Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2011.2699

32 (2011) 201–207
August

Application of air flow for mitigation of particle deposition in submerged membrane microfiltration

Muna Pradhan, Rupak Aryal, Saravanamuthu Vigneswaran*, Jaya Kandasamy

Faculty of Engineering and Information Technology, University of Technology, Sydney, P.O. Box 123, Broadway, NSW 2007, Australia
Tel. +61 (2) 95142641; Fax +61 (2) 95142633; email: s.vigneswaran@uts.edu.au

Received 4 August 2010; Accepted in revised form 5 January 2011

ABSTRACT

This study investigates the effect of microfiltration operating conditions on membrane fouling of colloidal particles of kaolin clay. Experiments were conducted with a flat sheet membrane submerged in a suspension prepared from kaolin clay powder of size varying from 0.1 to 4 μm (Sigma) with a mean particle size 2.10 μm. The particle size distribution of clay was unimodal and the concentration of kaolin clay was similar to the biomass concentration in a membrane bioreactor (10 g/L). The effects of scouring and permeate flux rates were studied in terms of the membrane fouling rate. A linear relationship between the transmembrane pressure (TMP) and particle deposition was established for different air flow rates and permeate flow rates. Air scouring was more effective at a low permeate flux. There was only a minor change in the mean particle size of deposited colloidal particles on the membrane at a given flux under varying air flows and at the beginning all had a similar rise in TMP. However, at the later stages as particles accumulated on the membrane surface there was a significant rise in TMP. 15 LMH flux was observed as critical flux beyond which a rise in the permeate flux showed a sharp rise in the TMP which varied with air flow rates and particle deposition. The sharp TMP rise that occurred during the initial few hours of operation indicated that air flow for fouling mitigation strategies should target this period to optimise the membrane process. The study showed that air flow and flux rates are the two major governing factors for particle deposition on the membrane surface.

Keywords: Air flow; Membrane fouling; Membrane technology; Permeate flux

1. Introduction

The microfiltration process is a high performance separation technique for processing particulate suspensions in wastewater treatment, drinking water production and industrial applications such as biotechnology, food and beverage manufacture and mineral processing. It is a pressure driven separation process typically applied to remove macromolecules, colloidal and suspended particles with linear dimensions ranging from 0.02 to 10 μm and covers most of the pollutants in water and wastewater.

The major limitation of microfiltration is membrane fouling caused by the deposition and intrusion of macromolecules, colloids and particles onto and into the microporous membrane [1]. Fouling leads to a significant increase in hydraulic resistance, causing permeate flux to decline or TMP to rise when the process is operated under constant-TMP or constant-flux conditions respectively. Frequent membrane cleaning and replacement is therefore required, increasing significantly the energy

* Corresponding author.

Presented at the Third International Conference on Challenges in Environmental Science & Engineering, CESE-2010
26 September – 1 October 2010, The Sebel, Cairns, Queensland, Australia

consumption leading to high operating costs. Therefore, numerous studies have focused on understanding the activated sludge behaviour and membrane fouling mechanisms to improve the design and operation of membrane systems and reduce costs. The effects of the main operating conditions and sludge characteristics on membrane fouling have been a key interest among researchers. The activated sludge is divided into different fractions and their individual influences on fouling are reported in literature. Bouhabila et al. [2] established that the three fractions of the sludge, suspended solids, colloid and solutes, had different levels of influences on membrane fouling. They also showed that membrane fouling was mainly caused by colloids, because the MLSS, colloids, and solutes accounted for 24%, 50%, and 26% of fouling resistance, respectively. Wisniewski and Grasmick [3] concluded that the solutes, colloids, and mixed liquor suspended solids (MLSS) accounted for 52%, 25%, and 23% of the total fouling resistance, respectively. From these previous studies, it can be concluded that colloidal particulate have a significant effect on membrane fouling.

Several practical approaches have been applied to mitigate membrane fouling. Application of air flow (scouring) is a popular strategy to minimise membrane fouling. Air bubbles keep the solids particles in suspension leading to a well mixed and homogeneous distribution of particulate and also acts to scour the deposited particle layer that develops on the membrane surface [4,5]. The induced shear stress causes the resuspension of deposited particles from the membrane surface [6]. Air bubbles pose less risk to a membrane surface compared to chemical agents and support media. Ueda et al. [7] also concluded that aeration was a significant factor governing the filtration conditions. They found reduced fouling by augmenting the air flow rate or aeration intensity.

Despite the progress in terms of membrane system design and operation in recent years, membrane aeration still contributes significantly to the energy demand and the operating costs. Therefore optimising the air flow directly leads to reduced operation cost. Understanding the hydrodynamics of particulate fouling could lead to optimisation of air flow requirements and enhance the system performance. This study investigated the effect of air flow and permeate flux on membrane fouling.

2. Experimental system

A laboratory scale membrane study was carried out with a flat sheet membrane (Maxflow Membrane Filtration, Germany) submerged in a 10 L reactor containing kaolin clay suspension (10 g/L). The membrane had a pore size of 0.14 μm and an effective filtration area of 0.2 m^2. Kaolin clay powder had a size range between 0.1–4 μm (Sigma). The unimodel particle size distribution is shown in Fig. 1. The mean particle size of kaolin clay was 2.10 μm which was much higher than the membrane

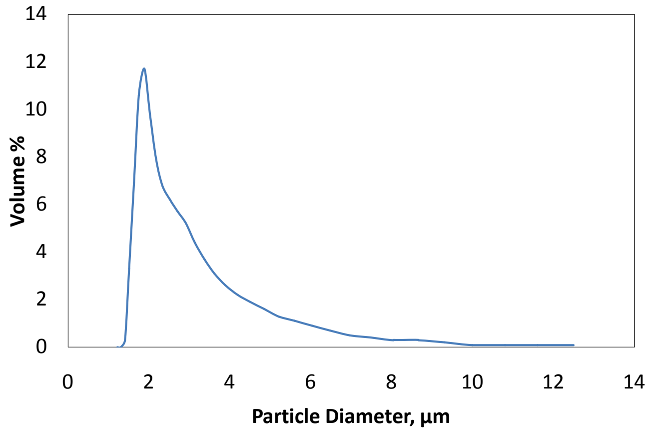

Fig. 1. Particle size distribution of kaolin clay.

pore size (0.14 μm). The D[v,0.9], D[v,0.5] and D[v,0.1] were 3.91 μm, 2.10 μm and 1.61 μm respectively. Here D[v, 0.9], D[v, 0.5] and D[v, 0.1] represent the particle size below which 90%, 50% and 10% of the sample lines. Hence internal pore blocking phenomena was considered negligible and all particle deposition occurred on the membrane surface.

Air bubbles were estimated at between 2–4 mm in diameter and were injected into the reactor from the bottom at different flow rates (600, 1200 and 1800 L/h/m^2). The schematic diagram of the submerged membrane reactor is presented in Fig. 2.

The permeate flow was from outside to inside flow and was induced by developing a reduced pressure on the permeate side using a peristaltic pump operating at a constant permeate flux. A continuous filtration process and constant concentration of suspension was maintained by returning the permeate back to the feed suspension. No backwash was applied within the operating period.

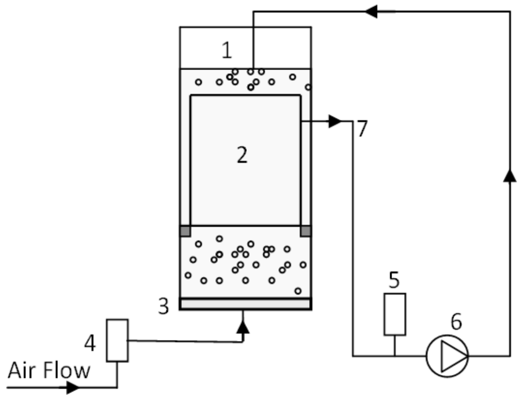

Fig. 2. Schematic diagram of experimental set-up. 1 Reactor tank, 2 Flat sheet membrane module, 3 Airflow meter, 4 Aerometer, 5 Pressure transducer, 6 Recirculating pump, 7 Permeate.

Experiments were carried out at different air flow rates (600, 1200 and 1800 L/h/m^2 of membrane area) and different fixed permeate flux rates (5, 10, 15 and 20 LMH). The transmembrane pressure was monitored online by a pressure transducer placed between the suction pump and the membrane.

Prior to each experiment, the membrane was tested for its hydraulic resistance after three stages of cleaning (cleaning with tap water, shaking and cleaning with tap water and cleaning with chemical). The membrane was first cleaned with tap water. It was then placed in a specially designed holding unit attached to the shaker for an hour at 120 rpm and cleaned with tap water again. Finally the membrane was submerged in chemical solution (3% w/w sodium hypochlorite) for 3 h. If the hydraulic resistance had not reduced to its original state (new), the process was repeated again.

Particle deposition on the membrane surface was calculated indirectly by measuring the suspended solids concentration. Due to the particle deposition on the membrane, the concentration in the suspension decreased continuously. From the material balance of the particle mass in the whole system it was possible to calculate the amount of mass deposited on the membrane. A sample from the reactor was collected at 1 h intervals, passed through a 0.45 μm filter and the mass was measured. The particle size distribution was also measured using a particle size analyser (Malvern 2600, United Kingdom).

3. Results and discussion

3.1. Effect of air flow on TMP reduction

During membrane filtration, suspended particles are transported to the membrane surface due to the suction pressure. The deposited particles are scoured and back transported to the suspension by the application of air flow which ultimately causes a reduction in fouling and TMP [8]. Ueda et al. [7] observed a rapid increase in pressure when the air flow rate was reduced which was possibly due to cake layer development and less membrane scouring from a reduced air flow rate.

Fig. 3 shows the experimental results of TMP reduction at four different flux rates (5, 10, 15 and 20 LMH) and three different air flow rates (600, 1200 and 1800 L/h/m^2). Four different fluxes produced four distinct patterns. At a lower flux rate (5 LMH), the rise in TMP was negligible and was almost constant throughout the experiment for all air flow rates indicating negligible deposition of particles (Fig. 3a). At a higher flux of 10 LMH, the rise in

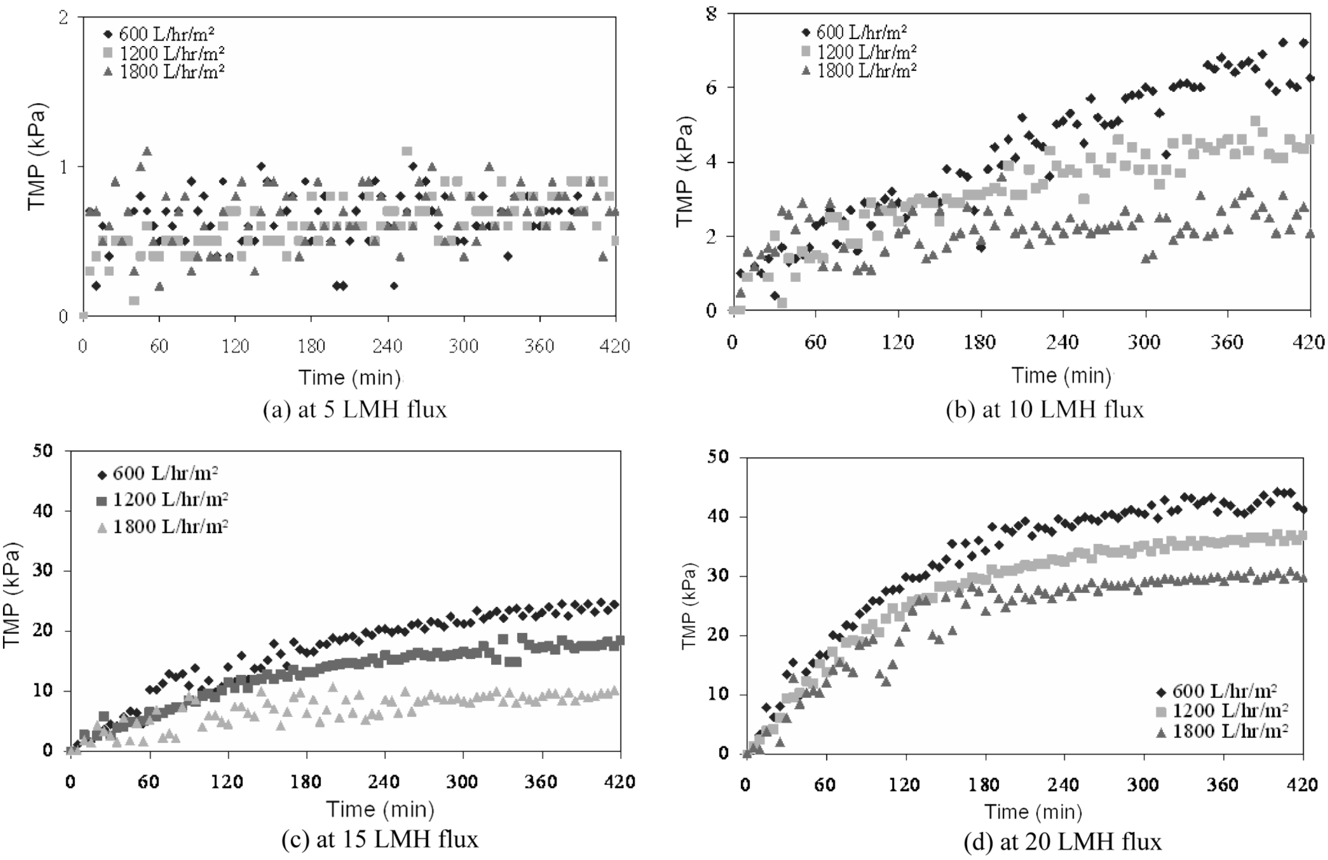

Fig. 3. Effect of air flow on TMP at different permeate fluxes.

TMP was similar up to a certain time (120 min) but the rising trend of the TMP became distinct after this period (Fig. 3b). This result shows that air flow has influence on the particle deposition only after certain time. Most likely at an early stage the deposition was not enough to be scoured. Once the deposit was sufficiently formed, air bubbles started scouring and transporting back the deposited mass to the suspension. At 15 LMH, the particle deposition became distinct from the beginning indicating a strong influence of air flow (Fig. 3c). This showed equilibrium between the flux and air flow rate. Beyond 15 LMH, a sharp rise in TMP was observed which suggested the existence of a critical flux beyond this permeate flow rate. At 20 LMH, the result was similar to 10 LMH showing a similar trend upto 120 min for all three air flow rates but becoming distinct after this for all air flow rates (Fig. 3d). Most likely, at the beginning (1 h) the drag force (flux rate) was too high for smaller particles to be deposited during which air flow had no effect and scouring was not effective. However during this period due to a small particle deposition on the membrane, the rise in the TMP was high. At a later stage once coarse particles had deposited, air flow had a significant influence on scouring and mixing.

Table 1 shows the reduction in TMP when air flow was increased. Doubling and tripling the air flow rate had negligible effect on the reduction of TMP for a very low permeate flux (5 LMH). Increasing the air flow rate from 600 to 1200 L/h/m^2 caused a 33, 25 and 20% reduction in TMP for 10, 15 and 20 LMH respectively whereas tripling the air flow (600–1800 L/h/m^2), caused a 51, 60 and 33% reduction in TMP for 10, 15 and 20 LMH respectively. Low permeate fluxes (10 and 15 LMH) were found to be more efficient than higher flux (20 LMH) in terms of the reduction in TMP for the different air flow rates. While tripling air flow rates, the 15 LMH flux was found to be the most efficient flux rate (for the suspension used) which was verified from the total water produced during the test (Table 1).

3.2. *Effect of air flow on particle deposition (fouling)*

The indicators of membrane performance such as the development of TMP with time or particle deposition show an apparent response to the application of air flow. Ivanovic and Leiknes [8] observed a higher fouling rate for lower aeration rates or low particle deposition at higher aeration rates. Their results confirmed the importance of aeration as a means to mitigate fouling in a submerged membrane system.

Fig. 4 presents the cumulative mass deposition of clay particles at different air flow rate (600, 1200 and 1800 L/h/m^2) and flux rate (5, 10, 15 and 20 LMH). At a lower flux rate, the mass deposition was low (compared to higher flux) but the increment in air flow only marginally helped to reduce the deposition (Fig. 4a). At 10 LMH, deposition was clearly affected by air flow. The mass deposition was significantly reduced from 193.97 to 94.15 g/m^2 when the air flow rate reduced from 600 to 1800 L/h/m^2 (Fig. 4b). At 15 LMH (Fig. 4c), there was a clear difference in the mass deposited at the three air flow rates. At 20 LMH (Fig. 4d), doubling the air flow rate (600–1200 L/h/m^2) showed minimal difference in deposition whereas a significant reduction was observed at 1800 L/h/m2 (261.58 g/m^2) compared to 600 L/h/m^2 (383 g/m^2). The particle deposition pattern is supported by the TMP graph where 15 LMH was the transition. The increasing deposition patterns were found along the time period for all adopted operating conditions. In conclusion, the increased air flow (scouring) helped to reduce the mass deposition which was significantly affected by the flux rate. Similar results were reported by Ivanovic and Leiknes [8].

Table 2 summarises the results of the reduction in mass deposition with increasing air flow rates. An increase of the air flow rate from 600 to 1200 L/h/m^2 reduced mass deposition by 36, 30 and 15% for 10, 15 and 20 LMH respectively whereas increasing the air flow three times (600 to 1800 L/h/m^2) resulted in a reduction of particle depositions by 64, 59 and 30% at 10, 15 and 20 LMH respectively. These data suggests that an increased air flow is more efficient for low flux rates. A three fold increase in air flow gave the most reduction in fouling at 10 LMH but in terms of the total volume of filtered water, 15 LMH flux was found to be the most influenced by the high air flow rate.

Table 1
TMP reduction with varying air flow rates

Flux (LMH)	Air flow increment (L/h/m^2)			Total volume of filtered water (L)
	600–1200	600–1800	1200–1800	
5	Negligible	Negligible	Negligible	7.0
10	33%	51%	31%	14.0
15	25%	60%	46%	21.0
20	20%	33%	16%	28.0

Table 2
Fouling reduction with increasing air flow rates

Flux (LMH)	Air flow increment (L/h/m^2)			Total volume of filtered water (L)
	600–1200	600–1800	1200–1800	
5	—	—	—	7.0
10	36%	64%	36%	14.0
15	30%	59%	42%	21.0
20	15%	30%	18%	28.0

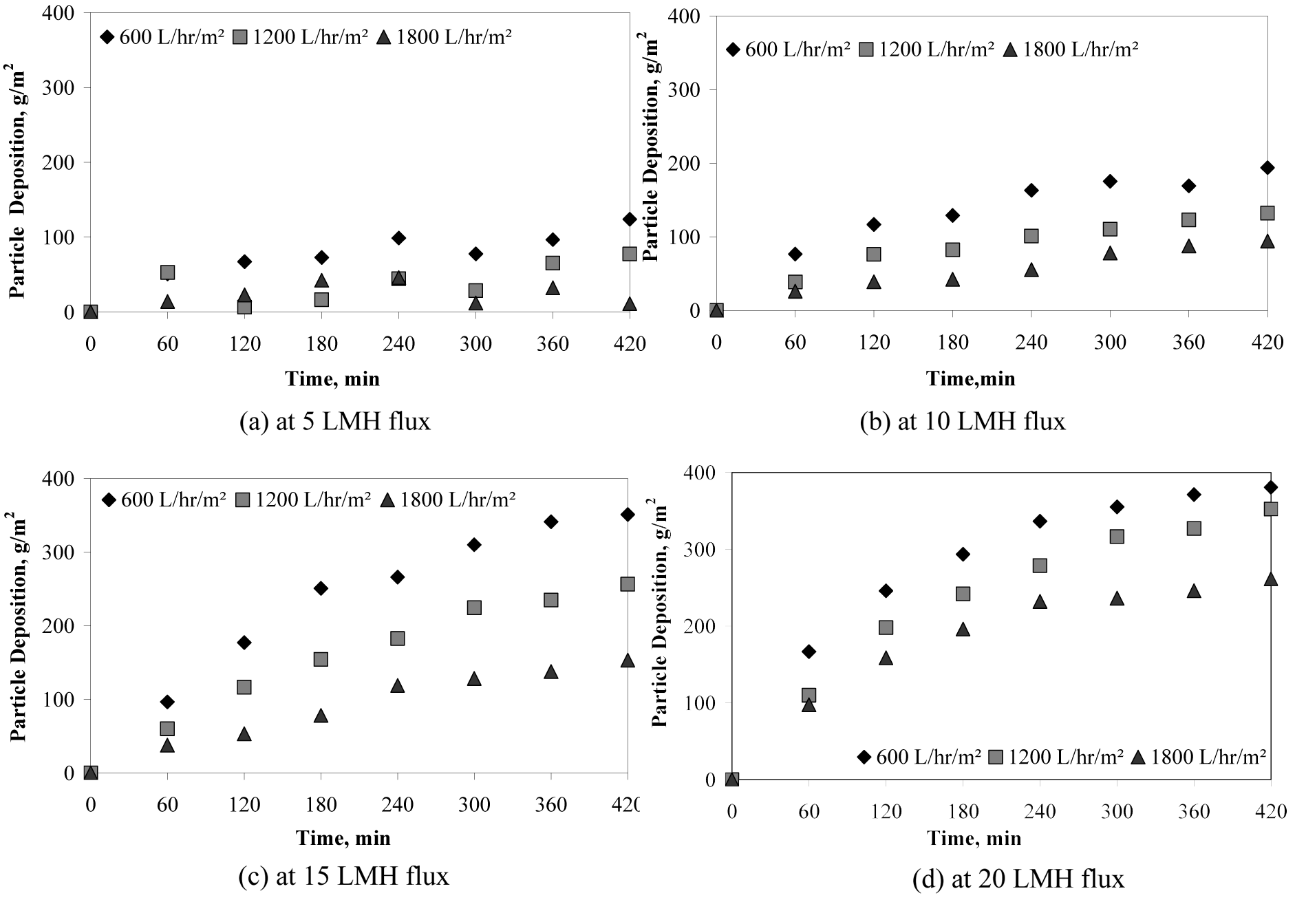

Fig. 4. Effect of air flow on particle deposition on membrane surface.

3.3. *Effect of air flow on particle size distribution*

The hydrodynamic forces in the immediate vicinity of the membrane are the major parameters which are responsible for particle deposition on the membrane surface. Particle size is one of the most important parameters affecting the hydrodynamic forces. TMP and particle deposition behaviour are also affected by particle size distribution of deposited particles. Small change in mean particle size shows significant affects the TMP and fouling. Fig. 5 describes the effect of operating conditions on the particle size distribution in suspension.

Figs. 5a and 5b present the mean particle size available in suspension for 5 LMH and 10 LMH respectively. The mean particle sizes were observed to be very similar with less fluctuation during the test period for both flow rates. This similarity in particle size during the process may be due to 1) the insufficient drag force to hold the deposited particle on the membrane wall and 2) sufficient air bubbles for scouring and back transport. This is supported by Figs. 3a and 3b (low TMP rise).

At 15 LMH, at lower air flow, a slow increase of particle size in the suspension was observed indicating deposition of fine particles on the membrane surface. However at a higher air flow rate, similar particle size were observed in lower permeate fluxes of 5 and 10 LMH. At higher air flow rate, a large reduction in TMP and low particle deposition were found compared to other permeate fluxes (Figs. 3c, 4c and Tables 1 and 2). These highlight that at critical flux (15 LMH) higher air flow rates were effective to maintain the equilibrium between the drag force and lift force so that air bubbles were sufficient to scour deposited particles resulting a lower rise in TMP and smaller particle deposition. This concludes that the mitigation of particle deposition on the membrane surface is not only a function of air flow rates but also the combined effects of air flow and permeate flux which determines the best operating condition for the filtration process. Based upon this analysis, 15 LMH was observed as the optimum operating condition.

In the case of 20 LMH, the drag force is sufficient to deposit the particle on the membrane wall. At lower air flow rate, the deposition of fine particles is observed to occur rapidly. An increase of air flow decreased the deposition of fine particle. This emphasises that small particles are attached to the membrane surface from the beginning of the test which produced high TMP and deposition.

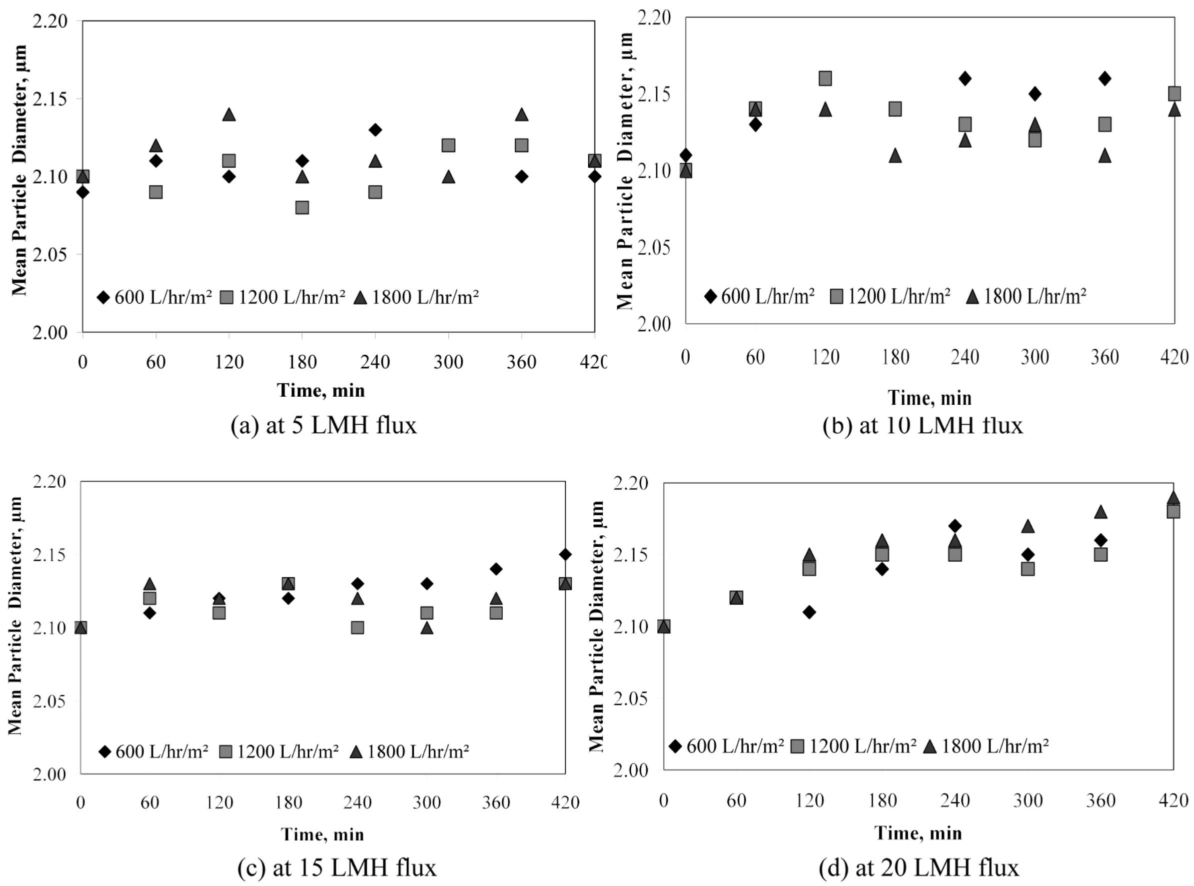

Fig. 5. Effect of air flow on particle size distribution.

3.4. TMP and particle deposition relation for different air flow rates

From the experimental results obtained, a relationship between the TMP and particle deposition was drawn for three air flow rates (600, 1200 and 1800 L/h/m^2) and four permeate flow rates (5, 10, 15 and 20 LMH). The graphical representations are shown in Fig. 6. A linear regression was applied between TMP and particle deposition. At lower flux, no relationship between TMP and particle deposition was observed. At this flux, an increase in particle deposition did not change the TMP. This showed the deposition was minimal and porous. Between 10–20 LMH, a linear relationship was observed between the TMP and particle deposition where a significant reduction in TMP and deposition was found to occur with increasing air flow rates. The linear equations developed for 5, 10, 15 and 20 LMH at 600, 1200 and 1800 L/h/m^2 are tabulated in Table 3.

4. Conclusion

This study investigated the effects of air flow and permeate flux on the deposition of particles on the membrane surface. The main conclusions are:

Table 3
Relationship between TMP and particle deposition for different permeate flux and air flow rates

Air flow rate	600 L/h/m^2		1200 L/h/m^2		1800 L/h/m^2	
Flux (LMH)	Equation	R^2	Equation	R^2	Equation	R^2
5	—	—	—	—	—	—
10	$Y = 0.044\ X - 1.969$	0.877	$Y = 0.048\ X - 0.545$	0.916	$Y = 0.024\ X + 0.805$	0.869
15	$Y = 0.055\ X + 4492$	0.979	$Y = 0.057\ X + 3.991$	0.982	$Y = 0.043\ X + 3.03$	0.971
20	$Y = 0.103\ X + 5.197$	0.965	$Y = 0.088\ X + 6.878$	0.975	$Y = 0.107\ X + 3.214$	0.952

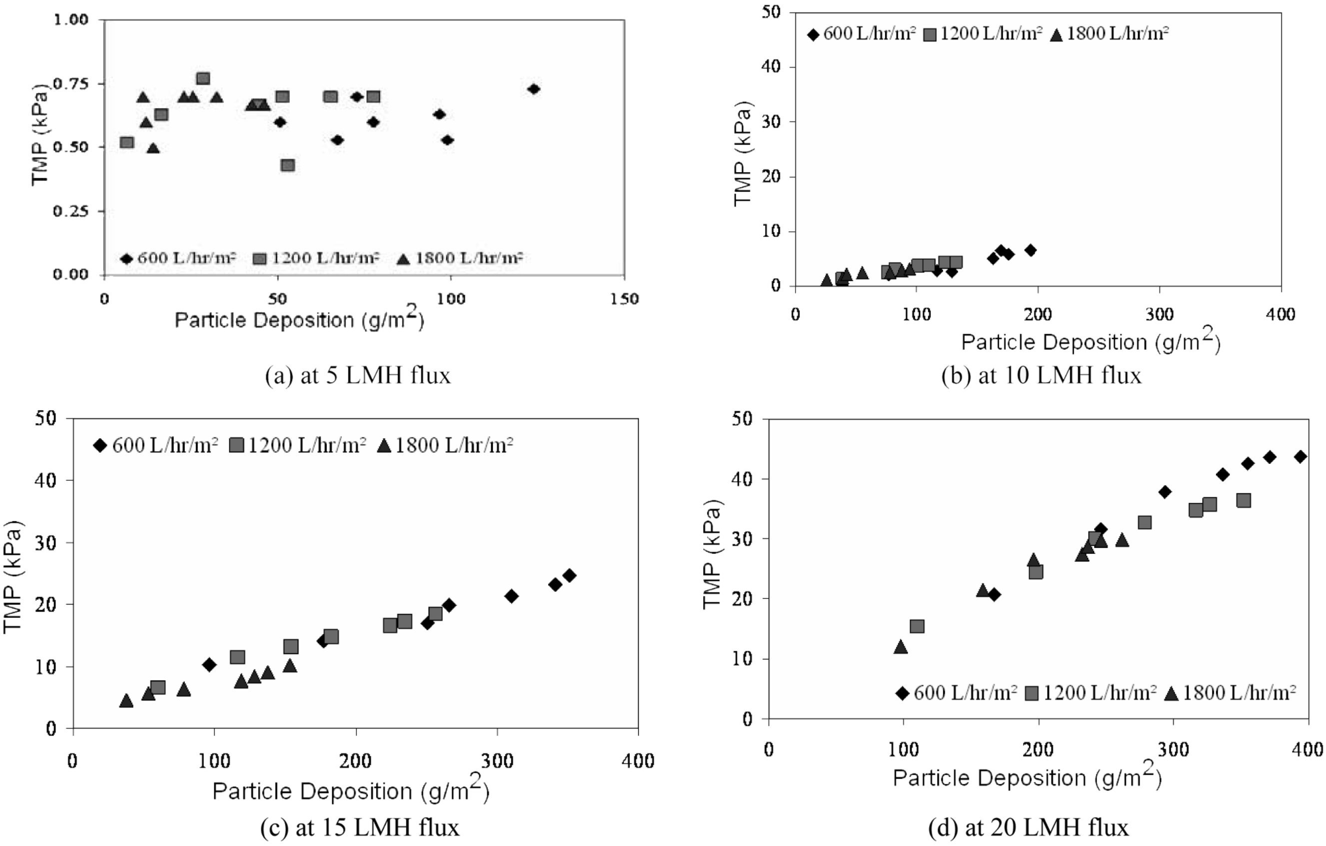

Fig. 6. Relationship between TMP and particle deposition for different air flow rates.

- A smaller amount of particle deposition was observed on the membrane surface at high air flow rates for all permeate flux rates whereas at low air flow rate there was a large deposition which caused a high TMP.
- At a lower permeate flux, an increase in air flow rate showed an effective reduction in particle deposition and TMP whereas at a higher flux rate, the reduction was minimal. A sharp rise in TMP occurred during the first few hours of operation indicating that air flow for deposition mitigation strategies should focus on this period to optimise the membrane operation.
- A flux of 15 LMH was found to be the critical flux beyond which a rise in the permeate flux showed a sharp rise in TMP and particle deposition
- A linear relationship between the TMP and particle deposition has been found for different air flow and permeate flow rates. This relation simply shows an interdependency between TMP and particle deposition at a high flux rate. An air flow and flux rates are the governing factors for particle deposition. A single parameter consideration may not be effective for efficient membrane filtration design process.

References

[1] G. Belfort, R.H. Davis and A.L. Zydney, The behavior of suspensions and macromolecular solutions in crossflow microfiltration. J. Membr. Sci., 96 (1994) 1–58.

[2] E.H. Bouhabila, R. Ben Aim and H. Buisson, Fouling characterisation in membrane bioreactors, Separ. Purif. Technol., 22–23 (2001) 123–132.

[3] C. Wisniewski and A. Grasmick, Floc size distribution in a membrane bioreactor and consequences for membrane fouling, Colloids Surfaces A: Physicochem. Eng. Aspects, 138 (1998) 403–411.

[4] Z.F. Cui, S. Chang and A.G. Fane, The use of gas bubbling to enhance membrane processes. J. Membr. Sci., 221 (2003) 1–35.

[5] R. Aryal, S. Vigneswaran and J. Kandasamy, Influence of buoyant media in particle layer dynamics in microfiltration membrane. Wat. Sci. Technol., 61(7) (2010) 1733–1737.

[6] R. Liu, X. Huang, C. Wang, L. Chen and Y Qian, Study on hydraulic characteristics in a submerged membrane bioreactor process. Process Biochem., 36(3) (2000) 249–254.

[7] T. Ueda, K. Hata, Y. Kikuoka and O. Seino, Effects of aeration on suction pressure in a submerged membrane bioreactor. Wat. Res., 31(3) (1997) 489–494.

[8] I. Ivanovic and T. Leiknes, Impact of aeration rates on particle colloidal fraction in the biofilm membrane bioreactor (BF-MBR). Desalination, 231 (2008) 182–190.