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Study of the relation between kinematic viscosity and SDI in polyethylene glycol solutions for predicting membrane fouling: preliminary test

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ABSTRACT

Nowadays, membrane technology plays an essential role in water treatment as a method of producing good-quality water. Its success is due to its ease of implementation, high efficiency and low cost. However, fouling of the active layer of the membranes is one of the main problems of this technology because it affects the operation conditions of the process, requires maintenance and limits the useful lifetime of membranes. Several parameters have been developed for the prediction of fouling being the most used Silt Density Index (SDI). However, it has some limitations that have prompted the search for alternative parameters such as Modified Fouling Index, Modified Fouling Index-UF, Mini Plugging Factor Index and Unified Membrane Fouling Index, among others. In this work, a prediction methodology of colloidal fouling is studied by means of a direct, simple and immediate measure of the combination of kinematic viscosity and SDI. To perform the tests, synthetic solutions of polyethylene glycol at a concentration ranging between 0.1 and 0.75 g/l were used. In kinematic viscosity tests, a Cannon–Fenske viscometer was used and SDI measurements were performed using a standard testing system. Results show that there is a linear relationship between the kinematic viscosity values and SDI in the concentration range studied. These preliminary results can be used to introduce a new parameter for predicting fouling potential in membranes based on the measurement of the kinematic viscosity in the feed water.

Keywords: Membrane; Fouling; Kinematic viscosity; SDI; PEG

1. Introduction

Membrane technology has a great success in the field of water treatment due to its easy implementation, high efficiency and low cost. However, this technology is limited by the fouling phenomenon. Suspended and colloidal particles of the feed stream are the main contamination sources of the active layer of membranes. Fouling affects operation process and limits membrane life, besides requiring periodical cleaning.

Therefore, prediction of fouling potential is a prerequisite for the successful control of membrane fouling. Several parameters have been developed for the prediction of fouling being the most used Silt Density Index (SDI). A number of specific parameters have

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been developed over time in order to identify the substances of feed causing fouling and to study their behaviour with respect to the mass transfer on the active layer of membranes. The most used of these parameters are, apart from SDI, Modified Fouling Index (MFI), Modified Fouling Index-UF (MFI-UF), Mini Plugging Factor Index (MPFI) and Unified Membrane Fouling Index (UMFI).

SDI of the feed stream is one of the most widely used parameters to measure the fouling potential for nanofiltration (NF) and reverse osmosis (RO) membranes. Its operating principle is based on the measurement of the decrease of water flux through a microfiltration (MF) membrane filter with a pore size of 0.45 μm at 207 kPa of pressure [1].

SDI experiments are simple and easy to perform and can be implemented in the plant. However, SDI has some negative aspects since no corrections for variations in pressure, temperature, pore size and membrane resistance are used. Furthermore, it is not based on any filtering mechanism and consequently there is no linear relationship between SDI and particle concentration [2]. Moreover, last ASTM D4189-07 indicates that SDI is not applicable for NF and RO systems due to the inability to capture the smallest particles that are the main cause of fouling, thus, resulting in fouling rates lower than real rates [3,4]. In fact, colloidal particles have a size from 1 to 10^{-3} μm [5–7], many of which are lower than pore size of SDI membranes used of 0.45 μm.

MFI was developed to cover the above SDI negative aspects. In this case, the test is based on filtration cake mechanism for NF and RO membranes. Furthermore, it can be corrected for temperature, pressure and membrane resistance parameters [8–10]. Equipment and operating mode is the same as in the SDI test, but in this case, the filtered volume (V) is measured at each time interval (t) in seconds until the filtering period is reached [2]. Test temperature is 20˚C, pressure is 207 kPa and pore size of filter is 0.45 μm. MFI equals the slope of the curve representing t/V vs. V in the cake filtration zone. However, one of the disadvantages of this parameter is that accurate and expensive equipment is needed to collect filtering data (V, t) [11–13].

MPFI is defined as the slope of the linear part of the curve representing the instantaneous measure of flow rate (Q) vs. filtering time (t) at cake filtration zone [2]. MPFI uses the same equipment and filters of 0.45 μm that are used in test of SDI and MFI. Researches state that this parameter is not as sensitive as MFI to membrane fouling, because MFI is obtained from measurement of the permeate stream volume, which directly reflects the fouling potential [14].

At present, there is only one parameter used to detect fouling potential due to colloidal particles smaller than 0.45 μm, the MFI-UF. MFI-UF value is based on cake filtration mechanism, is determined by MFI equipment, but in this case, to carry out the filtration, a 13 KDa cut-off UF membrane is used. MFI-UF shows best fouling prediction than SDI or MFI, as smallest particles are retained, resulting in a suitable parameter for NF membranes, but not for RO membranes. It also requires longer time filtering than MFI [8,11].

The most recently parameter studied is UMFI. UMFI has been introduced to evaluate the fouling of all low-pressure membranes used for water treatment, but it is still under study and development. Main advantages of UMFI vs. other fouling indices are universality (independent of scale filtration or mechanism) and specificity (based on real membrane of interest for large-scale application). With the application of UMFI, fouling potential of different membranes and water combinations can be shown in a homogeneous, concise and quantitative way, so as to allow quantitative and integrated assessment of fouling data and its relation to different factors of fouling potential [15,16].

As it has been shown, over the years, fouling prediction research has been trying to cover the disadvantages of the first parameters that were defined, such as dependence of physical parameters (temperature and pressure), increase the range of particles size that are able to detect (colloids specially), universality and independence of the filtration mechanism. But as new parameters have been developed, difficulty of testing has been increased, as it has become more specialized and requires expensive equipment.

For these reasons, in spite of being one of the parameters which has higher number of aspects to be improved, SDI remains as the most widely used parameter nowadays because it is the simplest test to perform in terms of equipment and measurement needed.

Therefore, it still remains the need to find a parameter that was simple and reliable for predicting fouling. In this work, viscosity is proposed as an alternative parameter for detecting presence of colloids in feed stream as a preliminary step to predict membrane fouling. Viscosity is defined as the resistance of a fluid to the relative motion of its molecules, thus, viscosity solution is influenced by its composition. For this reason, it could be an adequate parameter to detect the presence of these colloids and predict fouling caused when there is no proper pretreatment.

This paper studies the relationship of kinematic viscosity with the concentration of synthetic polyethylene glycol (PEG) solution, compares the results with the ones obtained for SDI test and establishes a relationship of kinematic viscosity with SDI.

2. Materials and methods

2.1. Synthetic solutions and food intake

To carry out the tests, synthetic PEG solutions with different concentrations were used. Concentration values are in the range of 0.1–0.75 g/l. PEG used had a molecular weight of 35 KDa and was supplied by Merck Schuchardt. To prepare the solutions, local tap water at 25˚C was used. Table 1 shows the main physical-chemical properties of tap water used.

2.2. Experimental procedure for SDI tests

To perform the SDI tests standard ASTM D4189 was followed. By definition, the SDI is calculated using Eq. (1):

$$\mathrm{SDI} = \frac{\left(1-\frac{t_1}{t_2}\right)}{t_f}\times 100\% = \frac{\%P_f}{t_f} \tag{1}$$

where t_1 is time required for filtering the first sample volume (s), t_2 is time required to filter the second volume of sample (s), t_f is time elapsed between two samples, which usually is 15 min (min), and $\%P_f$ is defined as plugging factor.

Table 1
Physical-chemical composition of local tap used for experimental tests

Parameter	Value
pH	7.9
Conductivity	986 µS/cm
Chloride	84 mg Cl/l
Sulphate	258 mg SO_4/l
Soluble silicate	3.3 mg SiO_2/l
Nitrate	8 mg NO_3/l
Dry residue	698 mg/l

To consider a value of SDI as reliable, $\%P_f$ value should be less than 75%, otherwise t_f should be modified to values lower than 15 min, being the most used 10 or 5 min.

Fig. 1 shows the diagram of the experimental installation used for SDI assay.

Cellulose acetate membrane filter with a pore size of 0.45 µm and 47 mm of diameter (ALBET Labscience) is used. During each test, a comprehensive control of the temperature and pressure was carried out. Each test was carried out four times.

2.3. Experimental procedure for viscosity tests

Viscometry was carried out taking into account the procedure established in UNE-EN ISO 3104-94 and UNE 400-313-98. These standards establish that kinematic viscosity is calculated using Eq. (2):

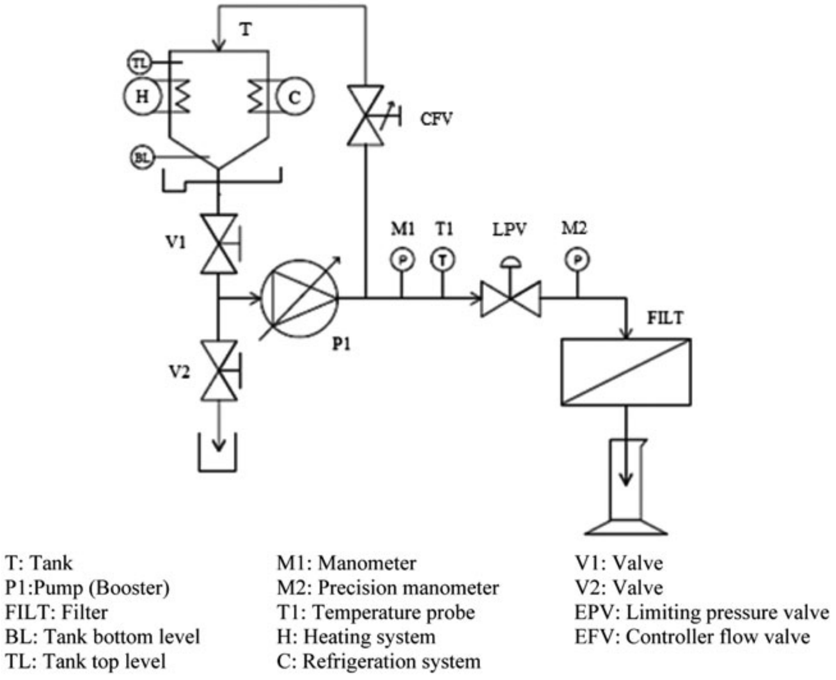

Fig. 1. Flow diagram of the installation used for SDI tests.

$$\upsilon = k \times t \tag{2}$$

where υ is kinematic viscosity (cSt), k is viscometer constant according to temperature (cSt/s), and t is the measured fall time (s).

To determine solution viscosity, firstly, a proper Cannon–Fenske viscometer should be selected. Selection is based on viscosity range to be measured, since fall time must exceed the minimum fall time established in the standard. In this case, a viscometer size 50 (Afora – 29692) was used.

From viscometer specifications, linear correlation for calculating the characteristic viscometer constant at working temperature is obtained according to Eq. (3):

$$k_{50}(\mathrm{cSt/s}) = -6.67^{-7} \times T(^{\circ}\mathrm{C}) + 0.00886 \tag{3}$$

Viscometry tests were performed at 25˚C, therefore, constant resulting to calculate viscosity is:

$$k_{50}(25^{\circ}\mathrm{C}) = 8.8825 \times 10^{-3} \quad \mathrm{cSt/s}$$

In the tests, the viscometer is filled with 7 ml of sample solution and it is introduced into a thermostatic bath (JP Selecta VB-1423), so that the whole upper bulb is immersed (A) and vertically positioned.

Fig. 2 shows a Cannon–Fenske viscometer and position of viscometer in a thermostatic bath.

To measure the fall time, the liquid is allowed to freely fall and it is measured the time passed since the liquid flows from the first mark (A) to the second mark at the lower bulb (B).

Six measurements of each PEG concentration were performed and, in the case of not exceeding ±5% difference between them, these measurements are averaged and plotted.

3. Results and discussions

3.1. SDI results

SDI tests were performed at solution concentrations of PEG 35 KDa between 0.1 and 0.75 g/l. Selected t_f was 5 min for obtaining a correct plugging factor value as standard ASTM D4189 sets.

Fig. 3 shows SDI_5 values vs. PEG concentration for a solution prepared with local tap water at 25˚C.

As shown in Fig. 3, SDI_5 values are in the range between 15 and 18 units. For concentration values from 0.1 to 0.75 g/l, it is observed a positive linear relationship with increasing SDI_5 values, as it was expected, because an increase of PEG concentration in solution corresponds to an increase of colloid concentration in feed solution, so SDI_5 should be higher.

However, results show a certain dispersion of SDI_5 values. Positive error in measurements is between 0.9 and 2.7 units and negative error is between 0.5 and 1.6 units. This dispersion is due to lack of homogeneity in the pore size distribution within a membrane filter. Since each test was carried out with a different filter, dispersion of pore size of filter results, unavoidably, in dispersion of SDI results.

On the other hand, there are some imprecisions in measurements associated with low PEG concentrations. For concentrations of PEG lower than 0.1 g/l, substances present in water, like dissolved matter, humic acids, and colloidal matter, can produce interferences in results that can be higher than the influence of PEG concentration. Thus, results obtained with PEG solutions in the low concentration tested range show some deficiencies of SDI to accurately detect changes in feed colloidal solution concentration.

The same tests were performed for viscosity determination, in order to examine the effectiveness of this parameter for detection of variations in feed colloid

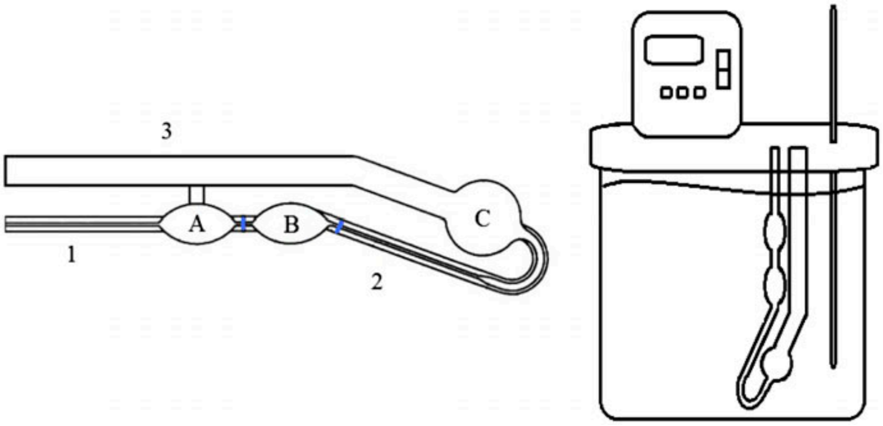

Fig. 2. Cannon–Fenske viscometer.

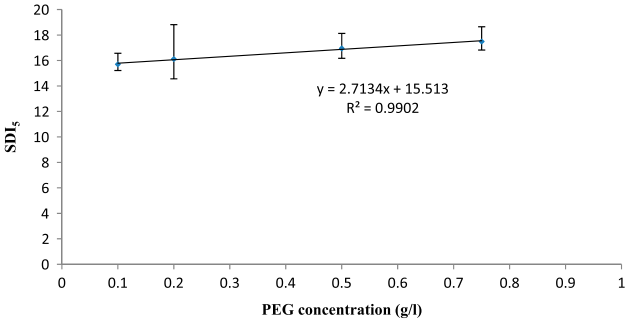

Fig. 3. SDI$_5$ vs. 35 kDa PEG concentration at 25°C.

solution concentration in the same low range of concentration values.

3.2. Viscosity results

For viscosity tests, PEG 35 KDa solution concentrations of study were the same as for SDI$_5$. Fig. 4 shows values obtained for solutions of PEG 35 KDa at 25°C.

In Fig. 4, it is observed that viscometer size 50 is suitable for viscosity measurements in the concentration range studied because values obtained range between 2.10 and 2.21 cSt, so they are within the optimal range indicated in the data sheet of the viscometer (between 0.8 and 3.2 cSt), and they also meet the values specified in UNE-EN ISO 3104-94 and UNE 400-313-98 standards for this type of testing.

For local tap water solution at 25°C, viscosity results show a linear trend with increasing PEG 35 KDa concentrations in the range between 0.1 and 0.75 g/l. Furthermore, Fig. 4 shows that viscosity values have much lower dispersion than SDI$_5$ results. Positive error in measurements is between 0.0015 and 0.0043 units and negative error is between 0.001 and 0.0022 units.

Therefore, viscosity could be a parameter which is very useful for detecting changes in feed colloid concentrations in a range between 0.1 and 0.75 g/l. Future research should be done with concentration higher than 0.75 g/l to confirm that viscosity is a suitable parameter for fouling prediction in a wider range of feed concentration.

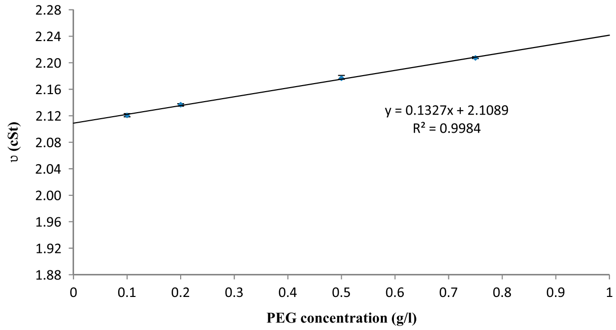

Fig. 4. Viscosity vs. 35 kDa PEG concentration at 25°C.

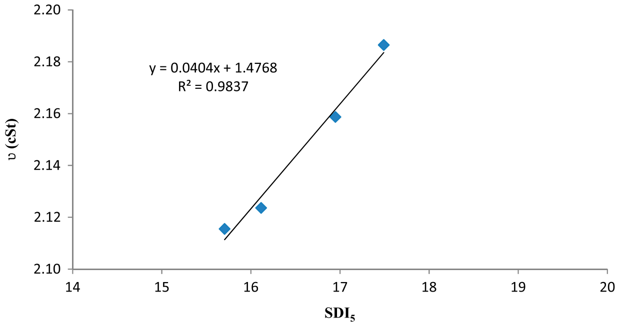

Fig. 5. Relation between viscosity and SDI$_5$ for 35 KDa PEG solution with local tap water at 25°C.

3.3. Relation between viscosity and SDI

Results of relation between viscosity and SDI$_5$ for local tap water at 25°C are shown in Fig. 5. For concentration values from 0.1 to 0.75 g/l, it is observed that there is a positive linear correlation of viscosity and SDI$_5$ values, in spite of dispersion of SDI measurements commented before. Therefore, it seems that viscosity could be an alternative parameter to SDI to predict membrane fouling, with the advantages of being a parameter very easy to determine, and which produces more reliable results even for low concentration values. Anyway, these advantages should be tested in higher concentration ranges of feed water before establishing viscosity as a real alternative for SDI.

4. Conclusions

The main conclusions of this work are the following ones:

- SDI tests with synthetic PEG solutions show deficiencies to detect variations in colloidal concentration of feed stream. SDI$_5$ shows a positive linear correlation with 35 KDa PEG concentration in the range between 0.1 and 0.75 g/l, but results have significant dispersion that can be associated to filter pore dispersion and imprecision due to low concentration measurements.
- Kinematic viscosity is a suitable parameter to detect colloidal concentration variations in synthetic PEG solutions. In fact, it shows a linear correlation with increasing 35 KDa PEG concentration values in the range from 0.1 to 0.75 g/l.

- There is a positive linear correlation between viscosity and SDI_5 in the range of 35 kDa PEG concentration between 0.1 and 0.75 g/l. Concentrations higher than 0.75 g/l are currently under study to confirm this correlation remains in a wider range.
- Kinematic viscosity results a parameter to be considered for the fouling prediction by colloidal matter present in feed solution. It is a simple and reliable parameter, and does not require complex equipment. Its potential applications are fouling prediction of NF and RO membranes and performance verification of MF/UF systems for removal of colloidal matter.

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