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A real trial of an innovative membrane bioreactor for saline sewage treatment

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ABSTRACT

We have recently developed non-woven membrane modules to be immersed in activated sludge bioreactor for treating saline sewage. To evaluate the feasibility and energy consumption of this technology, a pilot trial of up to 7 m^3/day was conducted over 270 days at the Hong Kong University of Science and Technology (HKUST). This paper reports part of the data obtained from this pilot trial. The pilot plant produced steady and good quality effluent. The average effluent total nitrogen (TN) was 7.7 mg N/L, total chemical oxygen demand (TCOD) 27 mg/L and total suspended solids (TSS) 15 mg/L, respectively. The maximum effective permeate flux was found to be up to 6 m/d, while the air-to-water volumetric ratio could be as low as 15. The trans-membrane pressure (TMP) was maintained at 0.1 bars after each backwash with around 1% of the effluent. The backwash was conducted once in 48 hrs. The membrane modules worked well without clogging for 270 days until an accidental failure of power source, which lasted for 30 hrs without aeration and thus resulted in fouling of the coarse membrane. The tested mixed liquor suspended solids (MLSS) ranged from 2200 to 6000 mg/L without purposeful sludge withdrawal during this trial period. This study clearly demonstrated that the developed treatment technology offers competitive applications in sewage treatment in terms of low membrane and operational costs as well as long-lasting dynamic filter without clogging.

Keywords: Dynamic membrane filter; Low-cost MBR; Saline sewage treatment; Pilot trial

1. Introduction

Membrane bioreactor (MBR) defines a combination of an activated sludge process and a membrane separation. Due to recent innovations and significant cost reductions, the applicability of MBR technology in wastewater treatment has rapidly increased (van der Roest *et al.*, 2002). The size of installations has grown from few thousands to hundreds thousands population equivalent in recent years (Kanai *et al.*, 2007). However, frequent membrane cleanings (Melin *et al.*, 2006), high air-to-water ratios (30-50) (Wang *et al.*, 2008), low permeate fluxes (0.2-1 m/day) (Melin *et al.*, 2006) and substantial reduction of excess sludge (Wang *et al.*, 2008). All these constraints limit applications of MBR in municipal sewage treatment in view of relatively low capital and operation & maintenance (O&M) cost requirements.

In order to reduce both the capital and O&M costs, dynamic filters or coarse membranes have recently emerged to develop low-cost MBRs (Daido *et al.*, 2000; Kiso *et al.*, 2000; Ozaki and Yamamoto, 2001; Huang *et al.*, 2001; Alavi Moghaddam *et al.*, 2002, 2003; Seo et al., 2002; Fuchs *et al.*, 2005; Chen and Pang, 2006). Although the suspended solids (SS) and pathogens rejection ability of

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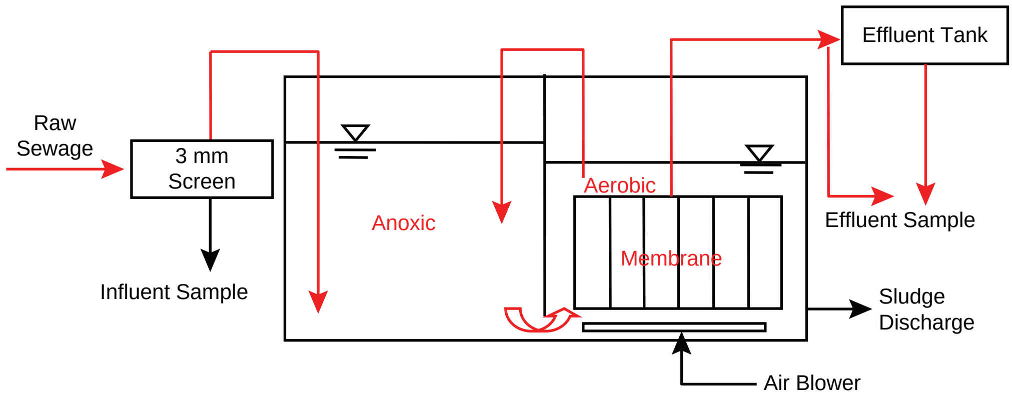

Fig. 1. Schematic diagram of the pilot plant.

such an MBR is inferior to an MF or UF MBR, the effluent quality in terms of TSS and TCOD removal is better than conventional activated sludge processes (Chen and Pang, 2006). In the recent few years, pilot-scale demonstrations of such dynamic filter/coarse membrane-based MBRs have increased (Huang *et al.*, 2001). However, their air-to-water ratios are still too high while the permeate fluxes are low (less than 2 m/day), in addition to easy clogging of the coarsemembranes. To overcome these shortcomings, we have successfully devised a novel coarse MBR system. This paper focused on a pilot-trial of our low-cost MBR technology under continuous operation conditions to treat up to 7 m^3/day screened saline sewage over a period of 270 days. The objectives of this study were to evaluate the plant performance in terms of effluent quality, maximum MLSS and permeate minimum air-to-water ratio and excess sludge withdrawing. The pilot-plant testing data will facilitate full-scale application of this new technology in sewage treatment.

2. Pilot plant outline

Fig. 1 shows the pilot plant configuration. Raw sewage was pumped from a sewer section receiving sewage discharge from a student hall of HKUST. The raw sewage passed through a 3-mm screen before being fed to an equalization tank having a hydraulic retention time (HRT) of less than 3 hrs. Screened sewage was continuously pumped to a 1.5 m^3 bioreactor which contained two compartments: an aerobic and anoxic compartment. Permeate was withdrawn from the coarse membrane modules installed in the aerobic compartment. A mixed liquor recirculation was made between the aerobic and anoxic compartments at 300% inflow rate. The effluent tank supplied treated water for backwash. The backwash wastewater was returned to the reactor automatically. The membrane used in this study was non-woven material with special surface treatment. The membrane modules were flat type.

2.1. Operational conditions

Table 1 shows five testing phases involving different permeate fluxes and mixed liquor suspended solids (MLSS) concentrations. The average daily inflow rate was up to 7 m^3 and the corresponding HRT was 5.5 hrs. Since the sewer sewage flow varied diurnally, two water level sensors were used to control the water level in both the bioreactor and the equalization tank so that a constant inflow rate can be maintained according to a tested permeate flux. The MLSS concentration was usually around 2600 mg/L, except that MLSS was changed for investigating the effects of MLSS on the TMP and effluent quality. The increase in MLSS was made by adding appropriate amount of activated sludge taken from a local secondary sewage treatment works. When different membrane fluxes were tested the sludge retention time (SRT) changed correspondingly, which could be determined from the daily escape of SS via the effluent since there was no withdrawal of sludge from the bioreactor. When the flux was tested between 2 and 4 m/day, the SRT was found to be 35.9 and 172.4 days, respectively. Different air supply rates from 60 to 72 m^3/d were also tested in order to determine the minimum air-to-water ratio. The resulted DO in the aerobic compartment was

Table 1
Tested membrane fluxes and MLSS concentrations.

Phase	Operation Day	Flux (m/d)	MLSS (mg/L)
1	0–60	3	2200–3400
2	61–120	3.2	4800–3500
3	121–145	2–4	6000
4	146–270	4	2500

maintained between 2.2 and 2.8 mg/L, while pH was between 6.5 and 6.9. The water temperature varied from 18 to 30 °C from winter to summer. Backwash was conducted within several minutes using around 1% of treated water taken from the effluent tank. The frequency was once per 48 hrs.

2.2. Analysis of influent and effluent qualities and sludge concentration

Daily composite samples were taken from the equalization tank and the effluent, while grab samples were collected from both the anoxic and aerobic compartment as well as the effluent. All composite samples were formed in refrigerators at 4°C. SS, MLSS, mixed liquor volatile suspended solids (MLVSS), and 5-day biochemical oxygen demand (BOD_5) were determined according to the Standard Methods (APHA, 1998). Colorimetric flow injection analysis (FIA, QuikChem, 8000 FIA+, Lachat) was used to measure ammonium nitrogen (Bromocresol purple method) and nitrite and nitrate (Sulfanilamide method). COD was measured using Hach COD. Total nitrogen was determined with a TOC-TN analyzer (Shimadzu TOC-5000A) and TKN was analyzed by the FIA method after sample digestion was conducted using digestion solution according to the Standard Methods (APHA, 1998).

3. Results

3.1. Transmembrane pressure (TMP)

In 270 days operation, our coarse membrane MBR performed steadily, which TMP was controlled below 0.25 bars before backwash and 0.1 bars after backwash. During the entire operation period, neither in-tank nor off-tank membrane chemical cleaning was conducted except moderate air scouring and backwash. Due to unpredicted power failure on Day 270 for 30 hrs, the TMP sharply increased from 0.2 bars to 0.6 bars under a no aeration condition, as shown in Fig. 2. We, therefore,

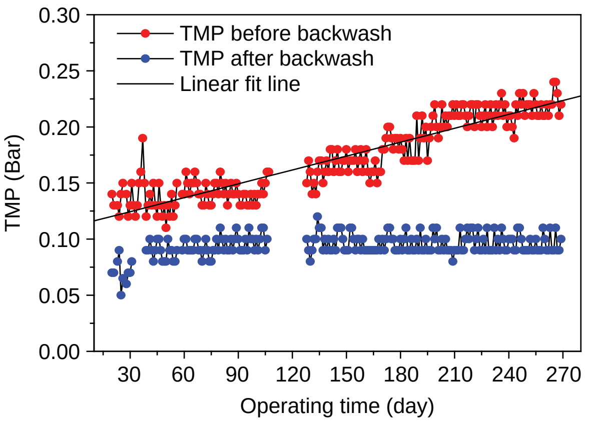

Fig. 2. Variation of TMP.

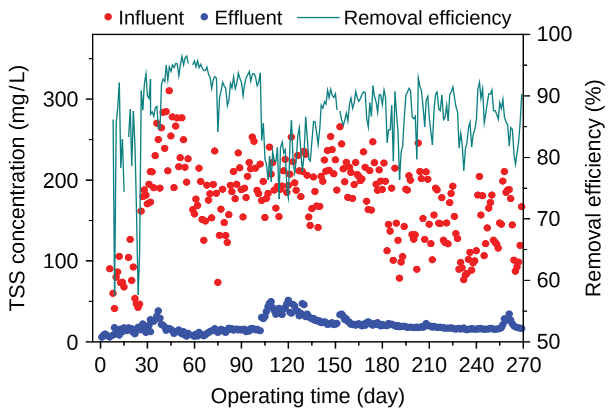

Fig. 3. SS removal.

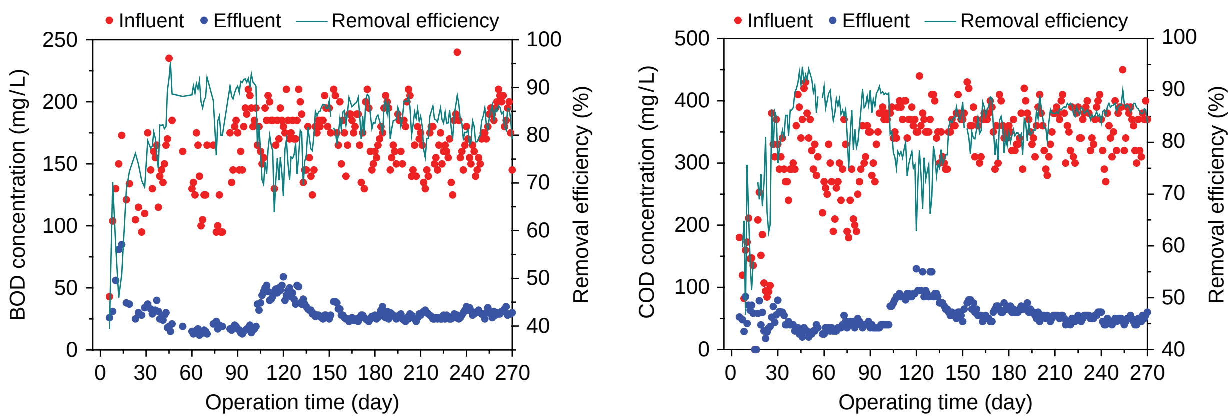

Fig. 4. BOD_5 and COD removal.

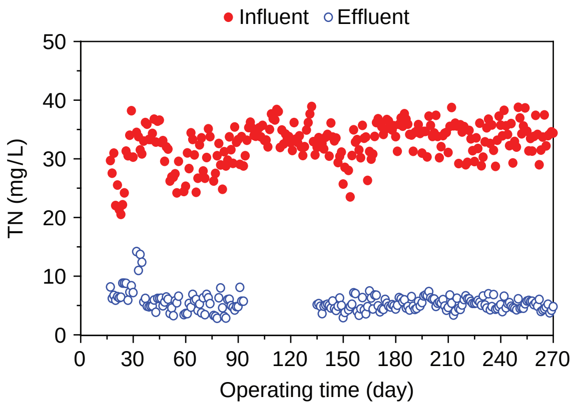

Fig. 5. The change of TN removal.

decided to take all modules out for examination and the operation was suspended.

3.2. SS, COD, and TN removal

Fig. 3 shows the removal of SS in this plant, which was 92% and Fig. 4 shows both BOD_5 and COD removal efficiencies were 90%. Although the influent qualities varied significantly, the effluent qualities were stable.

Fig. 5 shows the nitrogen removal. More than 82% TN was removed and the effluent was less than 7 mg/L on average in which 92% ammonia removal and 93% total Kjeldahl nitrogen (TKN) removal were achieved.

3.3. Effluent quality

Fig. 6 shows the photos of influent and effluent composite samples and Table 2 summaries the average effluent qualities.

3.4. Other results

The air flow rate was reduced from 72 to 60 m^3/d on Day 255, the removal efficiencies of SS, BOD_5, COD and TN all remained the same, while the operation flux was unchanged. Fig. 7 shows the effect of permeate flux on the performance of the pilot plant under different sludge concentrations were evaluated. When MLSS varied from 2000 to 4000 mg/L, the TMP increased with an increase in the influent flow rate; when MLSS further increased to around 6000 mg/L, the effluent quality in terms of TKN and NH_4-N improved compared with that with MLSS of 2000-4000 mg/L, though the effluent COD and TSS became slightly higher, indicating that

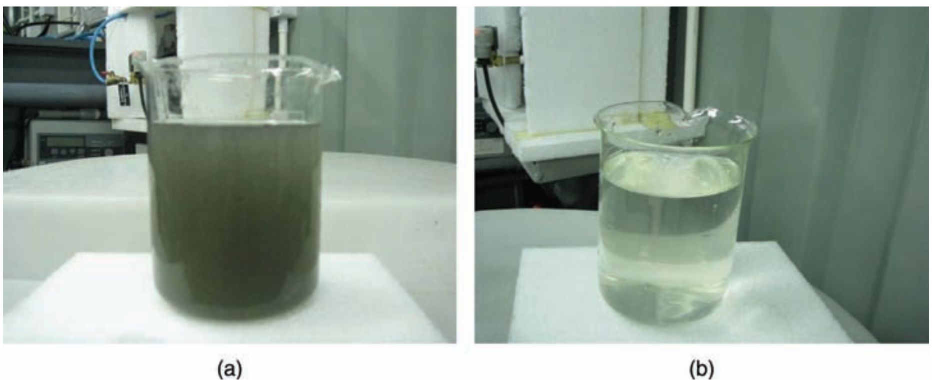

Fig. 6. Photos of (a) influent and (b)effluent.

Table 2
Summary of average influent and effluent qualities.

Parameter	Influent (mg/L)	Effluent (mg/L)	Hong Kong secondary treatment discharge standards
COD	287	27	<70
TSS	236	15	<30
NOx-N	-	2.7	<5
Ammonium-N	27.5	1.9	<2
Total nitrogen (TN)	32.5	7.7	<10
E. Coli	~10^6	<5 CFU/100 mL (after 1-min UV disinfection)	<1,000 CFU/100 mL

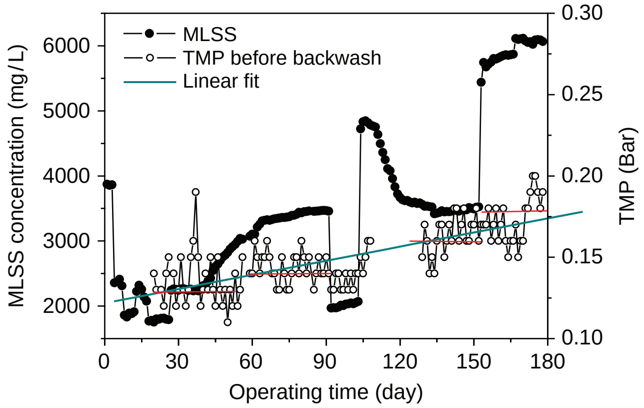

Fig. 7. The change of TMP with MLSS changing.

the maximum MLSS can be up to 6000 mg/L. This high MLSS helps to increase treatment capacity. However, with the increase of MLSS concentration, TMP increased although not very obviously. TMP can be affected by many factors such as sludge cake thickness, sludge concentration, extra-cellular polymeric substance (EPS) and activity of biomass etc. As shown in the Fig. 7, the higher MLSS concentration the higher TMP value correspondingly. When the MLSS concentration increased from 2000 mg/L to 6000 mg/L, the TMP increased from 0.14 to 0.2 bars, though it is still below the critical TMP of 0.3 bars. However, a high rate TMP value increases an opportunity of membrane fouling.

4. Conclusions

The main results of this study are as follows:

1. The pilot plant was successfully operated for 270 days without fouling. It produced steady and good quality effluent.
2. The plant effluent quality met the Hong Kong secondary sewage discharge standards. The average effluent TN, COD, and SS was 7.7, 27 and 15 mg/L, respectively.
3. The maximum effective permeate flux can be up to 7 m/d, while the air-to-water volumetric ratio could be as low as 15.
4. TMP was maintained at 0.1 bar after each backwash with the effluent. The backwash was conducted once only in 48 hrs using about 1 % of treated water.
5. The maximum MLSS can be up to 6000 mg/L without increasing TMP significantly.

Acknowledgments

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