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Investigating the Effect of Colloidal Foulants on SDI and MFI Tests

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Abstract

Silt density index (SDI) and Modified fouling index (MFI) are tests to measure and assess the fouling potential of pressure driven membranes such as reverse osmosis (RO) and nanofiltration (NF), which are widely used in water treatment applications. The process efficiency and the useful membrane life of such systems are mainly affected by the fouling phenomenon. Membrane fouling happens by the deposition of solid matters present in the feed water onto the membrane surface. Foulants such as particulate and colloidal matters cause plugging of the membrane and adversely impact the process productivity and operating costs. A comprehensive understanding to the fouling potential of the feed water and the reliability of the fouling index is crucially important in the design and operation phases of such systems. In this study, SDI and MFI experiments were carried out with synthetic feed water solutions containing different combinations of particle and colloidal foulant concentrations. The filtration performance data were presented systematically, and the reliability and sensitivity of both indices were compared. MFI values were sensitive to both particle and colloidal foulants and exhibited good consistency with increasing foulant concentration. Plant operators and academicians are encouraged to utilize the MFI test as a fouling prediction tool.

Keywords SDI, MFI, Fouling Index, RO, and NF membranes

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Introduction

Membranes are frequently used in water treatment systems. Fouling is the most important factor affecting the membrane performance. Fouling occurs as a result of the build-up of particles and colloids existing in the raw feed water on the membrane surface, and it has a negative influence on process productivity and operating costs(Alhadidi et al., 2013; Voutchkov, 2017). Organic matters, particles and colloids are responsible for a major part of fouling problems in membrane systems (Yiantsios & Karabelas, 2003).

A better understanding of the fouling risk of raw water allows improved treatment system design and simplicity of operation. As a result, determining the fouling potential of the water is critical to the efficiency and reliability of the system. SDI and MFI are the most popular fouling indexes to predict and evaluate the fouling potential of a given water sample. Both are based on the measurement of the flux decline rate of a microfiltration membrane by particle foulants under standardized testing conditions. SDI is an easy and practical testing method used in academia and industry for over decades. Membrane manufacturers recommend that the SDI value of the feed water be less than 3 for trouble-free operation. However, this fouling index is an empirical method based on the observed flux decline during the test filtration and lacks a theoretical background. It has been reported that this index is not always correlated with the real fouling behavior of the water (Salinas Rodriguez, 2011).

Schippers and Verdouw introduced the MFI as an enhanced version of SDI to address and overcome the drawbacks of this fouling index (Schippers & Verdouw, 1980). The MFI test utilizes the same materials and filtration system as the SDI, but it considers the cake filtering mechanism as the primary cause of flux drop and allows for temperature, membrane size, and applied pressure correction. MFI is calculated as the minimum slope of the linear portion of the inverse flow graph. This line in the graph corresponds to the cake filtration mechanism.

The resistance of the cake layer increases proportionally as its thickness increases. In this phase, the membrane's water flow decreases linearly. The cake compression process is shown by the final section of the curve with a rapid rise.

MFI is gaining popularity in recent years and comparable results were reported (Salinas et al., 2019). This study aims to conduct both fouling index tests simultaneously to the same feed water and compare the results and the performance of the indexes in terms of consistency, sensitivity, and reliability.

Material and Method

To simulate the natural waters with fouling potential for membrane applications, synthetic feed water samples containing a combination of colloidal and particle foulants were prepared. Aluminum oxide (Al_2O_3) was used as particle foulants. Particle size was 1-2 µm for aluminum oxide. Particles were procured from Nanografi in powder form, reagent grade. Alumina nanoparticles were used as colloidal foulants in 50 nm nominal particle size (Sigma Aldrich). Stock

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solutions were prepared at 2 g/L concentration with deionized water for each foulant and then diluted with tap water to the required concentrations.

The test setup for the SDI and MFI experiments is shown in Figure 1. A dead-end filtration cell and pressured air system were devised to conduct the experiments. A sample feed tank with a capacity of 5 liters was made of PE and sealed to maintain pressure. The prepared solution is fed to the filtration cell from the sample feed tank with the constantly applied pressure of 30 psi with the nitrogen gas. The feed gas pressure is controlled by a pressure regulation valve.

Membrane filters with a mean diameter of 0.45 µm and an external diameter of 47 mm made of hydrophilic cellulose acetate material was used for both SDI and MFI measurements. For each experimental run, a new piece of membrane was used. The membrane filter was carefully taken from the package with a pair of tweezers to avoid impairing the surface structure of the filter. The filters are placed on the porous membrane support plate. An O-ring is laid on the membrane and the cell is tightly closed with mechanical couplings after the membrane filter is rinsing with pure water to prevent air pockets.

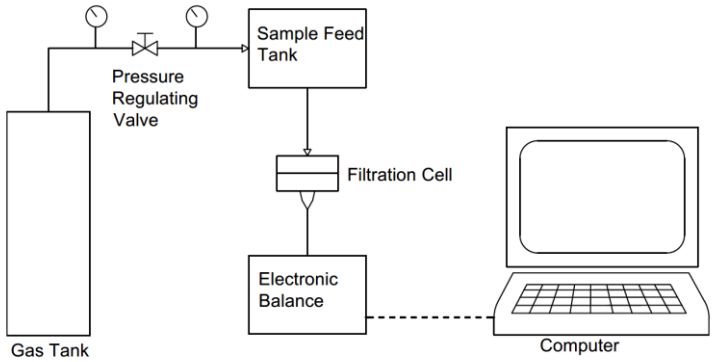


Figure 1 Flow scheme of the experimental setup

Silt Density Index (SDI)

ASTM Standard D4189 "Standard Test Method for Silt Density Index (SDI) of Water" describes the methodology for the SDI test as a measurement of the difference in the filtration time to collect a 500 mL filtrate through a microfiltration membrane with a 0.45 µm pore size and 47 mm diameter under constant pressure of 207 ± 7 kPa (30 ± 1 psi) constant pressure both at the beginning and at the end of the test after a total of 15 minutes test run time. The SDI is calculated with the formula in Eq. 1. The plugging rate is calculated as time difference and expressed as percentile flux decline per minute (%P). For a meaningful result, SDI should not exceed 75%, If it exceeds this value, the test should be conducted for a shorter filtration time e.g., 10 or 5 minutes.

$$SDI = \frac{1-\frac{t_1}{t_2}}{t_f} x100 = \frac{\%P}{t_f} \quad (1)$$

where t_1 is the time to collect the initial 500 mL sample filtrate (seconds), t_2 is the time to collect the final 500 mL sample filtrate (seconds) and t_f is the total filtration time (minutes).

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Modified Fouling Index (MFI)

The MFI experiments were implemented in accordance with ASTM D8002-15 "Standard Test Method for Modified Fouling Index (MFI) of Water". The tests were carried out with the same constant pressure (30 psi) and the same membrane material as the SDI tests. The weight of the filtrate is constantly measured with electric balance and the volume of the filtrate was calculated. Measurements were recorded throughout the experiment and exported to the computer via a data logger software. The filtration performance is plotted into the graph as an inverse flow rate against the accumulated volume for each experimental run. The graphs are analyzed with data analyzer software, and the slope of the linear portion of the filtration curve is embedded into each graph. The theory behind the MFI measurement is explained by the following formula (Eq. 2):

$$\frac{t}{V} = \frac{\mu . R_M}{\Delta P . A_M} + \frac{\mu . I}{2 . \Delta P . A_M^2} . V \qquad (2)$$

where V is the accumulated filtrate volume (L), t is time (seconds), AM is membrane area (m^2), ΔP applied pressure (Pa) (N/m^2), μ water viscosity ($N \cdot s/m^2$), RM clean membrane resistance (m^{-1}) and I is the fouling potential index (m^{-2}).

Derived from equation 2, the MFI value is calculated with the formula in Eq. 3 as the slope of the linear portion of the t/V versus V plot of the filtration experiment at constant pressure.

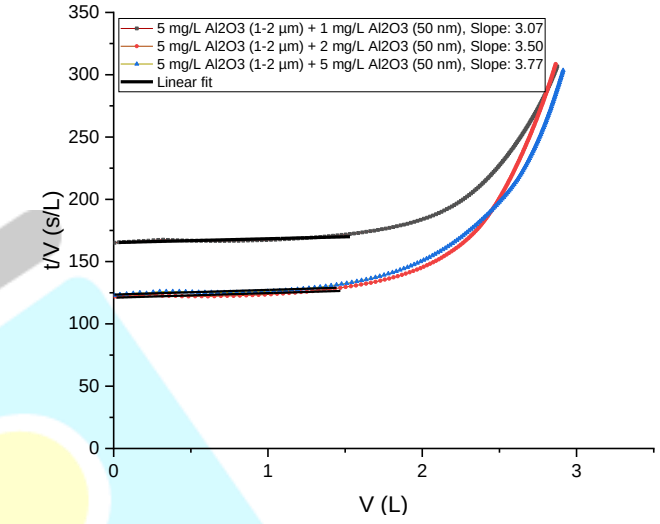
$$MFI = \frac{\mu . I}{2 . \Delta P . A_M^2} \qquad (2)$$

Result and Discussion

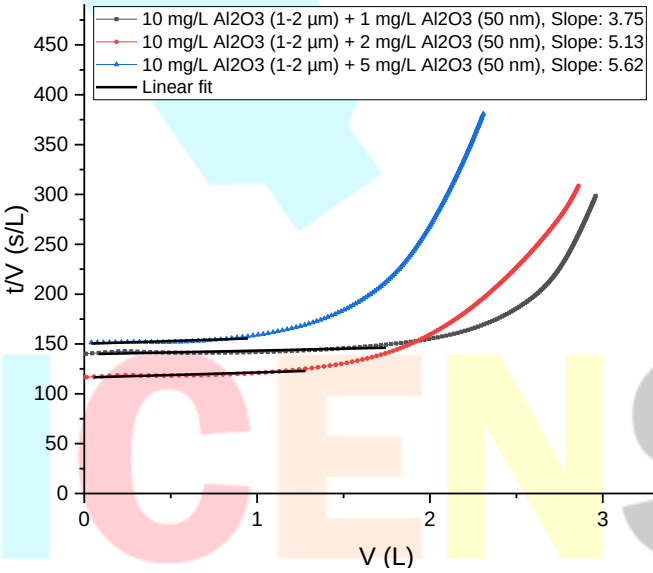
SDI and MFI tests were carried out to study the influence of colloidal foulants in the feed water solutions. Test solutions were prepared by adding incremental amounts of alumina colloids to the fixed particle concentrations of Al_2O_3. Alumina colloids were added to the separate solutions with 5 mg/L and 10mg/L of Al_2O_3 particles, so that the mixtures contained 1, 2, and 5 mg/L of colloidal foulant per each experimental repetition. The effect of increasing colloidal presence in the solution on the SDI and MFI fouling indexes was examined. The inverse flow performance of filtration tests containing alumina colloids and Al_2O_3 particles with 5 and 10 mg/L are set out in Figure 2 a. and b., respectively.

The MFI values of the tested foulant mixtures were determined by the slope of the specific filtration curve of the experiments. The MFI values of added 1, 2, and 5 mg/L alumina resulted in 3.07, 3.50, and 3.77 s/L^2 at 5 mg/L particle presence and 3.75, 5.13, and 5.62 s/L^2 at 10 mg/L particle presence, respectively. The addition of colloids to the particle solution increased the fouling indices of the samples. Each incremental increase in colloidal concentration resulted in higher fouling indication.

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a.



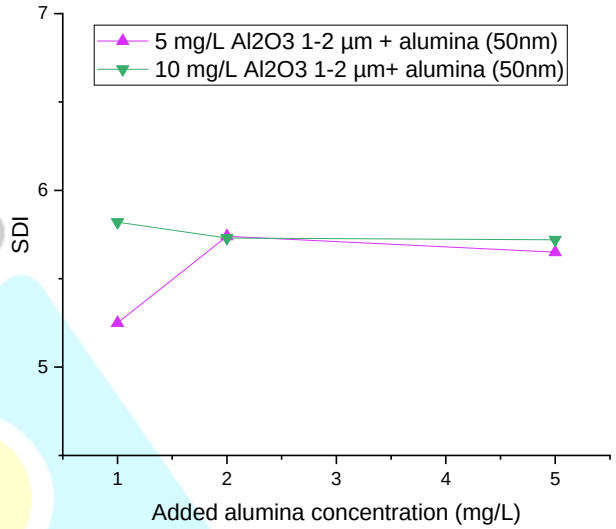
b.

Figure 2 Inverse flow against the volume of the collected sample for Al_2O_3 particles in the presence of alumina colloids **a.** 5 mg/L Al_2O_3 and alumina colloids, **b.** 10 mg/L Al_2O_3 and alumina colloids

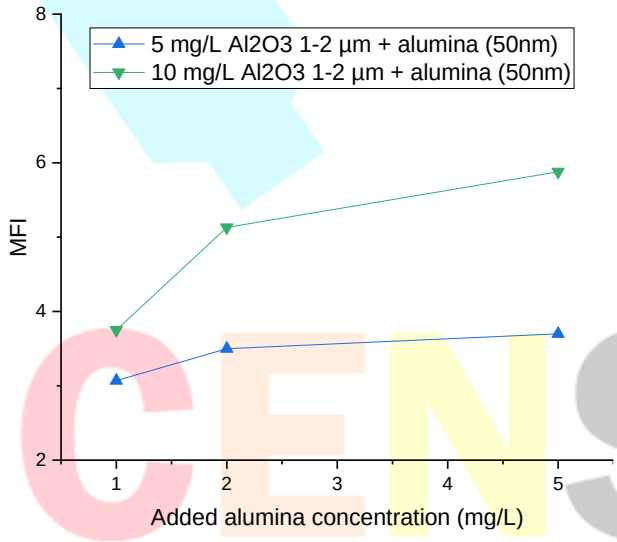
Comparison of SDI and MFI Results

In addition to the MFI test, the SDI fouling indices of the foulant samples given for each experimental run were measured simultaneously. A comparison was made between the two fouling indexes concerning sensitivity to the tested foulant concentrations. The collective SDI and MFI values of the tests are given in Figure 3 a. and b., respectively.

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a.



b.

Figure 3 a. SDI values, **b.** MFI values of the tested samples

In SDI test results, increased fouling indication was observed only when the colloid amount in the mixtures was increased from 1 to 2 mg/L in the samples containing 5 mg/L of particle foulant. The SDI value increased from 5,25 to 5,74 when the colloids in the mixture was increased from 1 to 2 mg/L. Contrarily, SDI value decreased to 5,65 when the colloid concentration increased to 5 mg/L, in contrast to the expected increase. Similarly, for the filtered sets containing 10 mg/L of particles, the SDI values showed a continuous decrease. The SDI value was 5,82 at 1 mg/L colloid concentration, then dropped to 5,73 and 5,72 with addition of 2 and 5 mg/L colloids.

Theoretically, an ideal fouling index should be giving increasing results in agreement with the increasing foulant concentrations. Similar findings have been reported in the literature, where

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SDI was not correlated with foulant concentration and filtration performance (Choi et al., 2009; Yu et al., 2010).

MFI test results displayed an increase along with the increasing colloidal foulant presence in the samples for all the combinations. For both sets of mixtures, the MFI values made a bigger leap as the concentration of alumina colloids were increased from 1 to 2 mg/L. The increase was rather moderate when the colloids further added to the mixture until the 5 mg/L concentration.

Interestingly, MFI was sensitive not only to the concentrations of colloids but also to the concentrations of the particles in the mixture. When 10 mg/L Al_2O_3 was present in the mixture the MFI values were higher than their 5 mg/L counterparts.

Conclusion

A laboratory-scale filtration setup was built to measure the SDI and MFI fouling index values of synthetic feed water containing particle and colloidal foulants. The effect of colloidal foulants incrementally added to the different particle solutions of fixed-concentrations on SDI and MFI readings was analyzed. The results of both indexes were compared in terms of reliability, and sensitivity to foulant concentration. The MFI was fully sensitive to the increasing presence of foulant in the feed water. An increase was observed in the MFI values of all the tested samples. SDI, on the other hand, was not responsive to the increasing concentration of the foulants.

According to our findings, MFI exhibited good performance in fouling prediction for RO and NF treatment systems. In this regard, MFI stands out as a promising tool for utilization in design and performance assessment steps in RO and NF water treatment plants. Further investigations should be conducted focusing on comparing the fouling predictions with the real performance of such treatment plants.

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