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Assessing the feasibility of a vertical double submerged membrane modules system for wastewater reclamation under different conditions

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Abstract

Nowadays, water is deteriorating for several reasons, such as an increase in wastewater that flows into rivers and the limitation of water resources. Therefore, we have concentrated our plans on securing water resources by reusing wastewater treatment effluent. In this study the reuse system was organized using a submerged membrane bioreactor (SMBR) consisting of an anoxic, select, and aerobic tank. Our plan to solve the problems mentioned above involved optimizing the operating hydraulic retention time (HRT), which was done by comparing the characteristics of water treatment for several HRTs. Also, the simple and vertical double membrane modules were analyzed to find more effective operating condition in SMBR. The Specific characteristics of the SMBR system were represented as follows. We could know below 10 mg/L of BOD, below 5 mg/L of COD, 0 mg/L of SS without changes of HRT, which was satisfied with the standard of reuse water. Optimized HRT was 2.3 h and by composing the vertical double membrane modules, air flow rate could be reduced by 28.5%, lower than that of the simple membrane module.

Keywords: Submerged membrane bioreactor (SMBR); Water reuse; Air flow rate; HRT; Membrane module

1. Introduction

Continuous economic development and growth in developed and developing countries around the world have led to a considerable increase in water demands. The worldwide demand for high quality water resources will be difficult to meet in the foreseeable future because of the dwindling supply. The imbalance in supply and demands of water resources will

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become a major problem confronting every country in the upcoming decades. Thus, water is becoming a limited resource and in the mean time, the most strategically important resource on earth [1]. An important point to be considered by the industrial sector is that the water shortage problem can also be alleviated considerably, through proper conservative measures. First of all, all industrial users would need to improve the efficiency of manufacturing processes with an aim to reducing water consumption. Secondly, an equally important alternative is to treat the wastewater effluents from the manufacturing processes and elevate its water quality to the standards for reuse [2]. Also water scarcity problems have been more and more prevalent around the world and so great attention is being paid into reclamation and reuse of wastewater by municipalities and industrial plants [3]. Wastewater reclamation and reuse has been an important option since recent industrialization and urbanization has accelerated the pollutants in the water and environment, making it a limited resource. When properly treated and recycled, wastewater can be an alternative water source which can reduce the demands for fresh water. Recycled wastewater can reduce stress on the environment as well [4]. Commonly the reclaimed water quality is established in terms of BOD or COD, turbidity, color, odor, coliform bacteria and viruses. Membrane separation technology, which is increasingly adoptive in the field of water and wastewater treatment, has shown good performance for removing these kinds of contaminants [5]. Membrane separation technologies for the removal of all suspended solids including microorganisms and a fraction of dissolved solids from wastewater are becoming more and more promising as well [6]. Membrane filtration is an effective method to remove particles, microorganisms and organic matter from drinking waters. Compared to conventional treatment methods, membrane processes (I) can provide higher quality water, (II) minimize disinfectant demand, (III) are more compact, (IV) provide easier operational control and less maintenance, and (V) generate less sludge [7]. SMBR has recently been gaining much attention for wastewater treatment in aspects of better effluent quality and lower sludge production compared to the conventional activated sludge processes [8,9]. Submerged membrane bioreactors are increasingly popular for the treatment of domestic and industrial effluents. They are compact, stable and provide a very high effluent quality that is increasingly desirable where discharges go to recreational waters, when there are space constraints on the plant or where upgrading of an existing installation is required. Submerged MBRs have been favored as their energy consumption is lower than those of side stream MBRs [10]. Membrane plants are found to be relatively easy to operate with minimal fumbling if the air flow rates are sufficiently high and the flux is sufficiently low [11]. This paper is intended to help move towards optimal design on operation of submerged reactor treatment plants. The optimum composition of a new reclamation system, satisfying a more stringent regulation of reclamation in order to reuse municipal wastewater has been studied.

2. Materials and methods

2.1. Experimental set up

The SMBR system was operated for treating 75 m^3 of the wastewater daily, consisting of two different lines. The bio-reactor was divided into an anoxic reactor, a selector reactor, and an aerobic reactor. According to the different configurations of the submerged membrane modules, line I and line II were distinguished from each other. The configuration of line I had a simple membrane module and line II had vertical double membrane modules. The schematic diagrams of line I and line II are shown in

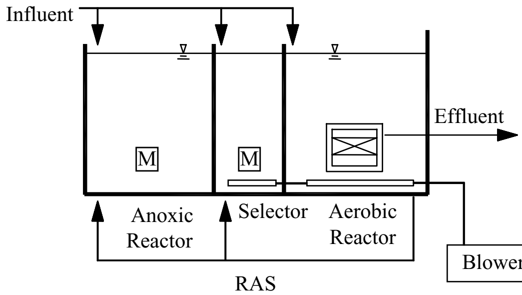

Fig. 1. Schematic diagram of the pilot-scale SMBR system (line I).

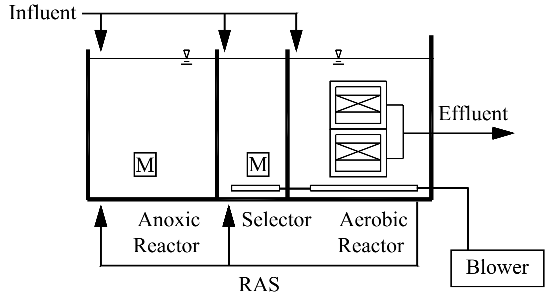

Fig. 2. Schematic diagram of the pilot-scale SMBR system (line II).

Figs. 1 and 2 respectively. Table 1 shows the operating conditions of each line.

2.2. Methods

To determine the optimal operating condition and configuration for meeting the stringent water reuse standards, the submerged membrane modules were set up as simple and vertical double configurations in each system. Moreover, the inflow point of raw water was changed to mode 1, 2, 3 and 4. The operating conditions of mode 1, 2, 3 and 4 are summarized and shown in Table 2. The behaviors of each membrane module were also investigated with the variations

Table 1
Operation conditions of SMBR system

Item	Line I			Line II		
	Anoxic	Selector	Aerobic	Anoxic	Selector	Aerobic
Volume (m^3)	4.8	2.4	4.8	4.8	2.4	4.8
Flow rates (m^3/day)		25			50	
Air flow rates (m^3/h)		20 ± 2			30 ± 4	
DO (mg/L)	0	0/3.0	3.0–5.0	0	0/3.0	3.0–5.0
MLSS (mg/L)		10,000–14,000			10,000–16,000	
SRT (day)		60			60	
HRT (h)	4.6	2.4	4.6	2.3	1.2	2.3
		11.6			5.8	
Suction pressure (kPa)		0–40			0–40	
Suction operation mode	Intermittent operation (10 min ON/2 min OFF)			Intermittent operation (10 min ON/2 min OFF)		
Membrane						
Type	Plate membrane module			Plate membrane module		
Pore size	0.4 μm (Nominal pore size : 0.25 μm)			0.4 μm (Nominal pore size : 0.25 μm)		
Dimension	490 W × H1000 × T7.5			490W × H1000 × T7.5		
Material	Synthetic resin			Synthetic resin		
Flux area	63 m^2			63 (×2) m^2		
Flux	0.397 m^3/m^2 . day			0.397 m^3/m^2 . day		

Table 2
Experimental condition

Mode	Configuration of bioreactor	HRT (h)		Test periods (days)
		Line I	Line II	
Mode 1	Anoxic-Selector (Anoxic)-Aerobic	11.6	5.8	21
Mode 2	Selector (Anoxic)-Aerobic	7.0	3.5	21
Mode 3	Selector (Aerobic)-Aerobic	7.0	3.5	22
Mode 4	Aerobic	4.6	2.3	23

of pressure and the flux resistance in the two different membrane module configurations. To develop the water reuse system, the high efficient and economic water reuse treatment technology was needed. Therefore, this study focused on the economic operating conditions for improving the aeration effects. Because of this, the vertical double membrane modules were immerged into the reactor which had the same area as the simple membrane module reactor. To evaluate the economic advantages of this configuration, A/L (aeration/flux) ratios were also calculated.

3. Results and discussion

3.1. Treatment characteristics with various inflow points of raw water

With various inflow points of raw water the experiment was conducted evaluating the removal efficiencies of the submerged membrane bioreactor, which was affected by both the variations of HRTs and system configurations. Fig. 3 shows the removal efficiencies of SS during the whole experiment. Although the SS concentrations of raw water ranged from 3 to 246 mg/L, average concentration was 176 mg/L; the concentration of the effluent was only 0 mg/L which indicated that 100% of SS was completely removed in mode 1, 2, 3 and 4. The removal characteristics of COD are shown in Fig. 4. The COD concentrations of influent were 76–128 mg/L, but the concentration of effluent was reduced to 5 mg/L in both line I and line II (over 95% of COD was removed). Fig. 5 shows the removal characteristics of BOD. The influent concentrations ranged 128 to 146 mg/L and the concentration of the effluent was reduced to below 10 mg/L which met the water reuse standards (93% of BOD mass was removed).

The BOD volumetric loading rates (VLRs), BOD removal efficiencies and the BOD mass according to the various inflow points of line I and II are shown in Figs. 6–8. The BOD VLRs of line I on mode 1 condition were 0.28–0.30 kg BOD m^3/day. BOD mass was removed to 3.13–3.44 kg/day and the average removal efficiency was 93.8%. But BOD mass was removed to 6.24–6.83 kg/day in line II with 0.56–0.61 kg BOD m^3/day of BOD VLRs. It was lower than

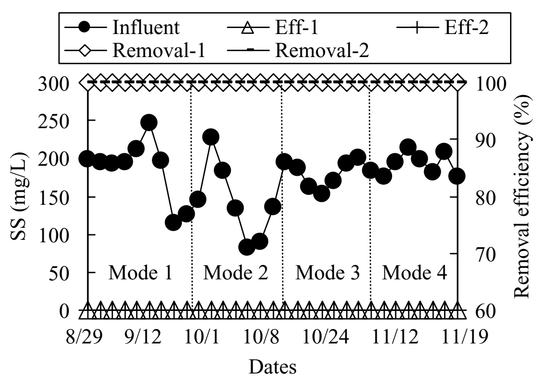

Fig. 3. SS removal efficiency in the SMBR.

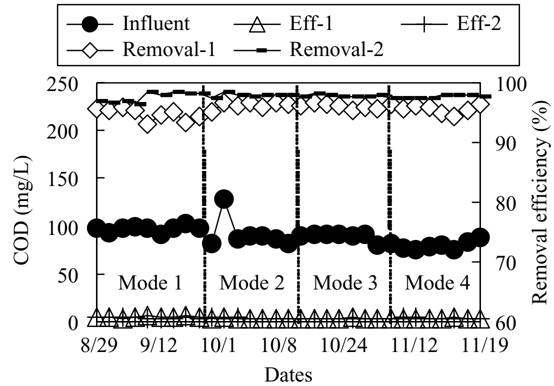

Fig. 4. COD removal efficiency in the SMBR.

line I (the removal efficiency in line II was 93.3%). During these experiments, the HRT was 11.6 and 5.8 h respectively. Fig. 7 shows the BOD removal characteristics on mode 2 and 3. The BOD mass of line I was removed to 3.0–3.43 kg/day with 0.44–0.51 kg BOD m^3/day which was 93.8% of the BOD removal efficiency. The BOD mass of line II was also removed to 5.92–6.83 kg/day with 0.89–1.01 kg.BOD m^3/day which was 93.1% of BOD removal efficiency. The HRTs on mode 2 and 3 were 7.0 and 3.5 h. Fig. 8 shows the results on mode 4 condition which the inflow point was connected to the MBR directly. Therefore, it was the shortest HRT of all modes. Although the BOD mass of line I

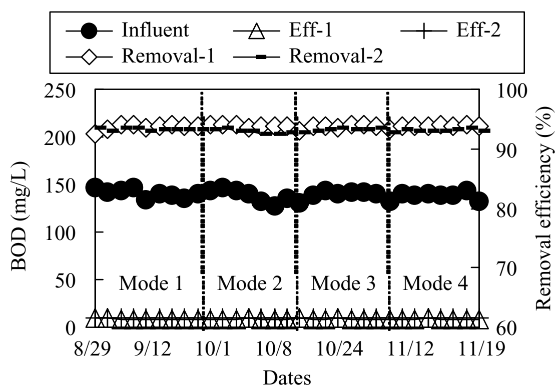

Fig. 5. BOD removal efficiency in the SMBR.

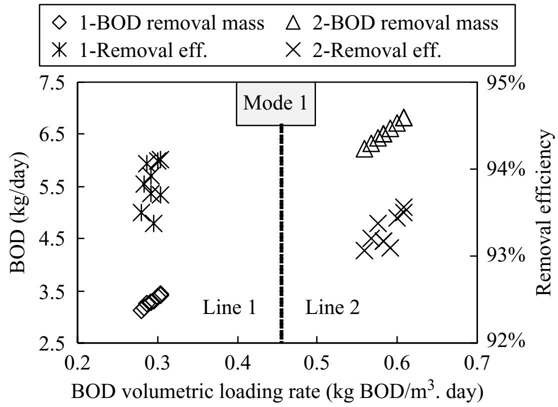

Fig. 6. BOD removal mass & efficiency with different BOD VLRs on mode 1.

was removed to 3.08–3.39 kg/day, the BOD VLRs were 0.69–0.75 kg BOD m^3/day. At that time the BOD removal efficiency was 93.8% with 4.6 h of HRT. The BOD VLRs of line II were 0.38–1.50 kg BOD m^3/day which was the highest VLRs, but BOD mass was removed to 6.13–6.74 kg/day and the removal efficiency was 93% with 2.3 h of the shortest HRT. In this experiment the BOD VLRs were 0.28–1.5 loading that was the very high range. In the case of line I the BOD VLRs were 0.28–0.75 loading, but the BOD concentration of the effluent was

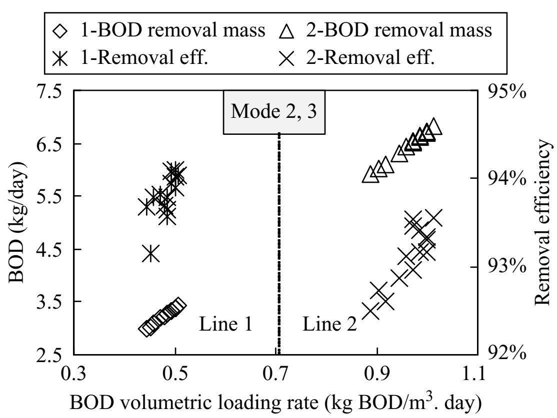

Fig. 7. BOD removal mass & efficiency with different BOD VLRs on mode 2, 3.

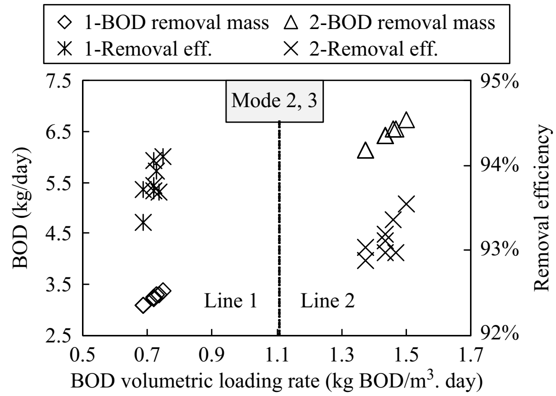

Fig. 8. BOD removal mass & efficiency with different BOD VLRs on mode 4.

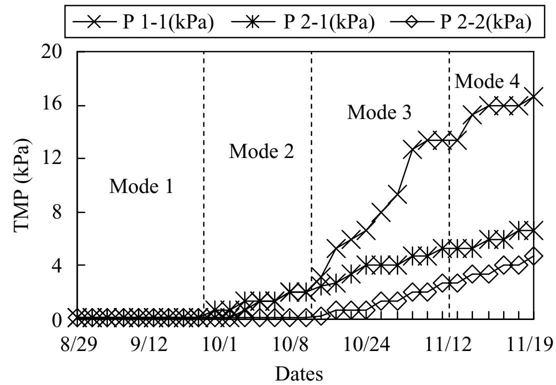

Fig. 9. Variation of TMP during operation period.

below 10 mg/L and the BOD removal efficiency was over 93%. The maximum BOD VLRs of line II was 1.50 kg.BOD m^3/day, but the concentration of the effluent was below 10 mg/L. Also, on mode 4 the conditions had the shortest HRT and the BOD removal efficiency was stable at over 93%.

3.2. Operating characteristics of the plate type membrane in SMBR

The experiment was conducted evaluating the various pressures of the membrane, permeated flux and total resistances in submerged membrane bio-reactor pilot-plant. Fig. 9 shows the various pressures of the membrane. It shows the various inhalation pressures of the simple membrane module in line I (1-1), the upper one of vertical double membrane modules in line II (2-1) and the bottom one of the vertical double membrane modules in line II (2-2). On the mode 3 the various pressure values of 1-1, 2-1 and 2-2 were 16.7 KPa, 6.7 KPa, 4.7 KPa respectively. The variations of the permeated flux are shown in Fig. 10. It was the same value among 1-1, 2-1 and 2-2 on the mode 1, but on the mode 4 the permeated flux decreased to 99 L/m^2/h/bar at the end of the experiment. The decreasing rate of the 2-2 membrane module's permeated flux was lower than the 2-1 membrane module's. Fig. 11 shows the total resistances of the each membrane module. At the early experiment, the total resistances were same value to 1.43E + 8 m^{-1}, but at the end of the experiment on mode 4, the total resistance of line I showed the highest value (1.78E + 10 m^{-1}). 2-1 and 2-2 membrane module in line II showed 7.14E + 09 m^{-1}, 5.00E + 09 m^{-1} of the total resistance respectively. It indicates that the total resistance of the upper membrane module (2-1) was much higher.

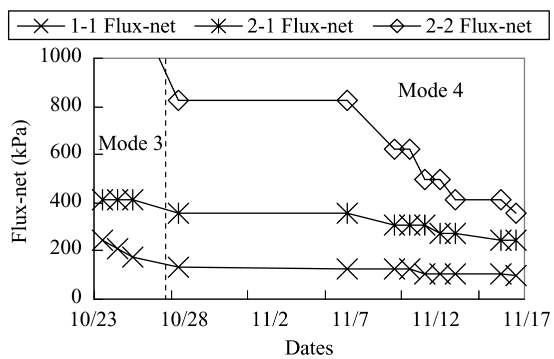

Fig. 10. Comparison between permeated fluxes of line I and line II.

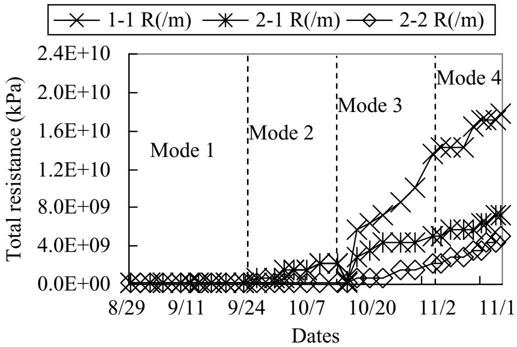

Fig. 11. Comparison between total resistance of line I and line II.

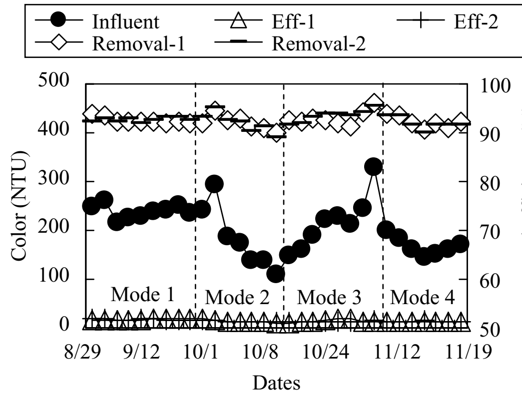

Fig. 13. Color removal efficiency in the SMBR system.

3.3. *Availability to meet water reuse standards and economic evaluation of SMBR*

To evaluate the availability of the submerged membrane bio-reactor to meet the water reuse standard, turbidity, color and total coliforms removal characteristics were investigated (Figs. 12–14). The turbidity concentrations of the influent were 43–446 NTU and the concentration of the effluent was below 0.49 NTU. The turbidity removal efficiency was average 99.6% regardless of the membrane module's configuration and the various inflow points. The color of the influent ranged from 110 to 328 degrees and the effluent concentration was below 20 degrees regardless of any operating condition changes. The simple membrane module removed below 11 degrees and the vertical double membrane modules removed below 12 degrees, both of them were over 90% of removal efficiency. Fig. 14 shows the removal efficiencies of total coliforms. The total coliforms were detected over 32,000 CFU in the influent but no total coliforms were detected in the effluent. It indicates that the removal efficiencies of total coliforms 100% completely.

These results prove that this SMBR system has an ability to meet the water reuse standards

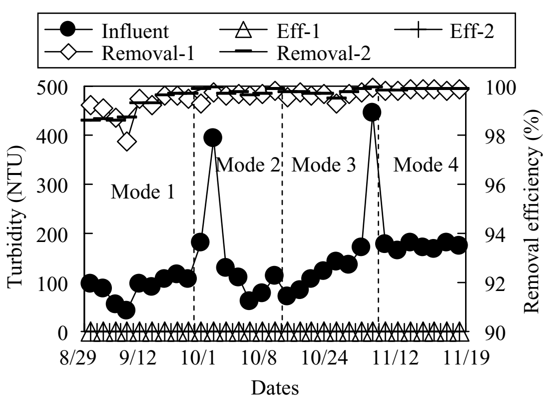

Fig. 12. Turbidity removal efficiency in the SMBR system.

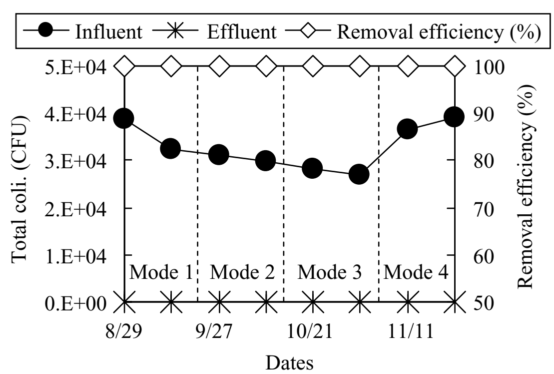

Fig. 14. Total coliforms removal efficiency in the SMBR system.

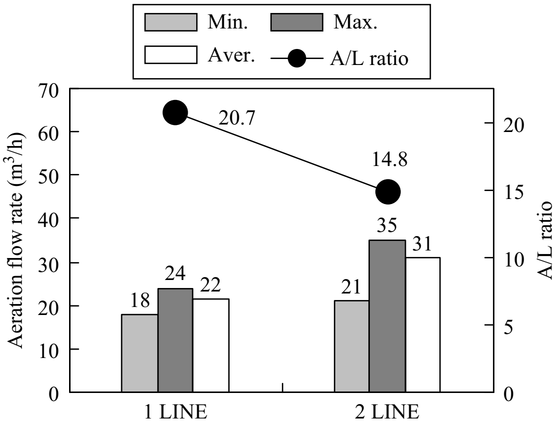

Fig. 15. Air flow rate and A/L ratio in the SMBR system.

regardless of the various inflow points that represent HRT. Fig. 15 shows the amounts of supplied air and A/L ratios which indicate the efficiency of aeration. Line I treated 25 m^3 daily and the amounts of supplied air were 22 m^3/h (A/L ratio:20.7). Also line II treated 50 m^3 daily, then the amounts of supplied air were 31 m^3/h (A/L ratio:14.8). According to these results the fact is proved that the vertical double membrane modules configuration can produce twice than the simple membrane module with same bio-reactor area. It means that only 1.5 times more the supplied air amounts can decrease the A/L ratio to 28.5%. Therefore, the production can be increased to double with decreasing the aeration to 28.5% in same reactor. This is the economic advantage of this system.

4. Conclusions

For water reuse of municipal wastewater the combined system, bio-reactor as the bio-treatment of Activated sludge system and submerged membrane module, creates the following results.

The removal efficiencies of the SS, COD and BOD in the submerged membrane bio-reactor with the various HRTs were 100, 95 and 93% respectively. Also Turbidity, color and total coliforms were removed on the mode 4 condition, which was the shortest HRT to 0.49 NTU, below 20 degrees and not detected respectively. Therefore, it could be possible to meet the water reuse standards even though the shortest HRT of line I and line II was applied (Line I: 4.6 h; Line II: 2.3 h).

The relationship between the COD, BOD volumetric loading rates and the effluent quality was investigated. The COD, BOD volumetric loading rates highly ranged 0.061–0.48 kg. COD m^3/day, 0.28–1.5 kg. BOD m^3/day respectively. But the average removal efficiencies of BOD and COD were 95 and 93% with the mode 4 condition which was the shortest HRT. It indicates that the organic loading is not the factor affected to the effluent quality, because the SMBR system is maintained over 10,000 mg/L of MLSS concentration which can reduce the loading impact from the inflow organic loading.

To evaluate the economic advantage of the SMBR, two different membrane module configurations were also investigated. The vertical double membrane modules configuration (line II) could operate with only increasing 1.5 times aeration amounts compared to the simple membrane module configuration (line I). At that time the A/L ratios were 20.7, 14.8 respectively. The A/L ration of line II decreased to 28.5%. As the results the vertical double membrane modules configuration can produce twice the quantity of water with the same bioreactor volume of the simple membrane module. It is the economic advantage of this system. Therefore, it proves that the vertical double membrane modules configuration is very effective configuration of the SMBR system.

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