PERFORMANCE OF AIRLIFT MEMBRANE BIOREACTOR TREATING WASTEWATER FROM INDUSTRIAL PARK IN HO CHI MINH CITY

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Abstract

This study investigated operational performance and fouling behavior of Airlift Membrane Bioreactor (AMBR) system for industrial wastewater treatment. Pilot scale study of AMBR was carried out at central wastewater treatment plant (CWWTP) of Tan Binh industrial park in Ho Chi Minh city, Viet Nam. The influent wastewater of AMBR was taken directly from equalization tank of CWWTP with the concentrations of COD and colour level was 350 ± 48 mg/L and 313 ±30 Pt-Co, respectively. The effluent quality from the AMBR system was relatively compared with the existing full-scale Sequencing Batch Reactor (SBR). The AMBR with external tubular membrane module was maintained at the hydraulic retention time (HRT) of 9.6 h and sludge retention time (SRT) of 30 days, and flux of 30 LMH (L/m^2.h). It is observed that the AMBR was in stable operation with the flux for months. The COD and colour of membrane permeate was 15 ± 6 mg/L and 35 ± 5 Pt-Co, respectively. Membrane permeate was free of suspended solids. In addition, membrane fouling was controlled and occurred very slowly during the study period. Only one chemical enhanced backwash was applied in every two months of operation. This reveals the treated water quality of AMBR could meet the Viet Nam national technical regulation for industrial wastewater (level A, QCVN 24:2009/ BTNMT) and water reuse standards. This airlift membrane bioreactor system could be an attractive technology for water reuse purpose for industrial parks in near future.

Keywords: Airlift membrane bioreactor (AMBR), Industrial wastewater, Membrane fouling, Water reuse

Introduction

Sequencing Batch Reactor (SBR) is widely applied in treating domestic and industrial wastewater which can be biodegradable. The advantages of SBR are single reactor (combining aeration tank and sedimentation tank), flexible control of reaction time, and easy operation and maintenance. In recent years, the membrane bioreactor (MBR) has been popular choice for the new system or for upgrading wastewater treatment plants. The MBR system has advantages over conventional biological treatment processes such as compactness, operation at higher loading rate and good treated effluent [1; 2]. It has higher removal efficiency for particles and organic matter, with an effluent COD ranging from 10 to 20 mg/L [5-7], high organic loading rate (OLR) up to 19.7 kg COD/ m^3.d [7], longer sludge retention time fluctuating from 5 to 100 days, sludge concentrations between 5 and 30 kg/m^3 [4], and less sludge production [2]. On the other hand, a disadvantage of MBR is that membrane is prone to fouling during operation. Fouling causes a decrease in flux due to suspended solids, colloids and soluble matters deposited on the membrane surface [1;5]. Furthermore, Lobos et al. [8] compared the performances of two laboratory-scale immersed membrane bioreactors with respect to effluent quality for water reuse. One was operating in a sequencing mode and the other was in a continuous mode. The MBR systems were operated for a long period (5 months) without any sludge purge except for sampling. A complex substrate with respect to soluble and suspended fraction was selected as feed and it was constituted of acetate and meat extracted. A volumetric organic loading of 1 g COD/L.d with a COD feed concentration of 2 g COD/L was used. The results show that the continuous MBR provided higher removal efficiency (94 %) and effluent quality (COD < 50 mg/L) while the sequencing MBR had permeate COD of around 125 mg/L. Besides, the MBR technology is consequently an attractive option for the treatment of such industrial wastewater. The removal efficiencies of MBR treating seafood processing wastewater has high removal of BOD_5 (99%), COD and TOC (85%) [6]. MBR is also able to treat the petrochemical wastewater to meet the requirement for discharge [9].

In this work, a pilot scale AMBR was used to treat the industrial wastewater. The main advantage of AMBR were an airlift external MBR with air injection at the bottom of the membrane module to reduce membrane fouling. Moreover, a much lower volume of activated sludge was aerated additionally outside the bioreactor than in a submerged system, so that the biological processes were influenced as little as possible. The AMBR could operate at concentration MLSS from 8 to 12 g/L and a high flux 30 LMH (maximum 65 LMH) and low trans-membrane pressure of 0.11 - 0.29 bar [10].

This study aimed to investigate the performance of the airlift membrane bioreactor treating industrial wastewater from an industrial park. The treated water quality of membrane system was compared with those of the existing full-scale SBR.

Materials and methods

Seed Sludge

Seed sludge for AMBR was taken from the full-scale SBR of Tan Binh industrial park.
The initial sludge concentration was 7 g MLSS/L.

Wastewater Characteristics

Influent wastewater of AMBR was taken directly from equalization tank of the wastewater treatment plan of Tan Binh industrial park, Ho Chi Minh City, Vietnam. The types of wastewater entered the central wastewater treatment plant were mainly from industries such as food and foodstuff processing, packaging, garment, textile, and paper. The majority wastewater came from food industries, approximately 70 %”. The wastewater characteristics are presented in Table 1.

Table 1: Wastewater Characteristics

Parameters	Unit	Value
SS	mg/L	430 ±50
TKN	mg/L	29 ±15
COD	mg/L	350 ± 48
P	mg/L	11 ± 5
Turbidity	NTU	439 ± 45
Colour	Pt – Co	313 ±30
pH	-	7 ± 0.5

Airlift Membrane Bioreactor System

The Pentair (Norit) Airlift membrane bioreactor (AMBR) is an external MBR with air injection at the bottom of the membrane module to reduce membrane fouling. Moreover, a much lower volume of activated sludge is aerated additionally outside the bioreactor than in a submerged system, so that the biological processes are influenced as little as possible. AMBR can operate at concentration MLSS from 8 to 12 g/L and high flux of 30 LMH (maximum 65 LMH) and low trans-membrane pressure (TMP) of 0.11 - 0.29 bar. This pilot system includes an aeration tank (working volume of 0.46 m^3), the membrane module, and the clean water tank (120 L). Wastewater was first pumped into the aeration tank, and eventually fed into membrane module by two pumps. The membrane permeate was taken up by a suction pump into a permeate container while the remaining concentrate line was recirculated into the aeration tank. Air was supplied into the membrane module at a flow rate of 1.5 Nm^3/h and to maintain DO in aeration tank ranging from 2-3 mg/L. The AMBR system and flow diagram is shown in Figure 1. The system had an operating cycle of 7 minutes for filtration step (flux of 30 LMH) and 15 seconds for backwash step with backwash flow rate of 480 L/h. The organic loading rate during study period varied from 1.0 – 1.5 kg COD/m^3.day.

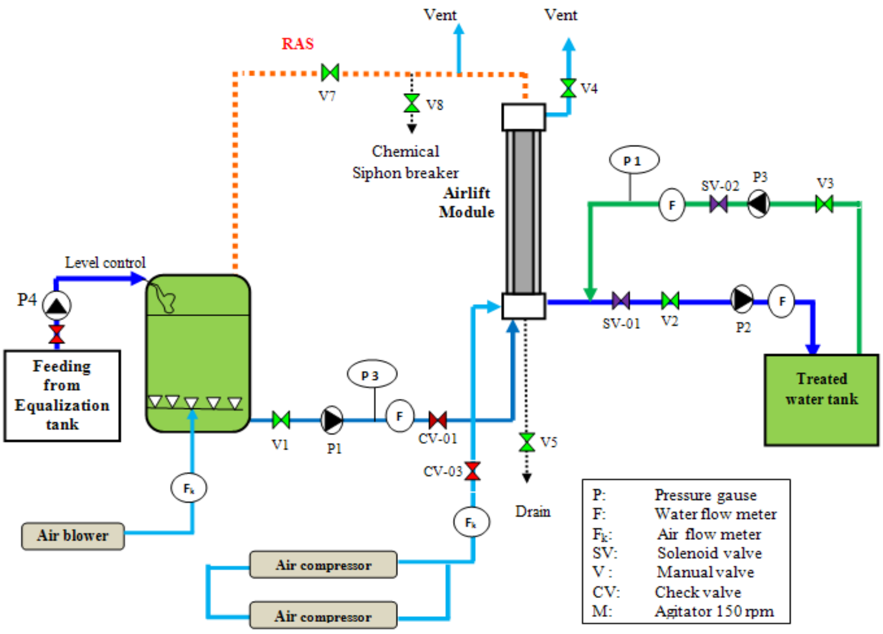

Figure 1. Process diagram of pilot scale Airlift Membrane Bioreactor

The one meter tubular PVDF membrane module used was provided by Pentair Corp (Norit). The diameter of membrane tube was 5.2 mm. The membrane pore size and surface area was 0.05 µm and 1.6 m2 respectively.

According to Pentair guideline, the drain-fill program was performed manually two times per day. The purpose of the drain function is to remove fibers, hairs and other matter trapped at the entrance to the membrane tubes after a period filtration. The drain line should be at a point below the membrane module to ensure complete draining of the Airlift module (V5 position). The drain waste was discharged daily [11].

SBR Operation

The SBR was operated at capacity of 2000 m^3/day with the F/M ratio of 0.13 day^{-1} and HRT of 7 hours. There were four stages per cycle: (1) 60 minutes feeding, (2) 180 minutes feeding and aeration, (3) 90 minutes settling, and (4) 60 minutes withdrawal. 30 percent of the SBR volume was withdrawn per cycle.

Membrane Cleaning

Chemical Enhanced Backwash (CEB) was performed once a month manually to remove adsorbed foulants which are not flushed by frequent hydraulic backwashing. Solution of 400 ppm NaOCl was used for CEB process. The membrane tubes were filled by the cleaning chemicals for duration from 30 minutes to 4 hours. The soaking time enabled the chemicals to react with the absorbed foulants, thereby removing them from the membrane surface. After soaking, the spent chemicals were drained from the membrane module by the drain valve [11].

Analytical Parameters

Trans-membrane (TMP) pressure, DO and pH were monitored daily at the site. Parameters of COD, SS, color were determined according to standard methods (APHA, 1998). Polysaccharides (PS), protein (PN), and UVA_{254} were measured as given by Thanh et al. [1].

Results and Discussion

The acclimation period was conducted at the following operating conditions: OLR of 1 kg $COD/m^3.d$, HRT of 9.6 h and initial MLSS of 7 g/L for first 21 days before first operating membrane flux. In day 22-60 the flux was 30 LMH.

Removal of Organic Matter

The influent COD (total) fluctuated from 304 to 680 mg/L while the permeate COD was quite stable at value of 15 mg/L during day 22-58 (Figure 2). This indicates that the permeate quality of AMBR was stable and did not depend on the influent COD concentration. On day 39, total COD in influent reached 1066 mg/L (with soluble COD of 152 mg/L) because the central wastewater treatment plant changed the operating condition, and the suspended solid became higher in the equalization tank.

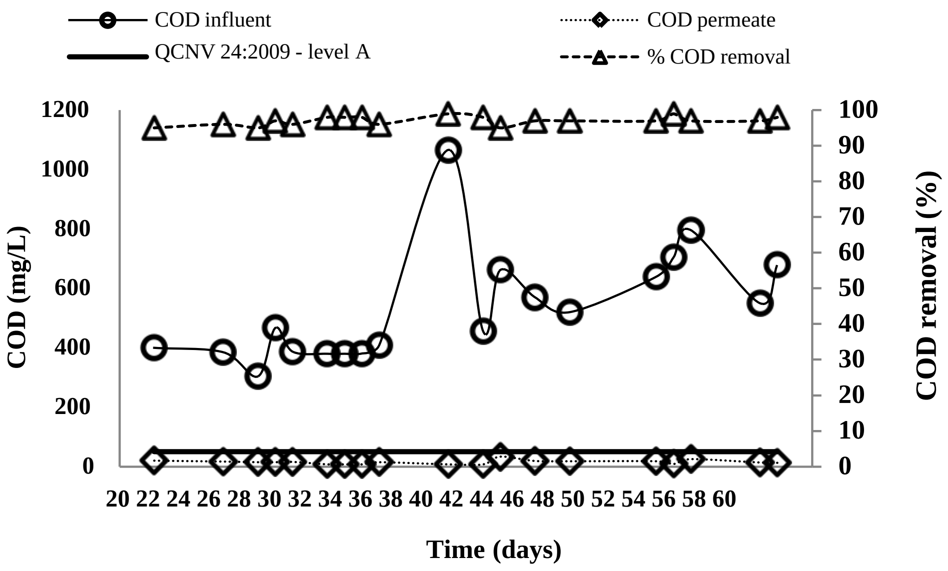

Figure 2. COD removal in the pilot scale AMBR

The COD removal in AMBR was due to mineralization and cell synthesis. In this study, the observed yield (Y_{obs}) is based on the amount of solids production measured relative to the substrate removal, and was calculated in terms of g VSS per g biodegradable soluble COD (i.e., g VSS/g bsCOD). In this research, the average influent and effluent biodegradable soluble (bsCOD) were 245 mg/L and 15 mg/L, respectively. The bsCOD removed and the total sludge production was calculated as 0.26 kg COD/d and 0.07 kg VSS/d, respectively. Thus, the observed solids yield was 0.28 g VSS/g COD. This result is similar with that of Tao et al. [12] for synthetic wastewater (Y_{obs} of 0.31 - 0.36 g VSS/g COD) which used three MBRs in parallel. During the operation, the influent COD concentration of AMBR fluctuated everyday and the COD removal efficiency was greater than 98 %. This indicates the AMBR could operate stably at different organic loading rates. It is an advantage of AMBR.

The permeate quality (COD) of the system was often lower than standard limits (50 mg/L) of Viet Nam National Technical Regulation on Industrial Wastewater (level A, QCVN 24:2009) and water reuse standards (CITAI, 2003) (Table 2).

Table 2. National Technical Regulation for Industrial Wastewater & Water Reuse Standard

Parameters	**QCVN 24:2009/BTNMT**		**CITAI, 2003**
	Level B	**Level A**	
pH	6-9	5.5-9.0	6.0 – 9.5
TSS, mg/L	100	50	10
BOD_5, mg/L	50	30	20
COD, mg/L	100	50	100
Total P, mg/L	6	4	2
Total N, mg/L	30	15	15
Ammonia, mg/L	10	5	2
Coliform, MPN/100mL	5000	3000	-

Remark: QCVN 24:2009/BTNMT: National Technical Regulation on Industrial Wastewater of Vietnam. CITAI: Comitano Interministeriale per la Tutela delle Acque, Italia [13].

Removal of Suspended Solids

The removal of suspended solids was very effective in the AMBR. The removal efficiency was almost 100% for all the days during operation even when the influent suspended solids strongly fluctuated from 240 to 1400 mg/L with time (Figure 3). This can be explained by the sieving mechanisms of membrane. The membrane pore size was about 0.05 µm which was much smaller than the size of microorganisms and sludge particles. The sieving mechanism played an effective role in solid removal in the AMBR.

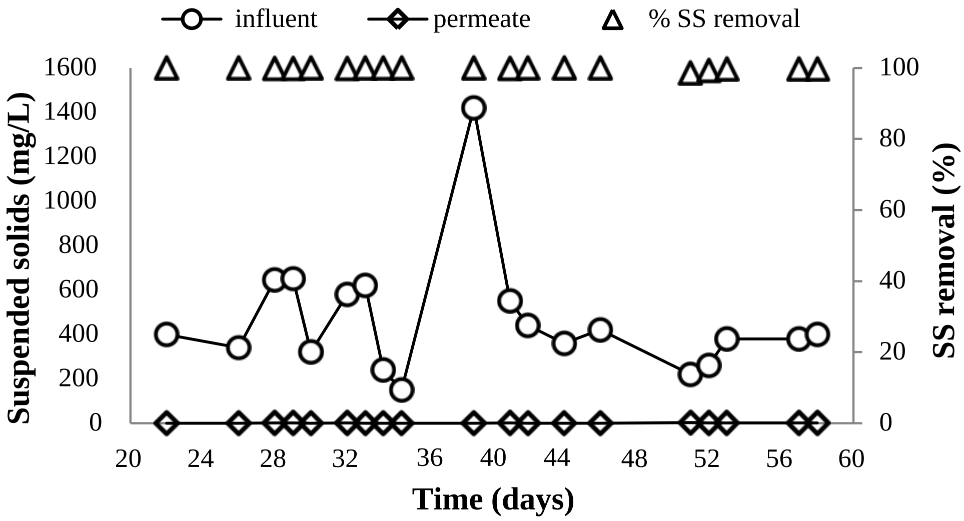

Figure 3. Suspended solid removal in the pilot scale AMBR

Removal of Colour

The colour of influent wastewater was less than 600 Pt-Co. The permeate colour was lower than 60 Pt-Co (average of 35 Pt-Co) (Figure 4) which was less than level B of QCVN 24:2009 (but higher than level A). The average color value of SBR effluent was 49 Pt-Co during the operation period while the color of the SBR effluent was always higher than that of MBR permeate. This shows that the AMBR could enhance color removal significantly. This could be due to the adsorption of sludge in AMBR. The effect could be due to the high concentration of sludge in AMBR. The sieving mechanism of membrane could be a contribution due to the rejection of dye macromolecules. The activated sludge was reported to be capable of absorbing colour.

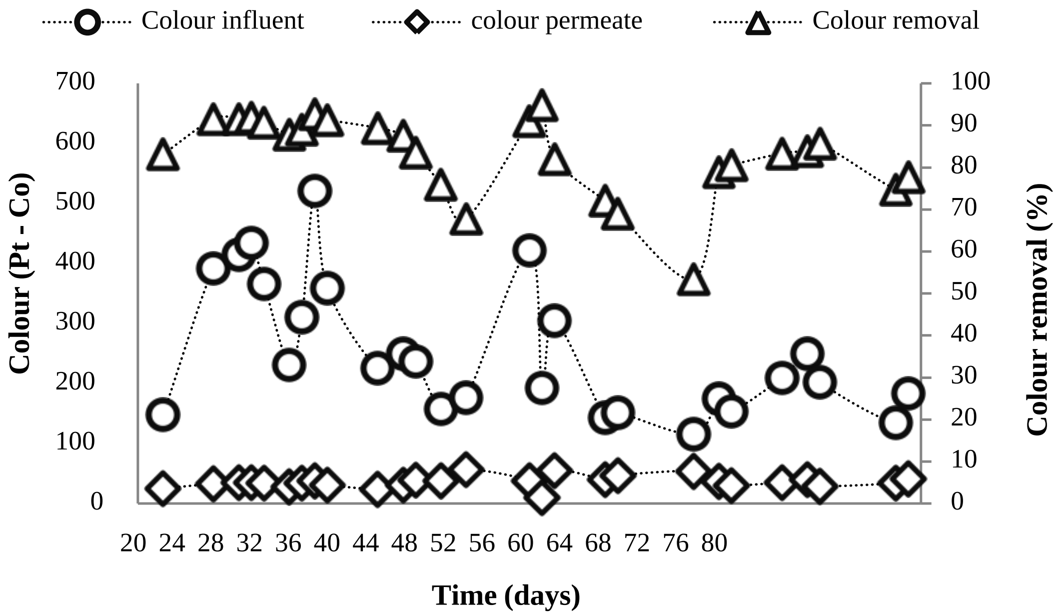

Figure 4. Color removal in the pilot scale AMBR

Membrane Fouling Behavior

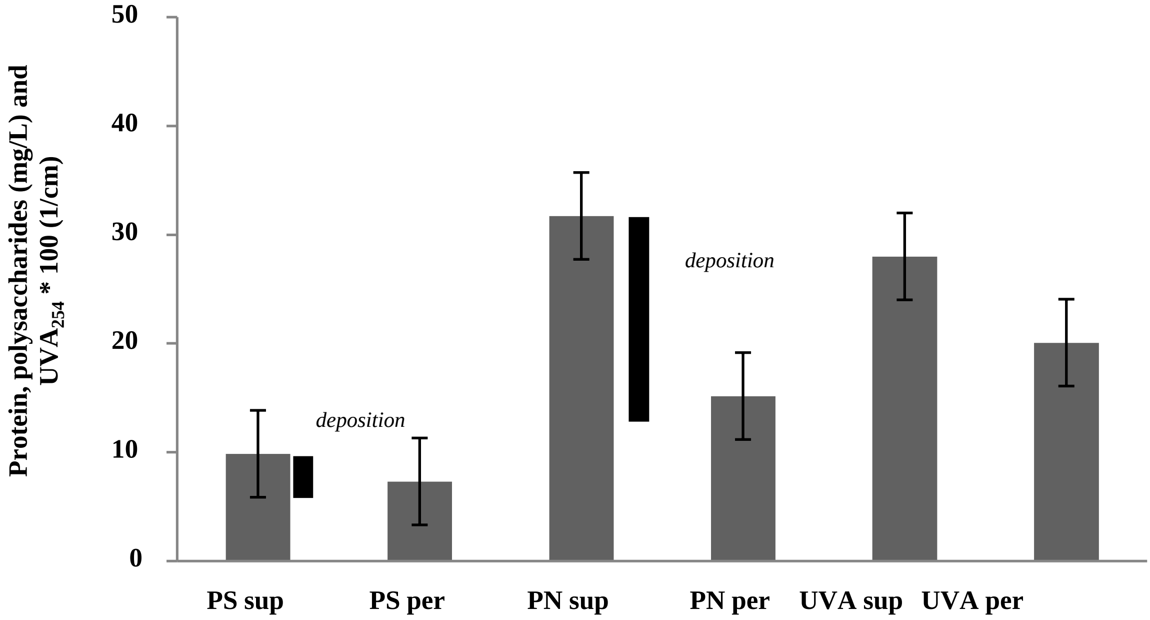

Figure 5. Concentration of polysaccharides (PS), protein (PN) in supernatant (sup) and permeate (per) and UVA_{254} (cm^{-1})

The higher value of ultraviolet absorbance at 254 nm wave length (UVA_{254}) indicates the higher amount of humic substances or double bond linkage substances in the water sample (Amy et al. [14]). In this study, UVA_{254} of supernatant (from aeration tank) was always higher than that of permeate. The average was 28 and 19 cm^{-1} for the supernatant and permeate, respectively (Figure 5). This can be explained by a possible entrapment of macromolecules on the membrane surface. In addition, this maner was similar in the cases of polysaccharides and protein, called extracellular polymeric substances (EPS).

In the sense of microbiology, PS and PN are storage polymers which are used for the living and the growth of microorganisms. The elevated levels of soluble EPS correlate to membrane fouling. The PS in supernatant and permeate was 6.5-12.3 mg/L and 4.5 to 10 mg/L, respectively. The PN supernatant and permeate average were 21.9 and 13.5 mg/L respectively. This reveals that PS and PN deposited on the membrane. Thus, these effects caused the irreversible fouling of membrane. The deposition of PN was higher than PS on the membrane. Therefore, the fouling was major contribution from protein deposition toward real wastewater in this study. It was different with results of Thanh et al [1] that PS was responsible to the main role in fouling for glucose-based synthetic wastewater.

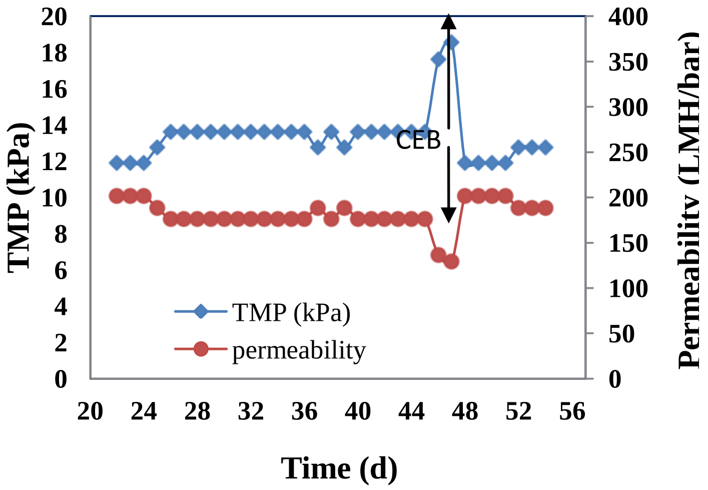

Figure 6. TMP profile and permeability of AMBR system with operation time

In line with soluble matter deposition, the membrane fouling was observed daily through trans-membrane pressure (TMP) presented in Figure 6. TMP is an overall indication of feed pressure requirement, used with the flux to assess the fouling of membrane [14]. The TMP fluctuated from 12 to 14 kPa between day 22 and 45. The slow increment of TMP was due to the frequent hydraulic backwash of membrane module during the operation. Since day 45, the TMP sharply increased from 14 kPa to over 18 kPa. This signal implied the CEB was required for membrane module. In other words, the deposition of soluble matter on the membrane surface was saturated. Therefore, the chemicals were used to remove any recalcitrant foulants on membrane including surface and inside the pores of membrane.

Membrane permeability is a pressure independent measurement of membrane filterability. Permeability was monitored during filtration, hydraulic backwash and CEB. Periodic backwashing improves membrane permeability and reduces fouling, thus leading to optimal, stable hydraulic operating conditions [15]. The permeability of membrane was 200 LMH/bar in three days during day 22 to day 25 (Figure 7). Then it decreased and remained stable at 175-178 LMH/bar during days 26 to 44. From day 45, membrane permeability decreased sharply to 129 LMH/bar and backwash pressure also sharply increased to 2 bar. This permeability decrease indicates membrane fouling [6,16]. Thus CEB was applied on this day. After that, the membrane was cleaned and permeability recovered to 202 LMH/bar. The TMP was fluctuated with the permeatability during the operation period. The TMP increased from 12 to 18 kPa from day 22 to 48. On the average, the fouling rate was as slow as 0.23 kPa/day for a CEB cycle.

Treated Effluent Quality of AMBR and SBR

The SBR system in Tan Binh Industrial park has effluent quality that complies with the standard limits of QCVN 24:2009/BTNMT, level B [17]. On the other hand, the AMBR permeate almost reached the level A and agriculture reuse standards. The energy consumption of full-scale SBR was higher than that of airlift MBR because it was applied for whole treatment system (submerged mixers, biological aeration, all pumps and equipment for SBR while Pentair (NORIT) reported the energy consumption for only membrane system (air scouring, sludge recirculation).

Table 3. Treated Water Quality of Full-Scale SBR and Pilot-Scale AMBR

Parameter	Full-Scale SBR	AMBR
COD	36 ±10 mg/L	15 ± 6 mg/L
SS in effluent	10 ± 2 mg/L	1.0 ± 0.5 mg/L
Colour	49 ± 12 Pt-Co	26 ± 15 Pt-Co
Energy consumption	0.37 kWh/m^3 wastewater	0.25 kWh/m^3 wastewater (for membrane module only)

Conclusions

Pilot-scale airlift membrane bioreactor operated stably and successfully for industrial wastewater at flux as high as 30 LMH. The treated water quality was much better compared to that of conventional sequencing batch reactor. The COD and color in permeate were as low as 15 mg/L and 35 Pt-Co, respectively. The removal of suspended solids was almost 100 percent during operation period. The treated wastewater met level A of the national technical regulation on industrial wastewater treatment and water reuse standards. Fouling was controlled and occurred very slowly during operation. This result confirmed that the airlift membrane bioreactor could operate effectively at high flux with excellent effluent quality for industrial wastewater treatment.

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