Optimal operating strategies of SFDM formation for MBR application

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This study develops process of self-forming dynamic membrane (SFDM) formation on mesh filter and investigates the capability of such process in treating municipal waste water. The formation process is mainly divided into two stages, i.e., the agitation and the aeration. At the agitation stage, the dynamic membrane is built up by deposition of suspended sludge particles on the mesh surface. The just-complete suspension of sludge flocs is performed using mechanical axial-flow agitator. Four imposed fluxes are applied to obtain the optimal flux for SFDM. Three parameters, i.e., effluent chemical oxygen demand (COD), filtrate turbidity, and trans-membrane pressure (TMP) are simultaneously measured to determine the time required for SFDM formation at agitation stage. The optimal aeration rate is also determined to steady operate the self-forming dynamic membrane bioreactor (SFDMBR). At the aeration stage, the rest of dynamic membrane is gradually formed during continuous operation. The compressibility index of dynamic membrane is also measured at the aeration stage. The results indicate that variations of the trans-membrane pressure correspond to the variations of compressibility index. Scanning electronic microscopy is also utilized to observe the development of SFDM. The performance of SFDMBR is evaluated in terms of total dissolved solids (TDS) and COD removal. The results reveal that the SFDMBR can be substituted for conventional membrane bio-reactors. A clean surface of mesh filter is restored by using two cleaning methods, i.e., air scouring and water backwash. Based on Fourier transform infrared analysis, proteins and carbohydrates are the dominant substances comprising the SFDM.

1. Introduction

The membrane bioreactor (MBR), integrating a separation process and biological degradation, is widely used as a proven technology in treating both domestic and industrial wastewater [1]. MBRs provide two main advantages, including a significantly improved effluent quality; due to high mixed liquor suspended solids (MLSS) concentration, and a substantially small footprint; due to absence of secondary settling tank [2,3]. However, a major obstacle, inevitably limiting the application of MBRs, is the rapid jump in the trans-membrane pressure (TMP) and/or rapid decline in the permeate flux because of fouling occurrence [4]. In recent years, there are considerable investigations focusing on development of efficient procedures to alleviate the fouling of membrane in MBRs [5,6]. The dynamic membrane process can be considered as an appropriate approach to solve the said bottleneck. The self-forming dynamic membrane coupled with a bioreactor is a new integrated approach applied in MBR technology using a coarse pore-sized material module, such as woven, non-woven fabric, and filter-cloth, instead of conventional membranes [7,8]. The SFDMBR has a low module cost and a high flux compared to MBR using micro-/ultra-filtration membrane [7]. Fan and Huang [8] applied Dacron mesh polyester with 30 μm nominal pore size in a MBR to evaluate the performance and formation of SFDM. They showed that MBR equipped with mesh filter for treating municipal wastewater could remove more that 84% interring chemical oxygen demand (COD) (97.9–371.7 mg/L COD). In this context, using low-cost filter materials including woven and non-woven can be considered as suitable alternatives to the conventional membrane [9]. Chu and Li [10] reported that dynamic membrane formed in the filter-cloth material could effectively reject the particular matter. They revealed that the effluent turbidity was nearly kept at stable level within 2–6 h for different concentrations of sludge. The average COD and NH₄⁻ N removal reached 80% and 74%, respectively. Liu et al. [11] separated the formation process of dynamic membrane into four stages under constant filtration pressure, i.e., substrate formation, separation layer formation, fouling layer formation and filtration cake formation. They also obtained that COD and turbidity contents in the filtrate became stable after 5 h, implying that the complete formation of dynamic membrane at sludge concentration of 7540 mg/L required 5 h. Zhang et al. [12] investigated the formation of dynamic membrane on the mesh filter with average pore size of 61 μm used in anaerobic membrane bioreactor. They showed that the dynamic membrane was completed after 20 days of operation. The results
presented by them showed that the dynamic membrane was formed by the sludge particles and the solutes and colloids content such as SMP and EPS. Ren et al. [13] demonstrated that the nonwoven fabric filter with a biomass layer effectively removed activated sludge. Kiso et al. [14] studied the performance of mesh filtration bioreactor equipped with a nylon mesh filter as the filter material with three pore sizes 100, 200, and 500 μm for activated sludge separation instead of microfiltration membrane in a MBR. They concluded that the mesh filter bioreactor retained suspended solids up to 9 g/L. They also investigated the performance of combined process of sequencing batch reactor and mesh filtration bioreactor [15]. Zahid and El-Shafai [16] evaluated the performance of cloth-media filters made of three materials (Acrylate, Polyester, and Nylon) for MBR treating municipal wastewater. The average COD was in the range of 30–37 mg/L for all the three filters. Poochichi et al. [17] also investigated the filtration characteristics and the hydraulic resistance of the polyester mesh filter with average pore size of 30 μm, submerged in MBR. In all studies related to the formation of SFDM the dynamic membrane was gradually formed during the operation thus the performance of dynamic membrane was being promoted with operation time. In order to obtain the good performance of dynamic membrane at the beginning stage of the filtration, in the present study, the formation of dynamic membrane is hastened by designing an additional stage here in after known as the agitation. The act of agitation helps to quickly-uniformly form the dynamic membrane in the polymeric mesh filter. The effects of operational conditions including aeration intensity and imposed flux on the formation of SFDM are also investigated in order to obtain the optimal values of these operational parameters for the SFDM formation at the agitation stage. Moreover, the rest of SFDM formation is then investigated at the aeration stage where the long-term operation of the SFDMBR is performed for wastewater treatment.

2. Material and methods

2.1. Experimental set up

The experimental setup is illustrated in Fig. 1(a). The rectangular Plexiglas tank is used as the bioreactor with 0.15 m width, 0.2 m length and 0.4 m height. A polyester flat sheet monofilamentous mesh filter is used with mean pore size of 30 μm with an initial hydraulic resistance of 7.36 × 10^7 m^-1. The area of the mesh is roughly about 0.016 m^2. The filter medium with its holding frame, as depicted in Fig. 1(b), is vertically submerged in the center of the bioreactor. Pressure drop across the filter medium is measured by an on-line pressure sensor. To adjust the permeate flow rate a peristaltic pump is used. The bioreactor is equipped with four fine bubbles air pipe distributors evenly placed at the bottom of the bioreactor, one of which is exactly below the filter module placed at a distance of 3 cm below the filter to provide appropriate flow-pattern.

2.2. Operation conditions of continuous bioreactor

The working volume of the bioreactor is 6 L. The bioreactor temperature is set in the range of 23–25 °C. The hydraulic retention time (HRT) and sludge residence time (SRT) are set on 12 h and 32 days, respectively. The four imposed fluxes are used to optimize the formation of the SFDM at the agitation stage. The four imposed fluxes of 62.47, 112.5, 150, and 190 LMH are used to optimize the formation of the SFDM at the agitation stage. The permeate flux is then kept constant at 30 LMH for long time operation of the SFDM at the aeration stage. The bioreactor operates with synthetic wastewater to avoid any fluctuation in the influent loading. The COD:N:P ratio of influent is 100:5:1 containing 1125 mg/L glucose, 231.76 mg/L ammonium sulfate, and 51.09 mg/L ammonium phosphate. Four aeration rates of 0.01, 0.05, 0.09, and 0.15 m^3 h^-1 are applied to observe the SFDM stability against the aeration intensity. Consequently, dissolved oxygen (DO) is varied in the range of 2–6.5 mgO2/L. The influent total dissolved solid (TDS) and turbidity are 687 mg/L and 288 NTU, respectively. NaHCO3 and H2SO4 are used to set pH in bioreactor neutral. Seed sludge is taken from the operating MBR plant (installed by Huber technology). The sludge suspensions are acclimatized for 107 days with the same operating parameters of the operating MBR. Mixed liquor suspended solids (MLSS) concentration is kept almost constant between 8.5 ± 0.8 g/L. When the TMP reaches 26 kPa after 15 days of operation, the SFDM is removed by using two physical cleaning methods, i.e., air scouring and water backwash.

2.3. Analytical procedures

The analytical parameters such as COD, turbidity, MLSS, and Mixed liquor volatile suspended solids (MLVSS) are analyzed using Merck reagents, according to APHA standard methods [18]. DO and temperature are measured with multi-meter (WTW 340 i, Germany). TDS is measured with TDS-meter (HM digital, America). Mass of suspended solids is measured with balance (Tecator, Germany) at a resolution of 0.0001 g. In order to minimize the errors due to the experimental conditions, all results are duplicated in two times and the average of the results is considered.

2.4. Field emission scanning electron microscopic (FESEM)

The surface of fresh mesh filter and surface of cake layer formed on the used mesh filter with corresponding cross-section structure were observed with scanning electron microscopy (S4160, Hitachi, Japan). At each sampling, the suction pump is stopped and the permeate valve is normally closed to prevent the back flow of the filtrate due to driving force owing to relatively high pressure difference between filter module and suction line. The filter with the SFDM is separated from the holding frame. The sample is fixed with 2% (v/v) glutaraldehyde in 0.1 M phosphate buffer at pH 7.2 for 2 h and then washed for 10 min and again immersed for 1 h in 0.1 M phosphate buffer. The fixed sample is dehydrated with ethanol. When the drying is accomplished, the sample of dynamic membrane is precisely obtained and it is accurately fixed to the welfare of SEM.

2.5. Filtration resistance analysis

The filter fouling phenomena can be described by using a theoretical model known as the resistance-in-series model [19,20]:

\[ R = \frac{\Delta P}{J} \]  

(1)

\[ R_t = R_{m} + R_{f} + R_{c} \]  

(2)

where \( J \) is the permeate flux (m^3/m^2 s), \( \Delta P \) is the trans-filter pressure (Pa), \( \mu \) is viscosity of permeate (Pa s), \( R_t \) is total filtration resistance (m^-1), \( R_m \) is the filter resistance (m^-1), \( R_c \) is the cake resistance (m^-1), and \( R_f \) is the gel layer resistance (m^-1). The mentioned resistances are calculated using the following equations:

\[ R_m = \frac{\Delta P_m}{J} \]  

(3)
\[ R_f = \frac{\Delta P_{wf}}{J} - R_m \]
\[ R_c = \frac{\Delta P_{AS}}{J} - R_m - R_f \]

where \( \Delta P_w \) is the initial of trans-filter pressure, \( \Delta P_{wf} \) is the final of trans-filter pressure after removing the cake layer by flushing with tap water and \( \Delta P_{AS} \) is the trans-filter pressure of the activated sludge at the steady state [21].
2.6. Fourier transform infrared (FT-IR) spectroscopy

The fouled mesh filter module is taken out from the bioreactor at the end of cycle when TMP reaches about 26 kPa. The SFDM on the mesh filter surface is scrapped off and then rinsed with pure water. The collected sample is placed on a magnetic stirrer where a good mixture is performed. KBr pellet of the dried foulant sample is analyzed by an FT-IR spectrophotometer (Tensor 27, Bruker Optics, Germany) at a resolution of 4 cm⁻¹.

3. Results and discussion

3.1. The SFDM formed at agitation stage

3.1.1. Formation process of SFDM

Schematic of process flow diagram for SFDM formation and the dismantled filter module is shown in Fig. 1(a, b). The formation process of SFDM is performed in the bioreactor at the agitation stage. As shown in Fig. 1(c), the suspended solids (SS) located near the membrane module are influenced by three forces, including drag force due to the permeate flow \( F_p \), the shear stress due to the agitation \( F_a \), and the friction force on the filter surface \( F_f \). When the shear stress and friction force are equivalent, solid particles near the membrane module tend to be immobilized, leading to deposition of particles on the surface of the mesh surface. During the SFDM formation process, the MLSS concentration is determined to be 8.5 ± 0.8 g/L, where the influent COD and turbidity are set at 1200 mg/L and 288 NTU, respectively. When the mixture level inside the bioreactor reaches the top of the filter module, the input flow is stopped and permeate peristaltic pump is switched on. Recycle flow is supplied by the permeate flow, thus the level of bioreactor remains constant. Due to providing an appropriate flow-pattern, having a better settling of sludge on the surface of filter, and promoting the SFDM formation, the agitation technique is selected at the beginning stage of the SFDM formation. Furthermore, the agitation provides the oxygen required for sludge activity in COD removal. The axial-flow agitator with the rotational speed of 350 rpm is used both to perform a just-complete suspension of the solids and to provide sufficient dissolved oxygen (DO). In all studies previously done in the field of the formation of SFDM [9–12], aeration intensity created the energy dissipation required for suspension of the activated sludge particles throughout the volume of the MBR system. In such system the sludge flocs suspended by aeration gradually deposited upon the porous media as well as woven and non-woven fabrics over the extended period of the operation of MBR. The SFDM was previously formed without using any additional accessories such as agitator and the aeration was the only method to suspend the particles in the bioreactor. The main differences between the formation of SFDM with and without agitator are the flow-pattern of suspension flocs and the presence of air bubbles in the bioreactor. In other word, with no agitator, the dynamic membrane is formed in the three-phase gas–liquid–solid membrane bioreactor since the dynamic membrane is formed in the two-phase solid–liquid membrane bioreactor with agitator. It is obvious that three-phase mixture has much more complex interactions rather than two-phase mixture. It can be concluded that when the agitation method is applied, the more reliability for the formation of SFDM is obtained as compared with aeration method. The main advantages of using agitator for the SFDM formation include the following: (1) to create regular flow-pattern throughout the volume of MBR system, (2) to generate the axial flow next to filter surface, depending on the agitator geometry. Since the axial-flow agitator uniformly creates the appropriate flow-pattern at the close proximity of mesh surface, the use of mechanical agitator expedites the time of the SFDM formation and improves the uniformity of the structure the SFDM. When the permeate flow is being returned back to the bioreactor the suspension of sludge flocs is gradually deposited on the filter surface. The time in which the effluent quality becomes stable is known as the required time for SFDM formation at the agitation stage. It can be expected that the mesh filter effectively adsorbs activated sludge when the binding of the biomass particles and filter surface happens. To provide a better understanding of development in formation of SFDM, SEM images is obtained from the cross-section of dynamic membrane at different periods of the agitation stage as shown in Fig. 2(a–d). Fig. 2(b) shows that colloidal matters attached to the intersection of yarns produced a gel layer known as substrate layer [12]. According to Fig. 2(c), flocs embedded in pores, grow rapidly and generate a separation layer attached loosely to the filter. Due to increasing the thickness of SFDM during the operation time at the aeration stage, the formation of SFDM is not completed at the agitation period. Certainly, the fouling layer is formed during the operation time at the aeration stage.

3.1.2. Optimization of the imposed flux for SFDM

To optimize the imposed flux during the formation of SFDM at the agitation stage, four imposed fluxes of 62.47, 112.5, 150, and 190 LMH are examined. Three parameters including the effluent COD, the filtrate turbidity, and the TMP are also measured to obtain the optimal value for the imposed flux. Fig. 3(a–c) depicts the variations of the effluent COD, the filtrate turbidity, and the TMP profile at aforementioned fluxes. For all four imposed fluxes the permeate quality increases with the SFDM formation time and finally reaches constant value. As shown in Fig. 3(a, b), when the imposed flux increases from 62.74 to 190 LMH, the ultimate permeate quality increases until 150 LMH and thereafter the quality of filtrate decreases. It may be due to the fact when increasing the imposed flux from 150 to 190 LMH, drag force overcomes shear stress so that colloids pass through the SFDM, and thus leading to increase in the permeate quality (effluent COD and turbidity). The final effluent COD and turbidity becomes equal to 81 mg/L and 43 NTU for the imposed flux 150 LMH, respectively. Correspondingly, the required time for the SFDM formation is equal to 840 s when the thickness of the SFDM becomes equal to 248 μm (as shown in Fig. 2(d)). It is also observed when increasing the imposed flux the time required for the SFDM formation is decreased. The monitoring of TMP profile is also performed for the applied fluxes as shown in Fig. 3(c). The TMP profile is close to each other for the imposed fluxes between 62.74 and 150 LMH. It means that no significant change in the TMP is observed during the SFDM formation. At the imposed flux of 190 LMH the TMP profile severely increases due to increasing the compressibility index of the SFDM, thus the over-compacting of the SFDM happens. According to the variations of the effluent quality and the TMP profile for the imposed fluxes, it can be resulted that the imposed flux of 150 LMH is the optimum flux whereas the effluent quality reaches the lowest limit and the TMP profile remained stable without any significant changes. Fan and Huang [8] reported that the effluent suspended solid concentrations were more than 1000 mg/L at the initial stages of operation. It should be pointed out that the thickness of cake layer plays a major role in filtration capability of dynamic membrane [12]; Kiso et al. [15] indicated that in the operation of mesh filtration the effluent suspended solid concentrations were less than 10 mg/L in only 600 s of the filtration.

3.1.3. Optimization of aeration rate for stability of SFDM

When the SFDM is built up at the agitation stage, the axial-flow agitator is switched off and the permeate flux is set to 30 LMH for long-term operation of the SFDM. The effect of aeration intensity on the SFDM stability is investigated. Aeration imparted to the membrane is denoted \( SAD_{\text{mem}} \), the specific aeration demand in the
volumetric rate of air per unit membrane area. The specific aeration demands (SAD m⁻³ m⁻² h⁻¹) are varied in the range of 0.625–9.375 m³ m⁻² h⁻¹ in order to obtain the optimum condition for stability of the SFDM previously formed at the agitation stage. The stability of SFDM is evaluated on the basis of its capability to retain the suspended particles and colloidal substances. Fig. 4 depicts a comparison of the final values of the effluent COD and turbidity at the short period of the applied aeration. According to data obtained, with increasing the SADm from 0.625 to 5.625 m³ m⁻² h⁻¹, no significant change in effluent quality values is observed. It means that the spatial structure of SFDM remains stable by increasing SADm up to 5.625 m³ m⁻² h⁻¹. A sudden increase in the effluent quality appears when the SADm is increased from 5.625 to 9.375 m³ m⁻² h⁻¹ as shown in Fig. 4. It can be expected that the SADm as the representative of aeration intensity impact on the structure of the SDFM, thus affecting the effluent quality. In addition to the proper stability of the SFDM, the aeration rate provides a good aerobic condition to the microorganisms for biodegradation. Fig. 5 shows the average concentrations of DO with the SADm. As depicted in Fig. 5, the DO values increase with increasing the SADm; the amount of DO is sufficient to microbial activity for biodegradation. In this case, the SADm of 5.625 m³ m⁻² h⁻¹ can be expected as the optimum value in which the stability of the SFDM with the sufficient oxygen occurs.

3.2. Operation of SFDM at aeration stage

3.2.1. Permeate quality

The recycling flow continues until the level of effluent quality remains constant. At that point, stirring is stopped and aeration will start. Simultaneously, peristaltic pump is set on flux of 30 LMH and the permeate flow is totally transferred to permeate tank. The treatment performance of the dynamic membrane is evaluated in terms of COD, turbidity and TDS. Fig. 6(a) shows variation of MLSS and MLVSS/MLSS in the mentioned period. Fig. 6(b–c) presents the turbidity, average COD concentrations, and efficiency of COD removal in the effluent during the operation, respectively. According to Fig. 6(b), SFDM can reduce turbidity from 288 NTU to 15 ± 1 NTU (before and after physical cleaning). Turbidity as an important index for colloidal particles (0.1–10 µm) reduces significantly through the process. Due to the fact that turbidity reduction is indicative of microfiltration process, a significant turbidity reduction indicates that the dynamic membrane is operated as a microfiltration process. This shows the benefit of using mesh filter instead of conventional membrane. As shown in Fig. 6(c), the SFDM is able to reduce COD from 1200 mg/L to 22 ± 2 mg/L (before and after physical cleaning). COD removal efficiency is about 98 ± 0.7% (before and after physical cleaning) which indicates that SFDM can approximately be reformed with the same performance. Fig. 6(d) shows TDS in the effluent before and after physical cleaning. According to Figs. 5, 6(d), TDS reduction during the operation can also be considered as an implication of dynamic membrane compression. This parameter represents the number of soluble solid particles which are smaller than 100 nm [4], are separated by ultra-filtration in MBR. Therefore, at the beginning of the operation, TDS does not change significantly, but from the second day it reduces to 350 ± 5 mg/L (before and after physical cleaning). As it is shown in Fig. 6(b–d), the variations in the values of measured parameters are related to the first 4 days of each 15-day operation and afterwards the values fluctuated in the same range so such that they can be considered constant. It can be explained that when forming the SFDM on the mesh filter during aeration stage, the biomass layer can effectively retain the fine particles and colloids. It can be concluded that as the capacity of the SFDM in rejection of solutes and colloids is balanced, the filtrate quality is kept constant at a stable level, but the TDS of the filtrate declines slightly because of the attachment of some solutes in the interior layer of SFDM. In fact, as filtration is processed, the increasing in dynamic membrane compressibility and thickness is observed, contributing to a higher pressure drop. To compare the operational performance of the SFDM formed by using agitator and the dynamic membrane formed by using
3.2.2. TMP monitoring and compressibility index

TMP diagram through the time is shown in Fig. 7. According to Fig. 7 there are three stages of pressure drop in each of the diagram before and after physical cleaning which are related to the dynamic membrane development and compressibility index. In each 15-day operation, when forming the dynamic membrane at agitation stage, the deposition rate of particles on the mesh filter surface increases till the second day, resulting in the development of dynamic membrane. From the second day, pressure drop increases due to cake layer compression but solid particles deposition reduces. From the eighth day, thickness of the dynamic membrane remains constant. As a result of membrane thickness getting constant and particles deposit decline, colloidal particles penetrate into membrane pores and bring about their blockage. In other word, from the eighth day, membrane compression increases besides, its porosity reduction gives rise to a drastic pressure drop. The layer compression and membrane pores blocking continue until the 15th day when the membrane thickness decreases to 380 μm and pressure drop reaches its maximum value.

Fig. 8(a–d) shows the thickness of dynamic membrane at 4 points of TMP diagram. As shown in Fig. 8, at the early stage of the operation, the increase of dynamic membrane thickness has a succeeding tendency while it turns to be falling in such way that at the end of the operation not only membrane thickness does not increase but also it decreases and gets more compressed in comparison to its thickness in the eighth day. The compressibility index, i.e. the index of SS/cake volume, indicates the compaction of SFDM; this is evaluated at three points as specified in Fig. 7. Liu et al. [11] presented the compressibility factor to evaluate the formation mechanism and the structure of dynamic membrane bioreactor. Zhang et al. [12] also represented that the index of SS/cake volume could predict the compactness and the voidage of the cake layer. After the dynamic membrane is formed at the agitation stage as above-mentioned, the rest particles are gradually deposited at the aeration stage under the drag force of permeate flow contributing to membrane thickness incensement. The dynamic membrane is not only formed by sludge particles, but also by the interception of the soluble and colloidal contents such as proteins and carbohydrates in dynamic membrane during filtration [23]. Fig. 9(a, b) presents the mass of suspended solid (SS), thickness, and compressibility index values at certain points, respectively. As can be seen, membrane thickness increases from 248 μm (after the agitation stage) to 361 μm (the second day), indicating that, thickness growth rate is high while compressibility index growth is not significant due to more porosity of the cake layer. At this stage, SFDM growth trend outweighs the tendency for compressibility index increase. However, from the second day till the eighth day, membrane thickness does not change much due to the fact that membrane pores are already filled with the soluble particles such that membrane thickness does merely increase from 361 μm to 385 μm on the eighth day which is trivial as compared to the previous level. As the thickness rate declines with operation time,
due to prevalence of drag force over shear stress, the dynamic membrane thickness remains somewhat constant and colloidal particles penetrate into the membrane pores which results in dynamic membrane mass incensement. After that, as a result of dynamic membrane compressibility, the thickness reduces to 380\( \mu \)m which leads to a drastic reduction of membrane porosity and a sharp increase in TMP. At this stage, membrane thickness decreases due to compression resulted from the drag force; thus it causes that the index reaches its highest value. These results are consistent with the study reported by Zhang et al. [12].

3.2.3. Filtration resistance analysis

The filtrations resistance involves in a MBR include membrane resistance \( (R_m) \), cake resistance \( (R_c) \), and blocking and irremovable fouling resistance \( (R_f) \) [21]. The hydraulic resistance analysis is conducted according to the resistance-in-series model as previously explained. Fig. 10 quantitatively shows the filtration resistances measured for the imposed flux of 30 LMH at three points specified in Fig. 7. Until the second day, the total hydraulic resistance is \( 1.8 \times 10^{11} \text{ m}^{-1} \) which contributions of cake and gel layer are 87% and more than 12%, respectively. When operation time is prolonged, pressure drop increases as a result of total resistance enhancement such that the obtained total resistance in the eighth day is \( 5.65 \times 10^{12} \text{ m}^{-1} \) out of which more than 95% and less than 5% are related to cake and gel, respectively, which are nearly similar to the resistance values reported in the previous studies for mesh media [24,25]. It is obvious that the accumulation of suspended solids major factor responsible for the increase of filtration resistance. Besides that, another important factor affecting membrane resistance is the layer of compaction [26].

3.2.4. SFDM cleaning

Permeability recovery is investigated by the ratio of water permeability after cleaning the initial water permeability. Two

<table>
<thead>
<tr>
<th>Type of medium</th>
<th>Pore size ((\mu \text{m}))</th>
<th>Dynamic membrane formation</th>
<th>Formation time ((\text{min}))</th>
<th>Influent COD ((\text{mg/L}))</th>
<th>Average COD removal (%)</th>
<th>Operation time ((\text{day}))</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dacron mesh</td>
<td>100</td>
<td>Aeration and recycling</td>
<td>60</td>
<td>97.9–371.7</td>
<td>84.2</td>
<td>90</td>
<td>[8]</td>
</tr>
<tr>
<td>Terylene filter-cloth</td>
<td>...</td>
<td>Aeration in batch test</td>
<td>200–300</td>
<td>328</td>
<td>81</td>
<td>30–35</td>
<td>[10]</td>
</tr>
<tr>
<td>Nonwoven polyester filter</td>
<td>100</td>
<td>Aeration</td>
<td>130</td>
<td>286.2 ± 10.86</td>
<td>85.5–89.3</td>
<td>160</td>
<td>[13]</td>
</tr>
<tr>
<td>Dacron mesh</td>
<td>61</td>
<td>Anaerobic</td>
<td>20 (day)</td>
<td>302.1 ± 87.9</td>
<td>57.3 ± 6.1</td>
<td>100</td>
<td>[12]</td>
</tr>
<tr>
<td>Stainless steel mesh</td>
<td>58</td>
<td>Aeration and recycling</td>
<td>15</td>
<td>140–380</td>
<td>40–60</td>
<td>7–20 (h)</td>
<td>[22]</td>
</tr>
<tr>
<td>Polyester mesh</td>
<td>30</td>
<td>Agitation and aeration</td>
<td>14</td>
<td>1200</td>
<td>97</td>
<td>32</td>
<td>This study</td>
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cleaning methods including air scouring and backwash are used to clean up the fouling layer. When the TMP reaches 26 kPa, the suction pump is set off and then the cleaning is started. The air scouring is performed by coarse sparger located below the filter module. The pressurized air is introduced for 30 min at an air flux of $0.3 \text{ m}^3/\text{h}$. The on-line water backwash is performed by returning back permeate flow to the filter module. The water backwash is run for 40 s at a water flux of 30 LMH [27]. The permeability recoveries are shown in Fig. 11. The cleaning recovery for air scouring and water backwash is restored to 98% and 96%, respectively. It results that the physical cleaning can recover effectively the mesh filter permeability, indicating that decrease in the TMP is mainly caused by the deposition of sludge flocs. The microscopic observation of the mesh filter cleaned shows that some colloids and solutes still attach between warp and weft fabrics (pictures not shown). In fact, it is concluded that mesh filter fouling is reversible so that its permeability recovery is more than 98%.

### 3.3. FT-IR analysis

FT-IR spectra analysis is performed to identify the biomass functional groups responsible for the dynamic membrane formed on the mesh filter. According to FT-IR results of virgin mesh filter and dynamic membrane, it is well accepted that the dominant
The aeration intensity equal to 0.09 m$^{3}$h$^{-1}$ LMH for dynamic membrane formation at the agitation stage. The optimum value of the permeate flux is found to be equal to 1.00 m$^{3}$h$^{-1}$ LMH. The self-forming dynamic membrane is formed in situ. Fig. 12 illustrates the FT-IR results of virgin mesh filter and dynamic membrane reactor for municipal waste water treatment, J. Membr. Sci. 326 (2009) 5245–5251.

4. Conclusions

In this study, the suitability of a monofilament mesh filter as a membrane media in synthetic wastewater treatment is investigated. The self-forming dynamic membrane is in situ formed at two stages, i.e., the agitation and the aeration. The dynamic membrane quickly built-up at the agitation stage provides a good capacity in rejecting the particular matter. The advantage of the addition of agitation stage is to expedite the SFDM formation as uniformly as possible. By comparing the effluent quality and the TMP profile, the optimum value of the permeate flux is found to be equal to 150 LMH for dynamic membrane formation at the agitation stage. The aeration intensity equal to 0.09 m$^{3}$h$^{-1}$ is obtained as the optimum value in which the SFDM formed at the agitation stage remains stable. Three sharp steeps are seen in trans-membrane pressure profile which can be attributed to the dynamic membrane thickness and compressibility index. Results showed that compressibility index increases through the aeration stage which implies SFDM compression. The efficiency of dynamic membrane in removing COD is outstanding, i.e. more than 97% at the hydraulic retention time of 12 h. Dynamic membrane also improves particle removal efficiency of mesh filter via reducing turbidity as much as microfiltration membrane does. During the aeration stage, no significant change in TDS value is observed. The results obtained from the analysis of filtration resistance show that the cake layer resistance increases throughout the aeration stage while gel layer resistance decreases. Mesh filter is completely recovered after physical cleaning to re-build up SFDM. The preferable method for cleaning is the air scouring. The results of the FT-IR analysis also reveal that the dynamic membrane is characterized as proteins and polysaccharides.

References


