Assessment of patterned membrane in a tilted panel filtration system for fouling control in activated sludge filtration

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Abstract. Membrane bioreactor (MBR) is a combination between advanced membrane filtration system and activated sludge biological treatment for sewage effluents treatment. Despite demonstrating a remarkable advantage over the conventional activated sludge process, MBR is still limited by the occurrence of membrane fouling problem, which reduces the performance and lifespan of the membrane causing higher maintenance and operation costs. Finding sustainable membrane fouling mitigation strategies has become the main concern in MBR operation. Hence, air bubbling method had been proven as one of the membrane fouling mitigation strategies. Ineffective air bubbling contributes to higher energy consumption for MBR operation. It must be pumped at high rates as low rates air bubbles only show poor contacts with the membrane surface in which limits its efficacy to scour-off the foulant. In this study, the performance of a patterned membrane in a tilted panel system was systematically evaluated to enhance air bubble effectiveness for membrane fouling control in activated sludge filtration. The patterned surface topography in a combination of the tilted panel is expected to enhance air bubbles contacts and increase their fouling control roles. An imprinting step was included into the fabrication procedure in order to create membrane with patterned surface. Results showed that the patterned outperform flat membrane in both tilted and vertical systems. Such an advantage can be ascribed by both the difference in membrane properties (effective surface area and pore size) and the nature of the surface (flat vs patterned). The patterned membrane yields higher permeance in the tilted panel over the vertical one in all tests, being the highest at shortest filtration/relaxation cycle of 5 min, shortest switching period of 2.5 min and highest aeration rate of 1.5 L/min corresponding to permeances of 465 vs 409, 369 vs 318 and 447 vs 381 L/(m²h.bar), respectively. However, since operation with tilting only allows one-sided membrane, the patterned membrane offers better panel productivity when operated in a vertical panel. Operation with switching (intermittent aeration) only offers the slight advantage of panel productivity over the vertical one (546-738 vs 440-632 L/m²h.bar).

Keywords: membrane bioreactor, corrugated membrane, tilted panel, fouling control, aeration

1. Introduction

The expansion of industrial development causing the volume of the wastewater with complex composition to be increased which could create pollution if were discharged without proper treatment. It is an advantage to be able to treat the wastewater in the most economical way. One of the options of wastewater treatment is activated sludge process. Activated sludge process able to produce high quality of effluent with low operating and maintenance cost. The basic principle of activated sludge process is the use of microorganisms to feed on organic contaminants existed in the wastewater. As the microorganism grew bigger, they clumped together and formed particles that able to settle down, leaving a clear effluent free of organic contaminants and suspended solids. However, activated sludge process are sensitive towards the external disturbances of physical and chemical nature of the wastewater and may produce high concentrations of suspended solids with high turbidity of effluent [1], [2]. Furthermore, other problems that affecting the activated sludge process are the settling of the sludge causing by poor flocculation of microflora and rapid increment of the number of filamentous bacteria [3], [4].
In order to overcome this limitation, membrane bioreactor (MBR) technology has been introduced. MBR is a new technology for wastewater treatment which combines the process of advanced membrane filtration system and activated sludge biological treatment in order to treat sewage effluents. MBR technology seems to be a good choice as most of the solids and colloids including bacteria will completely be eliminated through membrane separation hence, the final effluent does not contain any suspended materials which enables the final effluent to be directly discharged to the surface water [3]. MBR process involved the activated sludge treatment by the principle of membrane separation process. Membrane separation processes offer advantages of ability to run continuous and automatic operation with a low space requirement, hence able to reduce the number of unit operations [4]–[8]. Despite of the advantages provided by membrane separation process, the biggest challenge for membrane separation process is the rapid decline of the permeate flux over time due to the blockage of membrane pores caused by particles, organic matter as well as microorganism. This phenomenon is called as membrane fouling. It is generally referred to as the accumulation, deposition and adsorption of unwanted materials known as foulants on the exterior surfaces of membranes or within the membrane pores or both, which diminish membrane performance including the permeate flow (flux), solute removal efficiency, lifecycle of membrane and pressure drop across the membrane. Membrane fouling can be classified into four different types which are biofouling, organic fouling, inorganic fouling and colloidal fouling depending on the nature of foulant [5]. All of the membrane fouling types yield in similar disadvantages towards the membrane in which lowers membrane flux and permeance, increase cleaning chemical costs, energy demand and operating cost of the membrane system and shorten the lifetime of membrane [5].

Different approaches have been introduced to remove fouling in membrane such as membrane cleaning, unconventional pre-treatment of feed, coagulation-flocculation, adsorption, anti-scaling addition, disinfection, air bubbles generation and membrane surface modification [10]. Air bubbles generation had been introduced and been recognized as effective and efficient method to control membrane fouling and increase the membrane performance [10], [11]. Air bubbles induce hydrodynamic power in forms of drag force and lift-force when they travel along the membrane surface [10], [11]. It is reported that about 88% of fouling was removed while only 10% from exploiting cross flow velocity [10]. Air bubbles is an established method for membrane fouling control in vertical panel. However, there are less efficient as it provides only low contacts because air bubbles tend to move at the center space of the adjacent vertical panel, hence reducing their scouring effect [10]. These limitations can be overcome simply by increasing the size of the air bubbles. It is reported that the efficiency of membrane fouling control via air bubbles is affected by the bubble size [10]–[12]. Large pulse bubbles has better performance in removing foulant compared to coarse bubbles [10], [11]. However, it leads to high energy consumption required for high power compressor [10]. Instead of increasing the size of the air bubbles as an attempt to improve the air bubbles efficiency for membrane fouling control, a tilted membrane panel has been introduced as a promising option [10]. Membrane in a tilted panel can facilitate effective scouring the foulant, thanks to impact force between the air bubbles with the membrane surface [10]. Tilting also maximize the drag force of the air bubbles when it moves on top of the membrane surface [10].

In this study, the proposed method to control membrane fouling is by using membrane with patterned surface in a tilted panel system. The tilted panel helps to improve the membrane performance by increasing the contact between the air bubbles and the membrane surface [10]. The patterned surface is aimed to acts as turbulence promoter near the membrane surface wall as well as to enhance the effective filtration area [10]. Pattern on top of membrane surface acts as turbulence promoter due to the feed flow entering the system in scouring action where it kept repeatedly disrupts by additional resistance to the axial flow that promotes mixing in the boundary layer created at the membrane surface due to the formation of fluid eddies which increase the turbulence, friction and pressure drop [13], [14]. This is expected to reduce the fouling of the membrane and improve the membrane performance [14].
2. Materials and Method

2.1 Membrane fabrication, module assembly and characteristics

The membrane samples were fabricated via immersion precipitation by using the mixture 15 wt% of polyvinylidene difluoride as polymer, 84 wt% of dimethylacetamide as solvent, 0.5 wt% of polyethylene glycol as additive, 0.5 wt% of lithium chloride as additive and demineralized water as the non-solvent. The mixture then was stirred at 700 rpm and heated at 60°C for overnight to allow the complete dissolution. The dope solution was then casted atop non-woven support at a gap of 0.22 mm. After casting, a spacer was placed and pushed on top of the cast film as imprinting step in order to provide patterned surface. The imprinting step was excluded for fabrication of the flat membrane. The cast film was then immersed in a bath containing demineralized water immediately after casting.

To be applicable for filtration, the membrane sheet was assembled into a panel with an effective area of 120 cm² (one-sided surface of 10 x 12 cm). The prepared membranes were characterized in term of morphology, contact angle, pore size distribution, thickness and clean water permeance using scanning electron microscopy, goniometer, capillary flow porometer, micrometer and cell permeation. The properties of the flat and patterned membranes are listed as in Table 1.

| Properties                  | Flat Membrane | Patterned Membrane |
|-----------------------------|---------------|--------------------|
| Pore morphology            | Asymmetric    | Asymmetric         |
| Contact angle (°)           | 99            | 106                |
| Average pore size (μm)      | 0.5           | 0.78               |
| Average thickness (μm)      | 228           | 269                |
| Clean water permeance (L/m²h·bar) | 500           | 600                |

2.2 Filtration system configuration

The membrane filtration performance for this study was assessed in a constant-pressure submerged filtration system as shown in Figure 1. Membrane fouling was observed and recorded from the decreasing profile of permeate over time. In order to keep the trans-membrane pressure constant at -0.2 bar, suction pump was used to create a vacuum and the pressure was controlled by regulating a valve. The pumping system was equipped with valve, connected with permeate collector and linked with the membrane panel. Permeate was collected via semi-batch wise. The permeate was returned to the feed after volume being measured in order to fixed feed condition and to maintain the liquid level.
2.3 Filtration test

The flat and the patterned membrane performance was first compared in vertical and tilted panel with and without aeration. The patterned membrane performances were later evaluated under different system: panel orientation (vertical, 0° and tilted, 45°), intermittent aeration period (0, 2.5, 5 and 10 minutes), filtration cycle time involving relaxation (4.5/0.5, 9/1, 13.5/1.5 and 18/2 min) and aeration rate (0, 0.25, 0.75 and 1 L/min). The filtration cycle time of 10 minutes for filtration duration of 2 h were fixed for tests except for the ones on the effect of filtration cycle time involving relaxation. After each test, the membrane was cleaned by soaking membrane in 1% of sodium hypochlorite solution for 2 h. The volume of the permeate was measured to calculate the flux and permeance. The flux and permeance were calculated by using equation 1 and 2, respectively.

\[
I = \frac{V}{At} \quad \text{(m}^3\text{m}^{-2}\text{h}^{-1}) \quad (1)
\]

\[
L = \frac{J}{\Delta P} \quad \left(\frac{L}{m^2 h \text{ bar}}\right) \quad (2)
\]

Where \( V \) is volume of permeate (L), \( A \) is membrane area (m\(^2\)), \( t \) is filtration time (h) and \( \Delta P \) is trans-membrane pressure (bar).

3. Results and discussion

3.1 Comparison performance of patterned and flat membrane

Figure 2 shows a comparison performance of the flat sheet and the patterned membrane with and without aeration. Without aeration in Figure 2A, the permeances are almost similar which is 227 L/m\(^2\)h.bar for both flat and patterned. This value is lower than the permeance of both vertical and tilted membrane with aeration supply (Figure 2B). These situations indicate that without presence nor air bubbles, there is no effect of having membrane with surface corrugation or either membrane in a tilted panel. The air bubbles produced more favorable hydrodynamic conditions and thereby led to less severe membrane fouling [15]. Air bubbles scrub the foulant from membrane surface during filtration process, thus limit the concentration polarization and build up fouling layer on the membrane surface [16].
For the patterned membrane in the aerated and tilted panel, the permeance is 416 L/m² hbar. However, for the vertical panel, the permeance only reaches 361 L/m² hbar. As the membrane panel was in tilted condition, the air bubbles travel upward sliding atop the membrane surface to scour-off foulant [7]. It suggests that tilting the panel improves permeance by maximizing the contact of air bubbles onto the membrane surface and thus improving the scouring impact. For the aerated system, the permeance of patterned membrane in the tilted panel is 82% higher than the vertical. This result indicates the air bubbles produced more favorable hydrodynamic conditions on the patterned membrane and thereby led to less severe membrane fouling [8], thanks to the effect of the pattern on the membrane surface.

(A)                                                                 (B)

Figure 2 Comparison of flat sheet and patterned membrane in tilted and vertical panel without (A) and with aeration (B)

3.2 Effect of filtration cycle involving relaxation

Figure 3 shows that the permeance of patterned membrane has gradually decrease by increasing the filtration cycle time. Both tests have the same value of decline gradually, but the tilted system has the higher permeance than the vertical system. For the tilted system, the permeance reaches more than 450 L/m² hbar. However, for the vertical system, the permeance can only reach about 400 L/m² hbar. Permeance values on the membrane with a tilting angle greater because the air bubbles are held by the panel and are more directed towards the membrane surface than in the vertical angle. The membrane filtration performance inevitably decreases with filtration time. This is due to the deposition of soluble and particulate materials onto and into the membrane, attributed to the interactions between activated sludge components and the membrane [9]. Longer relaxation time will result in the fouling layers become more compact over time and become more difficult to remove [7].

Relaxation has become a common method for commercial membrane system such as Kubota and Toray membrane module run at cycle of 10 minutes with 20% relaxation to improve the membrane permeance [7]. The main idea is that foulant can be removed effectively during relaxation. However, the longer the filtration cycle time, the longer the relaxation time, the lesser permeance obtained as shown in Figure 3. This is due to the fouling mainly consists of irreversible foulant that attaches to the surface of the membrane, make it impossible to be removed and if it takes more time and accumulated, lower permeance obtained.
3.3 Effect of aeration rate

Figure 4 shows the permeance of the patterned membrane has gradually increases by increasing the aeration rate. The patterns are similar for both vertical and tilted panel, but the former has the higher permeance than the latter. Permeance values for the tilted panel is greater because the air bubbles are held by the panel and are more directed towards the membrane surface than in the vertical system. High aeration rates prove high permeance, especially for the tilted system with values greater than 400 L/m²hbar thanks to the greater number of air bubbles at higher rate to remove foulant on the surface of the membrane. Higher aeration rates increase the number of air bubbles, while increases the effective number of contacting bubbles onto the membrane surface for tilted system [7]. Besides that, higher aeration rate increases the turbulent hence more collisions occur between air bubbles and foulants.

Figure 4 Comparison of patterned membrane in vertical and tilted angle with different aeration rate
3.4 Effect of intermittent rate

Figure 5 shows the permeance of patterned membrane that gradually decreases by increasing the period of intermittent aeration showing similar trend for the vertical and tilted panels, but the later has the higher values. For the tilted panel using patterned membrane, the permeance can reach more than 400 L/m²hbar. However, for the vertical panel the permeance only able to reach about 350 L/m²hbar. In the vertical system the air bubbles are less directional and poorly in contacts with the surface of the membrane. Conversely, air bubbles are held by the tilted panel and thus slide atop the membrane surface to clear the foulant. Figure 5 also showed that the longer the intermittent aeration period being used, more foulant attached on top of the membrane surface. The concentration polarization and fouling layer would be easily formed on membrane surface during the idle time under intermittent bubbling mode, which could not be easily eliminated [10]. On the other hand, air bubbles became less effective due to the large amount of foulants that has accumulated on the surface of the membrane.

![Comparison of patterned membrane in vertical and tilted angle with different intermittence aeration](image)

**Figure 5** Comparison of patterned membrane in vertical and tilted angle with different intermittence aeration

4. Conclusions

This paper reports the performance of the corrugated membrane in the tilted panel system. Aeration improves permeance of flat and corrugated membrane by 33% and 59% respectively in the vertical panel system. The impact of aeration is enhanced as shown by 61% and 82% for flat and patterned membrane respectively in the tilted panel system suggesting that the combination of patterned membrane with the tilted panel can increase the permeance. Intermittent aeration decreases permeance and suggests that constant aeration in vertical system is better than operation under periodical switching using tilted panel. Prolonging of relaxation time also reduces permeance and hence it is recommended to operate the membrane in continuous aeration without involving relaxation. Despite offering higher permeance at higher aeration rate, one should carefully examine an optimum value since aeration contributes significantly to the energy input. Overall, this study suggests applying patterned membrane in the vertical system with constant aeration and minimum relaxation as these conditions offer the highest permeance of 465 L/m² h bar.
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