Analysis of membrane fouling by proteins during nanofiltration of chitin alkali wastewater

Juan Li, Liming Zhao, Yaosong Wang, Chaoqin Chen, Jiachun Zhou, Yongjun Qiu and Hailong Du

ABSTRACT

The membrane fouling mechanism used during the nanofiltration (NF) of chitin alkali effluent was investigated. Tests were carried out in three large-scale chitin-processing plants with three kinds of wastewater. An alkali resistant NF membrane with molecular weight cut-off of 250 Da was employed. The reflection coefficient ($\sigma$) and diffusion coefficient ($P_s$) of total proteins were deduced, assuming that the proteins were single entities in the feed. Viscosity and osmosis pressure were measured to evaluate their influences on the permeate flux. Furthermore, the fraction of the protein fouling was extracted and qualitatively analyzed by mass spectrometry. Results showed that the NF permeate flux of alkali wastewater with the highest protein concentration (4.00%) was the lowest, and that $\sigma$ and penetration $P_s$ decreased with protein content growth. Over 60% of the peptides in the permeate were hydrophobic, whereas 70% of the peptides in the adsorption cake were hydrophilic. Irreversible resistance was the predominant resistance during NF processing, and the fouling behaviour of hydrophilic fractions was dominant.

Key words | chitin alkali effluent, hydrophobic, protein fouling, nanofiltration

NOMENCLATURE

- $A_m$: effective membrane area, $m^2$
- $C_F$: crude protein concentration in the feed, Kg/Kg
- $C_P$: crude protein concentration in the permeate, Kg/Kg
- $J_{P\cdot w}$: pure water permeate fluxes measured with the fouling nanofiltration membrane (NFM) after the equipment is flushed with deionized (DI) water up to pH 7.0, L m$^{-2}$ h$^{-1}$
- $J_P$: permeate flux, L m$^{-2}$ h$^{-1}$
- $J_{P\cdot v}$: pure water permeate fluxes measured with the virgin NFM, L m$^{-2}$ h$^{-1}$
- $P_{in}$: pressures procured at the inlet of the membrane, bar
- $P_{out}$: pressures procured at the outlet of the membrane, bar
- $P_s$: penetration coefficient of the solute, L m$^{-2}$ h$^{-1}$
- $R$: rejection of protein hydrolysates, dimensionless
- $R_m$: contaminative membrane resistance, m$^{-1}$
- $R_f$: membrane fouling resistance, m$^{-1}$
- $R_{irr}$: irreversible fouling resistance, m$^{-1}$
- $R_m$: membrane inherent resistance, m$^{-1}$
- $R_r$: reversible fouling resistance, m$^{-1}$
- $\Delta t$: time of the flow, h
- $\Delta \Pi$: osmotic pressure difference between both sides of membrane, bar
- $\eta_w$: dynamic viscosities of DI water, bar $\cdot$ h
- $\sigma$: rejection coefficient of the membrane towards a solute, dimensionless

Greek letters

- $\sigma$: rejection coefficient of the membrane towards a solute, dimensionless

Subscripts

- $F$: feed
- $f$: fouling
- $in$: inlet

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INTRODUCTION

Nanofiltration (NF) is an effective and reliable method for the combined removal of a broad range of pollutants in surface water and effluent discharged from the food, industry and dye industries. However, one of the main obstacles to NF technology application is membrane fouling. Fouling in general causes deterioration in permeate quality and quantity, i.e. the ratio of permeate to feed stream, to values of about 80% in the drinking water industry (Nederlof et al. 2005), and eventually membrane replacement is unavoidable (Listiarini et al. 2009). In normal operation, fouling manifests itself as flux decline and decreased transmission over time, resulting from reversible accumulation of solutes at the membrane surface, more commonly known as ‘concentration polarization (CP)’, progressing to irreversible adsorption and cake build-up.

For deproteination processing in chitin production, approximately 4% (w/w) of NaOH is used at about 10–15 times concentration of shrimp discards (w/v). The alkali wastewater discharged from chitin processing is abundant in protein hydrolysates which can be separated and concentrated selectively by an alkali-tolerant nanofiltration membrane (NFM) (Tsuru et al. 1994; Gésan-Guiziou et al. 2007; Zhao & Xia 2009). The recovery of NaOH and protein hydrolytes could be essentially significant from both an ecological and economic point of view. However, the membrane fouling by proteins and their hydrolysates during the NF of chitin alkali effluents is far from certain, which plays an important role in the application of NF.

As the feed is abundant in proteins, especially in the case of chitin alkali wastewater, the principal membrane fouling is usually attributed to interaction between proteins and the membrane. Characterization of protein-fouling membranes is crucial to understanding the fouling mechanisms, for the optimization of fouling control and for the cleaning method. Like other types of solutes, fouling by proteins and their hydrolysates has traditionally been characterized via the monitoring of flux decline and observation of rejection changes. Some techniques, such as scanning electron microscopy and energy dispersive X-ray spectroscopy, have particularly highlighted the change in foulant morphology from cake to aggregate formation as a function of flux and membrane morphology. Improvement in fixation technique, staining and coating have reduced artifacts and even removed the need for a vacuum with the advent of the environmental scanning electron microscope (Baumgarten 1990). However, internal deposition with pore blocking at low foulant levels remains difficult to detect.

This study focused on the NF process characteristics of three kinds of chitin alkali effluents made up of portunid, Chionoecetes bairdi and Eriocheir sinensis carapaces, respectively, in three typical large-scale chitin-processing plants. Ultrafiltration as a pretreatment of the effluent was operated by a stainless steel membrane prior to NF, and detailed analysis of proteins fouling on the membrane during NF was conducted in this study.

MATERIALS AND METHODS

Materials and chemicals

The alkali wastewaters coming from different raw materials, i.e. Chionoecetes bairdi chitin (CBCAW), portunid chitin (PCAW) and Eriocheir sinensis chitin (ESCAW), discharged from chitin-processing, were supplied by Qingdao Yunzhou Biotech Co. Ltd (Qingdao, China), Jiangsu Shuanglin Biotech Co. Ltd (Nantong, China) and Rixing Biotech Co. Ltd (Yangzhou, China), respectively.

Concentrated sulfuric acid, boracic acid, cupric sulfate, potassium sulfate, sodium hydroxide, hydrochloric acid, ethylene diamine tetraacetic acid (EDTA) and barium hydroxide were purchased from China National Medicine Co. Ltd (Shanghai, China). Trifluoroacetic acid (TFA) and alpha-
cyano-4-hydroxycin-namic acid (CHCA) were obtained from Sigma Chemical Co. (St Louis, MO, USA). All reagents were of analytical grade.

Membrane modules

Stainless steel microfiltration (SSM) in a tube configuration was supplied by Hydrochem Ltd (Hyflux, Singapore). The alkali-tolerant NFM in spiral-wound configuration was purchased from Koch Co. (USA). The pilot setup was supplied by Shanghai Qiyu Biotech Ltd. Specifications of each module are summarized in Table 1.

Analysis of effluent

For the identical alkali effluents, the main components were analyzed in our previous work, and the total crude proteins are the primary component in the alkali effluent (Zhao et al. 2013). To explore the influence of the viscosity and osmosis pressure of the alkali effluent on the decline of permeate flux, the two parameters were measured. The viscosity of the effluent was measured at 40 °C (Butylina et al. 2006) and the osmotic pressure of the effluent was determined with a freezing point osmometer (Vilker et al. 1981).

Experimental protocol for NF

NF full circulation of three effluents and Matlab analog

Prior to the NF of the alkali effluents, the ultrafiltration of the effluents by SSM was carried out to remove insoluble substances. The operation of the SSM module was fixed at 80 ± 1 °C and a transmembrane pressure (TMP) of 3.1 bar (Zhao & Xia 2009). The permeate from the SSM-P module was pumped into the feed tank of the NF set-up and the retentate was recycled back to the feed tank of the SSM set-up. Upon the 30 L of SSM-P cooling down to 40 ± 1 °C, the NF was run at full-circulation mode at different TMP. After each TMP up to stabilization, before setting another pressure,

<table>
<thead>
<tr>
<th>Module</th>
<th>SSM(^a) module (L-400)</th>
<th>NF(^b) module (MPS-34 2540 A2X)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Membrane area (m(^2))</td>
<td>0.35</td>
<td>1.6</td>
</tr>
<tr>
<td>MWCO(^c) (g/mol)</td>
<td>50,000</td>
<td>200 (initial)</td>
</tr>
<tr>
<td>Module length (m)</td>
<td>1.50</td>
<td>1.02</td>
</tr>
<tr>
<td>Equipment version</td>
<td>L-400</td>
<td>M104-3</td>
</tr>
<tr>
<td>Membrane material</td>
<td>316 L Stainless + TiO(_2)</td>
<td>Proprietary composite NFM(^d)</td>
</tr>
<tr>
<td>Tube material</td>
<td>304 Stainless steel</td>
<td>304 Stainless steel</td>
</tr>
<tr>
<td>(P_{\text{max}}) (bar)</td>
<td>60</td>
<td>35</td>
</tr>
<tr>
<td>(T_{\text{max}}) (°C)</td>
<td>177</td>
<td>50</td>
</tr>
<tr>
<td>Construction</td>
<td>Tubular wound</td>
<td>Spiral wound</td>
</tr>
<tr>
<td>Nominal solute rejections (%)</td>
<td>— (^e)</td>
<td>95 Glucose/35 NaCl</td>
</tr>
<tr>
<td>Feed spacer (mm)</td>
<td>— (^e)</td>
<td>0.8</td>
</tr>
<tr>
<td>Allowable pH-continuous operation</td>
<td>2–14(^f)</td>
<td>1–14(^f)</td>
</tr>
<tr>
<td>Allowable pH-clean-in-place (CIP)</td>
<td>2–14(^f)</td>
<td>1–14(^f)</td>
</tr>
</tbody>
</table>

\(^a\)SSM refers to stainless steel microfiltration.

\(^b\)NF refers to nanofiltration.

\(^c\)MWCO refers to molecular weight cut-off.

\(^d\)NFM is made of chlorinated polyvinyl chloride.

\(^e\)‘‘-’’ represents permeated.

\(^f\)Avoid corrosive acid when using a stainless steel permeate tube.
permeate flux was essentially measured according to Equation (1):

\[ J_v = \frac{V_p}{A_m \cdot \Delta t} \]  

(1)

where \( J_v \) is permeate flux, \( V_p \) is permeate volume during the measured time, \( A_m \) is effect membrane area, and \( \Delta t \) is time of the flow. The sample was taken for calculating total rejection of crude proteins on the basis of Equation (2):

\[ R = 1 - \frac{C_p}{C_F} \]  

(2)

where \( R \) is rejection of the protein hydrolysates, and \( C_F \) and \( C_p \) are crude proteins concentrations in the feed and in the permeate, respectively.

Based on the Spiegler–Kedem (S–K) formula (Equation (3)), the relationship between permeates fluxes and rejections of crude proteins were simulated by Matlab, which was beneficial for deducing the reflection coefficient (\( \sigma \)) and diffusion coefficient (\( P_s \)) of crude proteins according to Equation (3):

\[ R = 1 - (1 - \sigma) / (1 - \delta \cdot \exp (1 - J_v \cdot (1 - \sigma) / P_s)) \]  

(3)

where \( R \) is real rejections, non-dimensional, \( J_v \) is permeate flux, \( \sigma \) is the rejection coefficient of the membrane towards a particular solute, and \( P_s \) is the penetration coefficient of the solute.

Under normal conditions, the S-K formula is applied to analog the NF characteristic parameters of the pure materials. However, as the total crude proteins and their hydrolysates are the main components in the effluents, it is feasible to assume that the crude proteins are a single component during the study to avoid complicated calculation.

**NF concentration of effluent**

NF was run at the maximum TMP (usually 35 bar below) that the NF equipment and NFM could withstand. Specifically, the SSM-P was continuously pumped into the feed tank of the NF set-up to maintain constant volume, preventing the density of the feed from instant growing. The back-flow velocity was set at 2.7 m/s (Gésan-Guiziou et al. 2007) to force the fluid surrounding the membrane surface to flow in turbulence, which could resist the tendency to CP and membrane fouling. The NF retentate returned to the NF feed tank while the NF permeate (NF-P) was collected in containers. The permeate fluxes were measured in every 2 L of permeate and calculated according to Equation (1). Samples of permeate and retentate were taken every hour for analysis. When the flux declined to approximately 5.0 L/(m² h) (LMH), the NF of the effluent was terminated.

**Loss ratio of DI water permeate flux**

Prior to measuring the NF concentration of each batch effluent, DI water permeate flux was measured with the virgin NF membrane (NFM). After finishing the NF concentration of each effluent, the NF module was flushed with DI water until the pH of feedback water was 7, which ensured that the effluent in the dead volume was completely removed from the NF system, and then DI water permeate fluxes were measured with the fouled NFM relevant to CBCAW, PCAW and ESCAW, respectively. The loss ratio of the DI water permeate flux was calculated in accordance with Equation (4):

\[ L_{\text{flux}} = \left(1 - \frac{J_{v_{w}}}{J_{v_{w}}} \right) \times 100\% \]  

(4)

where \( L_{\text{flux}} \) is loss of permeate flux, \( J_{v_{w}} \) is permeate flux of DI water measured with the virgin membrane, and \( J_{v_{w}} \) is permeate flux of DI water measured with the fouled membrane.

**Relevant resistance deduced**

The pure water flux of the virgin NF membrane was measured (at 30 °C, 17 bar) prior to the NF-concentration of the effluent, and that of the foul membrane was measured when the membrane was flushed to pH 7 with the DI water after the NF concentration of the wastewater. The procedure as stated above aimed to determine the relevant membrane resistances. The membrane inherent resistance could be calculated by Equations (5) and (6). Referring to Equations (7) and (8), the irreversible membrane fouling resistance (\( R_{irr} \)) could be deduced. Afterwards, the total membrane fouling resistance (\( R_{f} \)) could be deduced from Equation (9). Finally, the reversible membrane fouling resistance (\( R_{r} \)) could be acquired according to Equation (10).

\[ \text{TMP} = \frac{P_{\text{in}} + P_{\text{out}}}{2} - P_{p} \]  

(5)

where \( \text{TMP} \) is transmembrane pressure, \( P_{p} \) is pressure obtained after the transmitted membrane and usually
omitted, $P_{in}$ and $P_{out}$ are pressures procured at the inlet and at the outlet of the membrane, respectively.

$$J_{v,w} = \frac{\text{TMP}}{\eta_w \cdot R_m}$$ (6)

$$J_{v,0w} = \frac{\text{TMP}}{\eta_w \cdot R_{0m}}$$ (7)

$$R_{0m} = R_m + R_{irr}$$ (8)

$$J_v = \frac{dV_p}{Am \cdot dt} = \frac{\text{TMP} - \sigma \cdot \Delta \Pi}{\eta_s \cdot (R_m + R_f)}$$ (9)

$$R_f = R_r + R_{irr}$$ (10)

where $J_{v,w}$ and $J_{v,0w}$ are the pure water permeate fluxes measured with the virgin NF membrane with the fouling NF membrane after the equipment was flushed with DI water up to pH 7, respectively; $\eta_w$ and $\eta_s$ are dynamic viscosities of DI water and permeate solution, respectively; $R_m$, $R'_m$, $R_f$, $R_{irr}$, and $R_r$ are membrane inherent resistance, contaminative membrane resistance, membrane fouling resistance, irreversible fouling resistance and reversible fouling resistance, respectively; $\sigma$ is the rejection coefficient of the membrane towards a particular solute, and $\Delta \Pi$ is the osmotic pressure difference across the membrane.

**Fraction of protein-hydrolysates adsorbing NFM**

The NF system was then cleaned according to the following procedures specified by the manufacture and flushed with an adequate amount of DI water between each step: (1) full recirculation cycle with 1.5% (w/v) NaOH consisting of 0.05% (w/w) EDTA at TMP of 5 bar and 50°C for 30 min; (2) full recirculation cycle with 0.5% (v/v) HNO$_3$ at TMP of 5 bar and 50°C for 40 min; and (3) full recirculation cycle with 1.5% (w/v) NaOH consisting of 0.05% (w/w) EDTA at TMP of 5 bar and 50°C for 30 min. Finally, to extract the fraction of protein-hydrolysates adsorbed on the NFM, the alkali lotion procured from the two alkali flushing procedures was merged into the acid lotion obtained from the acid flushing procedure.

**Characterization of protein-hydrolysates adsorbed on the NFM**

**Sample preparation**

Because of the fraction of protein-hydrolysates adsorbed on the NFM containing inorganic compounds, it was essential to desalt the sample by a Strata$^\text{™}$ solid phase extraction column (Phenomenex, Torrance, CA, USA) prior to matrix-assisted laser desorption/ionization time-of-flight/time-of-flight tandem mass spectrometry (MALDI-TOF/TOF-MS/MS) analysis to ensure high accuracy. CHCA as the matrix was used at a concentration of 10 mg/mL and resuspended in a 1:1 mixture (v/v) of acetonitrile and 0.1% TFA/water. Finally, the resulting mixture (1 µL) was deposited on the MALDI-TOF sample holder.

**Peptides identified by MALDI-TOF/TOF-MS/MS**

Mass spectrometry followed the main procedure, as described by Cucu et al. (2012). A 4800 plus MALDI-TOF/TOF MS Analyzer (AB Sciex, Foster City, USA) equipped with an Nd:YAG laser emitting at 355 nm was employed to perform data acquisition in a positive-ion mode reflectron mode for peptide detection. The acceleration voltage was set at 20 kV and the extraction delay time used was 450 ns in reflector MS mode. Using calibration peptides, the amount of the peptides was determined. MS and MS/MS data were processed using a 4000 Series Explorer and further manually interpreted using DATA Explorer 4.8 (AB Sciex, USA) software. In MS mode, 400 shots were accumulated and in MS/MS mode 1,000 shots were accumulated for the peptides with high intensity. An amino acid sequence was performed on a DeNovo Explorer$^\text{™}$ (AB Sciex, USA). The amino acid sequence was confirmed by manual validation.

**RESULTS AND DISCUSSION**

**Physical characteristic analysis of the alkali effluent**

The contents of the different compounds in the three alkali wastewaters and their pH and viscosities are listed in Table 2, implying that crude proteins were the predominant
components in the three chitin alkali effluents, which was similar to our previous study (Zhao et al. 2015). It was also found that both the viscosity and osmosis pressure of the chitin alkali effluents were proportional to crude protein concentration (Figure 1). Within protein concentrations ranging from 0.7 to 4.2% (W/W), the viscosities of the stainless steel microfiltration permeate (SSM-P) ranged from 680 to 860 bar h, and the osmosis pressure differences ($\Delta \Pi$) between NF feed (NF-F) and NF permeate (NF-P) were in the range of 4 to 18 bar. Given that the total protein concentration (4.2%) of ESCAW was much bigger than those of CBCAW (1.57%) and PCAW (0.7%), the NF net drive forces of the three chitin alkali effluents decreased in the order of PCAW, CBCAW, ESCAW, which complied with the K-K formula (Jarzyn'ska & Pietruszka 2011).

**Characteristic parameters of NF of the effluent**

As seen from Figure 2(a), rejections of crude proteins are proportional to the permeate fluxes of chitin alkali effluent, complying with the S-K formula despite the chitin alkali wastewater being a complicated mixture. Furthermore, permeate fluxes relevant to the NF of ESCAW are substantially lower than those related to the NF of CBCAW, which are much lower than those relevant to the NF of PCAW chitin alkali effluent (Figure 1), which is mainly because the NF net drive forces of the three chitin alkali effluents decreased in the order of PCAW, CBCAW and ESCAW (as presented in Figure 1).

Otherwise, both $\sigma$ and $P_s$ decrease with the crude protein concentrations, as implied in Figure 2(b). Theoretically, $\sigma$ is approximately equal to the rejection of total proteins when permeate fluxes are infinitely great, and the rejections of total proteins and their concentrations had an inverse relationship (Catarino & Minhalma 2008; Curcio & Drioli 2009; Feng et al. 2009). Therefore, it was reasonable that $\sigma$ of total proteins was an inverse ratio to their concentration. On the basis of Equation (5), for the identical solution, $P_s$ of the solute is inversely proportional to the density and viscosity of the solution, both of which

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**Table 2 | Component analysis of three alkali effluents**

<table>
<thead>
<tr>
<th>Composition</th>
<th>PCAW</th>
<th>CBCAW</th>
<th>ESCAW</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Content in the crude (%)</strong></td>
<td><strong>Content in the SSM-P (%)</strong></td>
<td><strong>Content in the crude (%)</strong></td>
<td><strong>Content in the SSM-P (%)</strong></td>
</tr>
<tr>
<td>Dry matter</td>
<td>6.52</td>
<td>5.6</td>
<td>3.47</td>
</tr>
<tr>
<td>Ash</td>
<td>4.44</td>
<td>3.97</td>
<td>2.42</td>
</tr>
<tr>
<td>Protein</td>
<td>1.81</td>
<td>1.57</td>
<td>0.70</td>
</tr>
<tr>
<td>Lipid</td>
<td>0.11</td>
<td>0.03</td>
<td>0.28</td>
</tr>
<tr>
<td>Saccharide</td>
<td>0.09</td>
<td>0.02</td>
<td>0.12</td>
</tr>
<tr>
<td>NaOH</td>
<td>2.83</td>
<td>2.19</td>
<td>1.36</td>
</tr>
<tr>
<td>pH</td>
<td>14</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>Viscosity($\mu$Pa S)</td>
<td>ND$^a$</td>
<td>680</td>
<td>ND$^a$</td>
</tr>
</tbody>
</table>

$^a$ND (not detected) because of suspended solids.

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![Figure 1](https://iwa.silverchair.com/jwrd/article-pdf/4/4/253/378147/253.pdf)

**Figure 1** | Viscosity of the permeate and osmosis pressure difference between the permeate and the feed versus the concentration of crude protein in the alkali wastewater.
increase with solute concentration (Jarzyńska & Pietruszka 2011). As a consequence, $P_s$ of total proteins decreased with their content’s growth.

$$P_s = P_{sw} \cdot \left( \frac{n_{w} \rho_{w}}{n \rho} \right)$$ (11)

**Permeate flux and resistance**

Figure 3(a) shows that there is a steady decline in the permeate fluxes of the three chitin alkali wastewaters over permeate time growing. At the first stage of NF, permeate flux of the NF of PCAW is higher than that of CBCAW, which is higher than that of the NF of ESCAW, because the total protein concentration in PCAW is much lower than that in ESCAW followed by that in CBCAW. Both osmosis pressure and viscosity of the wastewater are proportional to the crude protein contents in the alkali effluents (Figure 1). As known, osmosis pressure usually lowers the net driven force and permeate flux is reverse proportional to the viscosity of the permeate. Therefore, it is reasonable that the difference among permeate fluxes is relevant to the three effluents. As illustrated in Figure 3(b), the resistance generated from the filtration cake ($R_c$) to the total resistance ($R_f$) ratios ($R_c/R_f$) increases over permeate time during NF. It is also implied that the $R_c/R_f$ relevant to the NF of CBCAW is the smallest one of the three ratios. Additionally, the loss of DI water permeate flux for CBCAW was the highest among the three alkali effluents (Figure 4). Therefore, it could be concluded that the ratio of irreversible resistance in the NF of CBCAW to the total resistance was much larger than those in the NF of PCAW and ESCAW.

Further, the irreversible adsorption and pore blocking also play an important role in the membrane resistance, and the results obtained in a previous work show that the total $R_{irr}$ formed by pore constriction to the total foul resistance $R_f$ was up to 14.06% (Zhao et al. 2013).
Analysis of protein fouling

A conclusion was drawn that the irreversible resistance produced from NF of CBCAW is much larger than those generated by the other two effluents. Hence, a mass spectrum (MS) analysis of the fraction of protein-hydrolysates adsorbed on the NFM was introduced to investigate the fouling mechanism underlying NF of CBCAW.

Tables 2–4 present the amino acid sequences, molecular weight (MW) and isoelectric points (pI) of the representative peptides in the feed, permeate and the adsorption of CBCAW. It could be concluded that the rejection of some peptides (KNSTP, FIPTSMHG, PEHAPVGID, FPLEYKTKVA, EDLYSTPKLEEL) in the NF-adsorption was mainly because of the higher MW than those in NF-P (Tables 4 and 5). In terms of the peptides’ GRAVY (grand average of hydropathy), 60% of the peptides in the permeate...
have a GRAVY greater than 0, whereas 70% of the peptides in the foulant cake have a GRAVY less than 0. In other words, most peptides in the permeate are hydrophobic while most peptides in the foulant are hydrophilic. Therefore, it could be indicated that the fouling behaviour of the hydrophilic fractions was dominant.

CONCLUSION

The NF membrane fouling mechanism of chitin processing alkali effluents was studied. Results indicate that σ and $P_i$ were reversely proportional to protein concentrations, and the permeate flux of a high protein concentration feed was the lowest. In comparison with permeate flux loss and $R_c/R_f$, it could be speculated that severe protein fouling on the membrane surface occurred during NF of CBCAW. Therefore, complete identification of the peptides was realized by MALDI-TOF-MS. Most of the peptides in the permeate were hydrophobic whereas most peptides in the foulant were hydrophilic, indicating that the fouling behaviour of hydrophilic fractions was dominant.

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