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Efficiency of membrane bioreactor system in treating primary treated wastewater in Kuwait

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ABSTRACT

A skid-mounted nonsubmerged membrane bioreactor (MBR) system was installed and operated at the Riqqa Wastewater Treatment Plant in Kuwait. This system was investigated as a substitute for secondary clarifier in the activated sludge process to treat primary treated wastewater. The MBR system was operated with aerobic and anoxic tanks and with the flux of 16–24 L/m^2.h and an HRT of 5 h. The mixed liquor wasting rate was set to give an SRT in the range of 22 d and an MLSS concentration of 6,000–8,500 g/l. MBR filtrate produced was found to be effluent from the plant's conventional treatment systems. Good removal of particulate contaminants, including coliform bacteria, was achieved. The overall results of this project indicate that the MBR system is capable of treating wastewater under the prevalent conditions in Kuwait. The average removal efficiencies of the MBR system for biological oxygen demand (BOD) and chemical oxygen demand (COD) were 93.9% and 92.7% respectively.

Keywords: Wastewater; Treatment; Activated sludge; Membrane

1. Introduction

The use of membrane technology for treatment of wastewater has increased in recent years because the membranes produce a better quality effluent than conventional wastewater treatment methods.

One promising membrane-based approach for treating municipal wastewater is utilization of membrane filtration within conventional biological treatment processes; this approach is known as the membrane bioreactor (MBR) system. This relatively new technology combines an activated sludge reactor with a membrane separation unit to treat wastewater, and, therefore, eliminate the need for a secondary clarifier. A low-pressure membrane, such as a microfiltration (MF) or an ultrafiltration (UF) membrane, performs the solids separation. In such a case, the MBR process contains the process elements of secondary, tertiary and advanced wastewater treatment in a single-unit operation. The MBR was first developed and applied to municipal wastewater in the 1960s by the Dorr-Oliver Company [1]. They used UF membranes for separation of activated sludge from the final effluent with recycling of the biomass to the aeration tank. The MBR can be operated in different configurations. In the first configuration (nonsubmerged), the membrane module can replace the clarifier outside of the bioreactor, whereas the alternative is to have the membrane module submerged in the bioreactor.

Inclusion of membrane separation technology in conventional biological processes for wastewater treatment has many advantages. In particular, high

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product water quality, high reliability, compactness and minimum sludge wastage are the most obvious. Typical permeate from a membrane is usually free from solids and macro-colloidal material. For example, water product qualities are below 5 mg/l TSS and less than 1 NTU turbidity [2]. A clear advantage of MBR is the complete separation of the HRT and SRT, which eliminate operational limitations imposed on the conventional activated sludge process. This allows MBRs to be operated at low HRTs and long SRTs without the wash-out of biomass common in activated sludge. Therefore, an optimal control of biological reactions can be obtained by controlling the residence time of the microorganisms in the reactor.

The MBR operates with different parameter ranges for SRT and F/M ratios than the conventional activated sludge processes. While the SRT falls in the range of 5–30 d for conventional activated sludge systems, the SRT values frequently exceed 30 d for MBRs and have been reported at levels as high as 125 d [3]. Attaining long sludge age is very important for the development of slow-growing microorganisms such as nitrifying bacteria [4]. This makes membrane separation in the bioreactor more attractive for situations where long SRT are necessary to achieve the removal of pollutants [5].

In this study the aim was to evaluate the efficiency of MBR system in treating primary wastewater effluent under the prevalent conditions in Kuwait. It is also aiming to assess the economic viability of utilizing MBR treatment for wastewater reuse.

The work was carried out at the Riqqa wastewater treatment plant. The plant is third largest sewage treatment facility in the State of Kuwait designed and operated using conventional treatment techniques. Its design capacity is 180,000 m^3/d, and it serves a population of 220,000.

2. Material and methods

The primary effluent feedwater passes through a 100 micron screen size made from fine stainless steel. The screen is built with support hangers and is designed to ensure that no large particles enter through the system. Such particles consist mainly from non-biodegradable solids, such as hair, grit and plastics which may foul or damage the membranes if allowed to pass into the bioreactor tank. The aerobic zone includes the process air blowers which are installed adjacent to the skid. The required process air flow is 134 scfm introduced at the bottom of the aerobic zone by air scour distribution header pipes. After the upstream flow the mixed liquor will be transferred by overflow to a suitable buffer flow tank and then pressurized to an operation pressure according to the membrane design. The module array is single stage, where the permeate passes through the flushing/cleaning tank. The brine is pumped back to the aerobic zone or discharged to the drain line. Flushing of the modules is performed at plant stop with permeate water, by means of the flushing pumps. In case of plugging of the membranes, indicated by increasing pressure differences across the membranes cleaning with suitable chemical solutions has to be performed.

Fig. 1 shows the layout of the MBR system whereas, technical details of the system are shown in Table 1.

In order to obtain the best operational parameters, optimization process was carried out in parallel with data collection and water analysis sampling. Operational parameters, such as flow rate, temperature, feed pressure, pH and turbidity (feed and filtrate) were monitored and recorded on daily basis. Table 2 shows the range of optimized and applied operational parameters.

3. Results and discussion

3.1. System operating conditions

The MBR system was fed with a primary treated wastewater at Riqqa wastewater treatment plant. Different parameters were monitored to determine physical quality of the feed water and system operating conditions. The system was operated between April and November 2007 in a continuous basis. Fig. 2 presents influent temperature, pH and turbidity of both feed and filtrate. The temperature of the feed was between 23 and 37°C, the pH of the feed water during this period was between 6.9 and 8. The figure also showed that the influent turbidity ranged from 15 to 300 NTU, whereas the turbidity of the MBR effluent ranged from 0.9 to 7.9 NTU. Feed water conductivity was also monitored and was between 960 and 1,865 μs/cm (Fig. 3).

At the beginning of the operational period, operational parameters were optimized for best performance of the process. The optimized parameters were membrane flux, HRT, SRT, DO and MLSS. The MBR system was operated with aerobic and anoxic tanks and with the flux of 16–24 $L/m^2.h$ and an HRT of 5 h. The mixed liquor wasting rate was set to give an SRT in the range of 22 d and an MLSS concentration of 6,000–8,500 mg/l. The SRT values are presented in Fig. 4. The DO concentrations in the biological treatment part are presented in Fig. 5. The DO concentrations in the anoxic and aerobic tank ranged from 0.1 to 0.30 mg/l and from 0.45 to 3.5 mg/l, respectively.

3.2. MBR feed and permeate quality

In addition to the daily in situ monitoring of the MBR unit, samples (feed and filtrate) were taken and

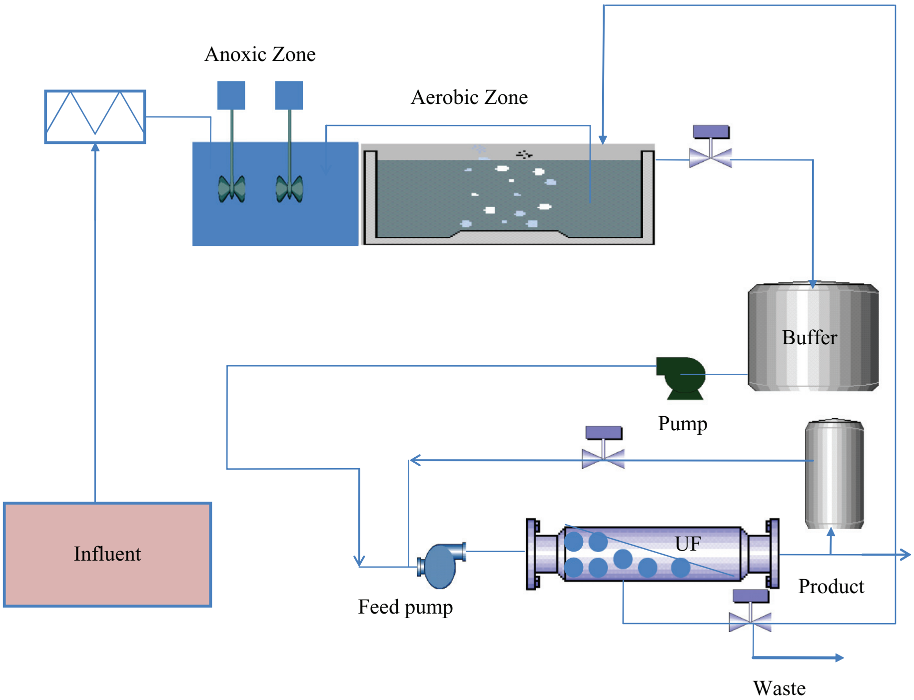

Fig. 1. Schematic diagram of the MBR system.

analyzed chemically and biologically. The results of the chemical and biological analyses of 26 samples of the feed and filtrate water from the MBR units are summarized in Table 3. The results show that the conductivity of the feed water is low with an average value of 1,326 µs/cm which explains the low operating pressure (1 bar). The turbidity fluctuates between minimum value of 18 and maximum value of 199 with an average value of 104 NTU. The average values of TSS, BOD, COD Phosphate, nitrate and TSS of the feed water as shown are 145, 162, 292, 2.7, and 14 mg/l, respectively. On the other hand, the analyses of the filtrate water show improvement in physical and chemical characteristics. The average values of TSS, BOD, COD, Phosphate and nitrate of the filtrate are 8.6, 9.8, 21.3, 1.6 and 3.6 mg/l, respectively. Biological analysis of both feed and filtrate water shows that MBR system significantly reduced the average values of total bacterial count and fecal coliform from 4.7E+7 to 1.9E+6 (coloni/100 ml) and 3.9E+6 to 2.5E+5 (coloni/100 ml), respectively.

3.3. BOD and COD

The BOD and COD measurements of primary effluent and MBR filtrate are shown in Figs. 6 and 7, respectively. The influent BOD and COD was highly fluctuating during the period of operation and was in the range of from 86 to 310 and 120 to 500 mg/l,

Table 1
Technical details of the MBR system

Description	Value
Anoxic tank	6 m^3
Aeration tank	6 m^3
Membrane	WW8000K UF, thin film composite
Membrane maximum capacity	5 m^3/h
Membrane effective area	25 m^2
Pressure pump	1 (SS 316 L)
Operating pressure	1 bar

Table 2
Operational parameters of the pilot MBR system

Parameter	Range
HRT (h)	2–5
F/M ratio (d^{-1})	0.95–1.2
Dissolved Oxygen, DO (mg/l)	0.7–3.5
Membrane flux (l/m^2.h)	16–24
Feed flow rate (l/h)	800–2100
pH	6.4–7.1
Electrical conductivity, E.C. (µs/cm)	945–1304
Operating pressure (bar)	1–3

HRT, hydraulic retention time; F/M, food/microorganism ratio.

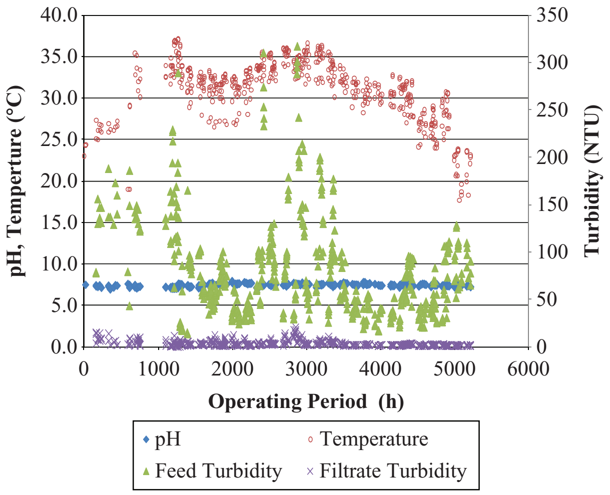

Fig. 2. Feed and filtrate temperature, pH, and turbidity versus running hours.

respectively. As can be seen, there were significant reductions in both BOD and COD values which revealed that the MBR system can provide consistently high organic removal efficiency during continuous long time of operation. BOD concentration in the effluent was varied from 1.3 to 19 mg/l with an average value of 10 mg/l, whereas the majority of COD values of the MBR filtrate were less than 26 mg/l, with an average value of 17 mg/l. The results clearly indicates the efficiency of the MBR system in biodegrading the organic matter in the Riqqa Wastewater Treatment Plant's primary effluent and showed that membrane separation played an important role in providing the excellent and stable effluent quality.

3.4. Nitrogen removal

Nitrification is the main process in removing total nitrogen from the wastewater and this removal is occurred in two step processes: nitrification followed

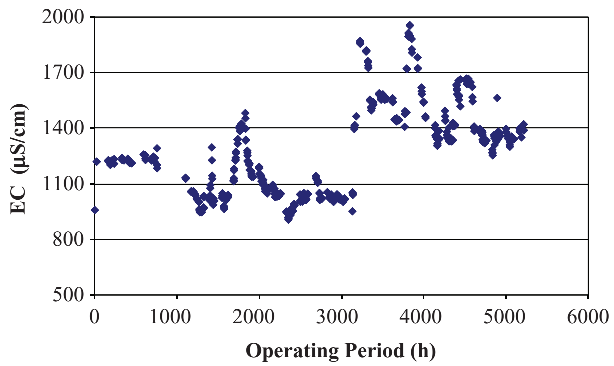

Fig. 3. Feed conductivity versus running hours.

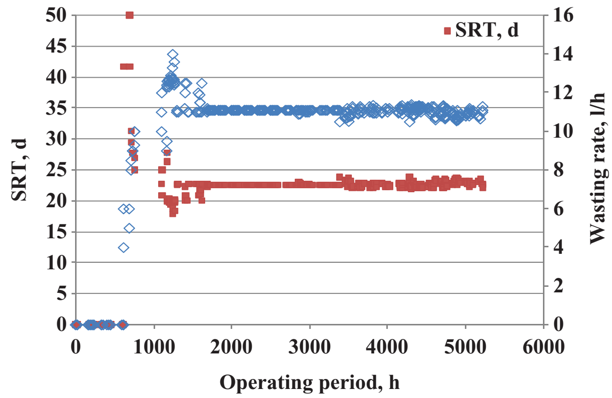

Fig. 4. SRT of the MBR system.

by denitrification [6]. In the first step ammonia is converted into nitrate under aerobic conditions and is susceptible to inhibition by variety of toxic materials and compounds [7].

$$NH_4^+ + 2O_2 \rightarrow NO_3^- + 2H^+ + H_2O$$

Incomplete nitrification resulted in decrease in TN removal efficiency of the system [8]. Dissolved oxygen (DO) is the principal parameter that controls nitrification. Nitrification efficiency goes down when DO decreases below 2.5 mg/l [9]. To ensure complete nitrification the DO in the aeration tank was maintained around 2.5 mg/l as shown in Fig. 5. In the anoxic tank low concentration of DO (less than 0.30 mg/l) was noticed and this was expected because influent primary wastewater contained trace DO as presented in Table 3. It was observed that the nitrogen removal process in the system was ineffective. Ammonia concentration in the effluent was relatively high and

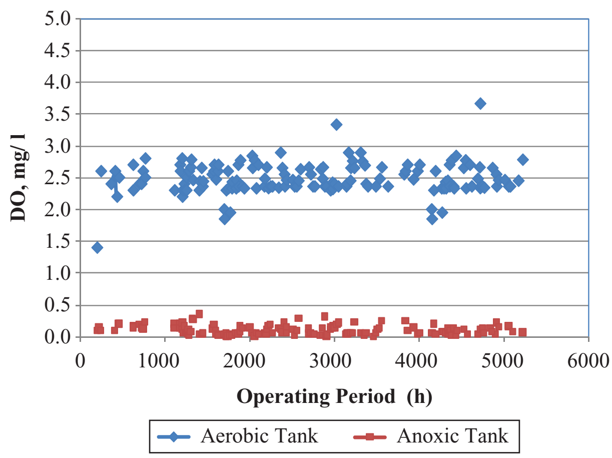

Fig. 5. Concentraion of dissolved oxygen in the biological treatemnt system.

Table 3
Chemical and biological analysis of feed and filtrate water of the MBR system.

	Primary feedwater			Filtrate water		
Parameter	Max	Min	Ave	Max	Min	Ave
E.c. (µs/cm)	1710	945	1304	1682	999	1326
pH	7.6	6.4	7.1	7.9	6.0	7.2
Turbidity (NTU)	199	18	104	7.9	0.9	3.3
DO (mg/l)	0.6	0.1	0.4	0.5	0.0	0.3
TSS (mg/l)	226	76	145	20.7	3.5	8.6
NO_3-N (mg/l)	19.3	6.6	14	11	1.0	3.6
Chloride (mg/l)	230	145	188	240	74	168
Sulfate (mg/l)	118	1.2	29.6	103	0.2	23.2
BOD_5 (mg/l)	310	86	162	19	1.3	9.8
COD (mg/l)	500	120	292	30	10	21.3
PO_4^- (mg/l)	4.9	1.8	2.7	3.0	0.7	1.6
NH_4-N (mg/l)	18.6	3.2	9	10.5	1.6	5.5
Total bacterial count (Heterophic) (colonies/100 ml)	9.6E+7	1.0E+7	4.7E+7	7.2E+6	1.2E+5	1.9E+6
F. coliform (colonies/100 ml)	9.2E+6	5.0E+5	3.9E+6	1.9E+6	9.6E+3	2.5E+5

Ec, electrical conductivity; DO, dissolved oxygen; TSS, total suspended solids; BOD, biological oxygen demand; COD, chemical oxygen demand.

was found to be in the range of 1.6–10.5 mg/l with average value of 5.5 mg/l as shown in Table 3. Average removal of ammonia was less than 40% and this result indicates that the nitrification process was incomplete. Poor ammonia removal mainly occurred because of insufficient DO concentration (2.5 mg/l) in the aeration tank. Similar results were observed by many researchers investigating nitrification process in wastewater treatment systems. They found that to ensure complete nitrification the DO in the aeration tank need to be maintained around 3.5 mg/l [10].

4. Conclusion

- The MBR system was efficient in producing a good-quality effluent, and there were consistent reductions over 93% in BOD, COD, TSS and total bacteria counts.
- The chemical analysis indicates that the MBR system significantly improved the quality of the primary treated wastewater effluents.
- DO concentration in aeration tank need to be increased in order to improve N removal process.
- The MBR process offers several benefits over conventional treatment including: smaller space requirements and better solids removal (MBR TSS removal was 94%).

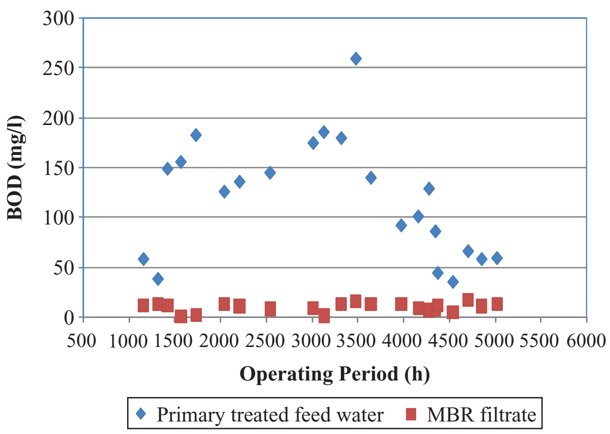

Fig. 6. BOD measurements of primary treated feed water and MBR filtrate.

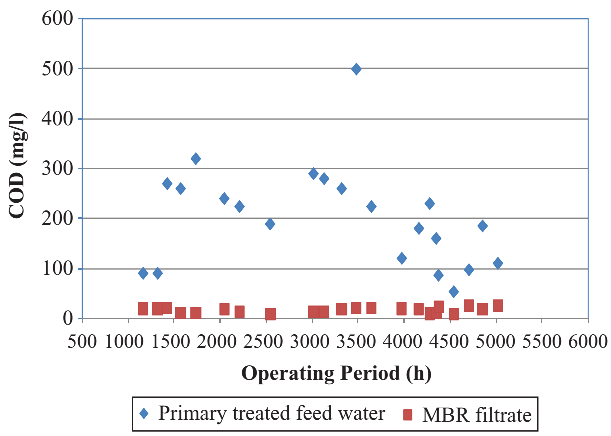

Fig. 7. COD measurements of primary treated feed water and MBR filtrate.

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