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Influence of released air on effective backwashing length in dead-end hollow fiber membrane system

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ABSTRACT

To obtain a better backwashing strategy, effects of released air on the effective backwashing length of dead-end hollow fiber membranes were investigated in this study. Ultrasonic spectrum and AGU-Vallen Wavelet software were imported to ensure a more intuitive understanding on effects of released air from echoes. 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. The recombination process contained air release as the pressure type changed from inside-outside to outside-inside and air dissolution in the outside-inside pressure condition. Moreover, longer fiber was more prone to the air accumulation in the most distant membrane lumen. The mathematical model predicted the volume of final remaining air that depended on the instantaneous pressure difference, backwashing flux, backwashing duration, membrane surface area, water viscosity and temperature. Experimental verification of ultrasonic waveforms was consistent with the model prediction. 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. These studies were expected to have implications for the design and operation of hollow fiber membrane backwashing.

1. Introduction

Hollow fiber membranes have been increasingly applied in various water treatment processes due to their high specific filtering area, self-supporting construction, low-cost, application flexibility, and easy installability [1]. However, membrane fouling is still one of the most challenging issues limiting the widespread application of hollow fiber membrane [2,3].

Backwashing as one of the standard operating strategies has been incorporated in most hollow fiber filtration systems to mitigate fouling [4,5]. Previous researches mainly focused on maximize the backwashing efficiency with a chemical enhanced backwashing mode. Zhou et al. [6] suggests that on-line NaOH backwashing could not only maintain membrane permeability but also simultaneously supply alkali to bioreactors to ultimately facilitate the operation of MBRs. Chang et al. [7] indicated NaCl solution backwashing greatly enhanced backwash efficiency (> 96.8%). Lee et al. [8] suggested chemical backwashing was effective for controlling fouling resistance and the activity of the microorganisms had not been harmed by chemical backwashing. These strategies all contribute to the understanding of backwashing effectiveness. Nevertheless, frequent chemical or mechanical backwashing could make a contribution to membrane aging, porosity change or membrane damage [9,10]. Moreover, 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 modes (backwashing duration, flow rate and cleaning agents) [11]. Thus, backwashing effectiveness obtained by membrane module optimization should outperforms that obtained by external factors. On this basis, a number of studies on backwashing effectiveness were also carried out. Wang et al. [12] investigated the effect of fiber length on non-uniform backwashing in dead-end 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 fixed length of the membrane module. Akhondi et al. [13] assessed the effects of filtration and backwashing cycles on the pore-size distribution of polyacrylonitrile (PAN) and polyvinylidene difluoride (PVDF) HF membranes by evapoporometry (EP) characterization. The modeling and experimental results could provide guidance

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Nomenclature

V_g	final volume of the air inside fiber lumen (L)
V_c	volume of released air as a result of the pressure change from filtration to backwashing (L)
V_b	volume of air dissolved in water during the backwashing process (L)
P_g	pressure in the air volume (kPa)
n	substance amount of trapped air (mol)
T	prevailing temperature (K)
R	gas constant
F_{pump}	initiating backwashing flow (L/h)
$F_{membrane}$	a volumetric flow owing to permeation caused by the lumen pressure initially (L/h)
J_a	nominal backwashing flux (L/m^2 h)
A	the membrane surface area (m^2)
L	total fiber length (m)
J_e	average flux of membrane (L/m^2 h)
D_o	outer diameters of membrane (m)
D_i	inner diameters of membrane (m)
μ	liquid viscosity (mPa s)
k	coefficient of filtration
x	distance from the outlet (m)
P	pressure from filtration to backwashing (kPa)
P_b	start pressure of backwashing (kPa)
P_f	final pressure of filtration (kPa)
m	mass of air (kg)
k_1	Henry's law constant
P_1	air-liquid equilibrium pressure (kPa)
$\gamma \rightarrow i^{\infty}$	infinite dilution activity coefficient
H_{ci}	air-liquid partition coefficient
V_L	partial molar volume of pure water (L)
P_i^{sat}	saturated vapor pressure of pure water at temperature of T (kPa)
ρ_g	air density under the pressure P_1 (kg/m^3)

for not only the design of operating parameters but the choosing a ultrafiltration (UF) membrane. Ye et al. [14] investigated effects of filtration duration, backwash duration, backwash strength and the aid of air scouring on backwash effectiveness. The underlying fouling limitation mechanisms resulting in those optimized operation parameters were also explored. It was found that periodical backwash with permeate favored effective removal of fouling layer and reduced the fouling rate during the filtration cycle. Excessive backwash strength could not minimize fouling, but exacerbating fouling rate during filtration. This study held the principle of membrane module optimization, mainly investigated the effect of released air in membrane backwashing system.

The effect of dissolved air owing to the TMP and its accumulation on the permeate side of submerged membrane modules have been reported in previous study. Influence of dissolved air on the effectiveness of cyclic backwashing in submerged membrane systems was studied by Akhondi et al. [15]. Evidence from transmembrane pressure (TMP) monitoring suggested that the sudden decrease in backwash efficiency occurred when the pressure on the permeate side of the membrane at the end of a backwash cycle did not reach the atmospheric pressure that on the feed side. The release of dissolved air from the permeate side of the membrane due to the pressure drop across the membrane was recognized as the major reason for reducing backwash effectiveness. The specific objectives of this study were listed as follows: (1) developing a model to establish a relationship between air volume and fiber length under different operating conditions; (2) verifying the effect of released air on the effective backwashing length via a novel monitoring method; (3) obtaining an approach to overcome the practical issue.

2. Model development

The model developed here was applied in ultrafiltration tests in the continuous filtration and backwashing process to get an efficient membrane backwashing. During the backwashing process for relatively longer membrane fiber, there was always a small portion out of the cleaning. The reasons could be that air release owing to the severer TMP variation in the system will finally accumulate on the most distant side of the system. And compressibility of the air accumulated on the distant side retarded the penetration of the cleaning agents into the membrane. The focus of the model development was to correlate the required time with the effective backwashing length to confirm the inadequate backwashing was attributed to the released air.

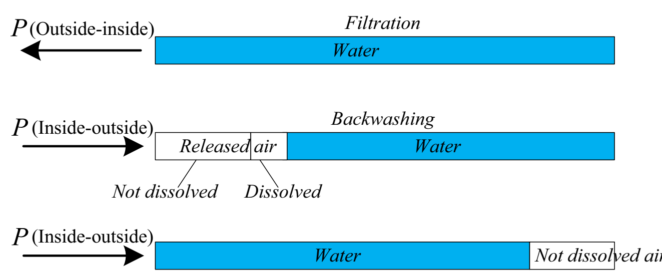

Fig. 1. Schematic of air accumulation in the filtration-backwashing process.

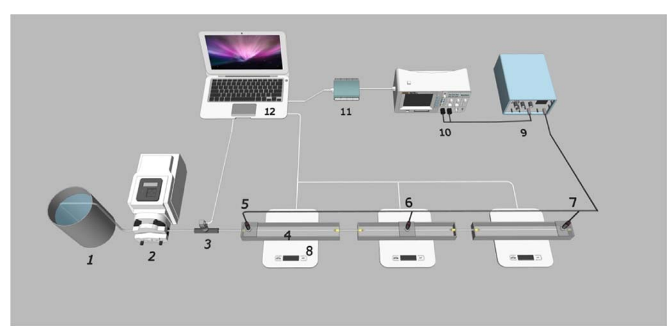

Fig. 2. Membrane filtration & backwashing system: 1, raw water tank; 2, peristaltic pump; 3, pressure sensor; 4, membrane fiber; 5–7, ultrasonic monitoring point 1–3; 8, electronic balance; 9, pulser-receiver 10, oscilloscope; 11, data acquisition card; 12, computer.

Fig. 1 shows a schematic of the filtration-backwashing process considered in the model development. The dissolution and release of the air should be divided into three processes. During the filtration process, the pressure is the outside-inside type which could promote the release of air. However, the air was finally sucked by the pump. So there is no residual air inside the fiber lumen during filtration. When the operating condition changed from filtration to backwashing, a large amount of air released due to the severe transmembrane pressure