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Preparation of *N*,*O*-carboxymethyl chitosan/cellulose acetate blend nanofiltration membrane and testing its performance in treating industrial wastewater

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ABSTRACT

An *N*,*O* carboxymethyl chitosan (NOCC)/cellulose acetate (CA) blend nanofiltration (NF) membrane was prepared in acetone solvent. From our previous work on miscibility experiments, it was proposed to take 0.4 wt% of NOCC in NOCC/CA blend membrane preparation. The newly prepared blend membrane was characterized with the help of scanning electron microscopy (SEM), thermal gravimetric analysis (TGA) and mechanical properties of membrane. Molecular weight cut-off (MWCO) of newly prepared blend membrane was found to be 710 Da, which was in the range of nanofiltration. The performance of the prepared NF membrane had been tested to separate chromium and copper from a common effluent treatment plant (CETP) wastewater at different operating conditions. The highest rejection for chromium and copper were observed to be 83.40 and 72.60%, respectively, at 1 MPa applied pressure and 16 L/min (LPM) feed flow rate.

1. Introduction

Industrial effluents from various industries are treated in a common effluent treatment plant (CETP). CETP is the concept of treating effluents by means of a collective effort mainly for a cluster of small scale industrial units. The main objective of CETP is to reduce the treatment cost for individual units while protecting the environment [1]. Heavy metals are toxic pollutants that have to be removed from wastewater streams due to their harmful effects on human physiology and ecological systems even at very low concentrations [2]. Conventional techniques such as adsorption and chemical precipitation have been used for the removal of metal ions from aqueous effluents [3–5], however, these techniques are either incapable of reducing the concentration to the required levels or expensive. The use of membrane separation processes in the treatment of wastewater and groundwater containing toxic metal ions are attractive, since they offer separation and/or concentration of metals or valuable chemicals without change of state and without the use of chemicals or thermal energy [6,7]. Membrane separation is a promising technology from the energy-saving point of view for the selective separation of heavy metal ions [8].

Nanofiltration (NF), a pressure-driven membrane process, has practical applications in water treatment and chemical industry [9]. The molecular weight cut-off (MWCO) of NF ranges from 200 to 2000 Da, which belongs to the domain between ultrafiltration (UF) and reverse osmosis (RO) and can be operated at relatively low operating pressures of 0.3–1.5 MPa [10,11]. NF is based on steric hindrance (sieving) effect and electrostatic interaction (Donnan) effect [11–14], hence, solute rejection in NF membrane involves mainly electrostatic interaction of membrane and solutes on the membrane surface and size exclusion [15]. When compared with RO, NF process has the advantage of low operating pressures and high rejection of multivalent ions.

Cellulose acetate (CA) is one of the first membrane polymers that has been used for aqueous based separation and used as both RO and UF membrane material [16]. CA is a commonly used membrane material due to its natural and renewable characteristics as well as the superior film-forming ability. CA is used as the polymer matrix in fabricating membranes and the choice of CA as the polymer matrix is due to its long-known good mechanical strength in fabricating membranes. But CA membranes have one disadvantage, which is the lack of reactive functional groups on the polymer backbones to enhance the separation efficiency of the membranes.

To obtain an ideal separation performance, i.e. higher selectivity and higher flux, CA membrane modifications are often required. Among the various modification methods, polymer blending is one of the effective methods for providing new, desirable polymeric materials for practical applications. The blended materials display a broad range of physical properties [17] and the blending is a favorable method for its versatility and simplicity [18]. A favorable synergestic effect of the two polymers can be achieved if the polymers are properly matched. By using blending with appropriate polymers the performance of CA membranes can be

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improved. To modified CA membrane, many researchers have worked on the blend of CA and chitosan (CS) [19–21]. CS has been chosen as a blend polymer to increase the hydrophilicity of the CA membrane by introducing reactive sites (amino and hydroxyl groups) in the membrane material. CS has some drawbacks, such as it is mainly soluble in aqueous medium in the presence of a small amount of acid and its mechanical properties were also not that good. Therefore, there was a need to modify CA properties where, *N*,*O* carboxymethyl chitosan (NOCC) comes into picture. NOCC is a water-soluble derivative of chitosan, and is the product of the chitosan carboxylation having carboxymethyl substituents on some or both the amino and primary hydroxyl sites of the glucosamine units of the chitosan structure [22]. NOCC is hydrophilic and at the same time it is a potential candidate for membrane material and has been applied to microfiltration [23] and pervaporation [24]. However, to our knowledge there was no literature available about the blend membranes of CA and NOCC.

In the present study, an attempt had been made to prepare a 0.4 wt% modified blend membrane by blending NOCC and CA, which combines the properties of both the polymers in membrane formation, such as CA acts as a matrix polymer and NOCC acts as a functional polymer, to provide the membrane with coupling or reactive sites for affinity-based separations. Resulting membrane was characterized with the help of scanning electron microscopy (SEM), thermal gravimetric analysis (TGA), filtration of uncharged solute at low concentration, i.e. by molecular weight cut-off (MWCO) method and mechanical strength by Universal mechanical tester. Then this membrane was used to treat CETP wastewater at different operating conditions, i.e. applied pressure, feed flow rate, feed pH, feed temperature and corresponding solute observed rejection (R_o) and permeate volume flux (J_v) were measured for both the constituents (chromium and copper) of CETP wastewater, to evaluate its performance.

2. Materials and methods

2.1. Materials used

The chemicals used were chitosan flakes (85% degree of acetylation, mean molecular mass is 125,000) obtained from M/S. Marine Chemicals (Cochin, Kerala, India), cellulose acetate (National Chemicals, Vadodara, India), hydrochloric acid (Merck-India) and sodium hydroxide (Thomas Baker, India). All the other laboratory grade chemicals used were procured from Merck, India. In all the experiments and for washing purpose, ultra-pure water (pH 5.9 ± 0.2 and conductivity 1.0 μS/cm) was used (MilliQ, Millipore, India). Microprocessor based pH system (model 1012E, Swastik, India) was used to find pH of the solutions. NOCC was prepared as per the method reported in literature [22,25].

The effluent used in this work was collected from the equalization tank of a Common Effluent Treatment Plant (CETP) from nearby industrial area. In all the experiments, except for the NF concentration experiments, the same batch of wastewater was used and the composition of this batch of wastewater can be seen from Table 1. From Table 1 it can be easily seen that the CETP wastewater has a higher chromium and copper content than other heavy metals. Therefore, the removal of chromium and copper from CETP wastewater with NF process was chosen.

The experiments were performed on a Perma®-pilot scale membrane system (Permionics, Vadodara, India). The chromium and copper concentrations were measured by UV–vis Spectrophotometer (SL-159, M/S. ELICO, India).

Table 1
Composition of the CETP wastewater.

Sr. no.	Parameters	Unit	Result
1	Colour	–	Black
2	pH	–	7.46
3	Electrical conductivity (EC)	mS	2.28
4	Total dissolved solids (TDS)	mg/L	1472
5	Total suspended solids	mg/L	110
6	COD	mg/L	436
7	BOD	mg/L	175
8	Chloride as Cl^-	mg/L	119.9
9	Sulfate as SO_4^{2-}	mg/L	73.85
10	Iron (Fe)	mg/L	19.8
11	Zinc (Zn)	mg/L	10.1
12	Mercury (Hg)	mg/L	7.43
13	Copper (Cu)	mg/L	110
14	Chromium (Cr)	mg/L	210
15	Lead (Pb)	mg/L	BDL
16	Nickel (Ni)	mg/L	BDL
17	Sodium (Na)	mg/L	61

2.2. Preparation of blend membrane

In our previous work [26], the miscibility experiments had been carried out for different proportions of NOCC blends with CA (2/8, 4/6, 5/5, 6/4 and 8/2) to check their miscibility and the results showed that NOCC and CA were miscible at all composition range, except 2/8, according to thermodynamic parameter α. Therefore, the starting composition range 4/6 for NOCC/CA was chosen for membrane preparation. NOCC and CA polymer solution were mixed in 0.4 wt% proportion by using appropriate solvent acetone. The solution was stirred at 1000 rpm (REMI model-R 24, India) for 12 h for getting homogeneous polymer mixture. The resultant homogeneous mixture was transferred to a conical flask and kept for 24 h in a refrigerator for the removal of entrapped air bubbles. For the preparation of new blend membranes, the homogeneous polymer blend solution of NOCC and CA was caste on a glass plate using a doctor blade and allowed it for natural solvent evaporation at room temperature (25 ± 2 °C). The newly prepared blend membrane needs to be cross-linked due to the water-solubility of NOCC. In this study, glutaraldehyde (GA) was employed as the cross-linking agent. When blend membrane was cross-linked with GA, a kind of network structure will be formed by means of Schiff's base formation. Therefore, the cured membrane was covered by the aqueous glutaraldehyde solution (0.25 wt%) and the excess solution was drained by holding the membrane vertically, followed by cross-linking at 60 °C for 1 h. After cross-linking, the membrane was washed extensively with deionized water and immersed in deionized water for 24 h to remove the remaining unreacted glutaraldehyde. The prepared blend membrane was stored in air tight polyethylene bags with 0.1% sodium meta bisulfate solution and characterized this membrane within 2–3 days after preparation.

2.3. Characterization of the resulting blend membrane

2.3.1. Scanning electron microscopy

The surface and cross-section morphologies of the membrane were studied using scanning electron microscopy (ESTM TMP +EDXA, Philips, Holland). The membrane was cryogenically fractured in liquid nitrogen before using for SEM.

2.3.2. Thermal gravimetric analysis

When a separation process is to be carried out at higher temperatures, membrane stability is one of the major aspects to be noted. This may be because of the feed that itself is available at higher temperatures. For example in Arabian Gulf the routine temperature of air goes over 40 °C. Therefore, it is possi-

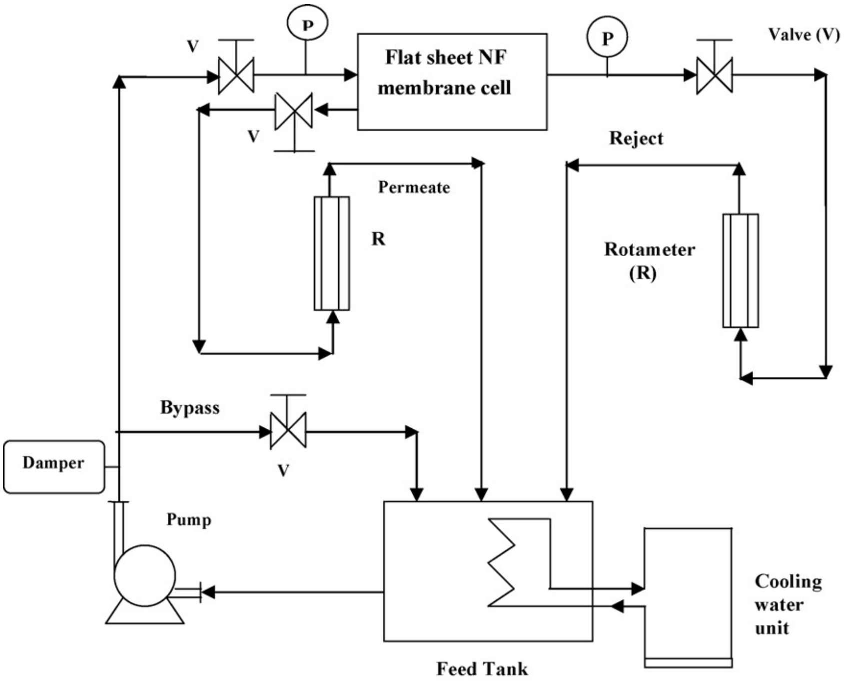

Fig. 1. Nanofiltration experimental setup.

ble to have a feed water temperature more than 40 °C. Thermal stability of the newly prepared blend membrane was examined using TGA (TGA-7, PerkinElmer, Norwalk, CT). Temperature range used was 30–500 °C, and heating rate employed at 10 °C/min. Nitrogen gas, at the rate of 20 mL/min, was utilized for flushing purpose.

2.3.3. *Molecular weight cut-off*

MWCO is an attribute of pore size of the membrane. Membrane performance is compared by its MWCO, which was usually defined as the smallest molecular weight species for which the membrane has more than 90% rejection [27]. Filtration of uncharged solutes at low concentrations is generally used to determine the MWCO of membranes. MWCO experiments were carried out using 1.0 g/L aqueous solutions of glucose, sucrose and polyethylene glycols (MW 600 and 800) at 25 °C at 1 MPa pressure. The concentrations of these neutral organic matters in feed and permeate samples were determined by total organic carbon (TOC) measurement, from which rejection can be obtained.

2.3.4. *Mechanical properties*

Tensile strength and elongation at break for prepared blend membrane was measured using Universal Testing Machine (KIPL-PC2000, Pune, India) as per procedure outlined in ASTM D-421A test method.

2.3.5. *% Water content*

Water content of the membranes was obtained after soaking membrane in water for 24 h and the membrane was weighed followed by mopping it with blotting paper. The wet membrane was placed in oven at 75 °C for 48 h and the dry weight of the membrane was determined [28]. The percent water content was calculated given by the following equation:

$$\%\text{Water content} = \frac{\text{wet sample weight} - \text{dry sample weight}}{\text{wet sample weight}} \times 100 \qquad (1)$$

2.4. *Permeation experiments*

To test the rejection properties of the new NOCC/CA blend membrane, CETP wastewater was used. As a pretreatment, 1 μm pore size filter cloth was used to remove the suspended solids from the wastewater, which removed almost all the suspended solids. After that the feed solution was passed through a spiral-wound polyamide (PA) UF membrane module (pH 2–11, thermal stability 90 °C, pure water flux 145 L/m^2 h, effective membrane area was 1 m^2). The concentration of chromium and copper in permeate of UF were 168 ppm and 74 ppm, respectively. The concentration of chromium and copper were measured according to standard methods [29]. The so-called treated end-product from UF, which was also not absolutely safe, therefore, there was a need to give more treatment. The permeate solution from the UF experiments were used as the feed solution to the NF experiments. The experiments were performed on Permionics® pilot plant (see Fig. 1) by blend membrane and the details of the experimental setup and experimentation procedure are given elsewhere [25,30]. The permeation tests were carried out using a flat sheet membrane test cell. It was assumed that the 1 mm thin passage channel in the membrane test cell and high cross-flow feed rates used in the experimentation help to control the concentration polarization to some extent. Both the retentate and permeate were recirculated to the feed tank to keep the feed concentration constant during the permeation experiments. The metal ions concentrations are measured by an UV–vis Spectrophotometer (SL-159, M/S. ELICO Limited, India) following standard methods [29].

The experiments were carried out for different feed pressures (0.4, 0.6, 0.8 and 1 MPa), feed flow rates (4, 8, 12 and 16 L/min (LPM)), feed pH (3, 4, 5, 6, 7 and 8), feed temperature (30, 35, 40, 45, 50, 55, 60, 65, 70, 75 and 80 °C) and the corresponding R_o and J_v were measured. The volumetric permeate flux of the membrane was measured for a certain period of time. The observed rejection was calculated from

$$R_o = 1 - \left(\frac{C_p}{C_f}\right) \qquad (2)$$

where C_p and C_f are the solute concentration of permeate and feed solutions, respectively. All the experimental data presented in this paper were the averages of three measurements conducted on newly prepared blend NF membrane. All the experiments were conducted at a feed solution pH of 7 ± 0.2, except the experiments related to pH variation. pH of the feed solution can be controlled by adding required amount of HCl and/or NaOH.

2.5. Pure water flux

The pure water flux (PWF) is a measure of permeability of a membrane. The permeate flux was measured at 0.4 MPa and 16 LPM. From the measured values, the PWF was determined from the below expression,

$$J_v = Q/A(\Delta t) \tag{3}$$

where J_v is the permeate water flux (L/m^2 h), Q is the quantity of water permeated (L), Δt is the sampling time (h) and A is the effective membrane area (0.015 m^2). After each set of experiments for a given operating condition, the setup was rinsed with distilled water for 30 min at 0.4 MPa to clean the system. This procedure was followed by measurement of pure water permeability (PWP) with distilled water to ensure that the initial membrane PWP was restored.

3. Results and discussion

3.1. Characterization of the resulting blend membrane

3.1.1. Scanning electron microscopy

To obtain a better performance from a membrane, the morphological structure of the membrane has to be manipulated. Fig. 2(a) shows the top surface of the newly prepared membrane. It can be seen from Fig. 2(a) that uneven membrane surface is formed and the smaller size pores are also observed. Fig. 2(b) shows the cross-sectional view of the prepared blend membrane and from Fig. 2(b), it can be clearly seen that the structure of the prepared membrane is an asymmetric type. This type of behavior/structure is reported for blend membranes in literature [20]. In asymmetric structure of blend membrane, having two different layers, the upper layer is an active layer formed from NOCC and the porous bottom layer is formed from CA, which will act as a support for the membrane [20]. But in the literature, the cross-sectional view of CA membrane alone is in symmetric structure [31]. Therefore, from the SEM analysis it is confirmed that the symmetric structure becomes asymmetric because of CA and NOCC blend.

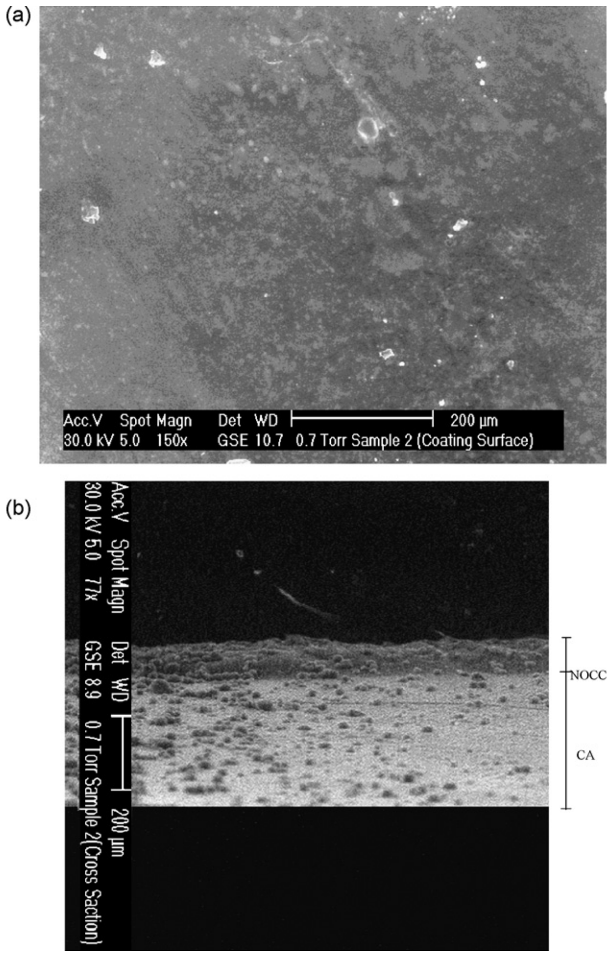

Fig. 2. Scanning electron microscopy (SEM) images of (a) top surface view of newly prepared blend membrane; (b) cross-sectional view of newly prepared blend membrane.

3.1.2. Thermal gravimetric analysis

The thermal stability of the blend membrane was measured by means of TGA. From Fig. 3 it can be seen that the thermal degradation of membrane starts at 100% mass. Accordingly, it may be clearly seen from the Fig. 3 that up to around 100 °C the membrane tested is found to be thermally stable. Beyond which, there is a gradual loss of mass of the membrane till 200 °C and then loss of mass of the membrane is sharp up to about 300 °C. Further, one may observe that at decomposition temperature of 400 °C, about 78% of membrane mass is lost. This may be due to the loss of both water and quaternary amine groups present in active layer. After 400 °C, only 22% membrane mass is remaining, i.e. incomplete decomposition of the membrane. Hence, it is suggested that beyond decomposition temperature of 400 °C, it may be possible that the membrane material may totally decompose. In the literature for CA membrane, the decomposition temperature is given as 300 °C [32] and from Fig. 3 it is confirmed that the decomposition temperature of blend membrane is 400 °C. Therefore, it can be said that if CA is blended with NOCC then the decomposition temperature is increased up to 400 °C, which is in line with other blended membranes also [32]. This type of behavior may be due to the stronger interaction between the two polymers in the blend by forming hydrogen bonds.

3.1.3. Molecular weight cut-off

As explained in Section 2.3.3, the rejection data on glucose, sucrose and polyethylene glycols (MW 600 and 800) for MWCO is shown in Fig. 4. It can be clearly seen from Fig. 4 that the MWCO

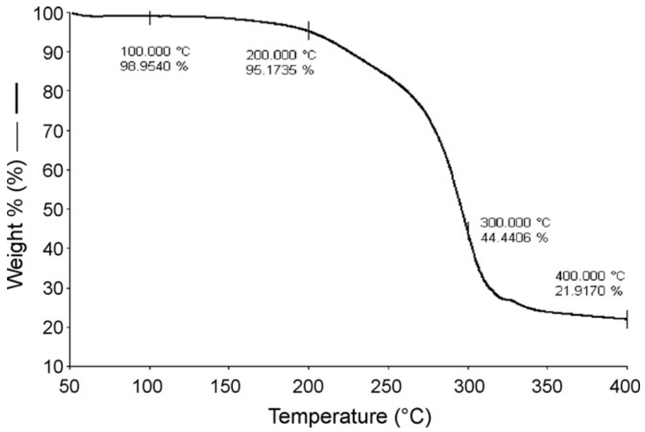

Fig. 3. Thermal gravimetric analysis of newly prepared blend membrane.

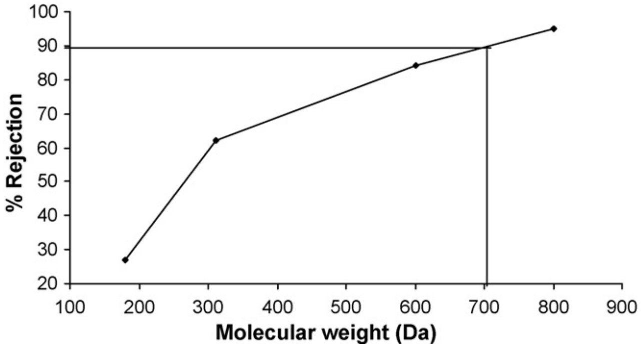

Fig. 4. Molecular weight cut-off curves for newly prepared blend membrane.

is 710 Da, which is in the range of nanofiltration [33]. Hence, the blend membrane is called NF membrane.

3.1.4. Universal mechanical tester

For blend membrane, the tensile strength was found to be 7.4 MPa and elongation at break was 23.45%, which are the typical values of nanofiltration membranes [34]. It is mentioned in the literature that tensile strength is 2.05 MPa and elongation at break is 8.84% for CA membrane [35]. Hence, it may be said that the blend membrane has good mechanical properties and can withstand the pressures used with repeated experiments, because blending of CA and NOCC resulted in a stronger interaction between the CA and NOCC molecules, thereby leading to an increase in the mechanical strength.

3.1.5. % Water content

Hydrophilicity of the membrane is directly related with % water content [36]. By using Eq. (1) the % water content was calculated. The calculated values of % water uptake of blend membrane are 79.59 for 17.5 wt% polymer solution. In literature it is given that for the same quantity of polymer mixture % water uptake is 76.59% for CA membrane alone [36]. From these two values, it can be said that for the blend membrane, water content is higher than that of CA membrane alone, i.e. hydrophilicity of the blend membrane is higher than that of CA membrane. This is because of the polymer chains detached from the NOCC surface and resulting interface voids, which gives higher void volume. These voids are converted into bigger size pores on the membrane surface. These pores are responsible for the higher water uptake. This type of behavior is also reported in literature [37]. Another reason is that the NOCC is a water-soluble polymer, which can also improve the % water uptake. After characterization of blend membrane, comparison between CA membrane alone and blend membrane is given in Table 2. From this Table 2, it is confirmed that blend membrane is superior to CA membrane alone.

3.2. Pure water flux

As per the procedure described in Section 2.5 and according to the Eq. (3), pure water permeability coefficient (L_P) for the prepared NF membrane was found to be 13.62 (L/m^2 h atm), which is a typical value of nanofiltration membranes [38,39]. This pure water flux value was considered to be a reference to evaluate cleaning procedure, concentration polarization and fouling of the membrane.

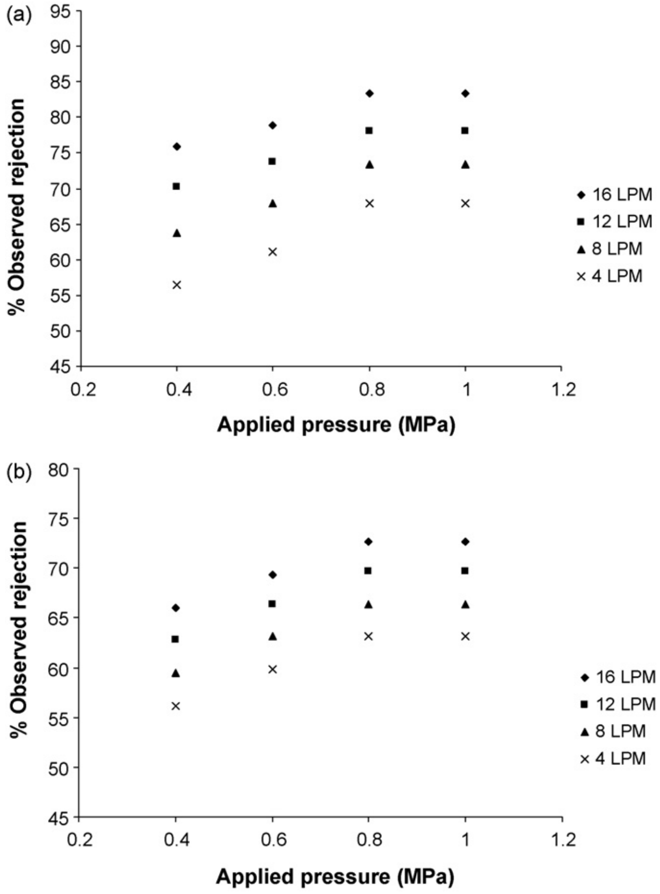

Fig. 5. Effect of applied pressure on percentage rejection of (a) chromium; (b) copper ions.

3.3. Effect of applied pressure and feed flow rate

Experiments were carried out to study the effect of applied pressure (0.4–1 MPa) on percentage solute rejection of chromium and copper ions and permeate volume flux at different feed flow rates (4–16 LPM). When we increase the pressure, the feed flow rate also increases; hence these two are controlled by respective control valves provided in the experimental setup. Fig. 5(a and b) indicates that the rejection increases with increase in feed pressure from 0.4 to 1 MPa for both the ions, which is expected in NF [39]. The highest rejection was found to be 83.40% and 72.60% for chromium and copper ions, respectively, at 1 MPa and 16 LPM feed flow rate.

Fig. 5(a and b) also indicates that the effect of feed flow rates (range of 4–16 L/min) on percentage rejection for the same applied pressures. It can be seen from Fig. 5(a and b) that increase in feed

Table 2
Comparison between CA membrane and NOCC/CA membrane.

Sr. no.	Parameters	CA membrane[a]	NOCC/CA blend membrane
1	Tensile strength	2.05 MPa	7.4 MPa
2	% Elongation at break	8.84%	23.45%
3	Decomposition temperature	300 °C	400 °C
4	SEM cross-sectional view	Symmetrical	Asymmetrical
5	% Water content	76.59%	79.59%

[a] CA membrane data taken from literature [32,33,36,37] details given in text].

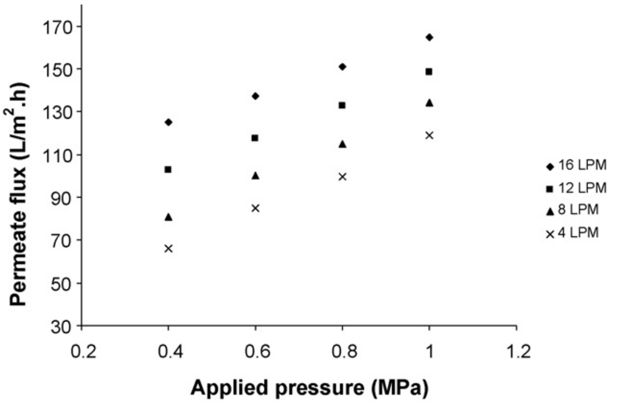

Fig. 6. Effect of applied pressure on permeate volume flux.

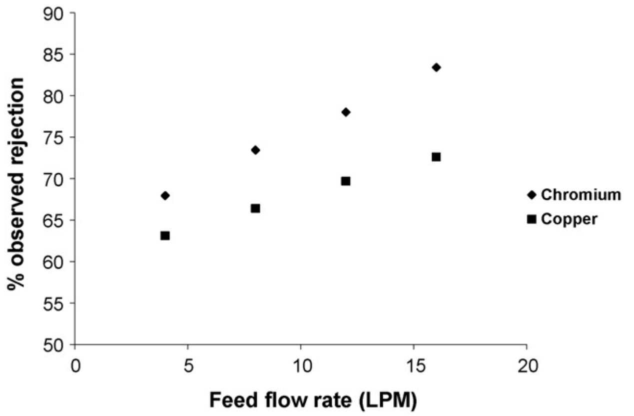

Fig. 8. Effect of feed flow rate on percentage rejection of (a) chromium; (b) copper ions at 1 MPa applied pressure.

flow rate leads to slight increase in the rejection percentage of chromium and copper ions. The main aim of increasing the feed flow rate was to increase the mass transfer coefficient, which in turn increases the solute rejection. Similar type of results can be found in literature [40,41].

Fig. 6 shows the effect of applied pressure on the permeate volume flux. The permeate volume flux increases linearly with increasing applied pressure. This may be due to that there may be negligible concentration polarization in the membrane cell. Also, permeate volume flux increases with increase in feed flow rate at the same applied pressure [40].

As shown in Fig. 7, percentage rejection of chromium ions increase slightly with increase in permeate flux for different feed flow rates. It is worthwhile mentioning that a high flux with high rejection is obtained at high feed flow rate. Similar trend is observed for copper ions too.

Fig. 8 clearly indicates that at same feed flow rate percentage rejection is high for chromium ions. This may be due to the fact that the atomic radius of chromium ion (140 pm) [42] is more than that of copper ion (128 pm).

3.4. Effect of pH on percentage rejection and permeate flux

Fig. 9 shows the effect of pH on percentage rejection of chromium and copper ions and permeate flux. It can be seen from Fig. 9 that the trends of rejection for chromium and copper ions, are different. For chromium ions, the percentage rejection increases with pH and reaches plateau from pH 7 to 8. This type of behavior explains by the fact that the hexavalent chromium is present in different ionic forms at different pH conditions. It is also observed from the literature that in the very acidic pH range hexavalent chromium normally remains in the form of chromic acid (H_2CrO_4) and as the pH increases it converts to acid chromates ($HCrO_4^-$). Further, in alkaline region, it gets transformed to chromates (CrO_4^{2-}) of different concentrations [6,43]. Fig. 9 also indicates gradual decrease in rejection of copper ions till pH 7, and then becomes nearly plateau. This may be due to the reason that free copper ions would form precipitate in neutral and alkaline solutions; therefore, it gives a constant rejection at pH 7, which is in line with the observation made in literature [44].

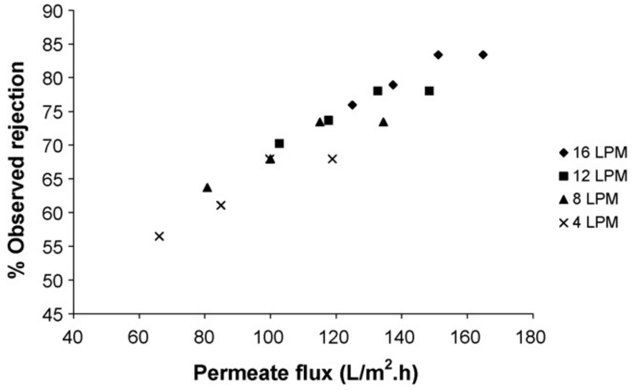

Fig. 7. Relation between observed chromium solute rejections and permeate volume flux.

Fig. 9 also indicates the effect of feed pH on the permeate volume flux. It shows that the pH variation is having more effect on permeate volume flux. The permeate volume flux reduced considerably with increase in feed solution pH. This may be because of the shrinking of the skin layer. This shrinking is presumably pH dependent due to the differences in the hydration of the ionized groups of the membrane [45].

3.5. Effect of temperature on percentage rejection and permeate flux

Fig. 10 indicates that as we increase the temperature of the feed solution the percentage rejection of both chromium and copper ions is decreased. Therefore, diffusivity of the solutes increases and transport of solutes through pores is mainly diffusive. Increase in diffusivity of solutes results in a decrease in solute rejection [46]. Fig. 10 also shows the effect of feed temperature on permeate volume flux. The trend of the plot shows that the performance of the

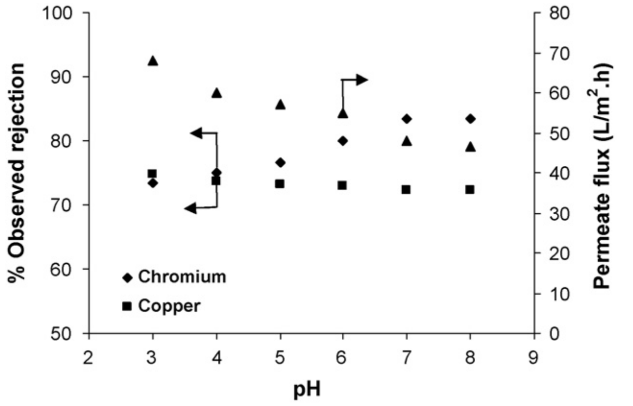

Fig. 9. Effect of pH on rejection of chromium and copper ions at 1 MPa feed pressure, 16 LPM feed flow rate and on permeate volume flux at 1 MPa feed pressure, 16 LPM feed flow rate.

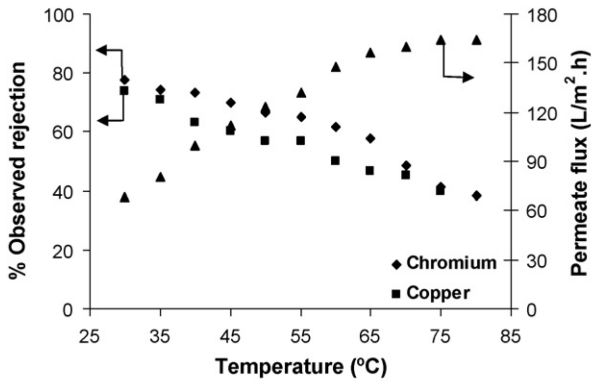

Fig. 10. Effect of temperature on rejection of chromium and copper ions at 1 MPa feed pressure, 16 LPM feed flow rate and on permeate volume flux at 1 MPa feed pressure, 16 LPM feed flow rate.

blend NF membrane is sensitive to changes in the feed temperature. There is a large gap in the permeate volume flux values when the feed temperature is increased (Fig. 10). This may be due to the changes in the physical properties of the NF membrane such as the pore size or possibly the diffusivity of solvent in the membrane. Another reason of increase in permeate volume flux is due to the decrease of viscosity of the feed solution with increase in temperature. One more reason is an increase of temperature enhances permeates flux due to increase of mass-transfer coefficient [47]. Therefore, this study is necessary to check the ability of a membrane to operate at elevated temperatures.

4. Conclusions

In this study, a NOCC/CA blend NF membrane was prepared by using blending of two polymers NOCC and CA and using acetone as a solvent. In the blend membrane, NOCC contributed to enhanced separation performance for metal ions and CA acts as a polymer matrix, which provides high mechanical strength for the membrane. The blend NF membrane was characterized by SEM, TGA, mechanical properties and MWCO. Then, the performance of the membrane in separating chromium and copper ions from a CETP wastewater was studied. It was observed from the experimental data that the rejection of chromium, copper ions and permeate volume flux increases with increase in applied pressure and feed flow rate. The maximum rejection for chromium and copper ions were observed to be 83.40% and 72.60% at 1 MPa applied pressure and 16 LPM feed flow rate, respectively. It was also observed that the feed solution pH and temperature have significant influence on permeate volume flux and solute percentage rejection.

Acknowledgement

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