Desalination 337 (2014) 98–108

Contents lists available at ScienceDirect

Desalination

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

The effect of fiber length on non-uniform and hysteresis phenomenon in hollow fiber membrane backflushing

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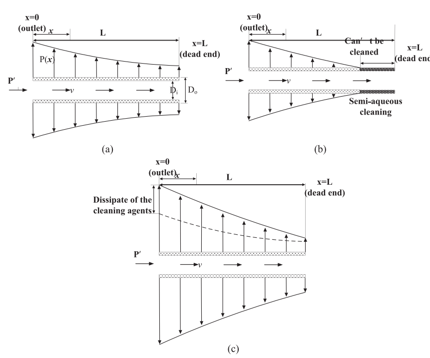
HIGHLIGHTS

- Optimal parameters were obtained in the backflushing process.
- During fiber cleaning, permeate production peaks.
- Hysteresis effect was initially investigated in this study.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 25 June 2013
Received in revised form 4 November 2013
Accepted 8 November 2013
Available online 8 December 2013

Keywords:
Hollow fiber membrane
Membrane backflushing
Fiber length
Hysteresis effect

ABSTRACT

Based on the operational performance of hollow fiber membrane, backflushing flow (BF) and backflushing pressure (BP), the two key parameters of cleaning in line (CIL) were experimentally investigated in this paper. It was assumed that the optimal parameters should meet the requirement for delivering cleaning agents to the most distant fiber surface. Based on Hagen-Poiseuille theory, the equation derivation of the CIL operation shows that when the membrane backflushing flow (pressure) is fixed, the corresponding BF and BP have an optimal value range which the design of the BF and BP could base on. The permeability recovery of cleaning with sodium hypochlorite, assessed at low and high flow (pressure), indicated that operation at a more conservative flow (pressure) could conserve energy. With the flow (pressure) increased experimentally, an interesting phenomenon was found that the effective backflushing length first presents a short increase followed by a downswing. Meanwhile, the effect was investigated to prove that as fiber length increased, the backflushing time also increased. Moreover, when taking into account both the flux recovery and hysteresis time, operation with constant flow outperformed that with constant pressure under the optimal parameters. Finally, a mathematic model was developed to verify the former conclusion by comparing the theoretical value with the experimental value.

Abbreviations: BP, backflushing pressure (Pa); BF, backflushing flux ($L \cdot m^{-2} \cdot s^{-1}$); CIL, cleaning in line.

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http://dx.doi.org/10.1016/j.desal.2013.11.016

1. Introduction

In recent years hollow fiber membrane modules have been increasingly adopted in water reuse for their high specific filtering area, self-supporting construction, low-cost, application flexibility, and easy installability [1]. Consequently, membrane filtration process has gradually replaced conventional filtration methods in raw water and wastewater treatments [2,3]. However, the development of membrane filtration process is significantly limited by membrane fouling which can cause the increase of TMP (transfer membrane pressure) and a decrease of water productivity during the pressure-driven membrane filtration [4]. To control membrane fouling and to maintain sustainable operation, many solutions have been proposed by researchers. Among those solutions for mitigating membrane fouling, membrane cleaning [5–8] and membrane module optimization [9–11] gain more popularity. Backflushing was first proposed by Kim [12], while the hollow fiber membrane backflushing is a highly complex process related to many variables such as the characteristics of the membrane (length, pore diameter and material) and operation modes (flux, pressure and cleaning agents) [13–15]. Researches have focused on how to maximize the recovery of membrane flux under low-power consumption, short duration conditions. Thus, novel experimental methods have been conducted with a view to improving the understanding of the relationship between the backflushing behavior of the submerged hollow fiber membranes and its operation parameters, such as ultrasonic methods, mixtures of cleaning agents, and packing density. Huihua Zhu et al. analyzed the cleaning results by assessing flux, streaming potential, and FTIR measurements [16]. The results showed that the best cleaning results were obtained at high temperature and without pressure. Foulants were easier to remove when it occurred only on the surface of the membranes, and a new technique was tested with different combinations of proteins and membranes, as well as more complicated cleaning sequences. Jia-yu Tian et al. cleaned the fouled hollow-fiber polyvinyl chloride (PVC) membrane with consecutive applications of sodium hydroxide and ethanol during the ultrafiltration of river water [17]. The results showed that through the chemical cleaning with 1% sodium hydroxide for 30 min, a negative cleaning efficiency of 14.6% was observed for the PVC membrane. A cleaning efficiency of 85.1% was obtained by the consecutive cleaning with 1% sodium hydroxide for 30 min and ethanol for 30 min. Beyer et al [18] found that under the same condition, the cleaning efficiency also depends strongly on the nature of the foulants or fouling mechanisms. High pH could increase the dissolution of organic matter thus facilitating the removal of organic foulants from the membrane surface.

Admittedly, the effect of module optimization, which could slow down the decay of the membrane flux and reduce membrane fouling, cannot be ignored [19,20]. Günther et al. [21] improved membrane module's filtration performance by changing its packing density. The results exhibited significant differences in the time variations of cake's spatial distribution along the fiber as a function of packing density for both filtration modes. This finding, in turn, underlines the importance of design parameters in the filtration performance of hollow fiber module. Porcelli et al. [22] demonstrated that temperature and concentration of the sodium hydroxide were the most critical factors in optimizing flux recovery in combination with backflushing. While Yoon et al. [23] obtained optimum design parameters for a vertically mounted, submerged hollow fiber module that demonstrably minimized energy consumption for aeration. Their study showed that longer fibers, which have larger lumens, provide better efficiency of footprint usage. When maximum fiber length is limited to 3 m, and one-side suction is performed, the optimum design parameters with reasonable energy efficiencies at 30 kPa are a fiber diameter of 2.16–3.25 mm and a fiber length of 1.03–1.90 m. In the case of two-side suction, where the permeate is sucked from both ends of fibers, a fiber length of 1.01–1.90 m and a diameter of 1.34–2.05 mm were optimal for the same flux and TMP. Whether in the field of backflushing or membrane

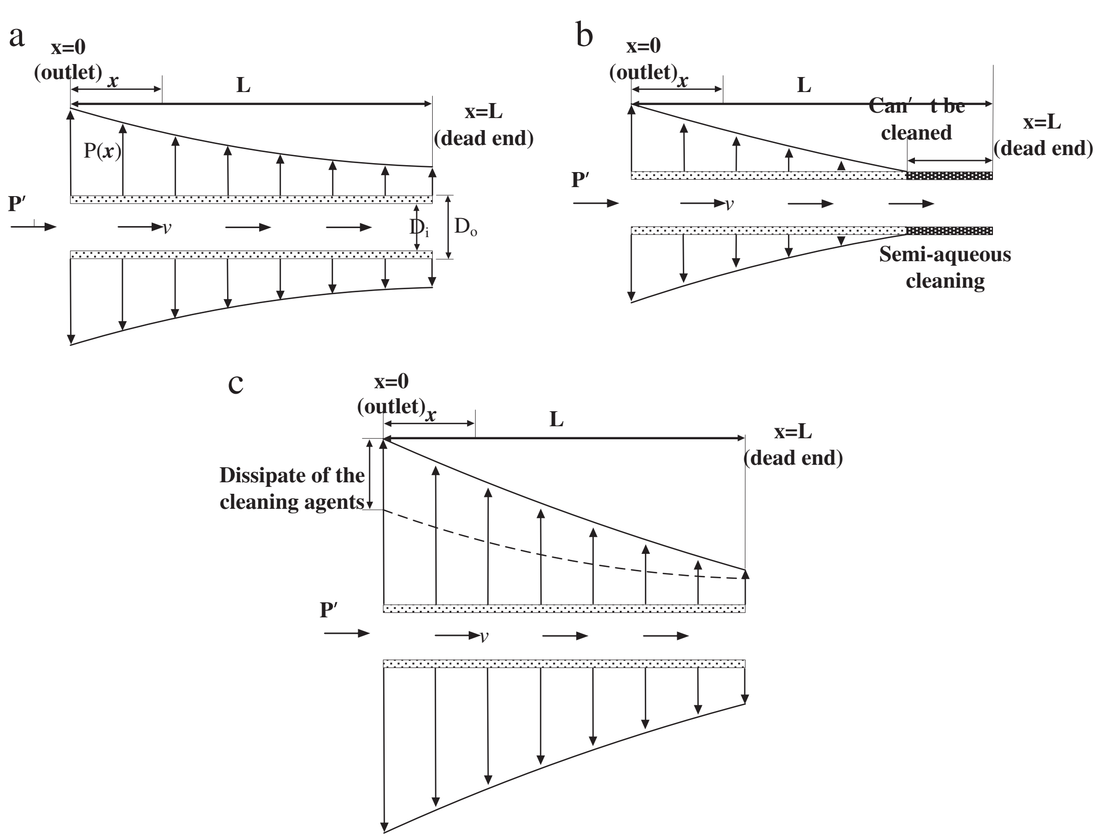

Fig. 1. Backflushing models of hollow fiber membrane.