, wastewater was collected in the equalization tank and treating

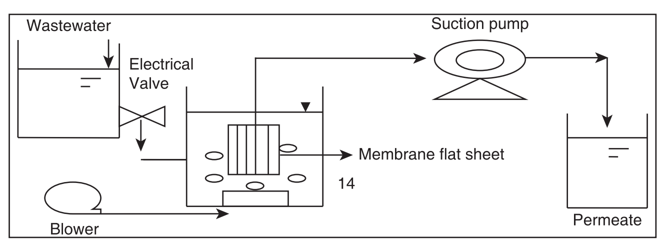

Figure 1: Schematic diagram of the membrane bioreactor

Table 1: Basic specifications of MF membrane

Membrane type	Pore size (MF/μm)	Material of membrane	pH	Effective area (m^2/ea)	Operating pressure (maximum: psi)
MF	0.2	Polyethersulfone	3-13	1	–8.54-0

MF: Microfiltration

in anaerobic contact reactor. Then, an aerobic sequencing batch reactor treated it.

The reactors are hereafter referring to as:

Membrane bioreactor 1; was the reactor fed by the raw wastewater in equalization. MBR2; was the reactor fed by anaerobic tank effluent. Both reactors were operated for 62 days and the average hydraulic retention time (HRT) for MBR1 and MBR2 were 21 and 19 h, respectively. The characterizations of used wastewaters in this experiment are given in Table 2.

Analytical methods

Methods for sampling and analyzing (pH, temperature, electrical conductivity [EC] turbidity, chemical oxygen demand [COD], biological oxygen demand [BOD_5], total dissolved solid [TDS], total suspended solid [TSS], mixed liquor suspended solids [MLSS], volatile suspended solids [VSS], dissolved oxygen, total coliform [TC], fecal coliform [FC]) were determined according to the "standard methods for the examination of water and wastewater."[18]

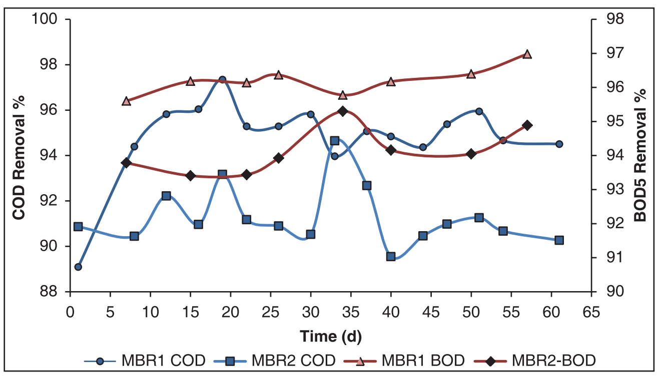

Figure 2: Removal percentage of chemical oxygen demand and biological oxygen demand in the membrane bioreactor 1 (MBR1) and MBR2 during the operation times

Flux was measured volumetrically by collecting permeate at the known time (8 min) every day. The operation duration was considered as sludge residence time because the sludge was not wasted from the reactors.

RESULTS

Figure 2 displays the trends of the COD and BOD_5 removal efficiency of MBR1 and MBR2 during the experiment. The MBR1 and MBR2 systems removed the COD, BOD5, TSS, turbidity and microbial indicators at a high efficiency in the whole operation time. Both systems removed the EC and TDS at a low efficiency. Figures 3 and 4 illustrate the average of COD, BOD_5, TSS, turbidity, microbial indicators, EC and TDS removal efficiency during the study. Both reactors were shown high BOD_5 reduction in compare to COD.

Table 2 summarizes the variation of influent and effluent quality of MBR1 and MBR2. Furthermore, Table 3 shows variation reactors condition in 62 days operation. Figures 5 and 6 depict

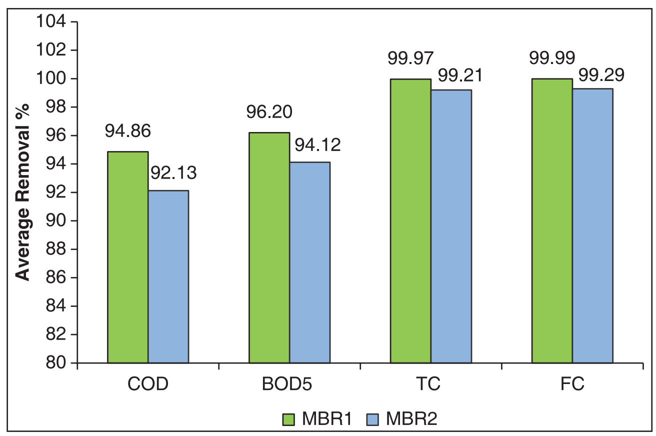

Figure 3: Average of the removal percent of chemical oxygen demand, biological oxygen demand, total coliform, and fecal coliform, in the membrane bioreactor 1 (MBR1) and MBR2

Table 2: The characteristics of influent wastewater and permeate in MBR1 and MBR2

Parameter	Sample number	Mean ± SD			
		MBR1 influent	MBR2 influent	MBR1 permeate	MBR2 permeate
pH	41	8.1 ± 0.62	8.20 ± 0.28	8.38 ± 0.23	8.35 ± 0.2
Temperature (Ċ)	41	27.23 ± 1.57	27.24 ± 1.65	26.45 ± 1.86	26.36 ± 1.86
EC (ms/cm)	41	5.17 ± 0.59	5.56 ± 0.4	4.43 ± 0.58	4.66 ± 0.74
Turbidity (NTU)	41	233.2 ± 98.42	65.7 ± 35.2	0.47 ± 0.23	0.33 ± 0.1
COD (mg/L)	16	1267 ± 625	444 ± 112	59.4 ± 15.1	34.2 ± 4.8
BOD_5 (mg/L)	8	507.1 ± 89.2	177.9 ± 27.2	19.4 ± 4.9	10.4 ± 1.6
BOD/COD	8	0.44 ± 0.07	0.43 ± 0.05	0.35 ± 0.06	0.31 ± 0.04
TSS (mg/L)	17	260.7 ± 72.4	159.9 ± 57.7	3 ± 1	2.82 ± 1.6
TDS (mg/L)	17	3425 ± 432	3940 ± 551	2955 ± 425	3349 ± 565
TC MPN/100 mL	8	$4.11 \times 10^8 \pm 8.17 \times 10^8$	$7.23 \times 10^5 \pm 1.58 \times 10^6$	$6.2 \times 10^3 \pm 1.65 \times 10^4$	$7.9 \times 10^2 + 1.6 \times 10^3$
FC MPN/100 mL	8	$4.78 \times 10^8 \pm 8.44 \times 10^8$	$4.16 \times 10^5 \pm 8.21 \times 10^5$	$4.83 \times 10^3 \pm 1.26 \times 10^4$	$1.79 \times 10^2 \pm 1.58 \times 10^2$

Table 3: The properties of MBR1 and reactor MBR2

Parameter	Sample number	Mean ± SD	
		MBR1	MBR2
pH	41	8.35±0.2	8.30±0.26
Temperature (Ċ)	41	25.48±1.79	25.29±1.59
DO (mg/L)	41	3.24±0.49	3.39±0.33
MLSS (mg/L)	16	4972±1343	4522±1167
MLVSS (mg/L)	16	3454±889	3218±768
MLVSS/MLSS	16	0.7±0.01	0.72±0.02

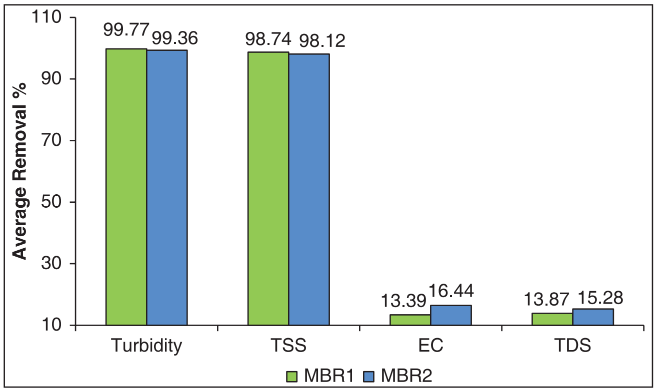

Figure 4: Average of the removal percent of turbidity, total suspended solid, electrical conductivity, total dissolved suspended solid in the membrane bioreactor 1 (MBR1) and MBR2

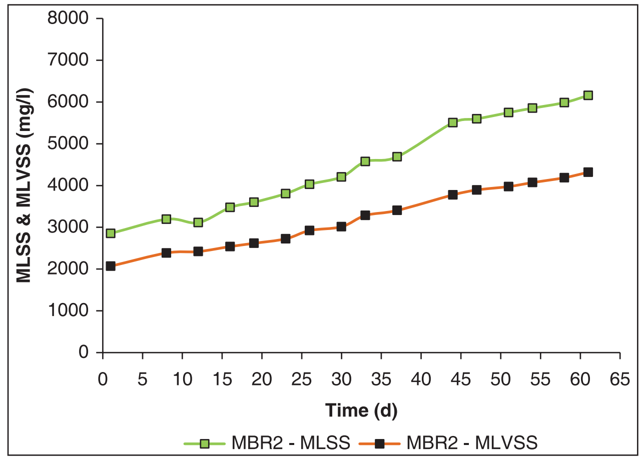

Figure 5: Mixed liquor suspended solids and mixed liquor volatile-suspended solids measured in the membrane bioreactor 1 with average organic loading rate 1.37 kg chemical oxygen demand/m³.day in sludge residence time 63 days

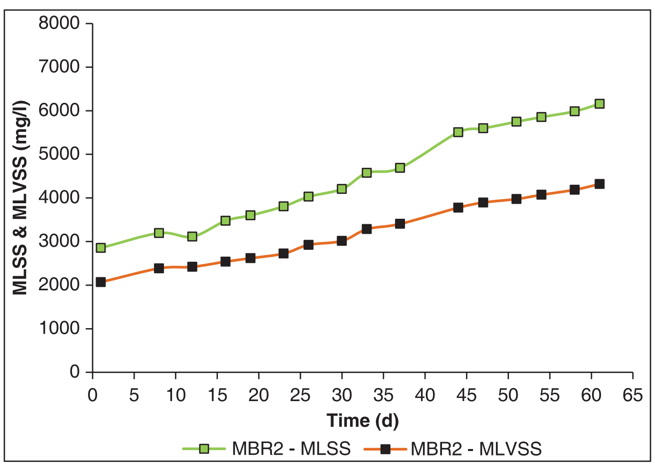

Figure 6: Mixed liquor suspended solids and mixed liquor volatile-suspended solids measured in the membrane bioreactor 2 with average organic loading rate 0.52 (kg chemical oxygen demand/m³.day) in sludge residence time 63 days

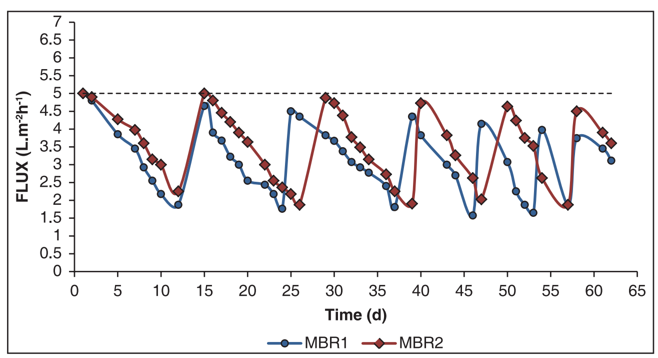

Figure 7: Flux profile in the MBR1 and MBR2 during the operation

the accumulation of MLSS and mixed liquor VSS (MLVSS) in both reactors after 62 days. The biomass concentration increases to 7000 and 6200 mg/L in MBR1 and MBR2, respectively.

Based on membrane dimensions, approximately maximum effluent flux for each reactor was 5 L/m^2 h. after flux was reduced to about 1.5 L/m^2 h, membranes were cleaned by tap water. Figure 7 depicts the fluxes profile in both reactors.

DISCUSSION

As shown in Figure 2 initially, the COD and BOD$_5$ removal efficiency by MBR1 was in minimum, it was due to not adapted used sludge by the raw wastewater. In MBR2, condition was same as MIEWWTP. According to Figure 3 and Table 2, the average COD, and BOD$_5$ removal percentage was 94.86 and 96.2 in organic loading rate (OLR) 1.37 (kg COD/m^3.day) for MBR1 and 92.13, and 94.12 in OLR 0.52 (kg COD/m^3.day) for MBR2, respectively. Higher average removal of MBR1 shows that the quality of influent wastewater to MBR systems has a high influence on average removal efficiency.

Despite fluctuations influent characteristics (especially in MBR1) the concentration of organic matter in the effluent of both reactors was lower than 100 mg COD/L and 30 mg BOD_5/L for MBR1, and lower than 50 mg COD/L and 13 mg BOD_5/L for MBR2 in steady state conditions [Table 2]. Residual COD in permeate was as a result of nonbiodegradable substances from industrial activities. Decreasing BOD_5/COD in permeate of both reactors were indicated fraction potential of MBR systems for industrial wastewaters, it can be explicated the fact that high MLSS concentration was raised capability of biodegradation of a wide range of contamination. The effect of anaerobic pretreatment was made clear by lower BOD_5/COD ratio in the second reactor effluent. Hoinkis *et al.*, 2012, reported elimination rate higher than 90% for COD.[3] Also, Kurian *et al.*, 2006, investigated high strength oily pet food wastewater treatment by MBR. They obtained at the 10 days HRT, a remarkable COD and BOD_5 removal efficiency of 97% and 99%, respectively.[19] Durai and Rajasimman in 2011 stated that 0.3 BOD_5/COD ratio for tannery wastewater is low in comparison with domestic wastewater ratio, because it contains BOD_5 inhibitor.[20] Sánchez *et al.*, 2013, had the same opinion about anaerobic pretreatment.[21]

Figures 3 and 4 exhibit the average percentage reduction of over 98% in turbidity, TSS, FC, TC, but in TDS and EC were lower than 20%.

Total coliform and FC, used as indicators of sewage treatment effectiveness, which is the coliform species normally, found in human excretory, is commonly accepted as being a suitable indicator of reduction of bacterial pathogens in effluent wastewater treatment plant.[22] In this investigation, both the TC and FC indicators declined 5 $\log_{10}$ for MBR1, and these were 3 $\log_{10}$ for MBR2, respectively. As shown in Table 2 (influent 2) pretreatment anaerobic unit was redacted microbial contamination. Microbial contamination of MBR1 permeate was over the standard levels, therefore, an additional treatment is needed (disinfection) to achieve the microbial quality required for water reuse purpose. In a similar study, Valderrama *et al.*, 2012, was obtained a reduction of 6 $\log_{10}$ for microbial indicators while microbial concentration of MBR effluent was lower than 10 CFU/100 mL.[16]

Total suspended solid concentration in permeate of both reactors were <5 mg/L, so, membranes performance was not affected by influent TSS concentration. The TSS analyze was monitored the integrity of the membrane, probably released algae grown in the suction pips show this value of TSS in the results. The effluents from the MBR systems produced high-quality of treated water with a turbidity of approximately <0.5 nephelometric turbidity unit (NTU) that is, suitable for water reuse [Table 2 and Figure 4]. Residual suspended solids in effluent of clarifiers are one of the major problems of conventional activated sludge processes to reclaiming water that is a main MBR advantage, preserved the sludge in the reactor by filtration, in comparison with conventional activated sludge processes. Qin *et al.*, 2007,[23] Yigit *et al.*, 2009,[24] reported TSS <2.5 mg/L and Jin *et al.*, 2013, have expressed turbidity <0.56 NTU for MBR outlet.[25]

Average removal of TDS and EC of MBRs effluents was not considerable because the size of dissolved components is <0.1 μm, whereas pore size of the membrane used in this study was 0.2 μm. The cations an anions are the most part of TDS, which biological processes are not be able to remove them.[26] Thus, separation of the flows with high TDS is required to reclaim the water for reuse.

As shown in Figures 5 and 6, during the whole experiment the biomass concentration was accumulated without any sludge withdrawal despite sampling. Both reactors started in almost 2600 mg/L MLSS concentration, but at the end of the operation, the sludge amount approximately were 7000 mg TSS L^{-1} and 6200 mg TSS L^{-1} for MBR1 and MBR2, respectively. In addition, the average range of OLR was 1.37-0.52 (kg COD/m^3.day) and female/male ratio was 0.14-0.07 day^{-1}, for MBR1 - MBR2, respectively. During the experimental period, the ratio of MLVSS/MLSS was not constant and was lower than the initially with the sludge increasing. As a result, more influent TSS and OLR in MBR1, this ratio was lower in comparison with MBR2.

Due to the application of real wastewater in this research, high variations of female/male and OLR in the reactor one influent confirmed the stability of MBR in the treatment process. The relation between sludge productions with female/male ratio was considerable, as low female/male was caused less MLSS concentration in the second reactor. Artiga *et al.*, 2005, in a similar study reported sludge production is lower in MBR than conventional aerobic system, due to low female/male ratio applied.[10]

Fluxes reduction was the main difference between the two used membranes. Figure 7 shows the daily measurement of membrane fluxes. Both systems were started in a same flux (5 L/h), and after that decreased due to fouling. The MBR filtration performance naturally decreases with filtration time. This is due to the deposition of soluble and suspended materials onto and into the membrane, as a result of the interactions between biomass components and the membrane. Frequency of cleaning was influenced directly by initial wastewater quality and MLSS concentration. After the middle of operation days, the interval between cleaning points was more compressed. As can be seen, the initial flux was not recovered after second cleaning in MBR1 but this phenomenon was happened after 3rd for MBR2. Reduction of the initial flux in the first reactor was higher after each physical cleaning, No chemical cleaning was needed during the pilot test period. Mutamim *et al*., 2012, dealing with high strength wastewater containing high load of contaminants, it will lead to high clogging of the membrane due to the membrane characteristics, biomass, and operating condition.[4] Bienati *et al*., 2008 in the same investigation stated, reduction initial water flux after each cleaning due to This fact indicated that most probably, during the bioreactor operation, in the pore structure of the membranes, there was a deposition of materials that could not be removed completely.[6]

CONCLUSIONS

Regardless of well removal efficiency, average concentrations of COD, BOD_5, and TDS of the second reactor permeate were lower than the first one. Low BOD/COD ratio in the effluent of both reactors makes this system efficient for treating combined different industrial wastewater.

Despite high biomass concentration, the quality of inlet wastewater has a main effect on frequent of required cleaning.

Finally, it can be concluded that by an anaerobic unit pretreatment, membrane biological treatment system will be more effective with long time operation and can control the flux reduction. High both MBRs effluent quality was made it suitable for the treatment of centralized combined industrial wastewater and water reuse.

Acknowledgments
This article is the result of MSc. Approved Thesis in the Isfahan University of Medical Sciences (IUMS). The authors wish to acknowledge to Vice Chancellery of Research of IUMS for the financial support, Research Project, #393299, and the supported grant from Isfahan-Iran Industrial Estates Company.

Financial support and sponsorship
Isfahan University of Medical Sciences, Isfahan, Iran

Conflicts of interest
There are no conflicts of interest.

REFERENCES

1. Sartor M, Kaschek M, Mavrov V. Feasibility study for evaluating the client application of membrane bioreactor (MBR) technology for decentralised municipal wastewater treatment in Vietnam. Desalination 2008;224:172-7.
2. Chen FA, Shue MF, Chen TC. Evaluation on estrogenicity and oxidative hepatotoxicity of fossil fuel industrial wastewater before and after the powdered activated carbon treatment. Chemosphere 2004;55:1377-85.
3. Hoinkis J, Deowan SA, Panten V, Figoli A, Huang RR, Drioli E. Membrane bioreactor (MBR) technology - A promising approach for industrial water reuse. Procedia Eng 2012;33:234-41.
4. Mutamim NS, Noor ZZ, Hassan MA, Olsson G. Application of membrane bioreactor technology in treating high strength industrial wastewater: A performance review. Desalination 2012;305:1-11.
5. Wozniak T. MBR design and operation using MPE-technology (Membrane Performance Enhancer). Desalination 2010;250:723-8.
6. Bienati B, Bottino A, Capannelli G, Comite A. Characterization and performance of different types of hollow fibre membranes in a laboratory-scale MBR for the treatment of industrial wastewater. Desalination 2008;231:133-40.
7. Matos M, Benito JM, Cambiella Á, Coca J, Pazos C. Ultrafiltration of activated sludge: Flocculation and membrane fouling. Desalination 2011;281:142-50.
8. Pollice A, Giordano C, Laera G, Saturno D, Mininni G. Physical characteristics of the sludge in a complete retention membrane bioreactor. Water Research 2007;41:1832-40.
9. López-Fernández R, Martínez L, Villaverde S. Membrane bioreactor for the treatment of pharmaceutical wastewater containing corticosteroids. Desalination 2012;300:19-23.
10. Artiga P, Ficara E, Malpei F, Garrido JM, Méndez R. Treatment of two industrial wastewaters in a submerged membrane bioreactor. Desalination 2005;179:161-9.
11. Buntner D, Sánchez A, Garrido J. Feasibility of combined UASB and MBR system in dairy wastewater treatment at ambient temperatures. Chem Eng J 2013;230:475-81.
12. Bae TH, Han SS, Tak TM. Membrane sequencing batch reactor system for the treatment of dairy industry wastewater. Process Biochem 2003; 39:221-31.
13. Roberts JA, Sutton PM, Mishra PN. Application of the membrane biological reactor system for combined sanitary and industrial wastewater treatment. Int Biodeterior Biodegradation 2000;46:37-42.
14. Jamal Khan S, Ilyas S, Javid S, Visvanathan C, Jegatheesan V. Performance of suspended and attached growth MBR systems in treating high strength synthetic wastewater. Bioresour Technol 2011;102:5331-6.
15. Scholz W, Fuchs W. Treatment of oil contaminated wastewater in a membrane bioreactor. Water Res 2000;34:3621-9.
16. Valderrama C, Ribera G, Bahí N, Rovira M, Giménez T, Nomen R, *et al*. Winery wastewater treatment for water reuse purpose: Conventional activated sludge versus membrane bioreactor (MBR): A comparative case study. Desalination 2012;306:1-7.
17. Lin H, Gao W, Meng F, Liao BQ, Leung KT, Zhao L, *et al*. Membrane bioreactors for industrial wastewater treatment: A critical review. Crit Rev Environ Sci Technol 2012;42:677-740.
18. APHA, AWWA, WEF. Standard Methods for the Examination of Water and Wastewater. 22nd Ed. American Public Health Association; New York, 2012.
19. Kurian R, Nakhla G, Bassi A. Biodegradation kinetics of high strength oily pet food wastewater in a membrane-coupled bioreactor (MBR). Chemosphere 2006;65:1204-11.
20. Durai G, Rajasimman M. Biological treatment of tannery wastewater - A review. J Environ Sci Technol 2011;4:1-17.
21. Sánchez A, Buntner D, Garrido JM. Impact of methanogenic pre-treatment on the performance of an aerobic MBR system. Water Res 2013;47:1229-36.
22. Bitton G. Wastewater Microbiology. 3rd Ed. John Wiley & Sons; New Jersey, 2005.
23. Qin JJ, Oo MH, Tao G, Kekre KA. Feasibility study on petrochemical wastewater treatment and reuse using submerged MBR. J Membr Sci 2007;293:161-6.
24. Yigit NO, Uzal N, Koseoglu H, Harman I, Yukseler H, Yetis U, *et al*. Treatment of a denim producing textile industry wastewater using pilot-scale membrane bioreactor. Desalination 2009;240:143-50.
25. Jin X, Li E, Lu S, Qiu Z, Sui Q. Coking wastewater treatment for industrial reuse purpose: Combining biological processes with ultrafiltration, nanofiltration and reverse osmosis. J Environ Sci 2013;25:1565-74.
26. Judd S. The MBR Book: Principles and Applications of Membrane Bioreactors for Water and Wastewater Treatment. 2nd Ed. Elsevier; Netherland, 2010.