Desalination and Water Treatment
www.deswater.com
doi: 10.1080/19443994.2013.781738

51 (2013) 3878–3882
May

Taylor & Francis
Taylor & Francis Group

Impact of operating conditions on the flux changing rate during dead-end microfiltration process

Wenyue Dong[a], Xu Wang[b], Xiao Ye[c], Zhan Wang[a,*], Ximing Zhang[a]

[a]*Department of Chemistry and Chemical Engineering, College of Environment and Energy Engineering, Beijing University of Technology, Beijing 100124, P.R. China*
Tel. +86 010 67396186; Fax: +86 010 67391983; email: wangzh@bjut.edu.cn
[b]*Weather Modification Office of Xingjiang Uygur Autonomous Region of China, Urumqi 830002, P.R. China*
[c]*Biochemical Engineering College of Beijing Union University, Beijing 100101, P.R. China*

Received 8 August 2012; Accepted 25 February 2013

ABSTRACT

Dead-end microfiltration experiments with the activated sludge suspension from submerged membrane bioreactors were performed to determine the critical flux, which is a very significant factor to indicate the membrane fouling in microfiltration process. In this study, the critical permeation fluxes were measured by successive variations of transmembrane pressure (step by step technique) under different operating conditions (temperatures, stirring rate and concentrations of the mixed liquor suspended solid [MLSS]) using polyvinylidene fluoride membranes with a pore size of 0.1 μm. A study of the impact of various operating conditions on the fouling rate when the critical flux is achieved was especially made. The experiments revealed that: the increase in stirring rate leads to a decrease in the rate of fouling; the fouling rate decreased with the increase in temperature when it was less than a certain values, after that, it increased with the continuous increase in temperature, while the variation of the concentration of the MLSS has a negative influence on the membrane fouling. The results obtained from the experiments can provide reliable information to the optimization of operating conditions to alleviate membrane fouling.

Keywords: Dead-end microfiltration; Critical flux; Fouling rate; Operating conditions

1. Introduction

Over the decades, submerged membrane bioreactors (MBRs), the combination of activated sludge biological degradation process and membrane filtration, have drawn great interest from researchers and engineers for its many advantages such as small footprint and reactor volume requirements, high effluent quality, good disinfection capability, high volumetric loading and small sludge production [1]. Despite its increasingly popular for wastewater treatment, the membrane fouling which causes the declining permeate flux, or increasing pressure drop with time has limited the MBRs wide application.

Many researchers have made studies into the cause of membrane fouling and the approach to improve flux decline, and a possible means is to carry out the filtration operation below the critical flux. The

*Corresponding author.

Presented at the 2012 Qingdao International Desalination Conference June 26–29, 2012, Qingdao, China

critical flux is classically defined as the flux below which there is no detectable fouling [1]. Two forms of hypothesis for the critical flux exist: strong and weak. The strong form is the flux at which the transmembrane pressure starts to deviate from the pure water line, which is of course linear. For the weak form, there is the assumption that there is very rapid fouling on start-up and so the flux–transmembrane pressure (TMP) relationship is below that of the pure water line. The critical flux (weak form) is the point at which this line becomes nonlinear [2]. Though the membrane fouling is inevitable, the subcritical flux operation may have a positive effect on the filtration process and the research on how the operating conditions influence the critical flux is of great importance.

In early research, Al-Amri and Razman compared the influence of three various temperatures (25, 35, and 45℃) on the membrane performance, and the conclusion was drawn that at low temperatures and fluxes, the membrane fouling occurred externally while at high temperatures and fluxes it becomes internal due to membrane bores widening [3]. Farquharson and Zhou conducted filtration tests using sludge samples collected from pilot-scale submerged membrane bioreactor plants. They found that no correlation between the concentration of the MLSS and the fouling rate could be observed. As well, there was no correlation between the MLVSS or MLVSS/MLSS ratio and fouling rate [4].

The current work sets out to investigate the effect of various operating conditions, such as stirring rate, temperature and the concentration of mixed liquor suspended solid (MLSS) on the critical flux using polyvinylidene fluoride (PVDF) microfiltration membranes for better understanding the membrane fouling in dead-end microfiltration of the activated sludge. Trends in critical flux behavior were similar to those obtained by other researchers whist the fouling rate represented by the changing rate of dJ/dt before and after the critical flux point can provide a reliable instruction for the optimization of the filtration process.

2. Materials and methods

2.1. Experimental set-up and operating conditions

The study was carried out using an experimental set-up previously described in detail [5]. The experimental system consists of an activated sludge bioreactor and a membrane device, as shown in Fig. 1. The dead-end micro filter cup has an efficient volume of 300 mL, in which MLSS of a known concentration was poured into it after each filtration experiment. Raw wastewater supplied from the storage tank is synthetic domestic sewage with the composition shown in Table 1. All the experiments were conducted at the speed of the electromagnetic stirrer ranging from 0 to 250 rpm and T from 18 to 27℃. The concentrated feed solution was diluted with tap water to the desired concentration prior to feeding it to the activated sludge reactor. The concentration of activated sludge suspensions changes from 4,500 to 6,300 mg/L.

2.2. Membrane

PVDF flat membranes with a pore diameter of 0.1 μm (Beijing Ande Membrane Separation Technology Engineering, China) were used as the filtration medium. Before conducting the experiment, the PVDF membranes were soaked in deionized water for 10–12 h to remove glycerin, which was used as a protective agent in membranes.

2.3. Experimental procedure

2.3.1. Determination of critical flux

Critical flux is most commonly determined by the step by step technique. In this study, the TMP-step technique [6] was used to determine it: the TMP was kept low firstly, and then, the transmembrane pressure was increased at fixed intervals of 0.02 MPa in time duration of 30 min. The data were noted at intervals of 30 s. If the TMP became non-linear with the permeate flux, it was indicative of a critical flux. The critical flux was the average value between the last time independent flux step and the first time dependent flux step as employed previously [1,7].

2.3.2. Comparation of the flux changing rate before and after the critical flux

The critical flux value obtained using the method described previously differed, while the changing rate of the flux at the TMP just before and after the critical flux point may have provide more reliable information about the fouling of the membrane. The flux changing rate means that when the critical flux is achieved at certain TMP, the increasing rate of flux in the prior or next 30 min during the corresponding TMP interval. If the flux changing rate increases with the increase of the value of certain operating condition, it means that the operating condition has a positive influence on the improving of the membrane fouling; otherwise the increase in the operating condition does not make any sense to suppressing the membrane fouling. In the following part, the analysis

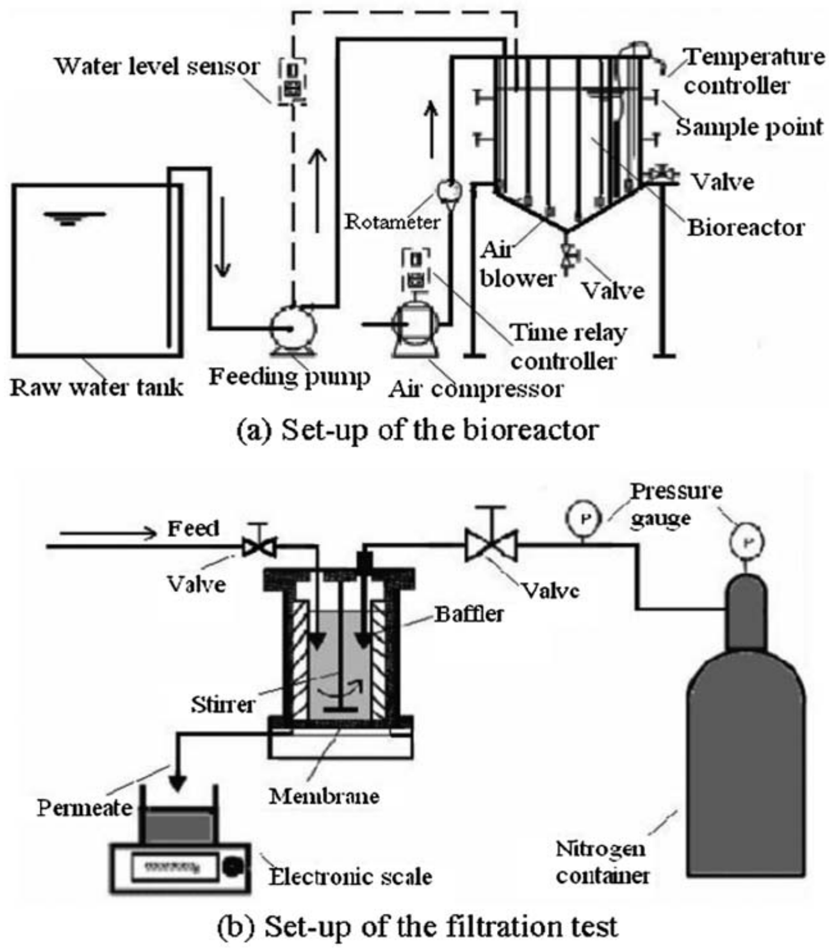

Fig. 1. Schematic diagram of the experimental system.

Table 1
Composition of synthetic wastewater

Components	Concentration (mg/L)	Components	Concentration (mg/L)
Glucose	278	$CaCl_2$	6.0
Starch soluble	278	$MgSO_4{\cdot}7H_2O$	66
Peptone	28	$MnSO_4{\cdot}7H_2O$	6.0
NH_4Cl	297	$FeSO_4$	0.3
$NaHCO_3$	111	NaH_2PO_4	52.8

was adopted to make an investigation on the influence of operating conditions on the membrane fouling.

3. Results and discussion

3.1. Effect of stirring rate

The effect of stirring rate on the critical flux and the membrane fouling during the dead-end microfiltration of activated sludge process is reflected in Fig. 2. Increasing the stirring rate from 0 to 250 rpm led to the increase in the critical flux and the increases in flux changing rate both before and after the critical flux point. This observation could be explained in terms of the wall shear stress, a force exerted by a fluid flowing

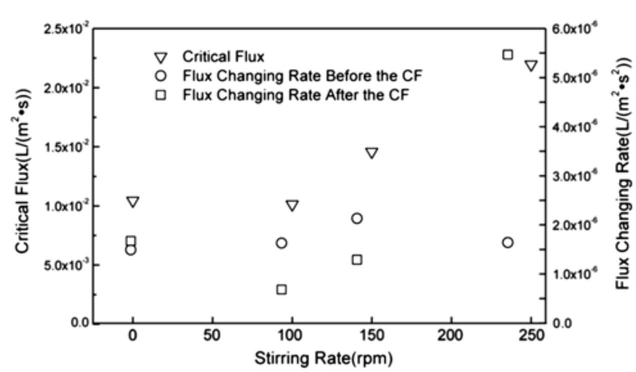

Fig. 2. The influence of stirring rate on critical flux and the membrane fouling for activated sludge (MLSS concentration of 4,500 mg/L and temperature of 21°C).

tangentially to the membrane on an element of its surface area, which was caused by the rolling of the electromagnetic stirrer. The fact is that the higher the wall shear stress, the lower the deposited mass and thickness, because the increasing wall shear stress may intend to sweep away more of the membrane fouling components in the retentate [8].

3.2. Effect of temperature

The influence of mixed liquor temperature on the critical flux and membrane fouling has been investigated in this study. Mixed liquor temperature is a significant operating parameter as it could change the biomass properties. It can be observed from Fig. 3 that the critical flux increases slightly with the increasing of temperature. While at the temperature range of 18–24℃, the changing rate of flux increases, which indicates that the membrane fouling decrease with the increasing temperature, that is to say the membrane fouling inversely proportional to the temperature. This phenomenon can be illustrated by the fact that the sludge viscosity becomes lower at a higher temperature, while the permeate flux is inversely proportional to the viscosity of liquid passing through the membrane [9]. On the other hand, the back transport of deposited particles from the membrane surface into the bulk solution depends on the shear force induced by the agitation of the electromagnetic stir, which will be accelerated in the liquid of a lower viscosity [10].

It is noticeable that when the temperature reaches to 27℃, the membrane fouling becomes severe. Therefore, a further increase in temperature does not contribute to substantially reduce membrane fouling for the experimental conditions tested, and the similar result has been reported in earlier research [11].

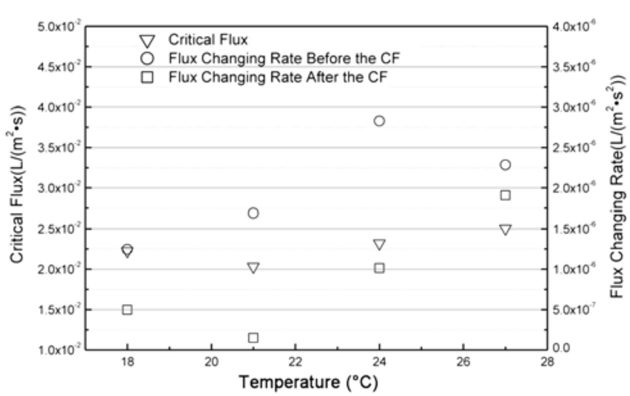

Fig. 3. The influence of temperature on critical flux and the membrane fouling for activated sludge (MLSS concentration of 4,500 mg/L and stirring rate of 200 rpm).

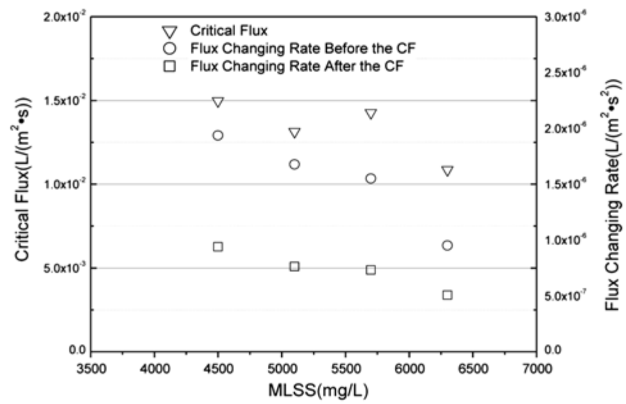

Fig. 4. The influence of the concentration of MLSS on critical flux and the membrane fouling for activated sludge (temperature of 21℃ and stirring rate of 200 rpm).

3.3. Effect of concentration of MLSS

The influence of concentration of MLSS on the critical flux and the flux changing rate has been demonstrated in Fig. 4. And it can be observed that the critical flux does not have an evident relationship with the concentration of MLSS as the data were floating. Fan and Zhou observed that MLSS concentration had little effects on critical flux when the MBRs were operated at normal scouring aeration condition. The effects of MLSS on fouling could be observed only when no or very low scouring aeration was applied [12].

From Fig. 4, the flux changing rate was observed to decrease from 1.935×10^{-6} to $9.498 \times 10^{-7}\,\mathrm{L/(m^2\,s^2)}$ for the sub-critical TMP filtration and to decrease from 9.643×10^{-7} to $5.329 \times 10^{-7}\,\mathrm{L/(m^2\,s^2)}$ for the super-critical TMP process. The conclusion can be drawn that the increase of concentration of MLSS can aggravate the membrane fouling not only during super-critical flux but also the subcritical flux filtration. The results can be illustrated that the increase in concentration will enhance the concentration polarization, and the higher the feed concentration, the higher concentration polarization, then a concentration polarization layer was formed. With more foulant deposited on concentration polarization layer, a stagnant fouling layer will form, thus a higher feed concentration led the foulant to transmit from the concentration to the stagnant fouling layer quickly, the flux changing rate decreases with the MLSS concentration [13,14].

4. Conclusion

The results obtained support the idea that the membrane fouling is affected by the operating conditions hydrodynamics, that is, stirring rate and the suspension solution properties (temperature and the concentration of mixed liquor). The results of experiments show that when the temperature is at a relatively low range of 18–24℃, the increasing of the temperature can suppress the membrane fouling, while when the temperature is higher to be 27℃, the membrane fouling becomes severer. Working under the stirring conditions was necessary for the dead-end microfiltration of the activated sludge to optimize the membrane filtration performance. Additional experiments revealed the inner relationship of the concentration of the activated sludge with the membrane fouling, and the results showed that with the increase in the concentration of the activated sludge, the membrane fouling becomes severe, although the influence of concentration of *MLSS* does not affect the critical flux evidently.

Acknowledgment

Support for this study was provided by National Natural Science Foundation of China (Project NO. 21176006).

References

[1] T.Y. Chiu, A.E. James, Critical flux determination of non-circular multi-channel ceramic membranes using TiO_2 suspensions, J. Membr. Sci. 254 (2005) 295–301.
[2] R.W. Field, D. Wu, J.A. Howell, B.B. Gupta, Critical flux concept for microfiltration fouling, J. Membr. Sci. 100 (1995) 259–272.
[3] A. Al-Amri, M. Razman Salim, A. Aris, The effect of different temperatures and fluxes on the performance of membrane bioreactor treating synthetic-municipal wastewater, Desalination 259 (2010) 111–119.
[4] A. Farquharson, H. Zhou, Relationships of activated sludge characteristics to fouling rate and critical flux in membrane bioreactors for wastewater treatment, Chemosphere 79 (2010) 149–155.
[5] Z. Wang, J. Chu, Y. Song, Y. Cui, H. Zhang, X. Zhao, Z. Li, J. Yao, Influence of operating conditions on the efficiency of domestic wastewater treatment in membrane bioreactors, Desalination 245 (2009) 73–81.
[6] T.Y. Chiu, A.E. James, Critical flux determination of non-circular multichannel ceramic membranes using TiO_2 suspensions, J. Membr. Sci. 254 (2005) 295–301.
[7] X. Wang, Z. Wang, Y. Zhou, X. Xi, W. Li, L. Yang, X. Wang, Study of the contribution of the main pollutants in the oilfield polymer-flooding wastewater to the critical flux, Desalination 273 (2011) 375–385.
[8] A.A. McCarthy, P.K. Walsh, G. Foley, Experimental techniques for quantifying the cake mass, the cake and membrane resistances and the specific cake resistance during crossflow filtration of microbial suspensions, J. Membr. Sci. 201 (2002) 31–45.
[9] G. Belfort, R.H. Davis, A.L. Zydney, The behavior of suspensions and macromolecular solutions in crossflow microfiltration, J. Membr. Sci. 96 (1994) 1–58.
[10] C.M. Silva, D.W. Reeve, H. Husain, H.R. Rabie, K.A. Woodhouse, Model for flux prediction in high-shear microfiltration systems, J. Membr. Sci. 173 (2000) 87–98.
[11] M.-C. Vincent-Vela, B. Cuartas-Uribe, S. Álvarez-Blanco, J. Lora-García, Analysis of an ultrafiltration model: Influence of operational conditions, Desalination 284 (2012) 14–21.
[12] F. Fan, H. Zhou, Interrelated effects of aeration and mixed liquor fractions on membrane fouling for submerged membrane bioreactor processes in wastewater treatment, Environ. Sci. Technol. 41 (2007) 2523–2528.
[13] M. Li, Y. Zhao, S. Zhou, W. Xing, F.-S. Wong, Resistance analysis for ceramic membrane microfiltration of raw soy sauce, J. Membr. Sci. 299 (2007) 122–129.
[14] Y. Ye, P. Le Clech, V. Chen, A.G. Fane, Evolution of fouling during crossflow filtration of model EPS solutions, J. Membr. Sci. 264 (2005) 190–199.