Journal of the Taiwan Institute of Chemical Engineers 000 (2016) 1–9

Contents lists available at ScienceDirect

Journal of the Taiwan Institute of Chemical Engineers

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

Fine particle removal from seawater by using cross-flow and rotating-disk dynamic filtration

Kuo-Jen Hwang[a,*], Shu-Yu Wang[a], Eiji Iritani[b], Nobuyuki Katagiri[b]

[a] *Department of Chemical and Materials Engineering, Tamkang University, Tamsui, New Taipei City, 25137, Taiwan, R.O.C*
[b] *Department of Chemical Engineering, Nagoya University, Furo-cho, Chikusa-ku, Nagoya, 464-8603, Japan*

ARTICLE INFO

Article history:
Received 27 June 2015
Revised 29 November 2015
Accepted 2 February 2016
Available online xxx

Keywords:
Cross-flow microfiltration
Cake properties
Dynamic filtration
Particle deposition
Seawater pretreatment

ABSTRACT

In the pretreatment preceding desalination, fine particles in seawater are removed using cross-flow and rotating-disk dynamic filtration. The effects of operating conditions, such as cross-flow velocity, transmembrane pressure, disk rotation speed, and the clearance between the disk and the membrane, on the filtration flux, cake properties, and power consumption are discussed. An increase in the cross-flow velocity or transmembrane pressure leads to higher filtration flux. The filtration flux and cake thickness can be accurately estimated using a force balance model for the particle deposition associated with the basic filtration equation. A dynamic filtration module is used to increase the filtration flux. The particles are easily swept away from the membrane surface because of the shear stress generated by the rotating disk. The filtration flux therefore increases by either increasing the disk rotation speed or reducing the clearance between the disk and the membrane. The specific filtration flux, defined for indicating the power effectiveness, decreased with an increase in the disk radius, an increase in the disk rotation speed, or a decrease in the clearance between the disk and the membrane because of a drastic increase in power consumption. A smaller disk is more effective in saving energy.

1. Introduction

In view of the increasing world population and the ever-increasing worldwide demand for water, seawater desalination offers an adequate source of water for the future. The growth in membrane applications for desalination (*e.g.*, in reverse osmosis units) has been exponential over the last decade because of the advantages of high product quality and low operating cost. However, one of the major problems persisting in membrane processes is membrane fouling. Because the performance of reverse osmosis or membrane distillation strongly depends on the raw seawater quality, appropriate pretreatment has become one of the most crucial factors influencing the successful long-term operation of a desalination process [1–3]. To increase product quality and operation efficiency, microfiltration and ultrafiltration membrane systems have been developed for the pretreatment of seawater desalination [4].

Major seawater foulants are particulate matter, colloids, organics, and microorganisms [5,6]. Luo and Wang [6] indicated that the preferential order of foulants was silica colloids > adsorbed organic compounds > particulate matter (iron and aluminum colloids) > microorganisms > metallic oxides. This reveals that the removal of fine particles and inorganic colloids is essential in seawater pretreatment. Xu et al. [3] used inside-out and outside-in hollow fiber ultrafiltration modules for seawater pretreatment prior to the processing of seawater in a desalination unit. The outside-in ultrafiltration module demonstrated superior performance, and the permeate quality for both modules met the requirement for the reverse osmosis feed. Profio et al. [7] used submerged hollow fiber ultrafiltration for seawater pretreatment. The module used by them showed low energy consumption and a small amount of particle deposition on the membrane. The authors found that the membrane showed irreversible particle adsorption during the early stages of seawater filtration, even under subcritical flux conditions.

Microfiltration and ultrafiltration have been widely used for separating fine particles from liquids. When filtration is performed in the cross-flow mode, cake growth is limited by the shear stress generated by the tangential flow. Thus, this mode has the advantages of high filtration flux and long operation time. Moreover, if membrane pore blocking is successfully prevented through appropriate membrane selection, then the main contribution to the overall filtration resistance is derived from the cake formed. The analysis of the cake properties, such as mass, porosity, and specific filtration resistance, under various conditions is therefore critical for determining methods to improve the cross-flow microfiltration

---

[*] Corresponding author. Tel.: +886 2 26215656x2726; fax: +886 2 26209887.
E-mail address: kjhwang@mail.tku.edu.tw (K.-J. Hwang).

http://dx.doi.org/10.1016/j.jtice.2016.02.007
1876-1070/

Nomenclature

C_1	correction factor for Stokes law defined in Eq. (2), [-]
C_2	correction factor for Stokes law defined in Eq. (4), [-]
d_p	diameter of particles, [m]
E	specific flux of dynamic filtration (filtration flux per unit power consumption), [m/J]
F_g	net gravitational force, [N]
F_i	net inter-particle force, [N]
F_l	inertial lift force, [N]
F_n	the normal drag force due to permeate flow, [N]
F_t	the tangential drag force due to cross-flow, [N]
f_c	a factor correlated to friction coefficient defined in Eq. (1), [-]
H	the clearance of filter channel, [m]
h	the distance between vanes and the membrane surface, [m]
L_c	cake thickness, [m]
n	coefficient defined in Eq. (12), [-]
P	power of dynamic filter, [W]
ΔP	transmembrane pressure, [N/m^2]
q_s	filtration rate at pseudo-steady state, [m^3/m^2 s]
R_c	filtration resistance of cake, [m^{-1}]
R_m	filtration resistance of membrane, [m^{-1}]
R_t	overall filtration resistance, [m^{-1}]
r_1	distance from disk center to inner edge of vanes, [m]
r_2	distance from disk center to outer edge of vanes, [m]
SDI$_{15}$	silt density index tested after 15 mins, [-]
T	torque, [N m]
u_l	lift velocity, [m/s]
u_s	cross-flow velocity, [m/s]
w_c	cake mass, [kg/m^2]

Greek letters

α_{av}	average specific filtration resistance of cake, [m/kg]
ε_{av}	average cake porosity, [-]
γ_o	shear rate at the membrane surface, [N/m^2]
κ	coefficient defined in Eq. (12), [-]
μ	viscosity of seawater, [kg/s m]
ν	kinematic viscosity of seawater, [m^2/s]
ρ	density of fluid, [kg/m^3]
ρ_s	density of particles, [kg/m^3]
τ_w	shear stress on the membrane surface, [kg/m^3]
ω	angular velocity of rotating-disk, [rpm]

Subscriptions

cal	calculated results
exp	experimental data

performance. Lu and coworkers [8,9] and Hwang et al. [10–12] used force balance models for analyzing particle deposition on the membrane surface. The diameter of the deposited particles, cake thickness, and filtration flux could be correlated with the operating conditions. The pseudosteady filtration flux was then calculated by solving the force balance equation and the basic filtration equation simultaneously. Almost all suspensions considered in previous studies have been water containing dispersed particles. An extension of such studies on filtration to seawater would be beneficial because the results can be useful for pretreatment in desalination systems.

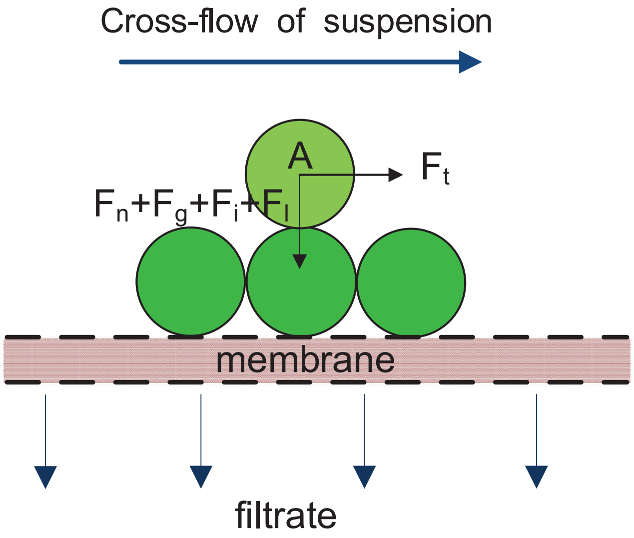

Fig. 1. Forces exerted on a depositing particle in the cross-flow microfiltration.

Another type of cake-less filtration, rotating-disk dynamic filtration, has been performed for the separation of fine particles from a liquid [13]. Bouzerar et al. [13] established correlations of permeate flux and filtration resistance with local shear stress and transmembrane pressure. Generally, equipping a rotating disk with vanes is beneficial for generating high shear stress at the membrane surface; high shear stress helps mitigate membrane fouling and produce high filtration flux [13–15]. Jaffrin et al. [14] and Moulai-Mostefa et al. [16] concluded that the effect of disk rotation speed on the permeate flux was strong and considerably greater than that of the transmembrane pressure. The filtration flux can be markedly improved by increasing the disk rotation speed or equipping the disk with large vanes.

In this study, cross-flow and rotating-disk dynamic filtration were used to remove fine particles in seawater. The effects of operating conditions, such as the cross-flow velocity, transmembrane pressure, disk rotation speed, and clearance between the disk and the membrane, on the filtration flux and power consumption were examined. A force balance model for particle deposition was constructed for estimating the cake thickness and filtration flux in cross-flow microfiltration of seawater.

2. Theory

2.1. Force balance model for particle deposition

Particles may be transported to the membrane surface by the permeate flow. Fig. 1 depicts a particle (Particle A) in the process of being deposited just arriving at the membrane surface and contacting deposited particles (filter cake). Whether the particle can be deposited stably or is swept away depends on the external forces acting on it. The forces include the drag forces generated by the tangential (F_t) and permeate flows (F_n), net interparticle force (F_i), inertial lift force (F_l), and net gravitational force (F_g) [8–12,17]. The critical condition for the stable deposition of particle A in the pseudosteady state is determined using a force balance model [11,12], and it can be expressed as

$$F_t = f_c(F_n + F_g + F_l + F_i) \tag{1}$$

where f_c is a factor correlated with the friction coefficient between particles. Some forces in Eq. (1) can be evaluated theoretically; for example, the tangential drag force can be calculated using the

Please cite this article as: K.-J. Hwang et al., Fine particle removal from seawater by using cross-flow and rotating-disk dynamic filtration, Journal of the Taiwan Institute of Chemical Engineers (2016), http://dx.doi.org/10.1016/j.jtice.2016.02.007