Journal of Membrane Science 546 (2018) 139–150

Contents lists available at ScienceDirect

Journal of Membrane Science

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

Influence of selective permeation of backwashing solution on the cleaning effectiveness in hollow fiber system

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ARTICLE INFO

Keywords:
Hollow fiber membrane
Backwashing
Selective permeation of backwashing solution
Laser bijection sensing

ABSTRACT

The effectiveness of backwashing is strongly affected by selective permeation of backwashing solution along the fiber length in dead-end hollow fiber membrane system. This critical issue was systematically investigated with laser bijection sensing (LBS) technology to detect the position reached by the cleaning agent inside the fiber lumen. The limited effective backwashing distance revealed by LBS could be attributed to the outflow flux of backwashing solution in axial direction, which dissipates the driving force (pressure) of the cleaning solution further to the longer distance along the hollow fibers. An instantaneous pressure jump of backwashing solution was measured in the first pressure sensor when the pump was opened on. The principle of pressure jumps in the fiber lumen and affecting factors were speculated with novel mathematical models. Pressure variation as well as modeling prediction showed that the pressure decrease inside fiber lumen was the fundamental reason for the ineffective backwashing for long membrane fibers. Inspired by the instantaneous pressure jump in backwashing process, an intermittent backwashing mode was employed and the experimental setup was also upgraded to provide a more accurate monitoring of the cleaning solution of long membrane fibers. The results showed that the intermittent backwashing mode outperformed the continuous backwashing mode by reaching a longer fiber length in a short washing period.

1. Introduction

Hollow fiber membrane modules have been increasingly adopted in water reuse in recent years for their high specific filtering area, self-supporting construction, low-cost, application flexibility, and easy installation [1,2]. Nevertheless even with the intensive pretreatment schemes, membrane fouling remains a big challenge in microfiltration (MF) and ultrafiltration (UF) systems [3]. Membrane fouling, which refers either the increase of TMP (transfer membrane pressure) or the decrease of water flux during the pressure-driven membrane filtration, is an inherent and unavoidable phenomenon of all membrane processes limits their wider and more efficient industrial application [4,5].

Many strategies have been implemented such as membrane cleaning [6,7] and developing antifouling membranes [8,9] to mitigate membrane fouling. Backwashing as one of the preferred membrane cleaning strategies has been incorporated in most hollow fiber MF/UF systems [10–14]. Nevertheless, even though more fouling is expected to be removed, thus chemical solutions was added into backwashing process. Several attempts to optimize backwashing conditions in order to enhance water productivity have been proposed, including different backwashing solutions [15–17]. Hollow fiber membrane backwashing is a highly complex process related to many variables such as the characteristics of the membrane (length, pore diameter and material) and operation parameters (time, frequency, flux, pressure and cleaning agents) [13,18–21].

Cogan et al. [22] proposed a control formulation to determine the timing and duration for membrane backwashing. The result demonstrated that irreversible attachment of bacteria has important ramifications for the effective timing of hydraulic backwashes as well as the efficiency in producing clean water. Wang et al. [23] investigated the effect of fiber length on backwashing effectiveness of hollow fiber membranes. A backwashing model was developed by combining with membrane backwashing to satisfy the needs of practical applications. Hence, the most suitable length of the fiber could be designed on this basis, while providing the most suitable flow rate (pressure) for the

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http://dx.doi.org/10.1016/j.memsci.2017.10.010
Received 10 September 2017; Received in revised form 2 October 2017; Accepted 4 October 2017
Available online 10 October 2017

Nomenclature

L	total fiber length (m)
J_e	average flux of membrane (L/m^2 h)
L_{sa}	length of semi-aqueous cleaning region (m)
k	coefficient of backwashing
x	distance from water inlet (m)
D_o	inner diameter of hollow fiber membrane (m)
D_i	outer diameter of hollow fiber membrane (m)
μ	liquid viscosity (mPa s)
R_t	total resistance of backwashing (m^{-1})
P_{TMP}	transfer membrane pressure (kPa)
Δp	pressure change (kPa)
P	pressure when pump close (kPa)
e	thickness of pipe wall (m)
t	time (h)
a	water hammer wave speed (m/s)

fixed length of the membrane module. Another insufficient backwashing caused by released air in dead-end hollow fiber membrane was investigated in the research of Cui et al. [24]. Modeling and experimental results in this study showed that the air accumulation at the most distant membrane point was a recombination process which contained air release and dissolution. To overcome the effects brought by released air and maintain backwashing effectiveness, a novel method was developed by adding a segment of gas filtration membrane at the end of the hollow fiber which had finally extended the effective backwashing length.

In this paper, a signal analysis technique of Laser Bijection Sensing (LBS) was used for the first time to assess the effectiveness of backwashing of hollow fiber membrane systems. The position that is reached by the backwashing solution inside the fiber lumen was detected by the variations of laser signals. Enhanced pressure changes with fiber length over the backwashing time periods in intermittent operation mode were also monitored with LBS. Experimental verifications were conducted to assess the effectiveness of the new technology in monitoring and optimizing backwashing in hollow fiber membrane systems.

2. Materials and methods

2.1. Materials

The pristine hollow fiber MF membrane module (Motimo, Tianjin, China) was made of polyvinylidene fluoride (PVDF). The parameters of the membranes are as follows: pore size, 0.22 µm; the outer/inner

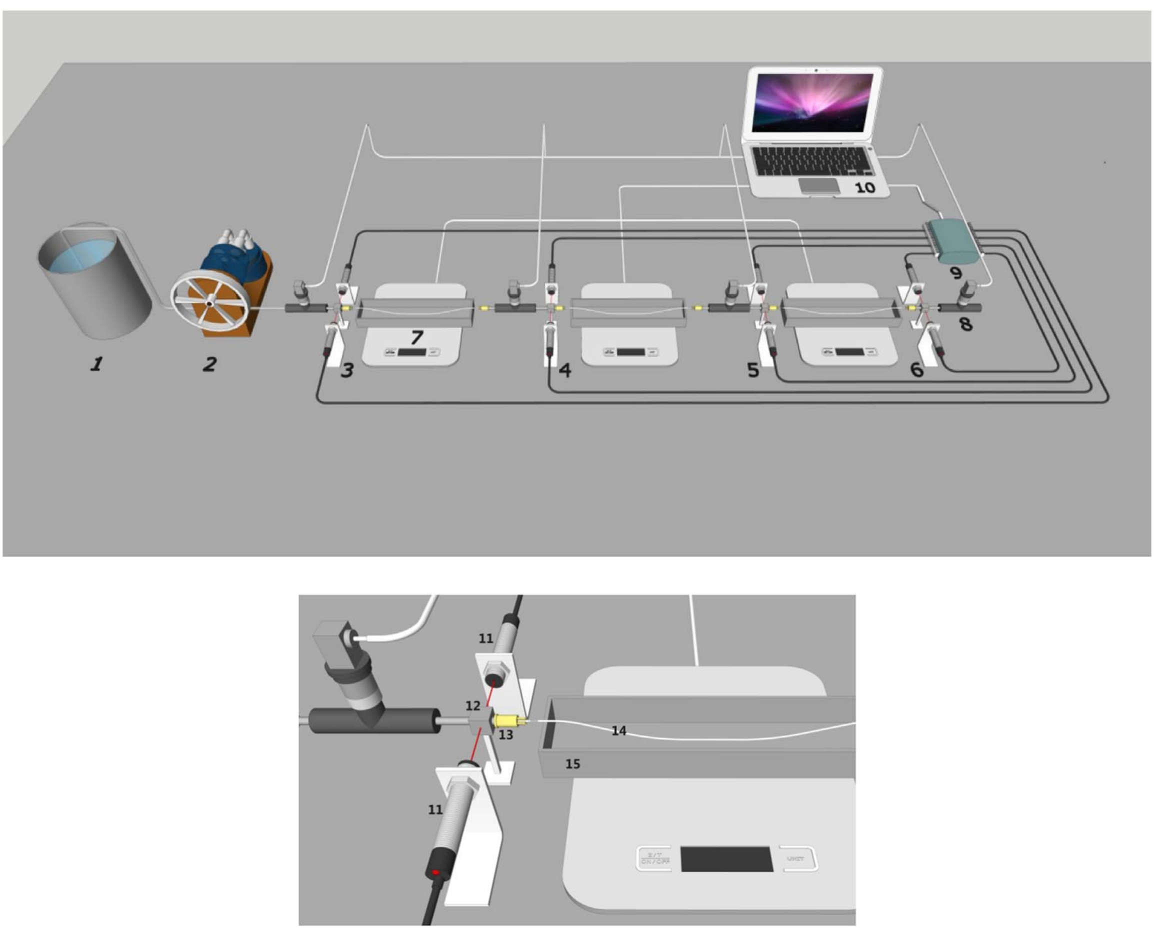

Fig. 1. Membrane backwashing system: 1, Raw water tank; 2, Piston pump; 3–6, Monitoring point (MP) 1–4 of laser bijection sensors 7, Electronic balance; 8, Pressure sensor; 9, Data acquisition card; 10, Computer; 11, Laser bijection; 12, Transparent cube; 13, syringe needle; 14, Membrane fiber; 15, Organic glass box.