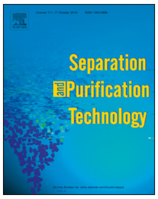
Separation and Purification Technology 204 (2018) 243–254

Contents lists available at ScienceDirect

Separation and Purification Technology

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



Gas and liquid backwash for flux restoration in latex paint effluent ultrafiltration

Amira Abdelrasoul[a,*], Huu Doan[b], Ali Lohi[b], Chil-Hung Cheng[b]

[a] Department of Chemical and Biological Engineering, University of Saskatchewan, 57 Campus Drive, Saskatoon, Saskatchewan S7N 5A9, Canada
[b] Department of Chemical Engineering, Ryerson University, 350 Victoria Street, Toronto, Ontario M5B 2K3, Canada

ARTICLE INFO

Keywords:
Fouling
Ultrafiltration
Backwash
Irreversible
Flux restoration

ABSTRACT

The main objective of this study was to evaluate the effectiveness of various backwash scenarios on fouling cleaning for flux restoration in ultra filtration of simulated latex effluent. The effects of water and injected air flow rates, backwash duration, and transmembrane pressure on the flux restoration were examined. Polycarbonate and Polysulfone flat membranes with uniform pore sizes of 0.05 µm and molecular weight cut of 60,000 were used under a constant feed flow rate and a cross-flow mode in ultrafiltration of the latex paint effluent. The cross flow water backwash could restore 60% and 52% of the permeate flux for Polycarbonate and Polysulfone membranes, respectively. Alternatively, cross flow air backwash restored the flux by 28% and 19% for the two membranes, respectively. These results reflect that the shear force created by air removes fouling materials on the membrane's surface, but does little to reduce the fouling within the membrane's pores. On the other hand, the combination of gas and liquid backwash was very effective, with optimum performance occurring at 4 LPM of water (cross-flow velocity of 41.6 cm/s), concurrent gas at 1 m/s and 15 psi for 5 min. This combination restored the permeate flux by75% and 63% for Polycarbonate and Polysulfone membranes, respectively.

1. Introduction

In recent years the applications of pressure-driven membrane processes as ultrafiltration (UF) have expanded as a promising alternative technology for obtaining drinking water acceptable for human consumption [1]. Despite the strong potential that exists in membrane filtration, one of the common problems encountered in applications is membrane fouling. The phenomenon of fouling is a process that results in loss of membrane performance due to the deposition of suspended or dissolved substances on its external surface, at its pore openings, or within its pores [2]. The main consequences of fouling include flux decline, permeate quality deterioration, and higher energy consumption. Our main research has focused on investigating the mechanism of membrane fouling in ultrafiltration of latex paint with a wide range of particle size distribution and non-uniform pore size membranes [3,4]. As a result, we developed, simulated, and validated a novel mechanistic mathematical model capable of accurately estimating the mass of fouling and the increase in the transmembrane pressure, applicable to both homogeneous and heterogeneous membranes with uniform and non-uniform pore size membranes, respectively [3–6]. Various effects of the operating conditions and membrane surface zeta potential on fouling attachments, the total mass of fouling, cake height, cumulative permeate flux, and specific power consumption in ultrafiltration of latex solution were also examined [5–8]. Membrane fouling remediation techniques capable of enhancing the ultrafiltration performance and reducing power consumption were also developed [9–14]. However, since membrane fouling has not been eliminated entirely, it was important to direct our research toward membrane cleaning that would facilitate flux restoration and increase membrane lifetime in ultrafiltration processes.

Membrane cleaning for flux restoration is an essential step in maintaining the permeability and selectivity of a membrane process [15,16]. Currently, cleaning techniques for membrane restoration could be broadly categorized into four types: physical, chemical, physico-chemical, and biochemical methods. The first three are the most commonly used techniques. Physical cleaning relies on mechanical forces to dislodge and remove foulants from the membrane's surface. Physical methods can include hydraulic cleaning (forward, reverse flushing, and backwashing), air flushing, and CO_2 back permeation [17,18]. Non-conventional physical cleaning methods may feature the application of ultrasonic [19,20], electrical fields [21] and magnetic fields [22]. Furthermore, hydraulic cleaning methods are often adopted in UF for

---

[*] Corresponding author. Tel.: +1 306 966 2946; fax: +1 306 966 4777.
E-mail address: amira.abdelrasoul@usask.ca (A. Abdelrasoul).

https://doi.org/10.1016/j.seppur.2018.03.056
Received 9 July 2017; Received in revised form 30 December 2017; Accepted 24 March 2018

Nomenclatures

Symbol	Physical meaning
a	particle radius [m]
B	mass transfer coefficient [m^{-2}]
B_i	mass transfer coefficient through the pore size [m^{-2}]
C_f	concentration of solid particles in the feed water [kg/m^3]
D	diffusion coefficient of colloidal particles [m^2/s]
D_m	membrane pore diameter [m]
D_{m_i}	membrane pore diameter of size [m]
J	permeate flux [m^3/m^2 s]
L_m	length of membrane pores [m]
m_{sS}	mass of small particles attaching to membrane surface in a unit membrane surface area [kg/m^2] (pore diameter/6 < particle size < pore diameter/2)
m_{sL}	mass of large particles attaching to membrane surface in a unit membrane surface area [kg/m^2]
m_{ppL}	mass of large particles attaching to other particles on the membrane surface normalized to a unit membrane surface area [kg/m^2]
m_{ppS}	mass of small particles attaching to other particles on the membrane surface normalized to a unit membrane surface area [kg/m^2]
m_w	mass of the particles attaching to the pore walls in all membrane pores normalized to unit membrane surface area [kg/m^2] (particle size < pore diameter/6)
m_{w_i}	mass of the particles attaching to the pore walls of size normalized to unit membrane surface area [kg/m^2] (particle size < /6)
m_{cIRR}	total mass of particles in the irreversible cake layer per unit membrane surface area [kg/m^2]
$m_{cIRR\ L}$	total mass of large particles in the irreversible cake layer per unit membrane surface area [kg/m^2]
$m_{cIRR\ S}$	total mass of small particles in the irreversible cake layer per unit membrane surface area [kg/m^2] (pore diameter/6 < particle size < pore diameter/2)
m_{IRR}	total mass of particles contribute to total irreversible fouling per unit membrane surface area [kg/m^2]
N	total number of the non-uniform pore sizes determined in the pore size distribution of the heterogeneous membranes
N_m	number density of membrane pores per a unit membrane surface area [$1/m^2$]
P'	the increase in transmembrane pressure during filtration normalized to that of clean membranes [dimensionless]
P'_{cIRR}	increase of transmembrane pressure due to irreversible cake [dimensionless]
$P'_{cIRR\ L}$	increase of transmembrane pressure due to irreversible cake by large particles [dimensionless]
$P'_{cIRR\ S}$	increase of transmembrane pressure due to irreversible cake by small particles [dimensionless] (pore diameter/6 < particle size < pore diameter/2)
P'_{IRR}	increase of transmembrane pressure due to total irreversible fouling [dimensionless]
$P'w$	increase of transmembrane pressure due to small particles attached to pore wall [dimensionless] (particle size < pore diameter/6)
Q	Feed flow rate [LPM]
Q_i	permeate flow rate in single pore of size [L/s]
Q_1	permeate flow rate in single pore [L/s]
R_m	resistance due to the membrane [m^{-1}]
$\widehat{R}c$	specific cake resistance [m/kg]
r	average radius of membrane pores [m]
TMP	transmembrane pressure [psi]
Vs	cumulative volume of the permeate normalized to membrane surface area [m^3/m^2]
x_i	number average percentage of the pore of size

Greek symbols

Symbol	Physical meaning
Σ	projected area of a unit mass of the particles (particle diameter ≥ pore diameter) on membrane surface [m^2/kg]
P	particle density [kg/m^3]
$\mathcal{E}_s$	membrane surface porosity [dimensionless]
τ	tortuosity of the membrane [dimensionless]
Ψ	sphericity of latex particles [dimensionless]
α_{pm}	the attachment probabilities between a particle and the membrane [dimensionless]
α_{pp}	the attachment probabilities between two particles [dimensionless]

Subscript

Symbol	Physical meaning
AVG	average
C	cake layer
IRR	irreversible fouling
L	large particles (particle diameter ≥ pore diameter)
M	membrane
P	pore blocking
S	small particles (pore diameter/6 < particle size < pore diameter/2)
T	total
w	pore wall
XS	very small particles (particle size < pore diameter/6)

drinking water treatment [23].

Despite its applications, physical cleaning techniques have become increasingly more attentive due to the recycle purposes of the leftover contaminated particles and the negative influences of the chemical used for backwashing on the environment. Studies focused on understanding of backwashing and its effects have been conducted [15–18]. Nevertheless, it remains difficult to accurately correlate key backwashing parameters, such as water flow rate, trans-membrane pressure (TMP), backwashing duration, or the mechanism of backwash cycles [24–29]. The extent of irreversible fouling is largely dependent on the cleaning efficiency, which in turn is closely related to fluids used in hydraulic backwashing. In depth understanding of the backwash operating conditions influence on the efficiency of backwash is also needed for a more reliable operation. In addition, a greater understanding of the influences of various backflushing scenarios is required for flux restoration and the increase of membrane lifetime. Furthermore, in the previous studies, mathematical models were developed for the prediction of membrane fouling, transmembrane pressure, and power consumption using uniform and non-uniform pore size membranes [3–6]. However, a much more profound understanding of particle-deposition and particle aggregation behavior on the membrane's surface and their effect on irreversible fouling is still needed. Such an understanding would allow further model development for prediction of the irreversible fouling after backwash in energy saving, pilot-scale, and industrial applications. There is also a lack of awareness when it comes to the influence of cross flow ultrafiltration operating condition on the irreversible fouling, as it it essential to understand how to manipulate the fouling attachment and reduce membrane fouling.

As a result, the objectives of the present study were to develop a comprehensive model for the prediction of irreversible fouling and the transmembrane pressure after backwash generalized for uniform and nonuniform pore size membranes. The study looks at the influence of