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]/m³.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 (BOD₅) in both reactors. In addition, the average turbidity, COD, BOD₅ 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...
management has become one of the important operational and environmental topics. Wastewater treatment and reuse are effective for sustainable industrial development plans. 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 very promising technology. During the last years, MBRs were extensively used for industrial wastewater treatment because of their high removal efficiencies. The membrane filtration coupled with the activated sludge treatment allows biodegradation of the organic substance and removal of the suspended solids. High-quality permeate can be recovered and reuse. 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. 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. In these systems membrane filtration units are used instead of the secondary clarifiers in traditional activated sludge systems. Worldwide >5000 MBR plants are under operation. 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.

Several studies have investigated evaluation of MBRs systems for treating several types of industrial wastewaters such as: Mineral oil, pharmaceutical, tannery, dairy, combined sanitary and industrial, high strength synthetic, oil contaminated wastewater, and winery wastewater. In this study, organic material removal efficiency was obtained >82%. Several studies have investigated evaluation of MBRs for treating industrial wastewaters in separate industries but in our 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.

**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 m². 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 m³/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

| Table 1: Basic specifications of MF membrane |
|---------------------------------------------|
| Membrane type | Pore size (MF/μm) | Material of membrane | pH | Effective area (m²/ea) | Operating pressure (maximum: psi) |
|----------------|-------------------|---------------------|----|----------------------|-------------------------------|
| MF             | 0.2               | Polyethersulfone    | 3-13 | 1                     | – 8.54-0                      |

MF: Microfiltration

![Figure 1: Schematic diagram of the membrane bioreactor](image-url)
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], 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.”[17]

**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, BOD\(_5\), 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 2: Removal percentage of chemical oxygen demand and biological oxygen demand in the membrane bioreactor 1 (MBR1) and MBR2 during the operation times](image)

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

| Parameter | Sample number | MBR1 influent Mean ± SD | MBR2 influent Mean ± SD | MBR1 permeate Mean ± SD | MBR2 permeate Mean ± SD |
|-----------|---------------|-------------------------|-------------------------|-------------------------|-------------------------|
| pH        | 41            | 8.1 ± 0.62              | 8.20 ± 0.28             | 8.38 ± 0.23             | 8.35 ± 0.2             |
| Temperature (C) | 41         | 27.23 ± 1.57           | 27.24 ± 1.65            | 26.46 ± 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 × 10\(^8\) ± 8.17 × 10\(^8\) | 7.23 × 10\(^8\) ± 1.58 × 10\(^8\) | 6.2 × 10\(^8\) ± 1.65 × 10\(^8\) | 7.9 × 10\(^8\) ± 1.6 × 10\(^3\) |
| FC MPN/100 mL | 8           | 4.78 × 10\(^8\) ± 8.44 × 10\(^8\) | 4.16 × 10\(^8\) ± 8.21 × 10\(^8\) | 4.83 × 10\(^2\) ± 1.26 × 10\(^4\) | 1.79 × 10\(^2\) ± 1.58 × 10\(^2\) |

![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](image)
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/m² h. after flux was reduced to about 1.5 L/m² 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 BOD₅ 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 BOD₅ removal percentage was 94.86 and 96.2 in organic loading rate (OLR) 1.37 kg chemical oxygen demand/m³ day in sludge residence time 63 days.
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 70 mg BOD/L for MBR1, and lower than 50 mg COD/L and 15 mg BOD/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/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/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 BOD5 removal efficiency of 97% and 99%, respectively.[19] Durai and Rajasimman in 2011 stated that 0.3 BOD5/COD ratio for tannery wastewater is low in comparison with domestic wastewater ratio, because it contains BOD5 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 log10 for MBR1, and these were 3 log10 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 log10 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 pipes 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,[21] 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 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/m3 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 34d for MBR2. Reduction of
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.

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Conflicts of interest
There are no conflicts of interest.

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