Journal of Water Process Engineering 3 (2014) 151–154

Contents lists available at ScienceDirect

Journal of Water Process Engineering

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

Short communication

Correlation between modified fouling index (MFI) and crossflow sampler-modified fouling index (CFS-MFI) under constant flux filtration

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ARTICLE INFO

Article history:
Received 30 April 2014
Received in revised form 9 June 2014
Accepted 19 June 2014
Available online 18 July 2014

Keywords:
Crossflow sampler
Membrane resistance
Ultrafiltration
Colloidal silica
Humic acid

ABSTRACT

This study presents the development of a simple correlation between modified fouling index (MFI) and crossflow sampler-modified fouling index (CFS-MFI) to assess fouling potential of feed under constant flux mode. The study was carried out using a bench-scale experimental set-up with variables including crossflow effect, feed concentration, particle types and sizes, and the intrinsic resistance of membrane. From the forty-eight experimental data, upper and lower bounds of the correlation between $\mathrm{MFI}_{\mathrm{const.flux}}$ and CFS-$\mathrm{MFI}_{\mathrm{const.flux}}$ were successfully established. The permissible range of coefficient ($1.007 \le m \le 1.561$) for the correlation was further verified by the dataset reported in previous study.

1. Introduction

Membrane filtration has emerged as a leading purification technology owing to its cost competitiveness and viability in water separation and purification industries. However, membrane fouling has been a major drawback in successful application of membrane separation processes. Even though membrane fouling is an inevitable phenomenon, it can be controlled by adopting appropriate prediction methods. Silt density index (SDI) and modified fouling index (MFI) are widely used to predict particulate/colloidal and organic fouling behaviours in feedwater [1,2]. Recent studies indicated that the viability of the SDI to represent actual fouling behaviours of a membrane is impaired by several deficiencies. For example, there is no linear relationship between particulate matters and feed concentration since SDI is not derived based on any fouling mechanisms [3–6]. On the contrary, MFI exhibits a linear relationship with feed concentration [7,8]. Considering the proven reliability of the MFI in predicting reverse osmosis (RO) fouling, subsequent research trend on the topic has shifted the focus from the conventional SDI to MFI [9]. Many studies have been carried out based on advancement of measurement methods including the type of membrane used in dead-end cell [5,10,11], operation mode (i.e. constant pressure/flux) [12,13], and flow configuration (i.e. with/without crossflow sampler) [12,14,15]. One of the findings from the studies highlighted that the MFI measurement incorporating the crossflow effect and constant flux modes (namely CFS-$\mathrm{MFI}_{\mathrm{const.flux}}$) is more representative to an actual RO system [14,16]. Despite of the fact that the CFS-$\mathrm{MFI}_{\mathrm{const.flux}}$ is more reliable, it is still a relatively new fouling index (FI) that has rarely been used in practice. For this reason, there is a pressing need to establish a correlation between the standard $\mathrm{MFI}_{\mathrm{const.flux}}$ and the innovated CFS-$\mathrm{MFI}_{\mathrm{const.flux}}$ in order to promote its practical application in the membrane filtration industry.

The aim of this paper is to establish a correlation between $\mathrm{MFI}_{\mathrm{const.flux}}$ and CFS-$\mathrm{MFI}_{\mathrm{const.flux}}$ through a series of experimental tests carried out under different experimental configurations including different feed concentrations, particle types and sizes, and the intrinsic resistance of membrane. The established correlation was further verified with the experimental dataset reported by Sim et al. [14]. The findings are expected to benefit the membrane

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http://dx.doi.org/10.1016/j.jwpe.2014.06.006
2214-7144/

Table 1
Properties of membranes used in this study.

Membrane	Material	Pore size/MWCO	R_m (m^{-1})	Surface properties	Manufacturer
PCTE (use in CFS cell)	Polycarbonate track-etch	5 μm	–	Hydrophobic	Membrane Solutions®
PVDF150	Polyvinylidene fluoride	150 kDa	1.55×10^{12}	Hydrophobic	Amfor Inc.
PVDF100	Polyvinylidene fluoride	100 kDa	1.96×10^{12}	Hydrophobic	Amfor Inc.
PES30	Polyether sulfone	30 kDa	4.15×10^{12}	Hydrophobic	Amfor Inc.
PES10	Polyether sulfone	10 kDa	6.16×10^{12}	Hydrophobic	Amfor Inc.
PES NF1	Polyether sulfone	200–400 Da	4.56×10^{13}	Hydrophilic	Amfor Inc.

technology industry particularly in controlling membrane fouling by answering questions such as how reliable are the $MFI_{const.flux}$ and CFS-$MFI_{const.flux}$ values from one study? What is the value of $MFI_{const.flux}$ if CFS-$MFI_{const.flux}$ is known, and vice versa? In general, a reliable FI could be used to evaluate the membrane fouling severity based on the quality of feedwater. This is particularly useful in assessing the efficiencies of RO/nanofiltration (NF) pretreatments, and hence the best pretreatment technologies could be distinguished.

2. Materials and methods

2.1. $MFI_{const.flux}$ and CFS-$MFI_{const.flux}$ measurement

The measurements of $MFI_{const.flux}$ and CFS-$MFI_{const.flux}$ have been discussed in detail in a previous article [16]. In brief, both $MFI_{const.flux}$ and CFS-$MFI_{const.flux}$ tests were carried out to obtain the trend of transmembrane pressure (TMP) increase under the constant flux of 30.9 Lm^{-2} h (LMH). The devices comprised of feed and collection tanks, feed pump, crossflow sampler (CFS) cell (SEPA CF, GE Osmonics©, Minnetonka, Masterflex, US), dead-end MFI cell, electronic balance, and data logging system. The dead-end MFI cell was a fabricated cell with a dimension of 11.0 cm in diameter. The main difference between the two measurements was on the CFS cell. For the measurement of $MFI_{const.flux}$, the feed water was first introduced into the CFS cell which was not installed with any membranes, followed by CFS bypass delivered into the dead-end MFI cell. Similar operation and flow stream were applied in the CFS-$MFI_{cons.flux}$ measurement with the microfiltration (MF) membrane of 5 μm pore size installed in the CFS cell. The crossflow velocity was maintained at 0.39 m/s throughout the CFS-$MFI_{const.flux}$ tests. The effective membrane area of CFS and dead-end MFI cell were 0.0155 m^2 and 0.0095 m^2, respectively. Five membranes of different molecular weight cut-off (MWCO) were considered in the dead-end cell. The properties of all the membranes used in this study are tabulated in Table 1. To enable a fair comparison between the membranes used in this study, the resistance of the membranes (R_m) was determined by filtering the membranes with ultrapure water. In fact, determining the R_m is one of the membrane characterisation methods. During the FI measurement, all new membranes were first compacted at a pressure of 5 bar with deionized (DI) water until a stable flux was achieved. The duration of the compaction process was found vary with the types of membranes used. The TMP increase by filtering foulants was continuously recorded over a period of 1 h for calculations of $MFI_{const.flux}$ and CFS-$MFI_{const.flux}$.

2.2. Foulants

The foulants used in the $MFI_{const.flux}$ and CFS-$MFI_{const.flux}$ measurements were synthetic colloidal silica and Aldrich humic acid (AHA). Colloidal silica was adopted to represent particulate type of foulant while AHA represented organic type. Two particle sizes of colloidal silica (70–100 nm and 22 nm) were chosen. All the synthetic feed solutions were prepared at varying concentrations to study their effect on the experimental results. The colloidal silica was prepared at three concentrations, i.e. 50, 100, and 200 mg/L. The AHA was prepared at relatively lower concentrations, i.e. 2, 5, and 10 mg/L. These selected concentrations represented typical ranges of concentration for the specific foulants [14,17]. A total of forty-eight combinations of experimental variables were designed to investigate the correlation between $MFI_{const.flux}$ and CFS-$MFI_{const.flux}$.

3. Results and discussion

3.1. Effect of feed concentration and membrane resistance on $MFI_{const.flux}$ and CFS-$MFI_{const.flux}$ values

The $MFI_{const.flux}$ and CFS-$MFI_{const.flux}$ measurements were carried out under various feed concentrations to compare their fouling potential. Table 2 tabulates the effect of feed concentration and membrane resistance on the $MFI_{const.flux}$ and CFS-$MFI_{const.flux}$ values. Both $MFI_{const.flux}$ and CFS-$MFI_{const.flux}$ showed that the FI values increased with increasing feed concentration. Moreover, the values of $MFI_{const.flux}$ were consistently higher than that of CFS-$MFI_{const.flux}$ which can be attributed to the hydrodynamic shear force generated under crossflow filtration mode. This shear force contributed to a reduction in fouling effect by preventing foulants from being deposited on the surface of the membrane [2,18,19]. A study conducted by Jermann et al. [20] has proven that the shear force which was found in a crossflow system is capable in reducing the membrane fouling by weakening the interactions of foulant-foulant and foulant-membrane. In terms of membrane resistance, the increase in membrane resistance resulted in higher values of FI and eventually contributed to higher fouling potentials.

3.2. Establishment of correlation between $MFI_{const.flux}$ and CFS-$MFI_{const.flux}$

It is widely accepted that the shear force generated in the crossflow sampler would help to reduce the fouling potential. To quantify the effect of crossflow sampler on the MFI, the $MFI_{const.flux}$ was plotted against CFS-$MFI_{const.flux}$, as shown in Fig. 1. The

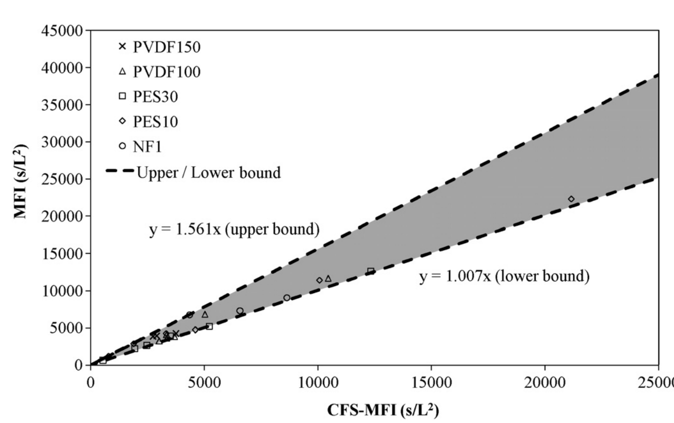

Fig. 1. Plot of $MFI_{const.flux}$ against CFS-$MFI_{const.flux}$.