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Fouling mitigation in a submerged membrane bioreactor treating dyeing and textile wastewater

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ABSTRACT

The present study aims to assess the treatment efficiency and membrane fouling propensity of a submerged membrane bioreactor (MBR) treating dyeing and textile wastewater by introducing Powder-Activated Carbon (PAC) and Alum (called "fouling reducer"). The treatment performance and fouling behavior of MBR when adding PAC and Alum were compared to those of the control MBR. The components of dyeing and textile wastewater were fluctuated with Chemical oxygen demand (COD), color, and turbidity of 500–2,500 mg/L, 370–2,700 Pt-Co, and 50–370 NTU, respectively. The Mixed Liquor Suspended Solids (MLSS) concentration in an MBR fluctuated from 6,000 to 9,000 mg/L. The mixed liquor volatile suspended solids (MLVSS) to MLSS ratio was 0.76. The organic loading rate was operated in the range of 1.4–1.7 kg COD/m^3 d. In the control MBR (without the addition of a fouling reducer into the bioreactor), the results showed that the MBR could only remove the color at a maximum efficiency of 50% and COD of 60–94% during the operation time. The trans-membrane pressure (TMP) increased from 2.1 to 4.4 kPa during 30 days of operation. When PAC and Alum were introduced into the MBR at the concentrations of 1,000 and 40 mg/L_{sludge}, respectively, the two compounds helped to enhance the removal efficiency of the COD, color, and fouling control. The treatment performance of the MBR and the fouling propensity were noticed to be much improved, compared to the control MBR. The efficiency to remove color was 40–80% and 80–90% for PAC and Alum, respectively. There is a significant difference in the COD removal efficiency between the addition of PAC and Alum. While the removal efficiency of COD removal ranged from 50 to 94% for PAC, it was stable at around 80–90% for Alum during the operation. Generally, the fouling mitigation of PAC and Alum was almost similar and even much effective compared to the control MBR. The TMP increased slowly from 2.2 to 2.9 kPa to 2.4 to –3.0 kPa in PAC and Alum in 22 days of operation. This fact reveals that Alum and PAC were excellent substances in fouling control, COD, and color removal for MBR treating the dyeing and textile wastewater.

Keywords: Membrane bioreactor (MBR); Fouling mitigation; Dyeing and textile wastewater; Alum; Powder activated carbon (PAC)

1.Introduction

The membrane bioreactor (MBR) is an emerging technology in terms of high organic loading rate (OLR), less space requirement, and good treated effluent. The treated wastewater could be reused for certain purposes. However, the disadvantage of MBR is

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the fouling issue, which leads to a decrease in the flux, so that the membrane needs to be frequently cleaned by chemical reagents. Thus, this factor could perhaps be the reason attributed to the application of a membrane system in the wastewater treatment getting slowed down.

Various reasons can be mentioned to elaborate on the causes of membrane fouling. Such causes include the following: adsorption of macro molecules or colloidal compounds on the surface and in the membrane, development of an attached growth on the membrane surface, deposition of soluble substances on membrane pores, disintegration of macro molecules in the membrane pores and aging of the membrane.

The appearance and development of membrane technology, especially a submerged membrane bioreactor (SMBR), has created a new trend in wastewater treatment when coming to meet the stringent requirements stipulated for treated water quality. When outstanding characteristics of SMBR technology are compared with those of the other treatment process, the SMBR would be a preferable choice for wastewater treatment in the near future. To overcome the disadvantages (fouling) of using an SMBR, the present study aimed to add PAC and Alum into the MBR to investigate the fouling behavior and treatment performance of MBR treating dyeing and textile wastewater.

2. Materials and method

2.1. Components of wastewater

The wastewater was taken from two companies in the Ho Chi Minh city. Components of the two wastewater sources are almost similar and are presented in Table 1. The Chemical oxygen demand (COD) of dyeing and textile wastewater depends on the products and/or dyes used in the factories during the experimental periods. Before feeding the wastewater into the MBR, the original wastewater was diluted to maintain the influent COD concentration in the range from 500 to 650 mg/L, which corresponds to an organic loading rate (OLR) of 1.4–1.7 kg COD/m^3 d.

Table 1
The composition of raw dyeing and textile wastewaters

Parameter	Unit	Source 1	Source 2
Temperature	℃	50–80	60–80
pH	–	3–11	4–13
COD	mg/L	3800–7500	1500–5000
Color	mg/L	1000–5000	400–5000
Turbidity	mg/L	18–1225	18–592
SS	mg/L	0–200	0–50
PO_4^{3-}	mg/L	0.12–0.25	0.15–0.2
TKN	mg/L	5–13	9–16

2.2. Powder activated carbon (PAC)

PAC was added into MBR tank at a dosage of 1 g PAC/L_{sludge}, with the dosage proposed by Lesage et al. [1]. With a working reactor volume of 22 L, an amount of 22 g PAC was thus initially added. After every three days, 1 g of PAC was supplemented to compensate for the lost amount through an excess sludge removal. The volume of sludge withdrawn per day was 0.35 L, corresponding to a daily loss of PAC at 0.35 g.

2.3. Alum

The alum was added into the MBR tank at a dosage of of 0.04 g Al/L_{sludge}, with the dosage optimized by Zaisheng et al. [2]. With a working reactor volume of 22 L, an amount of 7.87 g Alum was thus initially added. After every three days, 0.375 g Alum was added further to compensate for the lost amount through an excess sludge removal.

2.4. Seed sludge

The seed sludge was taken from the conventional activated sludge process with an initial Mixed Liquor Suspended Solids (MLSS) concentration of 3,000 mg/L.

2.5. Membrane bioreactor

MBR was operated during the three following stages, namely control MBR, MBR-PAC, and MBR-Alum. For the system operation, the wastewater was pumped into the MBR tank and controlled by a level sensor. Air was introduced into the bottom of the reactor and at the rear end of the membrane module by stone diffusers. Aeration was controlled with a DO value of around 5 mg/L. The permeate was sucked semi-continuously with a cycle of 8 min on and 2 min off. The trans-membrane pressure (TMP) was recorded daily through a digital pressure gage to evaluate the membrane fouling propensity. When the TMP value reaches a value of 43 kPa, the backwash pump will be operated to flush the cake layer covering on membrane fibers.

The membrane used was produced by Motimo Co. (China). It is made from PVDF with a surface area of 1 m^2 and a pore size of 0.2 μm.

2.6. Operating conditions of MBR

The operating conditions of MBR are presented in Table 2.

2.7. Analytical methods

The wastewater was diluted with tap water to achieve an OLR of 1.4–1.7 kg COD/m^3 day. The samples of influent wastewater and permeate were collected every two days. The analyzed parameters were COD, color, and suspended solids (SS). The sludge was characterized by MLSS, mixed liquor volatile suspended solids (MLVSS), SVI$_{30}$, and microscopic observation. The analytical methods were performed according to Standard Methods (APHA, 1998). Membrane fouling was investigated by the TMP and membrane resistance. The fouled membrane was cleaned after each operation period using both chlorine and sodium hydroxide according to Thanh et al. [3].

3. Results and discussion

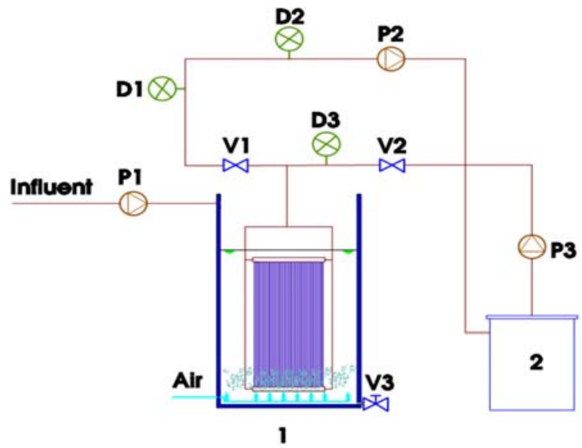
3.1. COD removal

The COD value in the feed was maintained in the range of 500–650 mg/L. However, in few days the COD value in feed exceeded the range. From Fig. 1, the addition of both PAC and Alum makes the permeate COD to decrease significantly, i.e. removal efficiencies are much better improved.

For the control MBR, the removal efficiency ranged from 44.6 to 85.1% (average of 62.2 ± 10.8%). The permeate COD was relatively as high as 227 ± 67 mg/L. This value was much higher than the value set by the Viet Nam National Technical Regulation for dyeing and textile wastewater (QCVN 13:2008/BTNMT, level B).

Table 2
Operating conditions of MBR

Parameter	Unit	Control MBR	MBR-PAC	MBR-Alum
Flux	L/m^2.h		2	
SRT	days		60	
OLR	kg COD/m^3.d		1.4–1.7	
HRT	h		10.5–11.5	
Operating duration	days	26	30	30
Initial amount of PAC/Alum added	g	None	22	7.87



Notes: Influent wastewater container 120 L;
(1) MBR with LxWxH = 0.4x0.1x0.7 m.
(2) MBR Permeate container 80 L;
P1, P2, P3: Feed pump, permeate pump & backwash pump;
V1, V2, and V3: Solenoid valves and bottom valve;
D1, D2, D3: Pressure gauge.

Fig. 1. Experimental setup of MBR.

For the MBR-PAC operation, the permeate COD fluctuated slightly during the first week. When the system became adapted, the permeate COD was stable at 75 ± 26 mg/L. The removal efficiency of COD in the MBR-PAC system was much better improved and more stable compared to that of control MBR whose removal efficiency stood at was 66.3–91.6% (average of 86.0 ± 6.4%).

For the MBR-Alum operation, the system was quite stable and improved compared to both control MBR and MBR-PAC. The permeate COD of this mode was in the range of 48–119 mg/L (average of 73 ± 18 mg/L). Thus, the treated efficiency of organic matter in this case is more stable than the two previous operation stages. The removal efficiency is stable in the range of 81.3–91.3% (average of 87.0 ± 2.6%).

Generally, the removal efficiency of COD was very much improved when adding either PAC or Alum. This can be explained by the fact that the adsorption and flocculation occurred during the operation of adding PAC and Alum, respectively. For the MBR-PAC case, the adsorption started clearly at the beginning when the PAC particles had just been supplied into the MBR. It was observed that the TMP value became reduced as soon as the quantity of PAC had been added into the MBR (Fig. 5). The reason attributed to this reaction was that the soluble matter and colloids adsorbed on the PAC surface. Then the microorganisms adhered to the PAC flocs and formed bigger particles. The adsorption only took place at an initial period in which the surface area of PAC was still

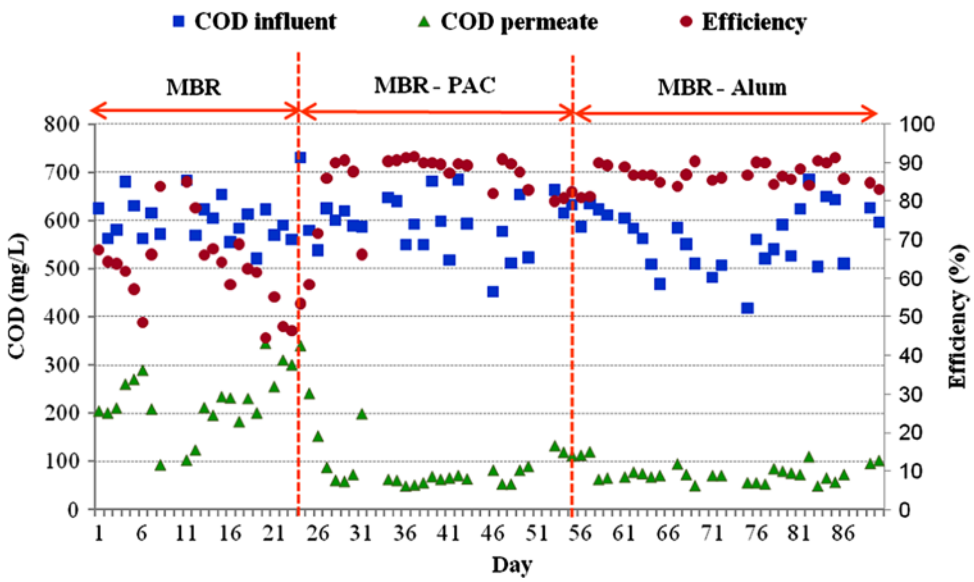


Fig. 2. The removal efficiency of the COD in an MBR.

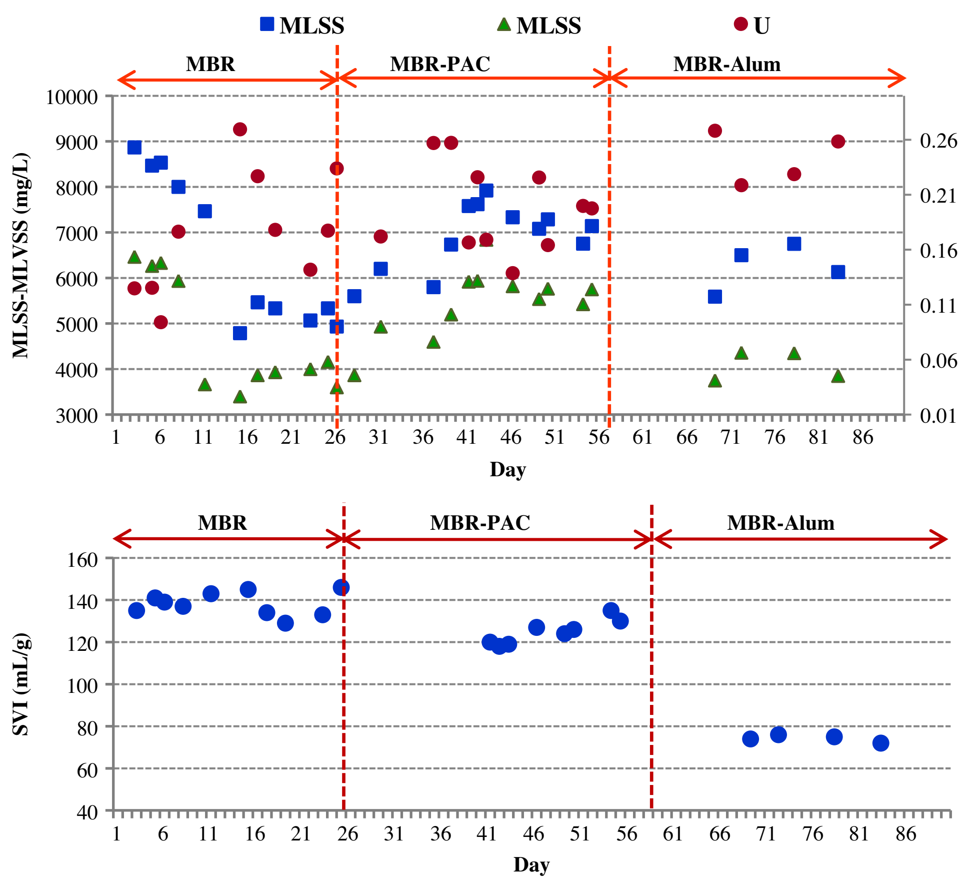


Fig. 3. Sludge concentration and SVI_{30} in the MBR.

intact. After that, the main mechanism is the attachment of microorganisms on the PAC flocs, which was similarly reported by Amy et al. [4]. For the case of MBR-Alum, a similar phenomenon was observed in the reactor. Initially, flocculation took place to form the flocs with a size of approximately 2 mm in the MBR. Then, soluble matter and colloids started adsorbing onto flocs. This phenomenon results in the formation of particles with a size of 2–5 mm attached on the membrane fibers, which was observed at the end of operation. Another researcher found a similar result that the average size of flocs when adding Alum was 150 µm [5–7].

Fig. 3 shows the values of MLSS, MLVSS, and a substrate utilization rate (U) of the MBR through the duration of operation. For the control MBR, the sludge concentration fluctuated from 4,800 to 8,800 mg/L. The ratio of MLVSS/MLSS was around 0.72 and the substrate utilization rate (U) was 0.186 mg COD/mg VSS.d. On day 15, there was a problem encountered when operating the sensor forcing the sludge to be washed out, with the sludge concentration reduced to 4,800 mg/L. For the MBR-PAC case, the sludge concentration varied from 4,900 to 8,000 mg/L. The ratio of MLVSS/MLVSS was 0.78 and U was 0.209 mg COD/mgVSS.d. This indicates that the addition of PAC brought about an increase in the substrate removal, which is presented in Fig. 2. The PAC flocs acted as moving media in the bulk liquid of the MBR. For the MBR-Alum case, the sludge concentration was maintained from 5,590 to 6,750 mg/L. The ratio of MLVSS/MLVSS was 0.65 and U was 0.244 mg COD/mg VSS.d. As a result, the substrate utilization rate of the MBR-Alum operation was the highest among all the cases. The addition of Alum into the reactor triggered both flocculation and adsorption phenomena. The Alum flocs showed a tendency to attach to the membrane, thus causing a reduction in the suspended biomass (MLSS) during the MBR-Alum operation period.

For a sludge settling ability, SVI_{30} was 138 ± 8, 125 ± 10, and 72 ± 4 mL/g for the control MBR, MBR-PAC, and MBR-Alum, respectively. The sludge settling ability was improved when adding either PAC or Alum. Further, the Alum shows a clear improvement in settling ability due to the flocculation effect, which makes the settled volume of sludge compacted and quick settling. These characteristics enhance the sludge dewatering ability for the sludge treatment process.

3.2. Color removal

The color of the raw wastewater strongly fluctuated with time depending on raw wastewater. The influent color ranged from 235 to 2,350 Pt-Co through the operation stages. The removal efficiency of the color was 2.6–48.9% (average of 27.8 ± 14.3%), 30.6–84.5% (average of 64.5 ± 13.6%), and 78.2–95.8% (average of 86.3 ± 4.5%) for control MBR, MBR-PAC, and MBR-Alum, respectively. When adding either PAC or Alum, the color of the permeate improved significantly and did not depend on the influent color. The color of the permeate was 987 ± 377 Pt-Co, 333 ± 163 Pt-Co, and 174 ± 132 Pt-Co for MBR, MBR-PAC, and MBR-Alum, respectively. The color removal efficiency of MBR-Alum was the most effective among the operating conditions. The flocculation and adsorption occurred simultaneously in the reactor. The color reduction due to addition of the PAC and Alum was quantified by the amount of color reduction over the addition of chemicals. On an averagely, the decolor-

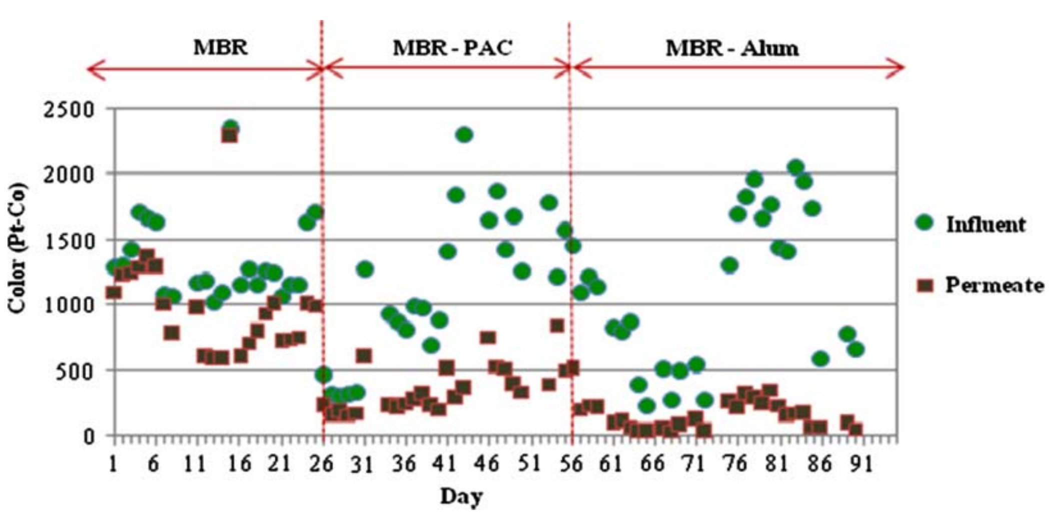


Fig. 4. Color removal in the MBR.

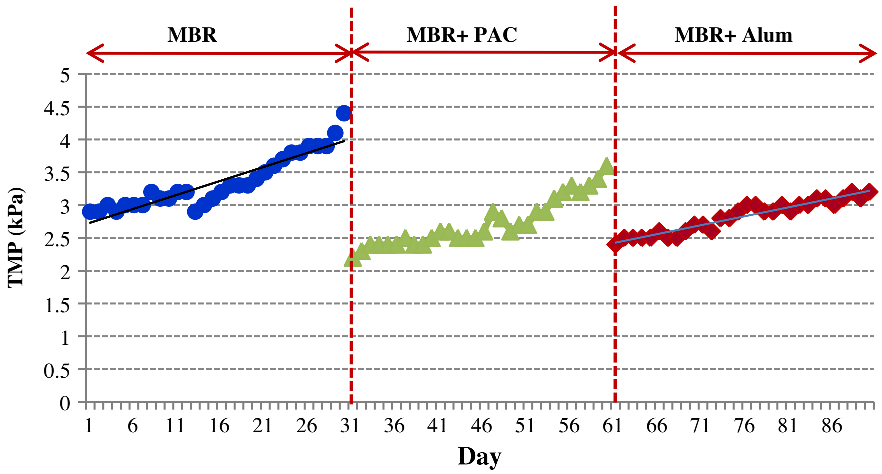


Fig. 5. TMP variation during the operation.

ation rate stood at 2.3 ± 1.4 Pt-Co/g PAC.d and 7.5 ± 4.0 Pt-Co/g Al.d, respectively (see Fig. 4).

3.3. Suspended solids

The SS in raw wastewater fluctuated in the range of 45–198 mg/L. However, this variation did not affect the removal efficiency of the suspended solids in MBR. The removal efficiency of the suspended solids was almost 100% through the stages. This was due to the membrane pore size of 0.2 μm, which can effectively remove the solids.

3.4. Membrane fouling

Fig. 5 reveals that the addition of either PAC or Alum could control membrane fouling. The fouling rate was identified by the slope of the TMP profile with time (dTMP/d*t*). The fouling rates were 0.042, 0.039, and 0.027 kPa/day for control MBR, MBR-PAC, and MBR-Alum, respectively. This phenomenon shows that the fouling propensity of system follows the order MBR-Alum, MBR-PAC, and control MBR.

The TMP values of the control MBR varied from 2.9 to 4.4 kPa for 26 days of operation, while the TMP value of MBR-PAC ranged from 2.2 to 3.6 kPa for 30 days of operation. It is interesting to note that the TMP values of MBR-PAC system suddenly reduced after 2 h of PAC addition. This reduction gets repeated whenever the PAC was periodically added periodically. This can be explained by the fact that the soluble matter and colloids absorbed onto PAC particles to form microbial flocs at the initial stage of PAC addition. The PAC flocs act as moving carriers in the bulk liquid. Similarly, moving particles in the MBR were reported to reduce fouling compared to conventional MBR due to enhanced scouring of the membrane surface by the moving particles. This could be the reason as to why the COD and color of membrane permeate reduced as well. This result is similar to that of Remy et al. [8]. In addition, the MBR-Alum operation shows the best fouling control among the studied modes of operation. The TMP increased slowly from 2.4 to 3.2 kPa for 30 days of operation. The Alum is known as a coagulant. Similar to a flocculation reaction, the Alum formed the Alum hydroxide first and the soluble and colloids started attaching on the metal flocs to form carriers mixing in the bulk liquid. The flocs were observed to be enlarged in this mode of operation. Further, several spherical particles of Alum flocs, with a size of 2–5 mm, were found to be attached on the membrane fibers when the membrane was taken out of the MBR. Therefore, the removal efficiency of COD and color in MBR-Alum operation was

Table 3
Membrane resistances

Operation	Total resistance (R_t)	Cake layer resistance (R_c)	Fouling resistance (R_f)	Membrane resistance (R_m)
Control MBR	10.59×10^{12}	8.47×10^{12}	0.61×10^{12}	1.51×10^{12}
MBR-PAC	3.51×10^{12}	2.45×10^{12}	0.53×10^{12}	1.53×10^{12}
MBR-Alum	3.48×10^{12}	2.32×10^{12}	0.12×10^{12}	1.04×10^{12}

found to be significantly improved compared to control MBR which is similar to the results of [5,9].

From Table 3 it is evident that the total resistance and cake layer resistance were found to be the highest for control MBR and the lowest for MBR-Alum. Moreover, the fouling resistance was the lowest for an MBR–Alum operation. This indicates that the soluble matter, colloids, and flocs (or foulants) tend to attach on the moving carrier (PAC flocs and Alum flocs) in a bulk liquid. On the other hand, the particles of Alum and PAC are effective fouling reduces for MBR treating dyeing and textile wastewater. These research results have found that the addition of either Alum or PAC could improve the treatment efficiency (COD and color) and control fouling of the MBR system. The addition of Alum is better than that of adding PAC in terms of color removal, fouling control, and sludge settling ability.

4. Conclusions

The present study aimed to assess the treatment performance and the fouling behavior of MBR treating dyeing and textile wastewater when adding PAC and Alum. Some conclusions are made as follows:

- The addition of PAC and Alum into the MBR could improve the treatment efficiency in terms of COD and color when treating dyeing and textile wastewater. The COD removal efficiencies were 62.2 $\pm$ 10.8, 86.0 $\pm$ 6.4%, and 87.0 $\pm$ 2.6% for control MBR, MBR-PAC, and MBR-Alum, respectively. As regards the the color treatment, the removal efficiencies were 27.8 $\pm$ 14.3, 64.5 $\pm$ 13.6, and 86.3 $\pm$ 4.5% for control MBR, MBR-PAC, and MBR-Alum, respectively.
- The removal efficiency of the suspended solids for all the three cases was almost 100%. Sludge characteristics quickly improved in terms of settling and dewatering ability when adding Alum. The SVI_{30} was 138 $\pm$ 8, 125 $\pm$ 10, and 72 $\pm$ 4 mL/g for control MBR, MBR-PAC, and MBR-Alum, respectively.
- Fouling was well controlled when either Alum or PAC was added into the MBR. The fouling rates were 0.042, 0.039, and 0.027 kPa/day for control MBR, MBR-PAC, and MBR-Alum, respectively.
- In the present study, Alum was found to be an effective fouling reducer and improving treated wastewater quality in MBR with the dosage of 0.04 g Al/L_{sludge}. Thus, Alum is suggested to be an additional substance for MBR treating dyeing and textile wastewater.

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