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Evaluating the membrane fouling control ability of a reciprocation membrane bioreactor (rMBR) system

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Abstract:

Membrane bioreactors (MBRs) are being increasingly applied to many full-scale plants around the world to treat both municipal and industrial wastewater. However, membrane fouling and energy consumption are significant challenges to broader applications of MBRs. By using a new MBR configuration, this research aims to compare the performance between a conventional MBR and a reciprocation MBR (rMBR) that uses inertial forces without air scouring for fouling reduction. The results show that there was no difference in chemical oxygen demand (COD) (92-98%) or total nitrogen (TN) (71-77%) after 280 d of operation under the same influent constraints. However, by using the inertial force, the fouling rates were 0.35 mbar/d for the rMBR, resulting in a significantly lower fouling rate in comparison with a conventional MBR and other literature reports. Thus, the lower energy consumption over long-term operation of a rMBR could be a promising solution to overcome the drawbacks of a MBR.

Keywords: **energy consumption, fouling, reciprocation membrane bioreactor.**

Classification numbers: **2.3, 3.5**

Introduction

With rapid population growth, the demand for water in daily life has increased, which poses many challenges to water supply efforts [1] leading to water shortage and water pollution. Therefore, strict standards and regulations have been proclaimed to force all industries to use appropriate treatment technologies to reduce pollution before discharging to receiving sources. Nowadays, many wastewater treatments plants have applied technologies such as conventional activated sludge, biological filters, and wastewater stabilisation ponds. However, these technologies have a limited scope of application due to their low energy recovery and high footprint, and improving effluent wastewater to meet a higher level of quality standards is needed. The use of traditional treatments faces many difficulties, namely fluctuations in flow rate and the composition of wastewater, which affects the quality of the effluent as well as increases suspended solids due to the sludge drift phenomenon. Moreover, in the situation of increasingly scarce land funds, simple technologies that save space and have high treatment efficiency are often considered for wastewater treatment.

MBR technology is a compact process that combines biodegradation by activated sludge with a membrane filtration process, and it is an advancement over the conventional activated sludge (CAS) technology [2, 3]. These features make it more natural to increase the capacity of an MBR system. For example, by increasing the membrane area, the MBR system can meet treatment efficiency standards as well as minimise the space used for the wastewater treatment system. The combination of an anoxic zone with MBR (i.e., AO-MBR technology)

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could enhance performance in terms of nutrient removal. However, during operation, the accumulation of colloids, suspended solids, and microorganisms on the membrane surface has contributed to reducing permeate flux and reducing the lifetime of the filter. As a result, MBR requires strict and intense air scouring and chemical cleaning for flux recovery, which results in a significant increase of total operating costs [4]. Air scouring and chemical cleaning also contributes to diminishing the lifetime of the membrane over long-term operation. Therefore, the idea of this work is to remove the air scouring system within an MBR module and replace it with a reciprocating mechanism for fouling reduction. This reciprocating movement is made by a motor with a rotation axis that pulls the membrane's support with varying amplitude and frequency. This study aims to evaluate the performance of the rMBR in comparison to a conventional MBR in terms of organic and nutrient removal, membrane fouling reduction, and energy consumption to satisfy the requirements for practical application.

Materials and methods

Pilot set-up

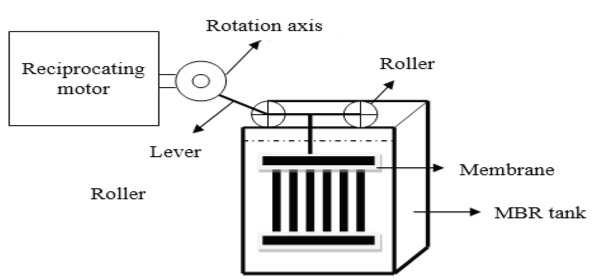

Fig. 1. Schematic diagram of the reciprocating module membrane.

The rMBR works similarly to the conventional MBR except air scouring is no longer used to minimise membrane fouling at the membrane tank. A detailed schematic of the reciprocating module membrane is shown in Fig. 1. The total system was designed with a group of treatment tanks, including an anoxic-oxic membrane tank. Other facilities such as a clean water tank, grease separating tank, equalization tank, and sludge storage tank were also investigated in this study. As shown in Fig. 1, a motor is attached to a rotation axis, which is controlled by a magnetometer that adjusts the rotational speed of the motor. The system was operated with a flux of 20 LMH, under a solids retention time (SRT) of 30 d, and organic loading rate (OLR) from 0.8 to 1.2 kg COD/m^3.d. The amplitude of the motor of the rMBR was set to 60 mm, the frequency at 0.46 Hz and 0.3 Hz, and the average movement speeds of the membrane module were 2.76 cm/s. This study uses a polyvinylidene fluoride (PVDF) hollow fibre membrane module (Kolon, Korea) with a pore size of 0.1 µm and a total surface area of 2.2 m^2. The membrane was attached to the rotation axis of the motor through the transmission bar. When the rotation axis moved circularly due to the transmission bar, the membrane was pushed, and the reciprocal movement created an inertial force on the fibres. This caused vibrations and inertial forces to facilitate the removal the pollutants on the surface and minimised fouling.

Wastewater and seed sludge

Wastewater in this study was taken from the manholes of canteen B4 of University of Technology, Vietnam National University, Ho Chi Minh city. Influent COD ranged between 400-900 mg/l, TN was between 18-38 mg/l, and total phosphorus (TP) was between 2-5 mg/l. Seed sludge used in the experiment was taken at the aerobic tank of the domestic wastewater treatment system of Coopmart Ly Thuong Kiet with a concentration of 1,955 mg/l with a sludge value index (SVI) equal to 153 ml/g. The seed sludge was acclimatised with domestic wastewater within 30 d for microorganisms' adaption and development with the new environment factor.

Analytical methods

Analytical methods for mixed liquor suspended solids (MLSS), COD, NH_4^+, NO_2^-, NO_3^-, TN, and TP are referenced in the Standard Methods for Examination of Wastewater [5]. The operation filtration of the membrane was automatically set up for 9 min of filtration, 0.5 min of backwashing, and 0.5 min of idle time for both the MBR and rMBR systems. To observe the membrane fouling, the trans-membrane pressure (TMP) was recorded daily, and the fouling rate (dTMP/dt) was determined by the slope between the TMP and operating time. The fouling membrane was washed with a NaOCl solution with a concentration of 250 ppm.

Results and discussion

Pollutant removal ability of pilot-scale system

After 280 d of operation, the quality of the treated water was assessed according to the following parameters: COD, NH_4^+, NO_2^-, NO_3^-, TN, and TP. The pollutant treatment ability of the MBR and rMBR systems at different operating conditions are shown in Fig. 2.

In the MBR stage, the COD treatment ability of the system was stable, which had an average treatment efficiency of 92-98%. This result was also found to be in line with other studies on MBR for domestic wastewater treatment [6, 7]. The COD concentration of the permeate reached an average value of 18±11.3 mg/l (mean ± standard deviation). The MBR system tended to stabilize very quickly after acclimatisation. Similarly, rMBR operation with a membrane movement speed of 2.76 cm/s saw the COD removal efficiency reach 92-99% concentration with 21±7 mg/l. It can be seen clearly that the new configuration did not affect the removal of organics, although the influent COD in the rMBR was significantly higher than in the MBR.

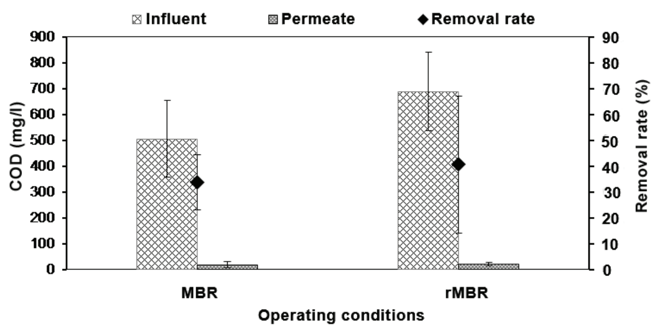

Fig. 2. COD treatment efficiency in different operating conditions.

The average specific substrate utilisation rate based on the MLSS of the COD in the MBR and rMBR were 0.33±0.1 and 0.4±0.1 kgCOD/kgMLSS.d, respectively. The average specific substrate utilisation rates did not affect the two MBRs. This is explained by the substrate consumption of microbials, which cause a decrease of COD. When using a membrane, it would act as a barrier to prevent the washing off of solids and biomass, which could contribute to improving the effluent [8, 9].

From Fig. 3, the TN treatment efficiency of conventional MBR in this period was 71±12%. Under rMBR conditions, the TN treatment efficiency was 77±11%, which was slightly higher than that of MBR. This implies that lacking air scouring, i.e. lowering dissolved oxygen (DO), could be induced to establish an anoxic zone rather than aerobic conditions for microorganisms in the membrane tank. Together with the anoxic tank, the rMBR supported the nitrification and denitrification processes much more effectively when compared with MBR. Overall, it can be seen that the nitrogen removal efficiencies were stable, with an average efficiency of 71-77%. This result was similar to the results from the previous studies of Ho, et al. (2015) and Liang, et al. (2014) [10, 11]. The process of treating nitrogen by biological methods in an AO-MBR system is quite complicated and done through the oxidation-reduction of nitrogen-containing compounds. For TN, the influent nitrogen was mainly ammonia and organic nitrogen, with an average ammonia concentration of about 40%.

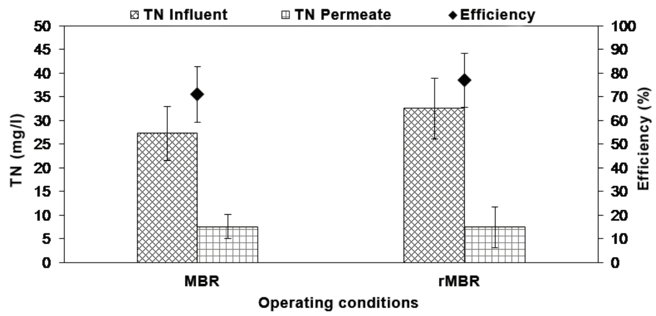

Fig. 3. TN concentration under different operating conditions.

The metabolism of ammonia and organic nitrogen in the MBR and rMBR achieved 82±14% and 96±4% average ammonia removal efficiency, respectively. Meanwhile, the average total Kjeldahl nitrogen (TKN) removal efficiency of each period was 74±9% and 83±13% for the MBR and rMBR, respectively. This demonstrates that the oxidation process occurred well enough to oxidise the ammonia in the wastewater and to reduce its concentration in the permeate. However, organic nitrogen was not as thoroughly treated, which is indicated by the TKN treatment efficiency. The average concentration of TKN in the permeate was still maintained and reached 6.6±2 mg/l and 5.5±2.5 mg/l for the MBR and rMBR, respectively. The average ammonia concentration in the permeate was 1.62±1.4 mg/l and 0.72±0.3 mg/l for the MBR and rMBR, respectively. Thus, the untreated organic nitrogen fraction during operation periods was 4.98 mg/l and 4.78 mg/l for the MBR and rMBR, respectively. The nitrate concentration in the oxic tank was almost higher than that of the anoxic tank. This can be explained by the circulation of nitrates from the oxic to anoxic zone had significantly reduced the amount of nitrate via the denitrification process. For the permeate, nitrite concentration was below 0.2 mg/l. Nitrites were still present in the system, but at low concentrations, which indicated that the metabolism was not complete.

Phosphorus was mainly absorbed into the biomass cell, which is then removed from the process through the sludge withdraw. This study had a SRT of 30 d, and the proper control of SRT could allow retention of high concentrations of biomass for phosphorous removal [12]. Moreover, influent phosphorus was quite low so that the phosphorus treatment process always met the discharge standards with efficiencies of 63±22% and 57±19% for the MBR and rMBR, respectively (Fig. 4).

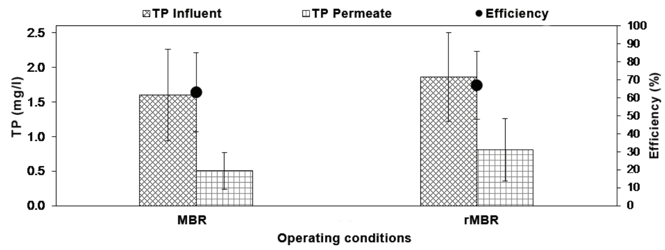

Fig. 4. TP concentration through each operating condition.

Fouling

Table 1. Fouling rates for the rMBR and MBR in comparison with literature reported using an MBR system.

System	SRT (d)	HRT (h)	OLR (kg COD/ m^3.d)	Flux (l/m^2.h)	Fouling rate (mbar/d)	References
FBMBR	48	36	0.9-1.1	12	2	[13]
Sponge-MBR	45	7.3	1.1	6	2.3	[14]
HF-MBR	45	7.3	0.4	6	8.7	[14]
AF-MBMBR	490	8	-	-	6.1	[15]
FS-MBR	30	15-25	-	16	0.31	[16]
FS-MBR	10	15-26	-	16	10.8	[16]
rMBR	30	8	0.8-1.2	20	0.35	This study
MBR	30	8	0.8-1.2	20	0.56	This study

The results show that the fouling control efficiencies of the rMBR were better and had a slower fouling rate than other MBR systems (Table 1). This demonstrates that the membrane fouling rate in rMBR, with an amplitude of 60 mm and frequency of 0.46 Hz (membrane movement speed of 2.76 cm/s), could potentially replace conventional MBR at a high flux range of 20 LMH and a low HRT of 8 h. This means that the rMBR could be used for treating a high capacity of wastewater while maintaining a significant reduction of fouling development, thereby holding promise to overcome the drawbacks of conventional MBR due to lower energy consumption over long term operation.

Conclusions

By using a pilot-scale rMBR system with different membrane movements, this research showed that the pollutant treatment efficiencies in wastewater were quite high, with average efficiencies were about 97% for COD, 75% for TN, and 62% for TP. In parallel, the fouling control ability of the MBR system combined with reciprocation was also shown, and the fouling rate was better controlled for the rMBR at a speed of 2.76 cm/s, amplitude of 60 mm, and frequency of 0.46 Hz.

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The authors declare that there is no conflict of interest regarding the publication of this article.

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