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Comparison between MBR and A/O processes treating saline wastewater

Jin Li*, Deshuang Yu, Peiyu Zhang

School of Chemical and Environmental Engineering, Qingdao University, Qingdao, China
Email: ljin0532@126.com

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ABSTRACT

Membrane bioreactor MBR and A/O processes are employed to treat saline wastewater. The mixed liquid suspended solids in the MBR and A/O were 7,000 and 3,500 mg/L, respectively. With the same influents, MBR process was more suitable for the treatment of high-salinity wastewater. The chemical oxygen demand and ammonia removal efficiencies were 75 and 82%, respectively, with the salinity of 24.5 g/L. Both were higher than that through the A/O process. Autotrophic nitrifying bacteria could be enriched and had sufficient time to accommodate to the saline environment. Both sludge volume index (SVI) decreased with salinity increment. However, the SVI of MBR dropped more than that of A/O, which indicated a better sludge-settling property in the MBR process. Filamentous bacteria existed in the A/O reactor and made the sludge-settling property worse than that in the MBR process. Membrane fouling occurred inevitably during the MBR process. Microbes and organics could be removed by combined physical and chemical cleaning.

Keywords: Saline wastewater; MBR; A/O; Sludge-settling property; Membrane fouling

1. Introduction

Due to fresh water shortage in many countries, it is imperative to save significant amounts of fresh water by utilizing seawater. This inevitably results in a large amount of saline wastewater. Our previous report indicated that the treatment of saline and hypersaline wastewater could represent as much as 5% of worldwide effluent treatment requirements [1]. This concerned both seawater-based food industries, such as fish processing and concentrated wastewaters, such as those coming from chemical industries and distilleries. When such effluent is discharged into the environment without prior treatment, it can inevitably cause severe contamination in soils, surface water and groundwater. As far as saline wastewater treatment is concerned, physicochemical means are adopted usually. However, physicochemical techniques are energy-consuming and their startup and running costs are high [2]. The biological treatment of saline wastewater has become a topic of increasing importance in the industrialized world. However, biological treatment of saline wastewater usually results in low chemical oxygen demand (COD) removal performance because of adverse effects of salt on microbial flora [3]. High salt concentration can cause plasmolysis and loss of activity of the cells [4]. Still, salinity shift

*Corresponding author.

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greatly affects the treatment performance [5-10]. Although biological treatment is inhibited by high salt levels, many studies proved that it is feasible to use salt-adapted microorganisms capable of withstanding high salinities and degrading the pollutants [11]. A variety of processes are applied to treat saline wastewater, such as a conventional aerobic wastewater treatment process [12], a sequencing batch reactor (SBR) [13], a sequencing batch biofilm reactor (SBBR) [14], an anaerobic/anoxic/aerobic process [15], an upflow anaerobic sludge blanket (UASB) [16] and an anaerobic contact system [17]. The COD and ammonia removal efficiencies obtained with this type of wastewater vary largely.

Compared with the conventional activated sludge process, membrane bioreactor (MBR) has many advantages such as excellent effluent quality, high biomass, low sludge production, small footprint, the separation of sludge retention time (SRT) and hydraulic retention time (HRT), and flexibility for future expansion and upgrade [18,19]. However, the comparison of MBR and conventional biological process in treating saline wastewater was studied little.

In this work, both MBR and A/O processes were employed to treat saline wastewater. Salinity effects on both processes were explored. The pollutant removal and sludge settling property with different salt contents were compared. Membrane fouling and cleaning during the operation was investigated.

Table 1
Salinities and Cl^- concentrations in wastewater containing different content of seawater

Percentages of seawater (%)	Salinities (mg/L)	Cl^- concentrations (mg/L)
10	3,500	1,900
20	7,000	3,800
30	10,500	5,700
40	14,000	7,600
50	17,500	9,500
60	21,000	11,400
70	24,500	13,300

2. Materials and methods

2.1. Wastewater characteristics

The synthetic feed was prepared with seawater, soybean milk, NH_4Cl, KH_2PO_4 and Na_2CO_3. In this study, varying salinity was achieved by adding different content of seawater. The COD and ammonium–N were 800–1,000 mg/L and 80–100 mg/L, respectively. The pH was 7.5–8.5. The salinities and Cl^- concentrations corresponding to the different content of seawater are shown in the Table 1.

2.2. Experimental setup and start-up

The MBR and A/O processes are shown in Fig. 1. Continuous operation was carried out during the whole experiment. As far as MBR is concerned, the reactor was equipped with eight hollow-fiber microfiltration (MF) membrane modules that were made of polyethylene with a total surface area of 2.57 m^2 and a nominal pore size of 0.4 μm, and its working volume was 257 L. Aeration was continuously carried out, and filtration was intermittently carried out (7 min filtration and 3 min pause) using a suction pump. The bubbles pushed the sludge to flow upward between the membrane modules to minimize membrane fouling. The mixed liquid suspended solids (MLSS) concentration in the MBR was maintained at 7,000 mg/L by extracting excess sludge. Dissolved oxygen and temperature sustained at 2–4 mg/L and 20–25 °C, respectively. When it came to the A/O process, the total volume was 195 L, and the ratio of anoxic to oxic volume was 1:2. The MLSS concentrations in both anoxic and oxic tanks were 3,500 mg/L. Inner and sludge recirculation ratios were 2 and 1, respectively. The HRT in both reactors was 15 h.

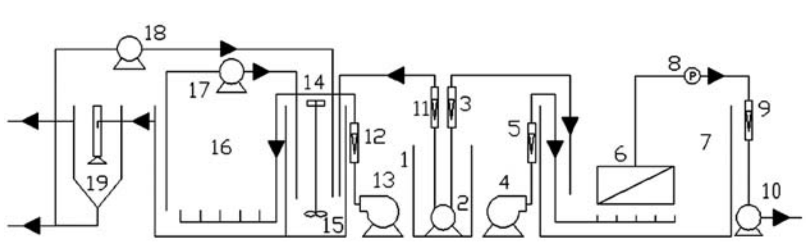

Fig. 1. Schematic diagram of submerged MBR and A/O processes. (1) Feed tank; (2) feed pump; (3,5,9,11,12) flowmeters; (4,13) air compressors; (6) membrane modules; (7) biological reactors; (9) pressure gauge; (10) suction pump; (14) stirrer; (15) anoxic tank; (16) aerobic tank; (17,18) recirculation pumps; (19) secondary settler.

2.3. Sample collection and preparation

Samples were withdrawn from the liquid media in both reactors and were centrifuged at 6,000 rpm for 30 min to remove microorganisms from the liquid medium. Sufficient amounts of $HgSO_4$ were added to precipitate chloride ions into $HgCl_2$ in order to avoid chloride ion interfering with COD measurement. The COD, NH_3–N contents of the supernatants were analyzed according to standard methods [20]. Samples were analyzed in triplicate and mean values were reported. DO and pH measurements were taken by using the relevant probes and analyzers (METTLER TOLEDO FiveGo^{TM} DO meter and METTLER TOLEDO FE20 pH meter). Samples were centrifuged to separate saline water from the biomass and the washed salt-free organisms were used to determine the biomass concentrations. The biomass was determined by filtering the washed salt-free samples through 0.45 μm membrane filter and drying the washed salt-free organisms in an oven at 105°C to constant weight.

3. Results and discussion

3.1. Organics removal with different salinities

Salinity effects on organic matters removal were tested. The operation was divided into seven stages based on the seawater content. The salinities in these stages were 3.5, 7, 10.5, 14, 17.5, 21 and 24.5 g/L, respectively. Fig. 2 shows the COD removal with different salinities in both MBR and A/O processes. When the salinity was not more than 10.5 g/L, the organics removal by both MBR and A/O was little affected. The effluent COD was around 105 mg/L, and the COD removal efficiency was 91%. However, the COD removal efficiencies dropped with the increasing salinity. The effluent COD from MBR was 133 mg/L corresponding to the salinity of 17.5 g/L, and the COD removal efficiency was 85%. When it came to the A/O process, the COD removal was worse than for MBR at the same salinity. The effluent COD and COD removal by A/O were 237 mg/L and 75%, respectively. When the salinity was 24.5 g/L, the effluent COD from MBR and A/O were 237 and 390 mg/L, respectively. The COD removal efficiencies were 75 and 57%, respectively.

When the MBR and A/O processes were employed to treat saline wastewater, the COD removal was affected little with the salinity not more than 10.5 g/L. However, both were affected with the increasing salinity, and especially the A/O process. When the MBR was employed to treat high saline wastewater, the effluent COD was less than that from the A/O process. The MBR process was more suitable for the treatment of high saline wastewater. First of all, the MLSS in MBR was higher, and a variety of microorganisms existed in the reactor. All of these microbes could be rejected by the membrane and retained in the reactor. As a result, they could have enough time to accommodate to saline surroundings and combat salt inhibition. Besides, refractory matters in wastewater could be rejected both by the membrane and biofilm. This could make the effluent COD decrease further.

3.2. Ammonia removal with different salinities

Ammonia removal with different salinities was investigated both in the MBR and in the A/O processes. Fig. 3 shows the effluent ammonia and

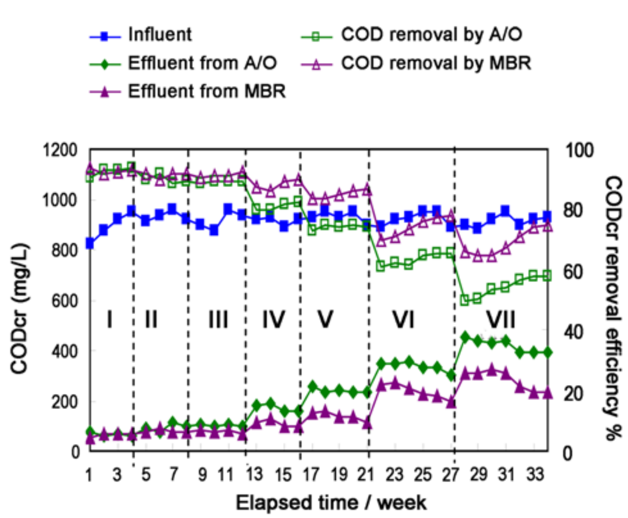

Fig. 2. COD removal with different salinities.

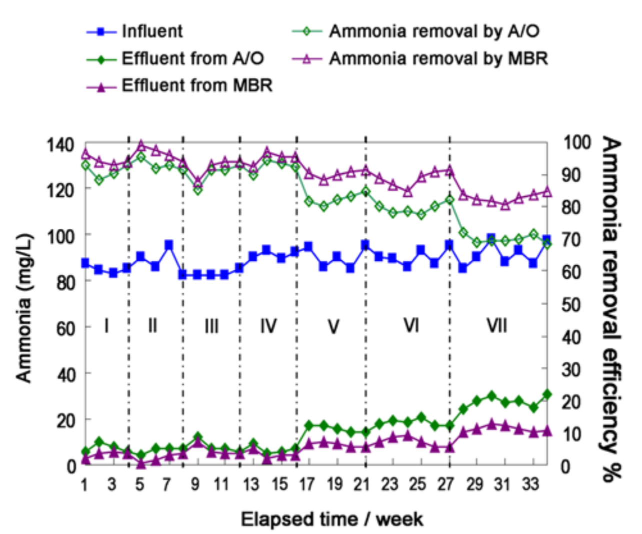

Fig. 3. Ammonia removal with different salinities.

ammonia removal throughout the operation. In general, the ammonia removal both in MBR and in A/O was affected little when the salinity was not more than 14 mg/L. The effluent ammonia from the MBR and A/O were 5 and 7 mg/L, respectively, and the ammonia removal efficiencies were 95 and 93% accordingly. With the salinity of 17.5 mg/L, the effluent ammonia increased. The ammonia removal by MBR and A/O were 90 and 82%, respectively. When the salinity increased to 24.5 g/L, the ammonia removal by MBR was kept at 82% while it decreased to 69% in A/O process. The effluent ammonia from MBR was much higher than that from A/O reactor.

Like the organics removal, ammonia removal was affected little in lower salinity surroundings, and high salinity worsened the ammonia removal. This was much aggravated in the A/O process. However, compared with the COD removal in this study, the ammonia removal was even better, and the MBR had more potential for ammonia removal from high-saline wastewater. Nitrifying bacteria belonged to autotrophic organisms that reproduced much slower than heterotrophic ones. As a result, the double time of nitrifiers was far longer than heterotrophic microbes'. Nitrifying bacteria were difficult to enrich in conventional activated sludge process. Although the membrane adopted by MBR failed to reject ammonia, it could keep all nitrifiers in the reactor. Consequently, autotrophic nitrifying bacteria could be enriched and have sufficient time to accommodate to the saline environment.

3.3. Sludge-settling property with different salinities

Settling property of sludge was important throughout the biological treatment process. It could be indexed well by sludge volume index (SVI). Fig. 4 shows the variation of SVI with different salinities both in MBR and in A/O processes. When the salinity

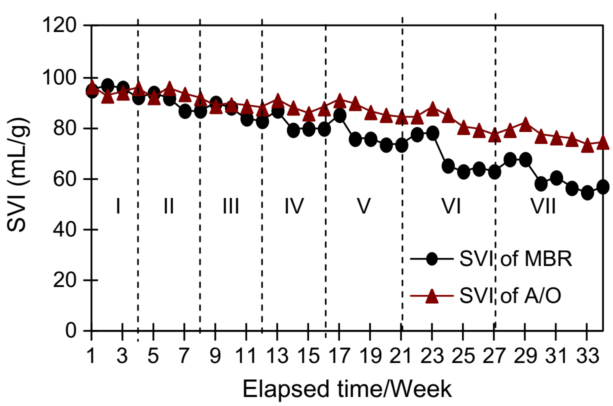

Fig. 4. Variations of SVI with different salinities.

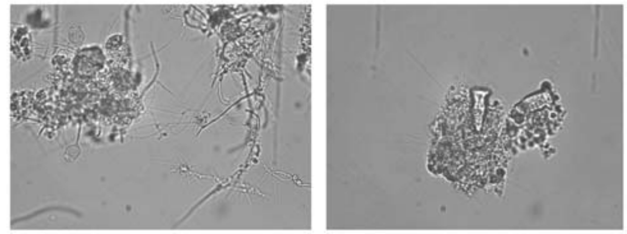

Fig. 5. Sludge images from A/O (left) and MBR (right) with the salinity of 24.5 g/L.

was 3.5 g/L, both SVI were around 97 mL/g. With the salinity added, sludge-settling property was enhanced in both reactors. With the salinity of 14 g/L, the SVI of MBR was 80 mL/g, while the SVI of A/O was 88 mL/g. When the salinity was 24.5 mL/g, the SVI of MBR and A/O were 55 and 75 mL/g, respectively. In general, both SVI decreased with salinity increment. However, the SVI of MBR dropped more greatly than that of A/O, which indicated the better sludge settling property in the MBR process.

As we all know, the density of seawater is higher than that of freshwater, thus creating greater resistance to sludge-settling because of larger buoyant forces. This contradicted our test results. In order to explore the phenomenon, the sludge structure was investigated further. Fig. 5 shows the sludge structures in MBR and A/O processes. Microbes in both reactors aggregated tightly, and the sludge was quite compact. In saline surroundings, both the activity and the growth of organisms were inhibited. In order to combat the salt inhibition, microbes secreted extracellular polymeric substances (EPS) to protect themselves. Our findings also agreed with the early research that high salinity greatly increased EPS content [21]. It was EPS that made microorganisms adhere to each other tightly, which could resist the salt effect better. However, there were filamentous bacteria in the A/O reactor. This made the sludge-settling property was not as good as that in the MBR process.

3.4. Membrane fouling and cleaning

When the MBR and A/O were employed to treat the saline wastewater, both the pollutants removal and sludge-settling property through MBR were better than A/O process. However, membrane fouling occurred inevitably during the MBR process. Viscosity of high-saline wastewater is much higher than that of fresh water. This aggravated the membrane fouling.

The membrane fouling of the MBR could be indexed by an increase in transmembrane pressure (TMP). At the beginning, the TMP was only 5 kPa. With the 198 day operation, however, it increased to 50 kPa. The membrane cleaning was performed. First of all, a sludge cake was flushed out by tap water. Secondly, membrane modules were cleaned chemically by mixed solutions of NaClO and NaOH. Finally, the modules were dipped into distilled water for 8 h. After the physical and chemical cleaning, the TMP dropped dramatically to 8 kPa and the filtration capacity of the membrane was almost recovered completely. It was indicated that the microorganisms and organic matters that were attached on the membrane surface were removed by the cleaning agents.

4. Conclusions

Based on the tests presented above, it was concluded that MBR process was more suitable for the treatment of high saline wastewater. The COD and ammonia removal efficiencies were 75 and 82%, respectively, with the salinity of 24.5 g/L. Both were higher than that through A/O process. Autotrophic nitrifying bacteria could be enriched and have sufficient time to acclimate to the saline environment. Both SVI decreased with salinity increment. However, the SVI of MBR dropped more greatly than that of A/O, which indicated the better sludge-settling property in the MBR process. Filamentous bacteria existed in the A/O reactor and made the sludge-settling property worse than that in the MBR process. Membrane fouling occurred inevitably during the MBR process. Microbes and organics could be removed by combined physical and chemical cleaning.

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