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Comparison of MFI-UF constant pressure, MFI-UF constant flux and Crossflow Sampler-Modified Fouling Index Ultrafiltration (CFS-MFI_{UF})

Lee Nuang Sim, Yun Ye, Vicki Chen, Anthony G. Fane*

UNESCO Centre for Membrane Science and Technology, University of New South Wales, 2052 Sydney, NSW, Australia

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ABSTRACT

Understanding the foulant deposition mechanism during crossflow filtration is critical in developing indices to predict fouling propensity of feed water for reverse osmosis (RO). Factors affecting the performance on different fouling indices such as MFI-UF constant pressure, MFI-UF constant flux and newly proposed fouling index, CFS-MFI_{UF} were investigated. Crossflow Sampler-Modified Fouling Index Ultrafiltration (CFS-MFI_{UF}) utilises a typical crossflow unit to simulate the hydrodynamic conditions in the actual RO units followed by a dead-end unit to measure the fouling propensity of foulants. CFS-MFI_{UF} was found sensitive to crossflow velocity. The crossflow velocity in the crossflow sampler unit influences the particle concentration and the particle size distribution in its permeate. CFS-MFI_{UF} was also found sensitive to the permeate flux of both CFS and the dead-end cell. To closely simulate the hydrodynamic conditions of a crossflow RO unit, the flux used for CFS-MFI_{UF} measurement was critical. The best option is to operate both the CFS and dead-end permeate flux at flux which is normally operated at industry RO units (~20 L/m^2 h), but this would prolong the test duration excessively. In this study, the dead-end flux was accelerated by reducing the dead-end membrane area while maintaining the CFS permeate flux at 20 L/m^2 h. By doing so, a flux correction factor was investigated and applied to correlate the CFS-MFI_{UF} measured at dead-end flux of 120 L/m^2 h to CFS-MFI_{UF} measured at dead-end flux of 20 L/m^2 h for RO fouling rate prediction. Using this flux correction factor, the test duration of CFS-MFI_{UF} can be shortened from 15 h to 2 h.

1. Introduction

Significant effort has been focused on developing a reliable and useful fouling index to assess fouling propensity of feed water prior to the reverse osmosis (RO) units. A fouling index can be used to predict how rapidly a given feed water will foul the RO system due to colloidal fouling. With this information in hand, appropriate pre-treatment schemes can then be selected prior to the RO system which can ultimately reduce colloidal fouling in RO.

There are several fouling indices such as the Silt Density Index (SDI), and the Modified Fouling Index ($MFI_{0.45}$). Due to its simplicity and the short duration of measurement, SDI is currently the most widely used index in water industry. However, SDI has been proven unreliable by many researchers (Boerlage et al., 2003a; Lipp et al., 1990; Schippers and Verdouw, 1980; Yiantsios and Karabelas, 2002). SDI was found to have no relationship with foulant concentration and is not derived from any fouling mechanism. These downsides led to the emergence of $MFI_{0.45}$ which is calculated based on cake filtration theory

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* *Corresponding author*. Tel.: +61 2 9385 4813; fax: +61 2 9385 5966.
E-mail address: v.chen@unsw.edu.au (V. Chen).

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Abbreviations

A	filtration area (m^2)
C_b	solid concentration (g/L)
CFS-MFI$_{UF}$	Crossflow Sampler-Modified Fouling Index Ultrafiltration ($s\,L^{-2}$)
ΔP_0	standard reference pressure (207 kPa)
ΔP	transmembrane pressure (Pa)
h	circular channel diameter (m)
I	cake resistivity (m^{-4})
J	flux ($L\,m^{-2}\,h^{-1}$)
m_c	cake mass per unit area (kg/m^2)
MFI-UF$_{const\ flux}$	Modified Fouling Index-Ultrafiltration constant flux ($s\,L^{-2}$)
MFI-UF$_{const.pressure}$	Modified Fouling Index-Ultrafiltration constant pressure ($s\,L^{-2}$)
Q	flowrate ($L\,h^{-1}$)
t	filtration time (s)
v	crossflow velocity ($m\,s^{-1}$)
V	permeate volume (L)

Greek symbols

α	specific cake resistance (m/kg)
γ	shear force (N)
ε	cake porosity
μ	viscosity of fluid (Pa s)
ω	compressibility factor
ρ_p	particle density ($kg\,m^{-3}$)

(Schippers and Verdouw, 1980). MFI$_{0.45}$ has a linear relationship with the feed concentration, but the subsequent research carried out by Schippers et al. (1981) indicated that MFI$_{0.45}$ was unable to account for small colloids (<0.45 μm).

The Modified Fouling Index-Ultrafiltration (MFI-UF) and Nanofiltration-Modified Fouling Index (NF-MFI) were subsequently introduced, where ultrafiltration and nanofiltration membranes are used respectively as the test filters. MFI-UF was originally measured under constant pressure conditions. However, due to the prolonged duration of the test, Boerlage et al. (2004) proposed a MFI-UF which can be measured under constant flux mode. From their findings, the duration of the MFI-UF test could be shortened from 20 h to approximately 2 h if operated at constant flux of 75 L/m^2 h using canal water. More recently, Choi et al. (2009) proposed a novel fouling index known as Combined Fouling Index (CFI) which uses a set of different membrane filters to determine the fouling potential of water. The authors suggested that no single method can be successfully used for accurate prediction of fouling potential of feed waters, but combination of different fouling indices using different types of test membranes such as hydrophobic MF, hydrophilic MF and hydrophilic UF may be possible as each of these membranes can capture different portions of foulants in a given feed. For example, hydrophobic MF is used to capture the fouling potential of hydrophobic foulants whereas hydrophilic UF is sensitive to the effects of colloidal matter and macromolecules on fouling. However, the capability of the fouling tests relied on their ability to capture the critical factor of feed water components which may contribute significantly to the fouling of RO.

The above mentioned indices are carried out in a pressurized dead-end filtration cell, whereas in actual RO systems, crossflow filtration is the most widely chosen operating condition. These two operation modes have very different hydrodynamic conditions. In crossflow filtration, particles movement to and from the membrane surface is governed by the flux towards the membrane and the back transport of particles which includes Brownian diffusion, inertial lift (Green and Belfort, 1980) and shear-induced diffusion (Romero and Davis, 1988, 1991). If conditions are such that the back transport is greater than the permeate flux, then the particles are not expected to be deposited on the membrane surface. This effect is more likely for larger particles because back transport velocities increase with the particle diameter (Green and Belfort, 1980; Romero and Davis, 1988, 1991). Therefore, in the crossflow process, large particles that have larger back transport velocities will tend to migrate away from the membrane surface. These hydrodynamic conditions that occur during crossflow membrane processes are neglected in the conventional dead-end MFI test. Without considering the hydrodynamics in the RO crossflow process and the mode of operation, some important issues regarding the fouling potential of the feed might be overlooked.

The Crossflow Sampler-Modified Fouling Index (CFS-MFI) was introduced to incorporate the crossflow hydrodynamic behaviour during fouling index measurement (Adham and Fane, 2008). SDI and MFI$_{0.45}$ constant pressure obtained after the crossflow sampler were found to be significantly lower than standard SDI and MFI$_{0.45}$ for different types of feed water, emphasising the importance of crossflow hydrodynamics (Adham and Fane, 2008; Javeed et al., 2009). Our recent work has further extended this work where the crossflow sampler unit (CFS) was directly connected with the dead-end cell and the test was carried out under constant flux, known as CFS-MFI$_{UF}$ constant flux (Sim et al., 2010). The aim of the CFS is to simulate the selective deposition of colloids during the crossflow RO process. Due to the shear, only the portion of the particles that will potentially deposit on the membrane can permeate through the CFS and enter the dead-end MFI device. These components represent the composition that is most likely to cause fouling in a RO crossflow system if the same feed was used. The fouling potential of these foulants can hence be determined through the dead-end device. In our previous study, the sensitivity of both MFI-UF$_{const.flux}$ and CFS-MFI$_{UF}$ was validated through lab scale RO experiments using synthetic silica suspension. MFI-UF$_{const.flux}$ was found less sensitive when compared to CFS-MFI$_{UF}$. The fouling rate prediction based on CFS-MFI$_{UF}$ agreed well with the actual RO fouling behaviour with the deviation of 11%, whereas MFI-UF$_{const.flux}$ deviated significantly from the actual trend (>30%) even with the deposition factor correction (Sim et al., 2010). However, the factors affecting the performance of this improved MFI test such as crossflow velocity on CFS-MFI$_{UF}$ values have not yet been presented.

This paper aims to understand the particle capture and fouling mechanism in different fouling indices at which the