Mitigation of reverse osmosis membrane fouling by electrochemical-microfiltration-activated carbon pretreatment

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Abstract

In this study, a hybrid electrochemical-microfiltration-granular activated carbon adsorption (e-MF-GAC) pretreatment process was developed and demonstrated for controlling reverse osmosis (RO) fouling. Compared to ultrafiltration (UF), e-MF-GAC pretreatment resulted in 30% higher permeate flux. Results in this study show the complementarity among individual treatment processes of e-MF-GAC for removing inorganic/organic foulants and small organic molecules, leading to superior performance over conventional UF pretreatment. This hypothesis is validated by systematic feed water and foulant composition analysis as well as fluorescence excitation-emission matrix and X-ray diffraction spectroscopic characterization of the organic and inorganic foulants on the membrane surface, respectively. Organic foulants on the membrane were mostly protein-like compounds and their disposition onto the membrane surface was much lower after pretreatment using e-MF-GAC compared to UF. Similarly, after e-MF-GAC-RO pretreatment, organic content in the RO concentrate was lower than that after UF pretreatment. Results in this study provide the basis for further research at pilot scale to assess the economic viability of the proposed e-MF-GAC process as an alternative to conventional UF pretreatment for mitigating RO membrane fouling.

Key words: Reverse osmosis, fouling, electrochemical, microfiltration, activated carbon.

1. Introduction

Water reuse has been increasingly applied around the world for a secured water supply [1]. With outstanding permeate quality, efficient energy consumption and small footprints, reverse osmosis (RO) is the most commonly used technology for water reuse [2]. The RO process is especially effective and efficient at removing micropollutants of concern for water reuse applications [3, 4]. However, membrane fouling, which could lead to significant flux decline and deteriorated permeate quality, remains a critical bottleneck to RO applications [5].

RO fouling can be categorized into inorganic scaling, organic fouling and biofouling. As the RO feed was generally pretreated by the microfiltration (MF) or ultrafiltration (UF) and preconditioned with anti-scalants and chloramine, membrane scaling and biofouling could be reduced to some extent [5-7]. However, small organic molecules that could not be removed by MF or UF can eventually cause severe organic fouling [8, 9]. In addition, multivalent cations such as Ca^{2+} and Mg^{2+} can complex with these small organic molecules to exacerbate membrane fouling [10, 11]. As such, an effective pretreatment technique to remove small organic molecules is essential for the sustainable RO filtration of reclaimed water.

To alleviate the organic fouling of RO, several pretreatment technologies (e.g., MF, UF, coagulation, activated carbon adsorption and oxidation) have been investigated for eliminating organics in the feed water [12, 13]. Amongst these technologies, MF/UF is mostly used for removing turbidity and suspended solids, where their capacity for removing dissolved organics was limited [14]. Coagulation and granular activated carbon (GAC) adsorption have been proven to be capable of removing organic matter and subsequently reducing the fouling of RO [15, 16]. However, coagulation generally produces significant amounts of sludge and the GAC adsorption requires frequent regeneration [17, 18]. One example of oxidation method is pre-ozonation to alter characteristics (e.g., charge and hydrophilicity) of organic molecules in the feed water and subsequently reduce the affinities of organic matter towards the membrane [19]. However, it is noteworthy that the RO fouling may be aggravated by ozonation when high concentration of divalent ions (e.g., Ca^{2+}) and polysaccharides were coexisted in the feed water [19]. As a result, developing effective oxidation method for sustainable fouling control is still required. Electrochemical process has recently emerged as a potentially effective advanced oxidation processes for organic removal. Electrochemical pretreatment has been successfully integrated with the membrane filtration processes [20, 21]. The electrochemical process generates strong oxidants (e.g., reactive oxygen species (ROS) and reactive chlorine species (RCS)) with the presence of chloride or oxygen contained in the bulk solution, which could decompose the organic matter or alter their physical properties (e.g., surface charge and hydrophilicity) [13]. Compared to ozonation, the electrochemical process has several advantages including: chemical free, effective in organic decomposition and low operation cost [22]. Several studies have achieved efficient fouling reductions in the membrane bioreactors with the application of electric field, where the fouling was significantly inhibited due to the removal of high fouling potential organic matters (e.g., biopolymers) and enhanced electrostatic repulsion between the foulants and the membrane surface [23-25]. Mameda et al. [26] observed that MF membrane fouling was significantly reduced after electrochemical pretreatment. However, the application of electrochemical pretreatment for controlling RO fouling has not yet been studied.

It is noted that most commercially available RO membranes (e.g., polyamide) could be significantly damaged on contacting the RCSs [27]. This suggests the electro-generated RCSs should be removed if the electrochemical approach were applied as the RO pretreatment. To eliminate the RCSs, GAC adsorption has proven to be a valid approach which was widely applied in water treatment process [28]. However, the information regarding to the coupling electrochemical process and GAC for RO fouling control is lacking.

As such, this study proposed a hybrid electrochemical process based pretreatments approaches to control the fouling of RO during the treatment of a biological treated industrial wastewater. The electrochemical process was coupled with the submerged ceramic MF process and activated carbon adsorptions, where the MF was used to remove the large particles and the activated carbon was employed to eliminate the RCS in the effluent to avoid the damage of RO membrane by the RCS. The effects of different electric fields on the treatment performances and membrane fouling control of RO were investigated and compared with those using conventional UF pretreatment. The detailed characterization of the organic transformation, foulant layer during the entire treatment was carried out for an in depth understanding of the mechanism associated with the fouling reduction.

2. Materials and methods

2.1. Feed wastewater

Biologically treated effluent from a wastewater treatment plant (WWTP) which receives the wastewater from an industrial complex in Shanghai was used as the feedwater. The industrial complex is mainly composed of the chemical and petrochemical processing incorporates, which produces a great amounts of high strength wastewaters. Key characteristics of the feed water are summarized in Table 1.

Table 1: Key characteristics of the raw wastewater.

Parameter	TDS	COD	TN	TP	pH	Ca^{2+}	Mg^{2+}	SO_4^{2-}	Na^+	K^+
Value (mg L^{-1})	3554.8	52.1	8.4	0.3	7.5	50.4	31.4	195.2	524.5	57.5

2.2. Pretreatment rig

The e-MF-GAC process was carried out in a custom-made unit (Fig.1). For the electrochemical device, two flat IrO_2/Ti electrodes with the dimension of 10 cm × 10 cm were vertically placed 1.5 cm apart in a 2 L reactor. These electrodes were connected to a DC power regulator. The feed water was continuously pumped into the reactor and a level sensor was used to regulate the water level in the reactor. The water was thoroughly mixed using a magnetic stirrer. A flat sheet ceramic MF membrane made of ZrO_2 (nominal pore size of 0.1 μm and effective membrane surface of 0.02 m^2) was submerged in the reactor. The ceramic membrane has a dimension of 10 cm × 12 cm × 0.5 cm. The membrane surface was hydrophilic since ZrO_2-based membranes usually have a contact angle less than 20°, and was negatively charged under the experimental conditions (i.e., at ~pH 7) [29]. The membrane module was vertically placed between the two electrodes, where the distance between the membrane and anode or cathode electrode was the same. The MF flux was regulated at 55 LMH corresponding to a hydraulic retention time (HRT) of 6 h. The permeate was transferred from the membrane permeate outlet to an activated carbon column for quenching any residual chlorine prior to the RO membrane. The activated carbon column was made of polymethyl methacrylate with length and diameter of 60 cm and 4 cm, respectively. The column was packed with GAC of 0.18-0.30

mm in size. The GAC has a specific surface area of about 1039 m^2 g^{-1} and iodine value of 800 mg g^{-1}. Prior to packing into the column, the granular activated carbon was sieved and cleaned using deionized water. The filtration rate for the operation of activated carbon was about 1.2 m h^{-1} (Empty bed contact time of 30 min). Fresh activated carbon was packed into the column after each pretreatment experiment.

A lab-scale RO filtration rig was used. The rig was equipped with a polyamide spiral wound membrane (Shandong Bolong Pty Ltd, China) with an effective size of 0.3 m^2 and a nominal NaCl rejection rate of 99.5% and a high pressure pump that deliver 2.8 MPa of pressure at 24 °C. The rig was operated at cross flow filtration mode and the crossflow velocity was set at 2 m s^{-1}. To accelerate membrane fouling, the initial flux for the RO was set at 14 LMH. The reverse osmosis concentrate was discharged during the filtration. The RO feed volume for UF, e-MF(1 V)-GAC, e-MF(3 V)-GAC and e-MF(6 V)-GAC was 24, 16, 13 and 12 L, respectively. The permeate was collected through the permeate line and weighed using a digital balance. The filtration of all experiments was 7 hours. The permeate sample was collected at the end of each filtration experiment. After each experiment, the fouled membrane was removed from the module and cut into small pieces. The fouled membrane samples were then soaked in 100 mL of 10 mM NaOH to extract the foulants for further analysis.

To evaluate the performance of electrochemical-MF-activated carbon adsorption pretreatment, conventional UF pretreatment was conducted. The UF membrane has a contact angle of ~70 ^{o}C and a negative surface charge of ~-10 mV under the experimental condition. The UF module was equipped on the same rig as RO. The UF membrane was spiral wound shaped and made of polyethersulfone (Shandong Bolong Pty Ltd, China), which has a nominal pore size of 0.01 μm and effective surface area of 0.4 m^2. The UF was conducted at crossflow mode, where the constant pressure of about 0.2 MPa was applied. The collected UF permeate was subjected to the following RO treatment.

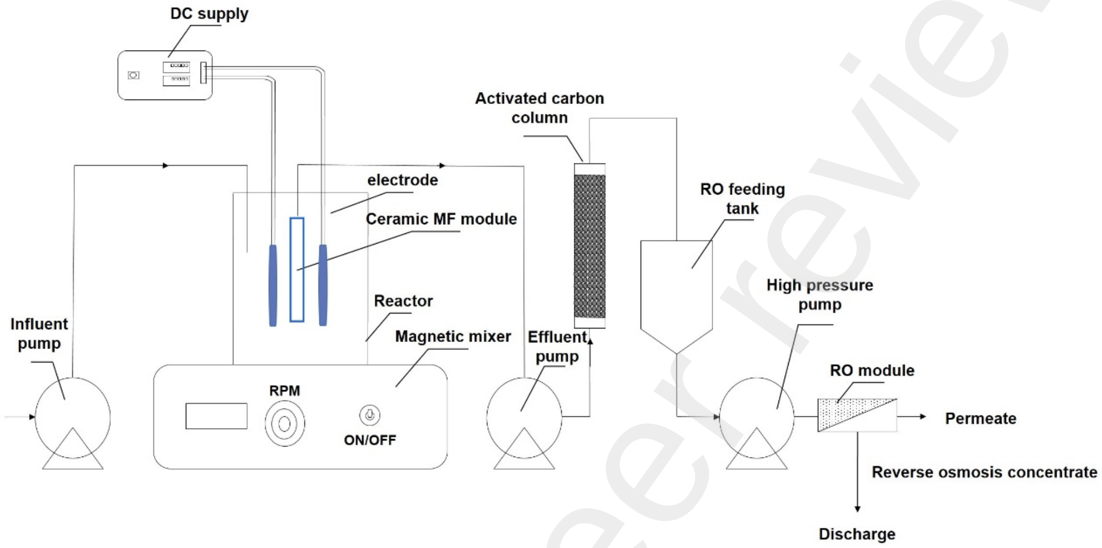

Fig.1 The electrochemical-MF-adsorption pretreatment setup

2.3 Analytical methods

The COD of water sample was monitored using the standard method (US-EPA 5200D). The content of total organic carbon in the solution was measured by a total organic carbon (TOC) analyzer (N/C 2100, Analytik Jena AG, Germany). The metal concentration was measured using an inductively coupled plasma spectrophotometer (ICP-AES, Leeman, Prodigy 7). The organic composition was characterised using the fluorescence excitation-emission matrix spectra (EEMs) at a fluorophotometer (F97, Lengguang, China). The obtained EEMs were calculated using parallel factor analysis (PARAFAC). The model calculation was carried out using Matlab (R2012a) with the tool box (drEEM 0.64) according to the protocol reported elsewhere [30, 31]. The particle size and zeta (ζ) potential of the samples were determined using a Malvern Zetasizer Nano ZS (Malvern Instruments). The composition of organic and inorganic foulants attached on the membrane was measured using a loss on ignition (LOI) analysis [32]. According to the protocol, the foulant attached on the membrane was completely washed from the membrane with 100 mL of 10 mM NaOH, and the foulant solution was then filtered through a pre-weighed GF/C filter. After filtering, the filtered paper was dried at 105 °C for more than 24 h and weighed again. Finally, the dried GF/C filter paper was combusted at 550 °C for 2 h. The weight loss was considered as the mass of organic foulant, whereas the remaining mass was considered as the inorganic foulant. Due to the high mass of cake layer, the weight of Na^+ and the foulant dissolved in the detaching liquid which could pass through the filter paper was considered as negligible. The crystal structure of the foulant layer on the membrane surface was characterised using an X-ray diffraction spectroscopy (D/MAX2500 X-ray powder) according to the previously reported protocol [33]. The active chlorine was measured using a diethylphenylenediamine (DPD) colorimetric method according to the Standard Method 4500-Cl.

3. Results and discussions

3.1. Filtration performance of RO after various pretreatments

The RO normalized flux profiles were evaluated after UF and e-MF-GAC pretreatments and shown in Fig. 2. After UF pretreatment, a rapid flux decline by 60% during the first 2 hours of RO filtration was observed and the flux was then stable for the rest of the experiment. After e-MF-GAC with 1 and 3 V, similar flux profiles were observed and the flux decline was much more gradual compared to that after UF pretreatment. However, at the end of the RO filtration experiment, the final flux was the same with that after UF pretreatment, at 40% of the initial flux. The flux of RO after e-MF-GAC with 6V voltage input has a similar profile but stable after 3 hours of filtration at a much high final flux. Compared to UF pretreatment, the final flux after pretreatment using 6V voltage input was enhanced by 25%. Results in Fig. 2 suggest that e-MF-GAC pretreatment efficiency is dependent on energy input and a sufficiently high voltage (i.e. 6 V) could achieve stably higher flux performance compared to conventional UF pretreatment. Based on results in Fig. 2, all subsequent e-MF-GAC pretreatment experiments were conducted at 6 V.

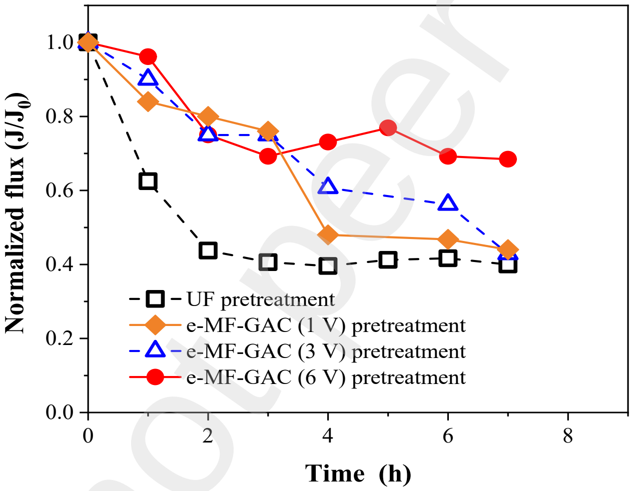

Fig.2 The comparison of UF and e-MF-GAC pretreatments with different electric input on the flux decline of RO

3.2. Characterisation of the organics during various treatments

Changes in organic content and composition due to pretreatment were evaluated to determine the underlying mechanisms. UF pretreatment did not significantly remove the organic matter (measured as COD) from the feed water (Fig. 3). By contrast, organic removal by a combination of electrochemical and MF pretreatment was >50% (Fig. 3). In this study, the nominal pore size of the MF membrane was ten times larger than the UF membrane (section 2.2), thus, better pretreatment performance of the electrochemical MF hybrid process was attributed to the oxidation of organics by electrochemical treatment. GAC adsorption only resulted in a marginal increase in organic removal (Fig. 3). It is noteworthy that active chlorine was detected in all the effluent samples after electrochemical and microfiltration pretreatment (Supplementary Data, Table S1). The concentration of active chlorine also increased with increasing voltage input. However, after the GAC adsorption, no active chlorine could be detected, confirming the efficiency of the GAC column for chlorine quenching. The reason of low COD removal by GAC in e-MF-GAC is unclear. However, due to the presence of the electrochemical prior to the GAC adsorption, it could be speculated that the RCS produced by electrochemical process could occupy the adsorption site on GAC grains leading to low organic removal. These results are consistent with the designed purpose of the GAC column to remove reactive chlorine prior to the RO membrane. The water quality was significantly improved by UF-RO treatment compared with the UF alone, where the COD in the RO permeate was below 10 mg L^{-1}. The COD content was reduced to almost zero after a combination of e-MF-GAC pretreatment and RO filtration and was significantly better than the UF-RO process. In addition, RO concentrate (ROC) collected from UF-RO process contained a significantly higher COD content compared with that of e-MF-GAC-RO (Supplementary data).

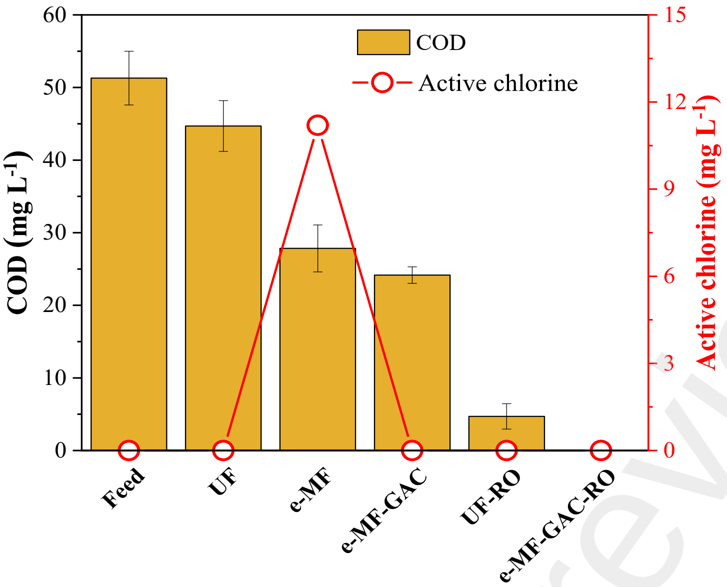

Fig. 3 The COD and active chlorine concentration variation in the raw wastewater and effluent after various treatment processes (error bars represent the standard deviation of for times of measurements).

To characterise the organic matter removed by UF and e-MF-GAC pretreatment processes, the treated water by them was determined using EEM spectroscopy. Major peaks from EEMs analysis of all samples were further separated and quantified by PARAFAC analysis. Three components (C1-3) extracted from the EEMs of the raw wastewater, treated effluent by UF, e-MF, e-MF-GAC, UF-RO and e-MF-GAC-RO using PARAFAC are shown in Supplementary information (Fig.S1). Component 1 (C1) showing the peak at Em/Ex=400/320 nm and 3 (C3) showing the peaks at Em/Ex=460/350 nm and Em/Ex=460/290 nm were associated with humic acid and fulvic acid-like compounds, respectively [30, 34], whereas component 2 (C2) with the peak at Em/Ex=320/290 nm represented the protein-like substances [34, 35].

The maximum fluorescence (F_{max}) values of each component in different samples are shown in Fig.4. The F_{max} values of all EEMs components in the raw wastewater were not significantly reduced by UF. As for the e-MF process, the F_{max} values of C1 and C3 were reduced by 90% compared with those in the raw wastewater, suggesting the humics-like materials were fairly susceptible to the electrochemical process. Besides, the F_{max} of C2 was eliminated by over 50% by the e-MF, suggesting protein-like compounds in the wastewater could also be significantly removed by e-MF process. It was noticed that the GAC following the e-MF gave a slight reduction of C1 and C2 components but no reduction in the content of C3 component. This suggested that the GAC could only adsorbed very limited amounts of fluorescent organics from the effluent of e-MF. Both UF-RO and e-MF-GAC-RO achieved almost 100% removal of all the components, which was attributed to the effective organic retention capacity of RO.

The EEMs of ROC was further characterised (Fig.S2 and S3, Supplementary data) to show the peaks related to humics (C1 and C3) and protein-like compounds (C2) according to the EEM-PARAFAC analysis for both UF and e-MF-GAC pretreatment methods. The F_{max} values for all the components of ROC for UF pretreatment were significantly higher compared with that of e-MF-GAC pretreatment, suggesting the e-MF-GAC could significantly lower the content of all organic components in the ROC compared with UF pretreatment.

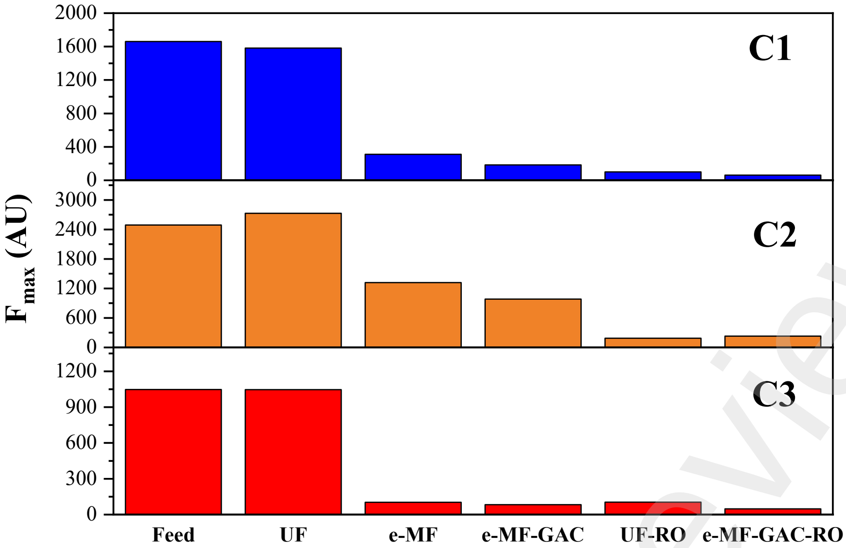

Fig.4 The F_{max} values of all components in the water samples calculated from EEMs-PARAFAC analysis

3.3. Variation of Ca^{2+} and Mg^{2+} concentration during various treatments

Multivalent cations such as Ca^{2+} and Mg^{2+} and anions SO_4^{2-} are potential scalants and can also aggravate organic fouling during RO filtration of reclaimed water. As a result, Ca^{2+}, Mg^{2+} and SO_4^{2-} concentrations before and after pretreatment were monitored and shown in Fig.6. Ca^{2+}, Mg^{2+} and SO_4^{2-} removal by UF, e-MF and e-MF-GAC from the raw wastewater was insignificant. After e-MF-GAC or UF pretreatment, the RO feed contained similar Ca^{2+}, Mg^{2+} and SO_4^{2-}contents (Fig, 5). These results suggest that the observed lower RO fouling after e-MF-GAC pretreatment compared with UF was attributed to the reduction of organic content rather than potential scalants such as Ca^{2+}, $Mg^{2+}$and SO_4^{2-}. Due to the significant presence of the high scaling potential components in the feedwater and pre-treated feedwater. The scaling of RO could still occur, even if the UF and e-MF-GAC pretreatments were applied. However, the enhancement of flux decline by e-MF-GAC suggested that the RO fouling could be mitigated to some extent by reducing the organics, though the scaling was evitable.

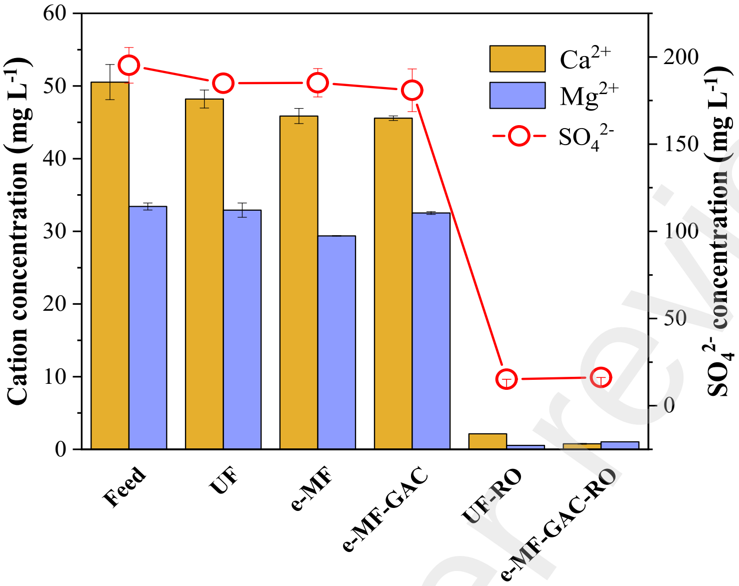

Fig.5 The Ca^{2+}, Mg^{2+} and SO$_4^{2-}$ concentration in the raw wastewater and effluent after various treatment processes (error bars represent the standard deviation of two replicate experiments).

3.4. Fouling characterisation

3.4.1 Organic and inorganic distribution within the fouling layer

For further insight in to the mechanism of fouling retardation, the fouling layer on the RO membrane surface after each test was extracted and characterised. Fig.6 shows the distribution of the organic and inorganic constituents in the RO fouling layer. Organic (~3.0 g m^{-2}) and inorganic (~2.2 g m^{-2}) foulants were present on the RO membrane surface after UF pretreatment. After e-MF-GAC pretreatment, the amounts of both of the organic (~0.43 g m^{-2}) and inorganic (~0.75 g m^{-2}) foulants on the RO membrane surface were significantly lower (Fig. 6). As discussed above, e-MF-GAC pretreatment could only remove organics more effectively than

UF pretreatment. Ca^{2+} and Mg^{2+} contents were unaffected by both pretreatment methods (section 3.3). Thus, results in Fig. 6 are consistent with the role of Ca^{2+} and Mg^{2+} to exacerbate fouling to form a dense organic fouling layer. Here, effective removal of organics by e-MF-GAC pretreatment could reduce their interactions and therefore prevent the formation of dense cake layer [19]. This observation is further supported by the XRD analysis of the fouling layer (Fig.7). As shown in the XRD spectra, only the RO membrane fouled by the effluent of e-MF-GAC pretreatment gave significant peaks of calcites, where no significant peaks could be observed on those for the UF pretreatment and pristine membrane. This was because the inorganics after UF pretreatment ended up being trapped by the organics during the formation of fouling layers on the RO membrane instead of directly crystallizing on the membrane surface. However, it appears that e-MF-GAC pretreatment significantly removed organic matter, which broke the associations between the organic and inorganics leading to some free inorganic ions being attached on the membrane.

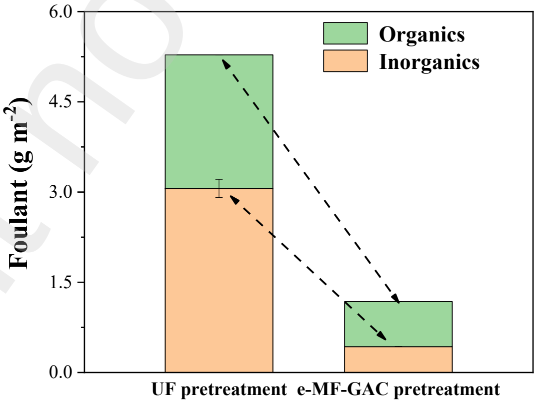

Fig.6 The distribution of the organic and inorganic component in the foulant layer of RO after UF and e-MF-GAC pretreatment.

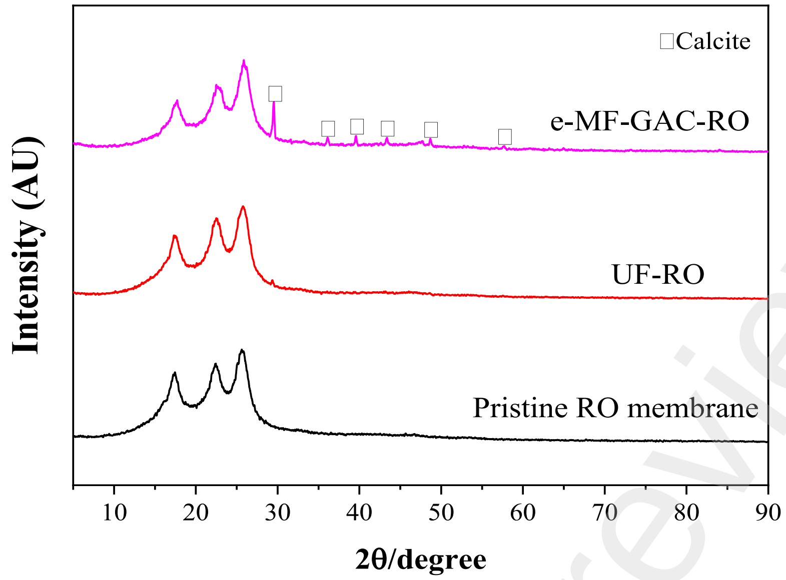

Fig.7 The XRD spectra of the pristine RO membrane and fouled RO membrane after UF and e-MF-GAC pretreatment.

3.4.2 Major organic components in the fouling layer

Fouling layers on the RO membrane surface after pretreatment were further characterised using EEM-PARAFAC analysis (Supplementary data，Fig.S1). It was found the F_{max} value related to protein-like substances (C2) in the fouling layers obtained from the RO membrane (Fig. 8) was much higher than that of the other two components. This observation suggests that the protein-like component was the major organics deposited on the RO membrane surface. The F_{max} of protein-like substances (C2) in the fouling layer with UF pretreatment was greater than that using e-MF-GAC pretreatment, which is consistent with the magnitude of their organic carbon content (2.6 g m^{-2} for the sample with UF pretreatment, c.f., 0.25 g m^{-2} for the sample with e-MF-GAC pretreatment). The results were also consistent with the results in Fig.4, where the e-MF-GAC was able to remove the protein-like compounds in the feed leading to less accumulation of these compounds on the membrane surface than UF pretreatment.

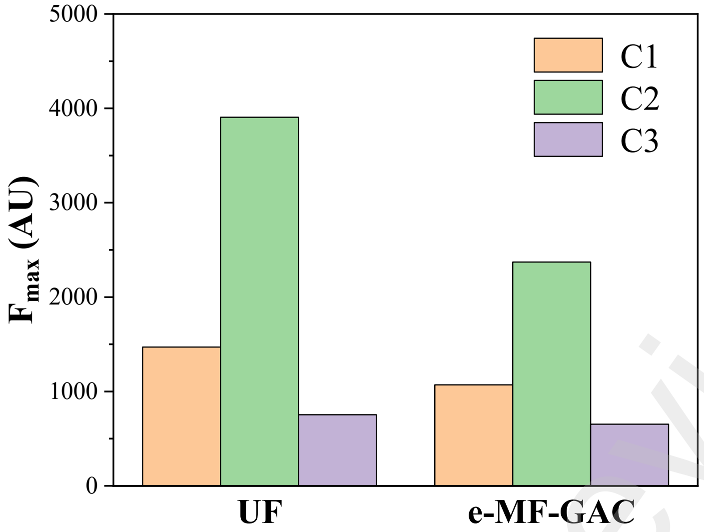

Fig.8 The EEM components in the foulant layer collected from the RO membrane after (a) UF and (b) e-MF-GAC pretreatment.

3.4.3 Size and zeta potential

Size distributions of the organic content in the feed water, UF pretreated water and e-MF-GAC pretreated water were measured and shown in Fig.9. The size of the molecules contained in the feed water being detected ranged from 250-750 nm. After the UF pretreatment, the large sized molecules were rejected by the UF membrane, where the majority of the molecules had the size of 250-400 nm. The size range of the molecules contained in the e-MF-GAC pretreated water was similar as those of UF pretreated water. However, it could be observed that the proportion of small organic molecules (size <300 nm) in the e-MF-GAC pretreated water was slightly higher than those of UF-pretreated water, but the content of large sized molecules (300-400 nm) of them was less. The average size of the molecules in the effluent of e-MF-GAC was slightly lower than that of UF. This result proved that the e-MF-GAC process could remove/decompose some of the organic molecules from the feed water and form smaller molecule. It was reported that the larger sized molecules often could cause greater RO fouling, as them could increase hydrodynamic drag and reduce the back-transport of these particles from the membrane surface [36]. This suggested the overall smaller sized molecules resulting from the e-MF-GAC than the UF was probably another reason for the more effective fouling mitigation of RO by the e-MF-GAC.

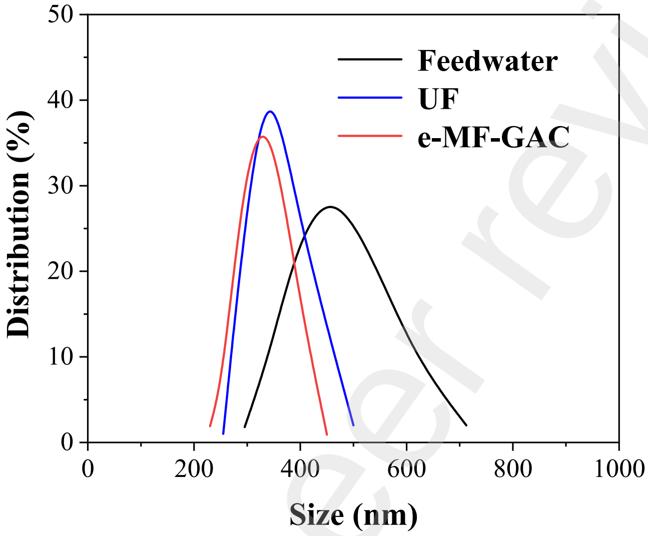

Fig.9 The size distribution of the raw feedwater, UF pretreated water and e-MF-GAC pretreated water.

The RO fouling could also be affected by the electrostatic interactions between the components in the RO feed and the RO membrane. The polyamide membrane surface is negatively charged, more negatively charged substances in the feed could be experienced greater electrostatic repulsive forces during the filtration. As shown in Table S3 (Supplementary data), the ζ potential of effluent of UF pretreatment was similar as that of raw wastewater, suggesting no significant alteration in organic characteristics was likely occurred during the UF. As for the effluent of e-MF-GAC, the ζ potential was slightly higher than those of raw wastewater and the effluent from UF pretreatment. This was likely because some of the organics were decomposed by the e-MF process leading to less negative surface charge. The slightly higher ζ potential for the effluent of e-MF-GAC pretreatment than UF pretreatment suggested that the fouling reduction of RO by the e-MF-GAC was not attributed to the enhanced electrostatic repulsion between the components in the RO feed and membrane.

3.5. Implications

The proposed e-MF-GAC hybrid process can replace convention UF pretreatment with superior performance and potentially at a lower cost. The energy consumption by the UF-RO and e-MF-GAC has been evaluated, where the UF-RO gave lower energy consumption compared with the e-MF-GAC under 6 V of DC input (0.26 kW L^{-1} for UF-RO, c.f., 0.48 kW L^{-1}). Though, the additional e-MF process increased overall energy consumption, in addition to fouling control, e-MF-GAC can offer several other benefits. Firstly, the results of this study suggested that the COD removal level by e-MF-GAC-RO process was better than UF-RO and equivalent to the UF-RO-RO process, suggesting the process could be possible to be an alternative for UF-RO-RO process for water reuse. Secondly, the organic content in the ROC was significantly reduced compared with the UF-RO process, which may reduce the difficulties in ROC treatment. Several studies have reported that advanced oxidation process (e.g., electrochemical process) can also be used for ROC treatment [37-39]. As a result, the application of electrochemical process as RO feed pretreatment could also save the steps for the ROC treatment using advanced oxidation, where the cost for the whole water reuse treatment system could be significantly reduced. Thirdly, due to the e-MF-GAC is a chemical free process, the cost for frequent chemical addition could be lowered. The production of RCSs by electrochemical process could enhance the bacterial inactivation efficiency, which could reduce the risk of membrane biofouling [40].

4. Conclusions

Results from this study demonstrate the potential of a new hybrid e-MF-GAC system for pretreating reclaimed wastewater to reduce RO fouling. Compare to UF pretreatment, e-MF-GAC pretreatment resulted in significantly less RO fouling, reflected by lower flux decline. The superior fouling mitigation by e-MF-GAC pretreatment was mainly due to the effective removal of inorganic/organic foulants and small organic molecules (which could not be rejected by UF) by the e-MF process. The GAC could eliminate the electrogenerated RCSs, which could avoid the destruction of the membrane *via* the contact of RCS. Systematic feed water and foulant composition analysis suggested that organic foulants on the membrane surface were mainly protein-like compounds. The deposition of these organic foulants on the membrane surface was much lower after e-MF-GAC compared to UF pretreatment. In addition, the organic content in the permeate and RO concentrate was lower after e-MF-GAC-RO pretreatment than that after UF pretreatment. This study proposed the e-MF-GAC process could be a promising alternative to conventional UF pretreatment for mitigating RO membrane fouling.

Acknowledgment

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