OPTIMIZING COAGULATION IN SEAWATER UF/RO SYSTEMS TO REDUCE FOULING BY TRANSPARENT EXOPOLYMER PARTICLES

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Abstract

The relevance of an abundant type of EPS – transparent exopolymer particles (TEP) – to fouling of UF and RO membranes in seawater desalination systems is a recent discovery. These sticky particles attach to the surface and within the pores of UF membranes causing irreversible fouling. In RO membranes, they can potentially initiate biofilm formation and growth by providing favourable conditions for bacterial colonization and a source of carbon. Moreover, they may contribute to particulate fouling of RO membranes. Inline coagulation, which is commonly applied in UF systems for fresh water, can reduce the adverse effect of TEP on membrane operation. However, the factors governing TEP coagulation in seawater are not known. This study focused on elucidating the effect of various process parameters such as dose, pH and flocculation by slow mixing on the coagulation behaviour of TEP with FeCl₃·6H₂O. In addition, an alternative mode of coagulation – precoat – was suggested to stabilize UF operation treating seawater with high TEP concentration.

Coagulation was performed at different conditions of dose, pH, slow mixing G and t for flocculation in a batch jar test unit. Filtration was performed in Amicon unstirred cells, through 100kDa PES membranes in dead-end constant pressure. UF hydraulic performance was evaluated using the Modified Fouling Index (MFI) as an indicator of floc filterability. Precoating experiments were done in dead-end constant flux mode using UF hollow fibres (⌀=0.8mm) with a MWCO of 150kDa. Membrane fibres were coated with a layer of preformed Fe(OH)₃ flocs at 200l/m²h prior to each filtration cycle. Thereafter, filtration was performed at 100l/m²h, followed by backwash at 250l/m²h. Several cycles were performed for each precoat condition. Membrane performance was evaluated by monitoring permeability recovery after multiple filtration cycles.

Results showed that pH and dose had the strongest influence on filterability of coagulated TEP. Flocculation by prolonged slow mixing time did not appear to be beneficial to TEP filterability. Furthermore, precoating at 4mgFe³⁺/L equivalent concentration resulted in the lowest loss of permeability and a stable permeability recovery after approximately 3 hours of operation.
I. INTRODUCTION

Transparent Exopolymer Particles (TEP) have recently been reported as a culprit in fouling of ultrafiltration (UF) and potentially reverse osmosis (RO) membranes in seawater desalination systems [1]. These sticky particles are abundant in fresh and saline surface waters and until recently have been exclusively studied by marine biologists, as they play an important role in carbon cycling in the oceans. However, their relevance to operation of membrane-based desalination plants has only recently been identified [2, 3].

TEP are negatively charged, hydrophilic, acidic polysaccharides that could be up to a few hundred microns in length [4, 5]. They are very sticky and transparent but can be visualized by staining with Alcian Blue [4]. A method has been established for the measurement of TEP in the particulate range (>0.4µm filters) [5]. Measurements of biopolymer concentrations using the Liquid Chromatography – Organic Carbon Detection (LC-OCD) provide supplementary information on the concentration of biopolymers (part of which is TEP) in source waters [3].

In membrane systems, TEP may cause operational problems by attaching to UF membrane surface or pores, resulting in both a higher rate of pressure increase during filtration and lower permeability recovery after backwashing.

In freshwater applications, coagulation/UF is commonly applied to control irreversible fouling of UF membranes. However, for seawater RO pretreatment, this application was recently demonstrated [1]. Ferric chloride is commonly used as coagulant in seawater pretreatment (including multi-media filtration) [6]. Coagulation is mostly done by inline dosing of coagulant upstream of the UF membranes, either directly into the feed stream or in a mixing tank. Inline coagulation is characterized by the absence of a settling or flotation process for solids removal. Consequently, feed water reaching UF membranes consists of partially and fully formed flocs, uncoagulated particulate and colloidal matter, and precipitated hydroxides of the metal salt. UF operation is therefore directly linked to the efficiency with which flocs are formed during coagulation, making the process sensitive to operational conditions such as pH, velocity gradient (G), Gt, dose and temperature.

No information is available on the required process conditions for using ferric as coagulant in front of UF (inline coagulation) in seawater desalination systems. Moreover, most conventional coagulation literature addresses optimum conditions for removal of inorganic particles, e.g. turbidity. As a result, factors governing the coagulation of organic matter (e.g. TEP) are poorly understood and optimum process conditions are not identified.

An alternative to continuous inline coagulation may be initial precoating of membranes followed by direct filtration of raw feed water. Preformed flocs of Fe(OH)₃ are dosed onto the membrane surface prior to (or at the start of) each filtration cycle. This precoat layer helps protect the membrane by trapping or adsorbing colloidal matter and macromolecules and preventing sticky extracellular substances such as TEP from attaching to the membrane surface or within the pores. This process is less sensitive to operational conditions as the flocs are formed under controlled conditions, by precipitation of metal hydroxides, and dosed on the membrane surface prior to filtration. Precoating membranes with iron flocs has proved efficient in providing a barrier to irreversible fouling in UF membranes for low salinity water at pilot scale [7]. However, no operational experience is available at full scale and in seawater applications [8].
This study aims at investigating the coagulation behaviour of TEP in seawater, for different conditions of dose, pH and mixing. Coagulation behaviour is quantified in terms of floc filterability by measuring the Modified Fouling Index (MFI). Moreover, the effect of precoating on membrane operation is studied for seawater with high TEP concentration. UF operation is quantified in terms of permeability decline over multiple filtration cycles.

II. MATERIALS AND METHODS

2.1 Filterability Studies

2.1.1 Feed Water - To investigate the coagulation behaviour of TEP, artificial seawater (ASW) was used. The ASW was prepared following the recipe provided in Table 1. Electrical conductivity (EC) of the ASW was measured at approximately 4800mS/m.

Table 1 Composition of artificial seawater (ASW) used for filterability experiments

<table>
<thead>
<tr>
<th>Salt</th>
<th>(g/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaCl</td>
<td>24.55</td>
</tr>
<tr>
<td>MgCl₂·6H₂O</td>
<td>9.52</td>
</tr>
<tr>
<td>CaCl₂·2H₂O</td>
<td>1.11</td>
</tr>
<tr>
<td>Na₂SO₄</td>
<td>3.21</td>
</tr>
<tr>
<td>K₂SO₄</td>
<td>0.85</td>
</tr>
<tr>
<td>NaHCO₃</td>
<td>0.2016</td>
</tr>
<tr>
<td>KBr</td>
<td>0.09681</td>
</tr>
<tr>
<td>Na₂CO₃</td>
<td>0.0062</td>
</tr>
</tbody>
</table>

2.1.2 TEP Source - TEP prepared and isolated from the species Chaetoceros affinis were used for the experiments (courtesy of Villacorte et al). To verify the presence of TEP in the solutions, samples were analyzed with liquid chromatography – organic carbon detection (LC-OCD) by DOC-Labor (Karlsruhe, Germany).

As the solutions were not expected to contain significant amounts of protein (confirmed by FEEM analysis and LC-OCD-OND), the biopolymer concentration obtained from the LC-OCD-OND analysis was considered as an indication of the concentration of TEP. Hence, TEP concentration is expressed as mgC/L as biopolymers for all experiments. TEP stock solutions were diluted to a concentration of 0.7mgC/L as biopolymers. This concentration was used in all filterability experiments in this study, and was chosen because it is in the upper range of measured biopolymer concentrations in seawater from the Oosterschelde in the Netherlands during the spring algal bloom [1].

2.1.3 Coagulation - Coagulation was done in batch mode with a calibrated jar test unit. FeCl₃·6H₂O was used as coagulant. pH adjustment was done by the addition of HCl or NaOH. Rapid mixing was applied for 20 seconds at an intensity of 1100s⁻¹. Slow mixing intensity and time were varied to identify the effect of flocculation on the characteristics of coagulated TEP.

2.1.4 Filtration - Filtration tests were conducted using an unstirred cell device schematically presented in Figure 2. Batch experiments were performed using filtration cells with a maximum process volume

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1 CLM4 – EC Engineering, Canada
2 Amicon (8400 series) – Millipore, USA
of 400 ml. The stirring assembly was removed from the cell to allow for cake formation. Filtration was achieved under dead-end, constant pressure mode. Feed water prepared under different process conditions was transferred to the cell unit. The solution was filtered through a hydrophilic PES filter with a MWCO of 100kDa at TMP = 0.3bar. Initial flux in the system was approximately 400 l/m²h.

![Schematic representation of the filtration setup](image)

Permeate from the cell was collected on a digital balance with an RS-232 interface. Data sets of collected filtrate weight and filtration time were recorded through data acquisition software.

### 2.2 Precoat Studies

#### 2.2.1 Feed Water

For the investigation of precoat efficiency in mitigating irreversible fouling in UF membranes, feed water was collected from the intake of a seawater UF/RO pilot desalination plant in the province of Zeeland, the Netherlands. Feed water characteristics are provided in Table 2. Samples were stored at 4°C and adjusted to room temperature prior to testing. Experiments were performed in less than a week after sample collection.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Min</th>
<th>Max</th>
<th>Avg</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7.5</td>
<td>8.5</td>
<td>8</td>
</tr>
<tr>
<td>Temperature</td>
<td>2.5</td>
<td>22.4</td>
<td>12.5</td>
</tr>
<tr>
<td>[°C]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turbidity [FTE]</td>
<td>0.05</td>
<td>34</td>
<td>5.69</td>
</tr>
<tr>
<td>EC [mS/m]</td>
<td>4400</td>
<td>5000</td>
<td>2720</td>
</tr>
<tr>
<td>TOC [mg/L]</td>
<td>1.3</td>
<td>2.3</td>
<td>1.8</td>
</tr>
</tbody>
</table>

#### 2.2.2 Precoat Solution

Optimum flocs for precoating UF hollow fibres were found to be those formed under pure sweep coagulation mechanism, i.e. full precipitation of metal hydroxide. Therefore, precoat stock solution was prepared in artificial seawater at 60mgFe³⁺/L, pH 8 and stirring at 45s⁻¹. Flocs formed under these conditions are readily settleable, and could reach up to a few millimetres in size. To avoid plugging of the hollow fibres with inner diameter of 0.8mm, a grinding step was employed for one minute prior to precoating, to reduce floc size and floc size distribution in the precoat solution. Grinding

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3 Omega – Pall Corporation, USA
4 Sartorius, Germany

*IDA World Congress – Perth Convention and Exhibition Centre (PCEC), Perth, Western Australia September 4-9, 2011*

*REF: IDAWC/PER11-347*
was achieved by applying a high mixing intensity of $1100 \text{s}^{-1}$ within the same jar test unit as the flocs were created.

To enable comparison with inline coagulation conditions, the amount of iron dosed per cycle is expressed as equivalent concentration in mgFe$^{3+}$/L, which is calculated by dividing the total amount of iron dosed on the membrane surface by the total filtration volume per cycle. Equivalent concentrations of 2, 4 and 8 mgFe$^{3+}$/L were tested for precoating.

2.2.3 Precoring and Filtration - The experiments were performed using a bench-scale filtration setup schematically presented in Figure 2. Precoring was done by dosing the precoat solution at the start of each filtration cycle for 1.5 or 3 minutes, depending on the desired equivalent concentration, at a flux of 200 l/m$^2$h, i.e. double the filtration flux. This condition was found to be optimum, since at lower flux values the precoat layer could not be firmly established on top of the membrane surface. Visual observations of autopsied hollow fibres precoated at lower flux revealed that the precoat layer was flushed to the dead end of the hollow fibres during filtration.

Filtration experiments were performed in constant flux dead-end mode for fixed filtration volumes per cycle. Multiple filtration and backwash cycles were performed for different experimental conditions. Solutions were filtered through PES hollow fibres of 0.8 mm diameter with a MWCO of 150kDa at a constant flux of 100 l/m$^2$h.

![Figure 2 Scheme of the filtration set-up](image)

2.3 Calculation of Modified Fouling Index (MFI) and Specific Cake Resistance ($\alpha$)

The MFI$_{0.45}$ was as an index of the fouling potential of a feed water containing particles when fixed reference values are used for pressure ($\Delta P = 2\text{bar}$), viscosity ($\eta = \eta^{20^\circ\text{C}}$) and area ($A = 13.8\times10^{-4}\text{m}^2$), with

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$^5$ Norit, the Netherlands
a 0.45µm membrane [9]. MFI$_{0.45}$ is expressed as the gradient of the straight portion of the plot of $t/V$ versus volume, and is presented in equation 1:

$$MFI = \frac{\eta \alpha C_b}{2 \Delta P A^2} \quad \text{.................................. (1)}$$

Where,

- $\eta$ = viscosity of water, (Pa.s)
- $\alpha$ = specific cake resistance, (m/kg)
- $C_b$ = particle concentration (aluminium dose in this case), (kg/m$^3$)
- $\Delta P$ = transmembrane pressure (Pa)
- $A$ = membrane surface area (m$^2$)

Specific cake resistance is constant for incompressible cakes under constant pressure filtration and can be calculated according to the Carman-Kozeny relationship (Equation 2). According to this relationship [10] a decrease in particle diameter size ($d_p$) increases the specific resistance of the deposited cake.

$$\alpha = \frac{180(1 - \varepsilon)}{\rho_p d_p^2 \varepsilon^3} \quad \text{.................................. (2)}$$

Where,

- $\alpha$ = specific cake resistance of particles per unit weight, (m/kg)
- $\varepsilon$ = cake porosity, (%)
- $\rho_p$ = average density of deposited particles, (kg/m$^3$)
- $d_p$ = average diameter of deposited particles, (m)

III. RESULTS

3.1 Filterability Studies

To investigate TEP coagulation behaviour pH, dose and slow mixing intensity and time for flocculation were varied. All other coagulation conditions i.e. temperature, rapid mixing time and intensity, chemical composition/water matrix, and TEP concentration were kept constant.

3.1.1 Effect of Dose and pH - The effect of coagulant dose and pH on TEP coagulation was evaluated. Coagulation was performed at 0.5 and 2mgFe$^{3+}$/L, at two different pH values of 6 and 8. Rapid mixing was done at 1100s$^{-1}$ for 20 seconds (RMGt 22,000), followed by slow mixing at 45s$^{-1}$ for 30 minutes (SMGt 81,000). Results are shown in Table 3. MFI of raw TEP solution (0.7mgC/L as biopolymers) without coagulant addition was measured at 16,800s/L$^2$.

<table>
<thead>
<tr>
<th>pH</th>
<th>Dose (mgFe$^{3+}$/L)</th>
<th>MFI (s/L$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>0.5</td>
<td>10,100</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>760</td>
</tr>
<tr>
<td>8</td>
<td>0.5</td>
<td>9,970</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>3,300</td>
</tr>
</tbody>
</table>

Table 3 MFI of coagulated TEP as a function of coagulant dose and pH at RMGt 22,000 and SMGt 81,000
Addition of coagulant resulted in an improvement in MFI of TEP solutions. However, MFI was consistently higher at lower coagulant dose for these mixing conditions. Increase in dose resulted in a dramatic decrease in MFI for both pH values of 6 and 8, with a 67% decrease at pH 8 and a 92% decrease at pH 6.

The effect of pH at coagulant dose of 0.5mgFe³⁺/L was negligible. However, at 2mgFe³⁺/L, decrease in pH resulted in better filterability of coagulated TEP aggregates (MFI was 4 times lower at pH 6 than at pH 8).

Subsequently, different coagulant concentrations of 0.5, 1 and 2 mgFe³⁺/L were considered at pH 6, RMGt 22,000 and SMGt 81,000 and the coagulation behaviour was studied in terms of flux decline during 15 minutes of filtration. Results are presented in Figure 3.

![Flux decline for different coagulant concentrations at pH 6, RMGt 22,000 and SMGt 81,000](TEP 0.7mgC/L as biopolymers)

Increase in coagulant dose at pH 6 results in improved filterability of TEP aggregates. Moreover, the rapid flux decline regime tends to fade at higher coagulant dose, resulting in a more linear trend in flux decline through time.

### 3.1.2 Effect of Slow Mixing Time

Increase in slow mixing (flocculation) time can result in the enlargement of coagulated particles. Larger particles are expected to impart lower resistance to filtration (refer equation 2), firstly, due to a size effect (d_p) and secondly, because larger flocs have higher porosity (ε). It is therefore of interest to verify whether TEP flocs aggregate with prolonged flocculation times. The experimental conditions and corresponding MFI values are presented in Table 4.

<table>
<thead>
<tr>
<th>Dose (ppm)</th>
<th>pH</th>
<th>RMG (s⁻¹)</th>
<th>RMt (s)</th>
<th>SMG (s⁻¹)</th>
<th>SMt (min)</th>
<th>MFI (s/L²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>8</td>
<td>1100</td>
<td>20</td>
<td>0</td>
<td>0</td>
<td>9,800</td>
</tr>
<tr>
<td>2.0</td>
<td>8</td>
<td>1100</td>
<td>20</td>
<td>0</td>
<td>0</td>
<td>10,000</td>
</tr>
<tr>
<td>0.5</td>
<td>8</td>
<td>1100</td>
<td>20</td>
<td>45</td>
<td>30</td>
<td>4,000</td>
</tr>
</tbody>
</table>

Figure 3 Flux decline for different coagulant concentrations at pH 6, RMGt 22,000 and SMGt 81,000 (TEP 0.7mgC/L as biopolymers)
At lower coagulant dose of 0.5mgFe$^{3+}$/L, the effect of slow mixing (flocculation) time is negligible. At this dose, increase in flocculation time from 0 to 30 minutes does not affect MFI, suggesting that the iron concentration is too low to allow for enhanced flocculation with longer slow mixing time.

At 2mgFe$^{3+}$/L, increase in flocculation time from 0 to 30 minutes, results in a decrease in MFI of approximately 15%. It may be that aggregation and growth does not occur at all, resulting in little improvement in MFI. However, it may also be possible that the size of flocculated TEP does not affect the filterability of their deposited cake. Particle size analysis could provide more insight on the effect of flocculation by prolonged slow mixing on the aggregation of coagulated TEP particles.

3.1.3 Effect of Slow Mixing Gt - As no apparent effect of slow mixing time on filterability of TEP flocs was observed, the effect of slow mixing Gt was investigated at different values of slow mixing G. Slow mixing G of 45s$^{-1}$ and 200s$^{-1}$ were chosen, and flocculation time was varied to achieve constant flocculation Gt of 24,000, 84,000 and 180,000. Details are provided in Table 5. Coagulation was performed at pH 8, 2mgFe$^{3+}$/L, rapid mixing intensity of 1100s$^{-1}$ and rapid mixing time of 20 seconds. Results are shown in Figure 4.

<table>
<thead>
<tr>
<th>SMG (s$^{-1}$)</th>
<th>SMt (min)</th>
<th>SMGt</th>
<th>SMG (s$^{-1}$)</th>
<th>SMt (min)</th>
<th>SMGt</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>0</td>
<td>0</td>
<td>200</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>45</td>
<td>9</td>
<td>24000</td>
<td>200</td>
<td>2</td>
<td>24000</td>
</tr>
<tr>
<td>45</td>
<td>30</td>
<td>84000</td>
<td>200</td>
<td>7</td>
<td>84000</td>
</tr>
<tr>
<td>45</td>
<td>67</td>
<td>180000</td>
<td>200</td>
<td>15</td>
<td>180000</td>
</tr>
</tbody>
</table>

The lowest MFI is observed at Gt 84,000 for both G values of 45s$^{-1}$ and 200s$^{-1}$. Furthermore, higher slow mixing G appears to favour filterability of TEP flocs in all but one case; at Gt 180,000, MFI is lower at 45s$^{-1}$.

As mentioned earlier, size may not be the dominating factor in filterability of TEP aggregates, and other characteristics (e.g. permeability) rather than size may be promoting their filterability. In this light, higher velocity gradients and shorter times can be employed for flocculation.
3.2 Precoat Studies

The first set of precoat experiments was conducted with equivalent concentrations of 4 and 8mgFe\(^{3+}\)/L. Membranes were precoated at a flux of 200 l/m\(^2\)h. Filtration flux was set at 100 l/m\(^2\)h for 45 minutes per cycle. Backwash flux was set at 250 l/m\(^2\)h for 1 minute. Real seawater collected from Oosterschelde in Zeeland, the Netherlands was used as feed for these experiments. The biopolymers concentration in the water was approximately 0.5mgC/L (which includes TEP). TMP profiles for direct seawater filtration (blank) and precoating with 4 and 8ppm equivalent concentration followed by seawater filtration is shown in Figure 5.

Figure 5 TMP profiles for direct filtration and different precoat conditions for seawater UF
\(J_f = 100 \text{ l/m}^2\text{h}, J_{BW} = 250 \text{ l/m}^2\text{h} \text{ and } J_{precoat} = 200 \text{ l/m}^2\text{h}\)
For direct seawater filtration (without precoating), a 700% increase in TMP was observed after 6 filtration cycles (approximately 5 hours of operation). The high fouling potential of the seawater is attributed to the presence of TEP in the feed water. Feed water for these experiments was collected in the algal bloom season in which elevated TEP concentrations are observed [1].

When UF hollow fibres are coated with 8ppm equivalent concentration, the increase in TMP after 6 filtration cycles drops to 200%. However, when a lower dose of 4ppm equivalent concentration is used this increase is further reduced to 150%. During backwashing of fibres coated with 8ppm equivalent concentration, rod like structures were observed, which were difficult to remove from the fibres, which could explain the lower backwash efficiency at 8ppm equivalent concentration.

The filterability (slope of the TMP curve) of the feed water improves dramatically with the application of precoa on the membrane hollow fibres, with the highest filterability at 4ppm equivalent concentration. The higher slope of the TMP curve for 8ppm equivalent concentration may be attributed to higher particle retention by depth filtration, as the precoat layer is thicker.

Moreover, permeability decline stabilizes after 3 filtration cycles for both precoat conditions, whereas for direct seawater filtration a steady decline in permeability is observed for multiple filtration cycles (Figure 6). Permeability declines by approximately 20% for 4ppm equivalent concentration and 30% for 8ppm equivalent concentration.

![Figure 6](image_url)

**Figure 6** Permeability decline for direct filtration and precoating for seawater UF

In the second set of precoat experiments, the same conditions of precoat time and flux were used. However, filtration time was increased to 90 minutes. In this way, the equivalent concentration was halved. Results for 2 and 4ppm equivalent concentration are presented in Figure 7.

4ppm equivalent concentration exhibits higher permeability recovery after approximately 5 hours of operation (3 filtration cycles). Permeability decline tends to stabilize after about 3 hours of operation. However, permeability declines steadily at 2ppm equivalent concentration for 5 hours of operation.
Although the slopes are similar for both precoat conditions, permeability recovery is higher for 4ppm equivalent concentration.

![Permeability decline for precoating at 4 ppm eq. conc. for 45 and 90 minutes filtration time](image)

**Figure 8** Permeability decline for precoating at 4 ppm eq. conc. for 45 and 90 minutes filtration time

It may be that precoat flocs do not form a uniform layer on the membrane surface at the lower precoat dose, and the non-coated parts are irreversibly fouled by TEP or other foulants.

To elucidate the effect of filtration time, precoat efficiency was compared for 45 and 90 minutes of filtration at equivalent concentration of 4ppm (Figure 8). Shorter filtration time (smaller thickness of precoat layer) of 45 minutes shows higher permeability decline during each filtration cycle than the longer filtration time of 90 minutes. However, permeability recovery after each filtration cycle is higher for the shorter filtration cycles.

![Backwashability for precoating at 2 and 4ppm eq. conc. for 90 minutes filtration](image)

**Figure 7** Backwashability for precoating at 2 and 4ppm eq. conc. for 90 minutes filtration
III. CONCLUSIONS

In conclusion, dose, pH and slow mixing G appear to be the most influential parameters on the coagulation efficiency of TEP. Increase in dose from 0.5 to 2mgFe³⁺/L substantially improved TEP filterability. TEP filterability was further improved by reducing the pH from 8 to 6. Applying flocculation by slow mixing for 30 minutes (floc growth) did not seem to have a significant effect on the filterability of coagulated TEP as compared to no flocculation.

Precoating proved to be effective in mitigating reversible and irreversible fouling in UF membranes treating seawater with high concentration of TEP. This was observed by an improvement in both filterability (TMP increase in a cycle) and backwashability (permeability recovery after a backwash) when precoat was applied. In the range of 2 to 8mgFe³+/L equivalent concentration, the best performance was observed at 4mgFe³+/L equivalent concentration, at which UF operation reached a stable recovery state after 3 hours.

IV. REFERENCES