WATER RESEARCH 46 (2012) 2535–2544

Available online at www.sciencedirect.com

SciVerse ScienceDirect

journal homepage: www.elsevier.com/locate/watres

A comparison of cake properties in traditional and turbulence promoter assisted microfiltration of particulate suspensions

Yuanfa Liu, Gaohong He, Baojun Li, Zhengwen Hu, Jia Ju*

State Key Laboratory of Fine Chemicals, R&D Center of Membrane Science and Technology, School of Chemical Engineering, Dalian University of Technology, 2 Linggong Road, Dalian 116024, China

ARTICLE INFO

Article history:
Received 13 October 2011
Received in revised form
29 January 2012
Accepted 1 February 2012
Available online 9 February 2012

Keywords:
Membrane fouling
Flux enhancement
Turbulence promoter
Cake properties

ABSTRACT

The use of turbulence promoter can effectively enhance the permeate flux in crossflow microfiltration (CFMF) of particulate suspensions. Flux enhancement which is generally attributed to the reduction in cake thickness, however, has still not been clearly understood. In this study, the effects of turbulence promoter on cake properties (thickness, porosity and particle size) were investigated during CFMF of calcium carbonate suspension. It indicates that turbulence promoter has important effects on cake properties that directly affect the cake resistance. The significant reduction in thickness and slight increase in porosity are positive to reduce the cake resistance. The remarkable decrease in particle size is the negative effect due to the increased specific resistance of a cake. As a whole, the overall cake resistance is still diminished by turbulence promoter and therefore permeate flux is improved. The theoretical calculation of cake resistance shows a good consistence with the experimental result. The cake properties in both cases (using a turbulence promoter or not) almost exhibit the similar trends under various operating conditions. Differently, the use of turbulence promoter can greatly alleviate the effects of transmembrane pressure or feed concentration on growth of cake layer and intensify the effects of inlet velocity on diminishing the particle deposition.

1. Introduction

Microfiltration (MF) is a pressure-driven membrane filtration process to retain colloidal particles including silica, iron oxides, calcite, and clays (Walker et al., 2006) during drinking water (Carroll et al., 2003; Lee et al., 2008) and wastewater (Al-Malack and Anderson, 1997; Geissen and Xi, 2001) treatment. However, the applications of MF are seriously hindered by the membrane fouling (Kimura et al., 2007; Li et al., 2011; Zhang et al., 2010) that causes an undesired decline of permeate flux (Lin et al., 2009) with time. The membrane fouling in crossflow microfiltration (CFMF) of particulate suspensions refers to the deposition of rejected particles on the membrane surface, leading to blockage of membrane pores and formation of a cake layer. Since surface deposition of cake particles is achieved quickly (about a few minutes) due to the high filtration flow during the initial filtration period, cake formation is regarded as the predominant mechanism responsible for the flux decline.

The cake permeability is generally much lower than membrane, and thus the cake layer plays an important role in the permeate flux of membrane. It is of great significance to

---

[*] *Corresponding author*. Tel.: +86 411 84707892; fax: +86 411 84007700.
E-mail address: hgaohong@dlut.edu.cn (G. He).

0043-1354/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
doi:10.1016/j.watres.2012.02.002

estimate cake properties and investigate their influences on the membrane filtration performance. Vyas et al. (2000b) developed a novel method to measure cake thickness which was conducted by reconstruction of cake layer, and investigated the effects of operating conditions on cake properties in CFMF of lactalbumin suspension. It was found that the cake thickness increased with an increase in transmembrane pressure (TMP) and with a decrease in crossflow velocity, but there was no significant effect of TMP or crossflow velocity on cake porosity. Ould-Dris et al. (2000) demonstrated that the cake thickness, porosity and particle size distribution had significant effects on permeate flux in CFMF of calcium carbonate suspensions. Hwang and Hsueh (2003) proposed a dynamic analysis method to estimate cake properties in microfiltration of soft colloid suspension, and found that the decay of permeate flux was closely related to a rapid increase in cake resistance and a decrease in cake porosity due to cake compression. Cabassud et al. (2001) suggested flux enhancement by air sparging had a close relationship with cake properties that were clearly modified by two-phase flow in CFMF of clay suspension.

To alleviate the adverse effects of membrane fouling, different types of turbulence promoters such as static mixer (Vatai et al., 2007), static rod (Chiu and James, 2006), twisted wire-rod (Yeh and Chen, 2006), disc or doughnut shape insert (Liu et al., 2009) and helical screw insert (Ahmad and Mariadas, 2004; Bellhouse et al., 2001; Millward et al., 1995) have been widely used during various CFMF processes. Among these approaches, helical screw insert attracts much interest owing to its excellent streamline shape which guarantees the relatively lower energy consumption. For the same reason, a helical screw insert was used to improve the permeate flux of membrane in this study.

High wall shear stress due to the presence of turbulence promoter can effectively reduce the thickness of cake layer deposited, resulting in high permeate flux of membrane. It therefore has been widely accepted that flux enhancement by turbulence promoter is attributed to the diminished cake thickness. Jokic et al. (2010) found the insertion of turbulence promoter changed the flow pattern in the channel and increased scouring of membrane surface. They proved the flux improvement was largely related to the reduction in cake thickness during CFMF of baker's yeast suspension. Pal et al. (2008a,b) demonstrated that the significant enhancement of permeate flux by incorporating a turbulence promoter was attributed to the reduction in cake thickness during the membrane filtration of fruit juice. However, the previous studies ignored the effects of turbulence promoter on the porosity and particle size of cakes, which are two important factors affecting the cake resistance. It indicates that the mechanism for flux enhancement by turbulence promoter has still not been fully understood.

In this study, a helical screw insert was used as turbulence promoter in CFMF of calcium carbonate ($CaCO_3$) suspension. Cake thickness, porosity and particle size were measured in both cases with and without a turbulence promoter under the same operating conditions to investigate the effects of turbulence promoter on cake properties. In addition, the effects of operating conditions on cake properties in both cases were also studied.

2. Experiment and method

2.1. *Ceramic tubular membrane*

The ceramic tubular membrane (Nanjing University of Technology, P.R. China) used in this study was 200 mm in length, with inner diameter of 15 mm and outer diameter of 18 mm. The pore size distribution of membrane is shown in Fig. 1, with average pore size of 0.91 μm.

2.2. *Turbulence promoter*

The helical screw insert which is made of the stainless steel is presented in Fig. 2. The outer diameter of helical screw insert is 13 mm, and the diameter of central rod is 6 mm. The thickness of helix ridge is 2 mm, and the depth and width of helical groove are 3.5 and 12 mm, respectively. The helical screw insert is inserted centrally into the tubular membrane with the help of two supporters at each end of membrane module.

2.3. *Filtration unit*

A laboratory-scale filtration unit was arranged, which consists of a feed reservoir (10 L) thermostated at 30 °C, a peristaltic pump and measuring equipments (pressure gauge, flow meter). In addition, a stirrer was utilized to ensure the complete mixing of feed concentration.

The test fluid is the suspension of calcium carbonate particles with the median particle size (D_{50}) of 6.18 μm and density of 2700 kg/m^3. During a run, both the permeate and the retentate were recycled back to the feed reservoir to maintain the constant feed concentration. After filtration, the membrane was backwashed with pure water to remove the cakes, and then was rinsed with 0.1 M hydrochloric acid (HCl) solution to dissolve the particles blocked in the pores. At last, the membrane was rinsed with pure water to remove the residual HCl solution.

In order to carry out a comparative study, filtration experiments with and without turbulence promoter were

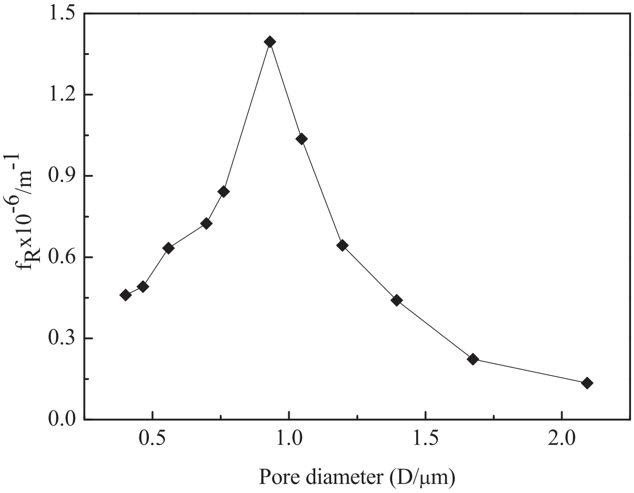

Fig. 1 – Pore size distribution of ceramic membrane.