Two stage intermittent aeration membrane bioreactor for simultaneous organic, nitrogen and phosphorus removal

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Abstract A submerged membrane bioreactor (SMBR) was operated in 2-stage intermittent aeration for simultaneous removal of organic matter, nitrogen and phosphorus. The system consists of two reactors with a total volume of 0.27 m^3 (1st reactor 0.09 m^3 and 2nd 0.18 m^3). Real domestic wastewater was used as influent to the system. Membrane used for this experiment was hollow fiber polyethylene membrane with pore size of 0.1µm and effective surface area, 4 m^2. The membrane was submerged in the 2nd reactor for suction type filtration. Experiment was carried out in two phases varying the time cycles of aeration and non-aeration. SRT was maintained at 25 days and HRT, 16~19 hours. MLSS concentration in the reactors was in the range of 2,700~3,400 mg/l. The MLSS internal recycling ratio was maintained at 100% of influent flow rate. When time cycles of aeration and non-aeration were set at 30/90 min and 60/60 min in reactor 1 and 2, the removal of BOD and COD was 98.3% and 95.6%, respectively. A relatively low nitrogen and phosphorus removal was observed in this condition (73.6% as T–N and 46.6% as T–P). However, with 60/60 min intermittent aeration conditions for both reactors, the removal rate of nitrogen and phosphorus for two weeks steady state were enhanced to 91.6% as TN and 66% as TP, respectively. Further a high organic removal (98% BOD and 96.2% COD) was achieved too. In these conditions, the membrane of flux declined from 0.1 m/d to 0.08 m/d and suction filtration was at 10~12 kPa for a month long operation period.

Keywords Domestic wastewater treatment; submerged membrane bioreactor (SMBR); organic and nutrient removal; oxidation-reduction potential; two stage intermittent aeration; water reuse

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Introduction

In early 1980s, a household wastewater treatment unit was introduced as an individual treatment system in Japan. This unit showed a good performance for organic removal and was popular in rural areas where the public sewer system was not available. However the original system was very poor in nutrient removal. Since nitrogen and phosphorus were considered as the main source of eutrophication, and had an unpleasant effect on lake and reservoir water quality it has been required to improve this system for nutrient removal. Household membrane bioreactor (MBR) is one application to domestic wastewater treatment for organic and nitrogen removal (Suwa *et al.*, 1992; Chiemchaisri *et al.*, 1993; Ueda *et al.*, 1996). This process is defined as the combination of two basic processes: biological degradation and membrane separation. The main advantages of MBR are the production of high-quality effluent in terms of organic matter and nutrients, disinfection, and the maintenance of higher biomass concentrations that lead to very compact treatment systems (Manem *et al.*, 1996). The submerged membrane bioreactor (SMBR) is cost effective and has a high potential to apply in small wastewater treatment systems. In addition, since the uplifting air bubble removes the cake layer on the membrane surface, aeration has in effect to keep low suction pressure for filtration besides supplying oxygen (Ueda *et al.*, 1996).

Intermittent aeration has been applied for nitrogen removal in a single stage SMBR by repeating anaerobic and aerobic conditions (Chiemchaisri, 1993). In fact, intermittent aeration can achieve nitrogen and phosphorus removal by simultaneous nitrification and denitrification, P-uptake and P-release in the same reactor in accordance with time cycle of aeration and non-aeration (Chiemchaisri *et al.*, 1993; Seo *et al.*, 1995). However, even though intermittent aeration was successful in removing nitrogen, phosphorus removal was difficult at the same time. In addition it showed unstable nitrogen removal in its application to treat domestic sewage in rural settlements because of incomplete denitrification (Ueda *et al.*, 1996). Recently, the double tank type intermittent aeration activated sludge process has been studied for simultaneous removal of nitrogen and phosphorus, and stable nitrogen (91% as TN) and phosphorus (85% as TP) removal was obtained (Ohchi *et al.*, 1997). Considering the above point, in this study, double stage intermittent aeration was applied to enhance the performance of SMBR for stable organic and nutrient removal. Further the options for recycling and reusing the effluent were investigated.

Materials and method

Experimental setup and operating conditions

A semi-pilot scale submerged membrane bioreactor (SMBR) was installed at a real domestic wastewater treatment plant at Kyungnam provincial government public health and environment institute, Changwon, Korea. The schematic flow diagram of the system is shown in Figure 1. The bioreactor consists of two compartments with working volume of 0.27 m^3 (0.09 m^3 for 1st reactor and 0.18 m^3 for 2nd one). Membrane was submerged in the 2nd reactor for suction type filtration. The characteristics of the membrane are given in Table 1.

The membrane module (Mitsubishi Rayon L type) was installed directly over the diffuser through which air is supplied. And so solid accumulation on membrane surface could be prevented by a sheering stress generated by the uplifting flow of bubbling air. The aeration, therefore, had two roles in this system: supply of oxygen to activated sludge and removing cake layer on membrane surface.

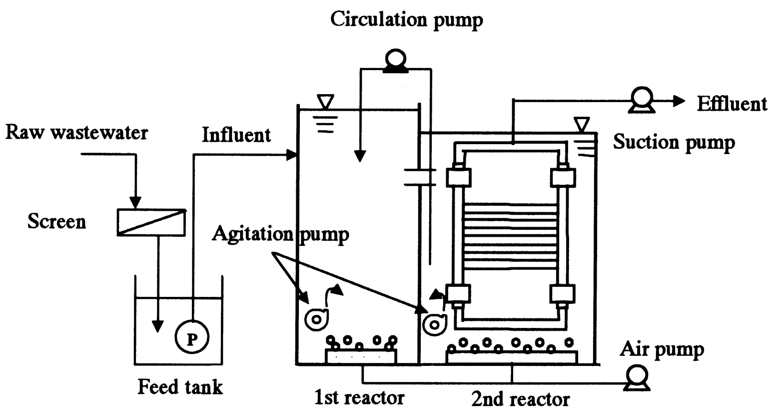

Figure 1 Schematic diagram of the membrane bioreactor for domestic wastewater

Table 1 Specification of hollow fiber membrane

Specification	Characteristics
Materials	Polyethylene hollow fiber membrane (hydrophilic)
Particle cut off	0.1 µm
Effective membrane surface area	4.0 m^2
Outer/Inner diameter	0.41/0.27 mm
Operating differential pressure	< 30 kPa
Operating temperature range	Less than 40°C
Size	H486×L769×48 mm

Table 2 Operating conditions of SMBR

Classification	Aeration-nonaeration (min)	Suction-idle (min)	Aeration intensity (l/min)	Internal recycle	F/M ratio (kgBOD/kgMLSS · day)
Phase 1	1st 30–90 2nd 60–60	5–5	20	1Q	0.07
Phase 2	1st 60–60 2nd 60–60	60–60	20 15 10 5	1Q	0.06

Table 3 Characteristics of domestic wastewater (Unit: mg/l, except pH)

Classification	pH	BOD	CODcr	NH_4–N	T–N	PO_4–P	T–P
Max.	7.2	240	327	36.1	47.1	3.5	8.1
Ave.	6.9	145	283	25.7	37.2	2.8	4.9
Min.	6.6	63	216	15.4	27.9	2.4	3.8

As mentioned, in our study, performance of the SMBR system was investigated in two phases varying the time cycle of aeration and non-aeration. These operating conditions are shown in Table 2. SRT was maintained at 25 days and HRT, 16~19 hours. Water temperature in the reactor was maintained at 16~20ºC. Airflow rate was regulated in the range 5~20 l/min to determine the proper aeration intensity for optimum operation of the system.

MLSS concentration in the reactors was maintained at 2700–3400 mg/l by wasting sludge for the purpose of phosphorus removal. MLSS was circulated from the 2nd reactor to the 1st one at 100% of influent flow rate for further denitrification. The initial membrane of flux was set at 0.1 $m^3/m^2 \cdot d$ at a suction filtration pressure of 10 kPa. Chemical cleaning of the membrane was done with 0.1 N NaOH solution after the first phase of operation. Backwash of membrane was not carried out during the filtration.

Wastewater characteristics and analytical method

The characteristics of domestic wastewater used in this experiment are shown in Table 3. pH of the wastewater was in the range of 6.6 to 7.2 (average 6.9). Since the organic concentration of this wastewater was relatively low, 67 mg/l as BOD, glucose was added to the raw wastewater to fit the concentration to common domestic one at the level of 145 mgBOD/L and 283 mgCODcr/L on average. However nutrient concentration was maintained in the range 27.9~47.1 mg/l as TN and 3.8~8.1 mg/l as TP, respectively. The average NH_4–N concentration was about 70% of TN and 60% of TP was PO_4–P.

Analysis of organic substance in terms of BOD, COD, nitrogen and phosphorus was followed by the methods described in the Standard Methods for the examination of wastewater (APHA.AWWA.WEF, 1995). Dissolved Oxygen, pH and ORP were analyzed by DO meter (YSI-58, USA), pH meter (Orion 290A, USA) and ORP meter (Istek-735P, KOREA), respectively.

Results and discussion

System performance

Organic removal. Daily organic removal was observed at two operating conditions varying the time cycle of aeration/non-aeration. The removal of BOD and COD, and MLSS variation are shown in Figure 2.

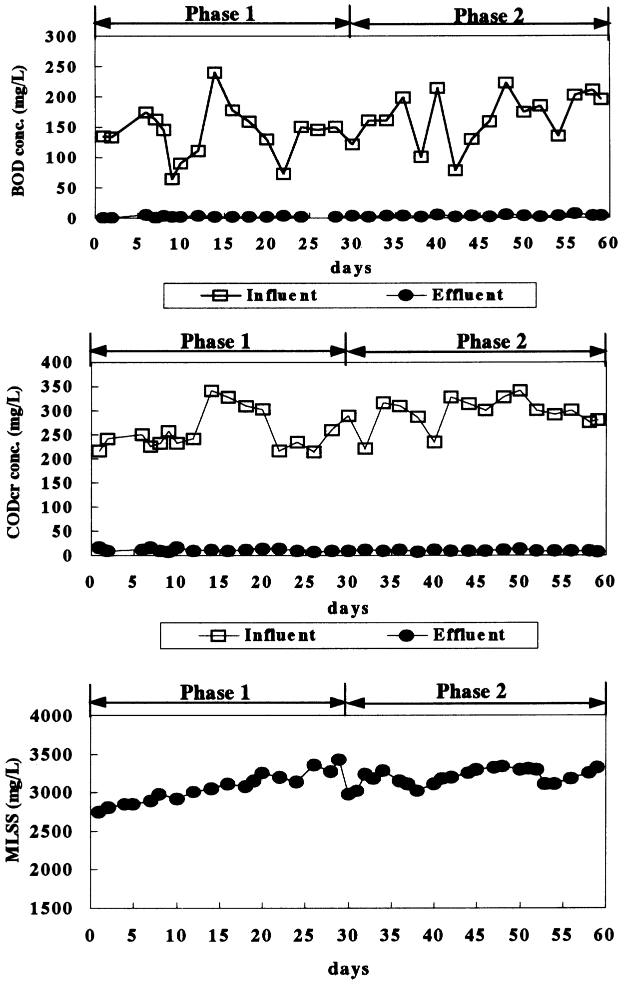

Figure 2 Removal of organic matter and variation of MLSS concentration in SMBR

Although the influent BOD concentration fluctuated in the range of 63 l–240 mg/l, stable effluent BOD concentration less than 5 mg/l (removal efficiency higher than 98%) was achieved regardless of the time cycle of intermittent aeration. Also the COD removal efficiency was higher than 95% at the influent concentration varying from 216 mg/l to 327.3 mg/l. The MLSS concentration (Figure 2) in the system increased gradually to 3,500 mg/l for the initial operation period and was constant at stable conditions. It was estimated that the average effluent COD concentration 9.6 mg/l was enough to meet the reclaimed water quality of the National Pollution Discharge Elimination System (NPDES) in the United States of America (WPCF, 1989).

Nitrogen and phosphorus removal. Figure 3 shows the total nitrogen removal at each phase. Influent total nitrogen concentration varied from 27.9~47.1 mg/l during the operation period. The effluent concentration of total nitrogen was maintained at 10.7 mg/l after 10 days operation and the removal efficiency was 73.6% in phase 1. On the other hand, it was reduced to 3.5 mg/l in phase 2 and removal efficiency was 91.6% at steady state. This sharp increase of removal efficiency is due to the change in time cycle for aeration and non-aeration in the 1st reactor. This shows that 60 min aeration is required for full nitrification in this system. In addition, the aeration intervals of 1st and 2nd reactor were set alternately to

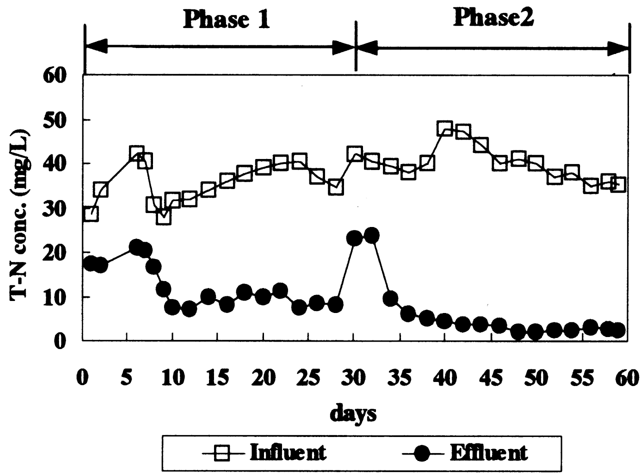

Figure 3 Daily observation of TN removal during operation period of SMBR

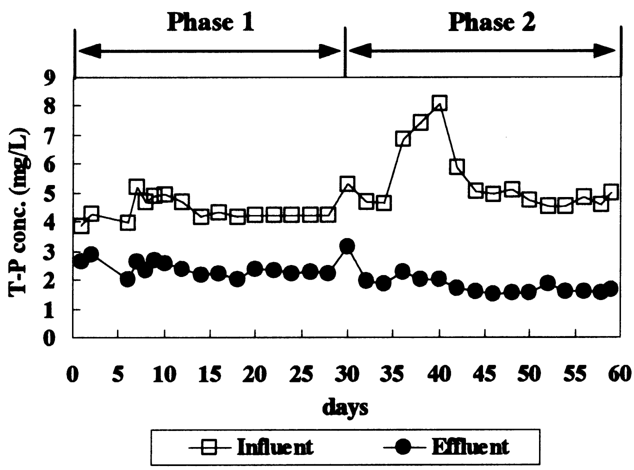

Figure 4 Daily observation of TP removal during operation period of SMBR

each other, such that when the 1st reactor was in aeration, the 2nd reactor was in non-aeration. Since the suction pump was controlled to run during the aeration period in the 2nd reactor, raw wastewater was fed into the 1st reactor during the non-aeration period. This operating condition is very important since this would concentrate the organic loading required for denitrification.

The variation of the phosphorus removal is shown in Figure 4. Total phosphorus in raw wastewater varied from 3.8 to 5.0 mg/l in phase 1. Stable effluent TP concentration was maintained at an average of 2.4 mg/l for two weeks after 15 days operation, which was considered as a steady state. The removal efficiency was 46.6% during the period. In phase 2, although the influent TP concentration was abnormally high for five days (from 35 to 40 day), the effluent concentration did not deteriorate and was maintained at around 2 mg/l. The reactor performance during the two week period from 44 to 59 days was also considered steady as the influent and effluent TP concentrations remained considerably stable. The removal efficiency of TP was 66% during this period. The increased removal of TP in phase 2 seems to be due to the extended time interval of non-aeration in the 1st reactor to form better conditions for phosphate release. However further investigation is required to identify the enhanced removal of phosphorus.

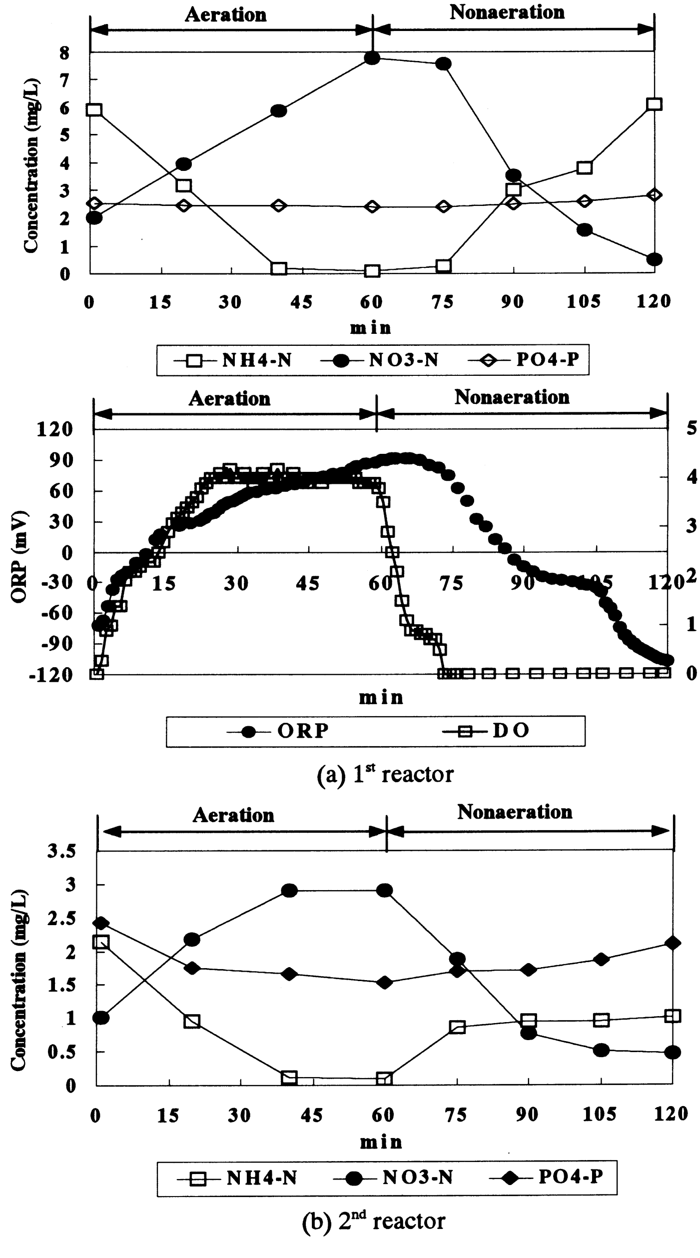

Figure 5 Water quality variation in SMBR during one cycle operation

Variation of nitrogen and phosphorus in the system

Water quality variation in the reactor was investigated during one cycle operation to obtain the removal efficiencies of nitrogen and phosphorus. Sampling was carried out at steady state in phase 2. As shown in Figure 5(a), ammonia was oxidized completely during the aeration period in the 1st reactor and nitrate concentration increased to 7.8 mg/l. DO concentration was maintained at about 4 mg/l and ORP 90 mV. Nitrate concentration was reduced to 0.45 mg/l during the subsequent non-aeration period. DO concentration rapidly dropped to zero in the 15 min after the non-aeration period started. A bending point appeared at around 105 min in the ORP curve. This point indicates complete denitrification in the reactor. However the uptake and release of phosphate was not observed clearly. Phosphate

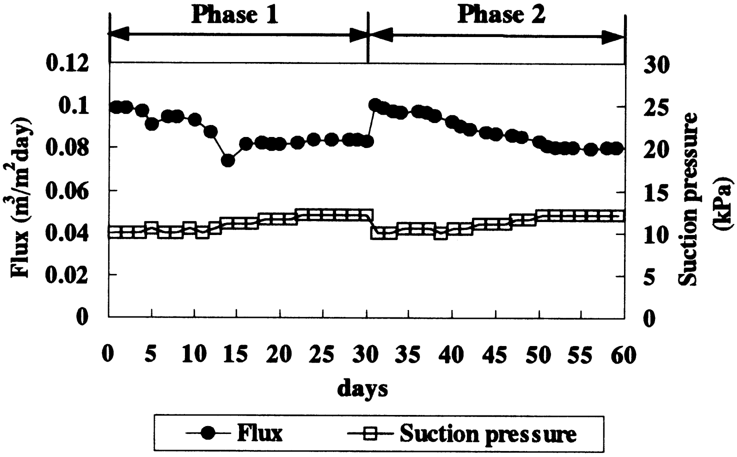

Figure 6 Variation of flux and suction pressure in SMBR

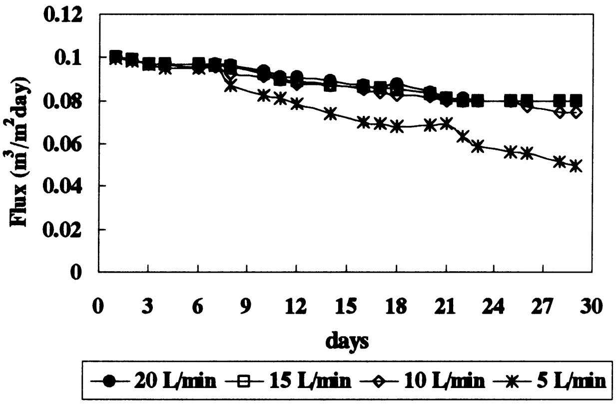

Figure 7 Flux decline at various airflow rates at suction pressure 10 kPa

concentration varied between 2.37 and 2.79 mg/l during the time cycle of aeration and non-aeration. This was caused by insufficient time for phosphate release after denitrification. A longer period of non-aeration might be required for enhanced phosphate release (such as 30 to 60 min after the appearance of the bending point of ORP).

Figure 5(b) shows the variation of nitrogen and phosphorus levels in the 2nd reactor. A similar phenomenon to the 1st reactor was observed but the nitrogen concentration was low. Ammonia concentration was reduced to almost zero level while nitrate increased to 3 mg/l during the aeration period. After the end of the non-aeration period, it was observed that ammonia increased to 1 mg/l and nitrate decreased to 0.5 mg/l. Although a distinct biological phosphorus removal was not obtained, the trend of phosphate uptake and release was observed in this reaction period.

Flux of membrane

Intermittent suction membrane filtration was applied in this system to keep a stable flux (Yamamoto *et al.*, 1989). The suction and idle time were 5 min/5 min for phase 1 and 60 min/60 min, phase 2. Figure 6 is the results of permeate flow rate measured during the operation period. The initial flux was set at 0.1 m/d and it declined slightly to 0.08 m/d during the 1st month of operation. Suction pressure increased very slowly from 10 kPa to 12 kPa during the same period. Although the water temperature varied from 16 to 23ºC the membrane of flux was at the same level for both time intervals of intermittent suction. Flux dropped temporally on the 14th day (Phase 1) because of a failure of the agitation pump in the 2nd reactor. No backwash of the membrane was carried out during this period. The membrane was cleaned by chemical (0.1N NaOH solution) after phase 1 for a new operation and it was recovered to the initial level (0.1 m/d).

Further, the effect of aeration intensity on the flux was investigated to determine an optimum air supply rate. Figure 7 shows permeate flux decline at different airflow rates between 5 to 20 l/min. The initial flux was set at 0.1 m/d. Similar flux decline was observed for the airflow rate of 20~10 l/min. The permeate flow rate was reduced gradually to about 0.08 m/d in a month. However the flux decreased more rapidly when the airflow rate was set at 5 l/min, reducing to 0.049 m/d at the 29th day. Thus, since the system performance did not deteriorate in terms of organic and nutrient removal even at the reduced airflow rate of 10 l/min, it is desirable to adopt the less flow rate of air for both oxygen supply and keeping stable flux in economic aspects.

Conclusions

From the experimental investigation, Following results were obtained.

1. For influent organic concentrations of 63~240 mg/l as BOD and 216~327 mg/l, COD, high effluent quality (2.3~3.1 mg/l in BOD and 7~13.5 mg/l, COD) was obtained regardless the operation condition of SMBR in this study. This effluent quality is good enough and complies with the standard of NPDES which is a strict reclaimed water quality criteria in USA.
2. Enhanced nitrogen removal efficiency (91.6% as TN) was achieved with a 60/60 min of intermittent time cycle in both reactors. Average effluent TN, 3.5 mg/l was maintained at stable levels for an influent concentrations of 27.9~47.1 mg/l. A bending point of ORP reduction curve during non-aeration period was a good indicator for complete denitrification.
3. Although the intermittent aeration time interval, 60/60 min was suitable for nitrogen removal, insufficient phosphorus removal was obtained. The removal efficiency of TP was 66% at the estimated steady state condition showing the effluent concentration less than 2 mg/l. Extended period of non-aeration might be required for enough phosphate release and subsequent uptake in aeration time.
4. Stable flux of membrane was maintained at 0.08 m/d after a month operation when initial flux was set at 0.1 m/d. Suction pressure was also kept at 10~12 kPa level regardless of intermittent suction time interval, 5 min/5 min and 60 min/60 min. Airflow rate 10 l/min was estimated to be the optimum level for the purpose of oxygen supply and preventing solid accumulation on membrane.

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