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Cellulose triacetate/LUDOX-SiO₂ nanocomposite for synthesis of pervaporation desalination membranes

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Abstract

A series of cellulose triacetate/Ludox-silica nanocomposite pervaporation membranes was successfully prepared via solution casting, aiming to improve the performance of cellulose triacetate membranes for desalination. The fabricated nanocomposite membranes were characterized to study the membrane morphology, chemical composition, mechanical properties, and surface hydrophilicity. Furthermore, the desalination performance was investigated as a function of silica (SiO₂) loading (ranging from 1 to 4 wt%) and feed concentration at 30 and 60 g/L of sodium chloride (NaCl). Pervaporation experiments showed that incorporating 4 wt% SiO₂ into a cellulose triacetate (CTA) membrane increased the water flux by a factor 2.5 compared with pristine CTA (from 2.2 to 6.1 kg m⁻² h⁻¹) for a 30 g/L NaCl feed solution at 70°C, while the salt rejection remained above 99%. The CTA/4 wt% SiO₂ membrane was found to have only 21% flux reduction when tested with a 60 g/L NaCl feed solution, without changes in membrane selectivity. This suggests that the developed CTA/Ludox-SiO₂ nanocomposite pervaporation membrane is suitable for desalination.

KEYWORDS

membranes, pervaporation, nanocomposites, desalination

1 | INTRODUCTION

Anthropogenic activities and human population growth have caused water pollution, groundwater exploitation, and increasing water consumption, which leads to fresh water scarcity.¹ Seawater desalination has become a growing practice in many parts of the world to resolve this issue as almost 97% of the world water resources are seawater. Reverse osmosis (RO) is currently the most established membrane desalination technology, worldwide with the majority of the installed capacity, due to its high-energy efficiency in comparison with conventional thermal desalination processes.² However, the high-applied pressure in RO, especially at elevated feed salinity, results in an unfavorable high operating cost. RO also

needs extensive feed pre-treatment due to the high susceptibility of the RO membranes to fouling and inorganic scaling, so that this technology is still relatively expensive to produce fresh water.³

Alternative membrane-based desalination processes aiming to integrate waste heat utilization or solar energy to drive the separation process, such as, forward osmosis (FO)⁴ and membrane distillation (MD),⁵ have been developed to address the aforementioned RO desalination issues. However, FO is facing significant challenges in finding effective and easily regenerable draw solution materials^{6–8} while MD often has a high fouling propensity due to the use of hydrophobic membranes.⁹ In recent years, there has been a growing interest in applying pervaporation (PV) as a desalination process due to its high

salt rejection performance,^{10,11} often without the need for extensive feed solution pre-treatment since hydrophilic membranes are used, leading to a lower membrane fouling propensity. In addition, PV is able to treat feed waters with high salinity without significantly losing the membrane selectivity. Therefore, PV would be a cost competitive desalination technology if tailored PV membranes having a high water permeability without compromising the salt selectivity would be available in the market.

Polymer-based membranes are currently used as state-of-the-art PV technology due to their simple fabrication process, low manufacturing costs, and excellent mechanical properties. For example, cellulose ester-based polymer, such as, cellulose triacetate, have been widely applied as membrane materials due to its excellent salt rejection properties.¹² Nevertheless, pristine cellulose triacetate PV membranes usually suffer from a low water flux due to the dense membrane morphology.¹⁰ One way to improve the membrane performance in PV is to develop nanocomposite membranes by incorporating inorganic or organic nanoparticles (NPs) into the polymer matrix. Several inorganic and organic nanofillers, such as, TiO_2 ,^{13–16} SiO_2 ,^{17–19} Al_2O_3 ,^{20,21} graphene oxide,^{22,23} carbon nanotubes,^{24,25} nanoclays,²⁶ and cellulose nanocrystals^{27,28} have been used to prepare nanocomposite membranes. Although cellulose-based nanocomposite membranes have been developed for PV process, these membranes have only been evaluated for organic–organic mixtures^{29–31} and solvent dehydration applications.^{32,33} To date, there is no study has investigated the CTA/silica nanocomposite membranes for pervaporation desalination process.^{34,35}

In this study, nanocomposite PV membranes prepared via solution casting from commercially available materials, that is, cellulose triacetate (CTA) and colloidal Ludox- SiO_2 nanoparticles. CTA was chosen as polymer matrix due to its high salt rejection, excellent mechanical and chemical properties strength, low cost, low fouling tendency, and the fact that it can be processed to yield dense films. On the other hand, silica nanoparticles were selected as nanofillers due to their attractive properties such as low toxicity, hydrophilic, and excellent mechanical enhancement properties. A series of nanocomposite CTA/Ludox- SiO_2 membranes was prepared and characterized in terms of water flux and salt rejection.

2 | EXPERIMENTAL

2.1 | Materials

Cellulose triacetate (CTA, acetyl content 43%–44%, molecular weight 966.846 g/mol, Across Organics TM,

China), and dimethyl sulfoxide (DMSO, 99% pure) were purchased from Honeywell, Japan. Colloidal silica, LUDOX AS-40 (40 wt% SiO_2 suspension in water), with surface area $135 \text{ m}^2/\text{g}$ was obtained from Sigma–Aldrich. Sodium chloride (NaCl , 99.5% purity) from Across Organics was dissolved in MilliQ water used as a feed solution for the pervaporation experiments.

2.2 | Preparation CTA/Ludox- SiO_2 nanocomposite membranes

CTA/Ludox- SiO_2 nanocomposite membranes were fabricated by first dispersing LUDOX AS-40 in DMSO. LUDOX AS-40 colloidal is a commercial suspension containing silica 40 wt% in water. A series of LUDOX AS-40 suspensions was prepared based on a different weight percentage of SiO_2 (1, 2, 3, and 4 wt%) in dope solutions. The calculation based on the solid content of SiO_2 in the dope solution (Figure S1). The LUDOX dispersion was then stirred at a speed of 1000 rpm for 3 h at 70°C . Subsequently, 6 wt% of CTA solid polymer was added to the LUDOX dispersion and stirred for another 3 h at 70°C . The dope solution was then sonicated for 2 h and was stirred overnight (the lid was opened for dope solution 3 and 4 wt% of SiO_2). The dope solution was left for another 2 h in the fume hood to remove air bubbles formed during the stirring. The dope solution was casted onto glass plates at room temperature and at the relative humidity of 35%. The casting knife height was set at 200 μm and the casting speed was 0.09 cm/s. It was then immediately placed in a vacuum oven set at 60°C for 4 h to evaporate the solvent. The dried membranes were peeled from the glass plate by immersing it into a water bath. The maximum SiO_2 loading was 4 wt% because adding 5 wt% SiO_2 in the dope solution leads to a dope solution with a very low viscosity. As a consequence, the membrane film stuck to the glass plate after solvent evaporation, so that the membrane was easily broken when it was peeled from the glass plate.

2.3 | Pore size distribution

The pore size distribution of SiO_2 nanoparticles was measured using surface area and pore size analyzer (Nova 2000e, Quantachrome and Anton Paar). The Brunauer–Emmett–Teller (BET) technique was used to measure the surface area and pore size distribution. The SiO_2 nanoparticle samples were prepared by evaporating the suspension of SiO_2 (Ludox As-40) to recover solid SiO_2 nanoparticles.

2.4 | Particle size analysis

A particle analyzer (Nanoplus 3-Zeta/nano particle analyzer) was used to characterize the particle size and particle size distribution of SiO_2 nanoparticles in the dispersions. The Nanoplus is capable to measure the particle size in the range of 0.1 nm to 12.30 μm in a concentration range of up to 40% w/v, and a sensitivity for molecular weight as low as 250 Da.

2.5 | Electron microscopy

Scanning electron microscopy (SEM) (Philips XL30 SEM, the Netherlands) analysis was performed to observe the surface and cross-sectional membrane morphology of the membranes. Each sample was sputter-coated with a thin layer of gold under vacuum to prompt conductivity before examining. The samples were fractured in cryogenic liquid nitrogen before obtaining cross section images.

2.6 | Fourier transform infrared spectroscopy

Fourier transform infrared spectroscopy (ATR-FTIR, Perkin Elmer, spectrum 100) was used to characterize the chemical composition of the pristine CTA and the change of the chemistry of CTA/ Ludox- SiO_2 nanocomposite membrane in the range of 4000–650 cm^{-1} . The device was used at the set default with resolution of 4 and averaged 4 scans. The procedure for measuring the sample was as follows: the ATR platform was first cleaned to remove any residuals and the background measurement was taken. Then the sample membrane was placed on the platform and the compression head was pressed

against the membrane up to a safe value of pressing force. Once the live transmission plot had stabilized, the measurement scans were carried out. After this, the sample was removed and the platform and the compression head were cleaned.

2.7 | Contact angle measurements

Contact angle measurements were conducted to determine the surface hydrophilicity of the membranes. A low contact angle indicates a high water affinity, which refers to a hydrophilic membrane.³⁶ Contact angle measurements were measured using a standard contact angle apparatus (Krüss GmbH Germany, model: DSA 10-Mk2), employing a drop-shape analysis software to study the video images of the water pendant drops. A syringe plunger was used for dropping 2 μl of water at rate of 24.79 $\mu\text{l}/\text{min}$ on the surface of the membrane at room temperature.

2.8 | Mechanical properties

A tensile test using a mini tensile/compression machine, model: Instron 5943 was used to measure the mechanical strength of the CTA/Ludox- SiO_2 membrane. At least four specimens with width of 10 mm and length of 10 mm were snipped into a rectangular shape in ambient condition.

2.9 | Performance of CTA/Ludox- SiO_2 PV nanocomposite membranes for desalination

The performance of CTA/Ludox- SiO_2 nanocomposite membranes was investigated in a laboratory scale setup

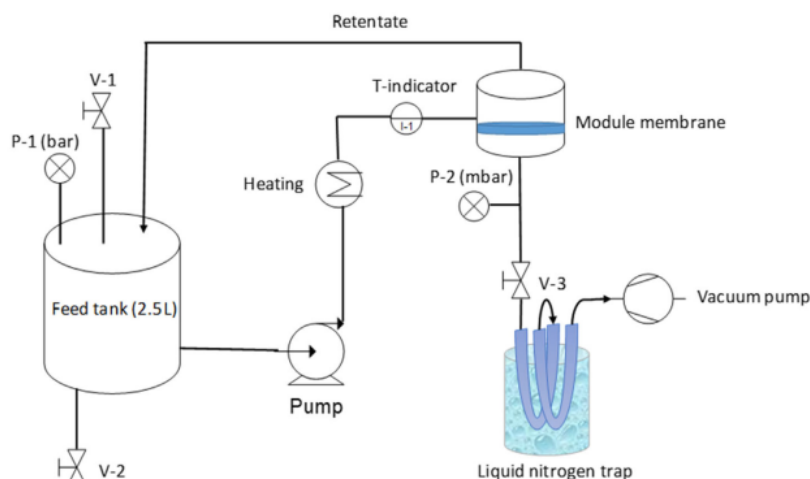


FIGURE 1 Schematic laboratory scale apparatus for pervaporation membrane desalination process [Color figure can be viewed at wileyonlinelibrary.com]

as shown schematically in Figure 1. The CTA/Ludox-SiO₂ membrane was placed in a stainless-steel module with an effective membrane area of 19.625 cm². The feed was heated at 70°C and was circulated with a pump into the membrane module at a flowrate of ±60–80 L/h. A vacuum pump with low pressure below 1 mbar was applied at the permeate side create the vapor pressure difference across the membrane. The permeate vapor was collected in a cold trap using a double U-shaped glass tube immersed in liquid nitrogen. The experiments were running continuously for 2 h. The membrane performance is determined by calculating the water flux using Equation 1 and rejection using Equation 2⁸:

$$J_w = \frac{m}{A \cdot t} \quad (1)$$

$$R(\%) = \left(1 - \frac{C_p}{C_f}\right) \times 100\% \quad (2)$$

where J_w is the water flux, m is the mass of permeate obtained (kg), A is the effective membrane area (m²), and t is the time interval (h). The salinity of water was measured by a Consort model C831-conductivity meter. The salt rejections (R , %), where C_p and C_f are the salinity in the permeate and feed solutions, respectively.

3 | RESULTS AND DISCUSSION

3.1 | Pore size distribution

The specific surface area of solid SiO₂ nanoparticles was calculated using the multipoint BET-equation. Figure 2 (a) shows the BET plot of SiO₂ nanoparticles and the specific surface area is 126.620 m²/g. While the pore size distribution of SiO₂ was measured by BJH method. The results of BJH adsorption is shown in Figure 2(b). The curve of Figure 2(b) reveals that the pore size diameter of SiO₂ is in the range of 1.4 nm (14.86 Å) to 6.9 nm

(69.62 Å). The average pore size diameter calculated from BJH method is 2.9 nm (29.71 Å), which indicating the pore size is in the mesoporous range (2–50 nm).³⁷

3.2 | Particle size analysis in solution

Figure 3 shows the particle size distribution of the original colloidal SiO₂ (LUDOX AS-40) dispersion and the particle size distributions of SiO₂ when it was mixed with DMSO for different concentrations. As shown in Figure 3(a), the mean particle size of the initial SiO₂ (LUDOX AS-40) is 41 nm. However, there was some agglomeration of SiO₂ when it was dispersed in DMSO. As shown in Figure 3(b)–(e), the particle size of SiO₂ increases as the particle concentration in DMSO increases. The results of the particle size analyzer show that the mean particle size with 1 wt% SiO₂ in the DMSO solution was 3.35, 0.97, 12.9, 3.17 μm, respectively, for 2, 3, and 4 wt% (see Figure 2(b)–(e)). The agglomeration of SiO₂ nanoparticles is due to the interactions between individual nanoparticles, dominated by two major forces, that is, the intermolecular force (Van der Waals force) and the electrostatic force.³⁸ Often, the intermolecular force has more pronounced effect than the electrostatic force (repulsive force).³⁹ The larger main particle size of 3 wt% SiO₂ in DMSO compared with those of 1, 2, and 4 wt% might be attributed to the effect of dispersion on the aggregation nanoparticles. An aqueous solution containing SiO₂ nanoparticles (40% SiO₂ in water) was added into DMSO, and loaded SiO₂ will lead to a less viscous dispersion compared to the CTA dope solution (See Figure S2). Figure S2 shows that increasing SiO₂ slightly increases the viscosity.

Ludox is a colloidal SiO₂ dispersion in which SiO₂ particles form a stable dispersion, as shown in Figure 3 (a). Nevertheless, the agglomeration of SiO₂ started when 1 wt% of SiO₂ in colloidal form was added to DMSO. Figure 3(c) shows that the aggregation of the colloidal solution containing 2 wt%-SiO₂ in DMSO resulted in the

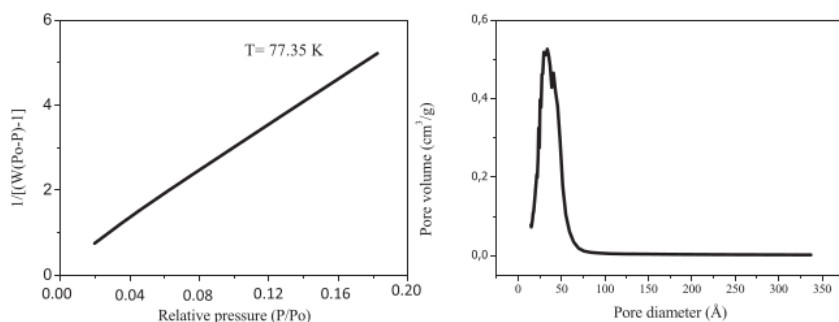


FIGURE 2 (a) BET result. (b) BJH pore size distribution curves of SiO₂ nanoparticles

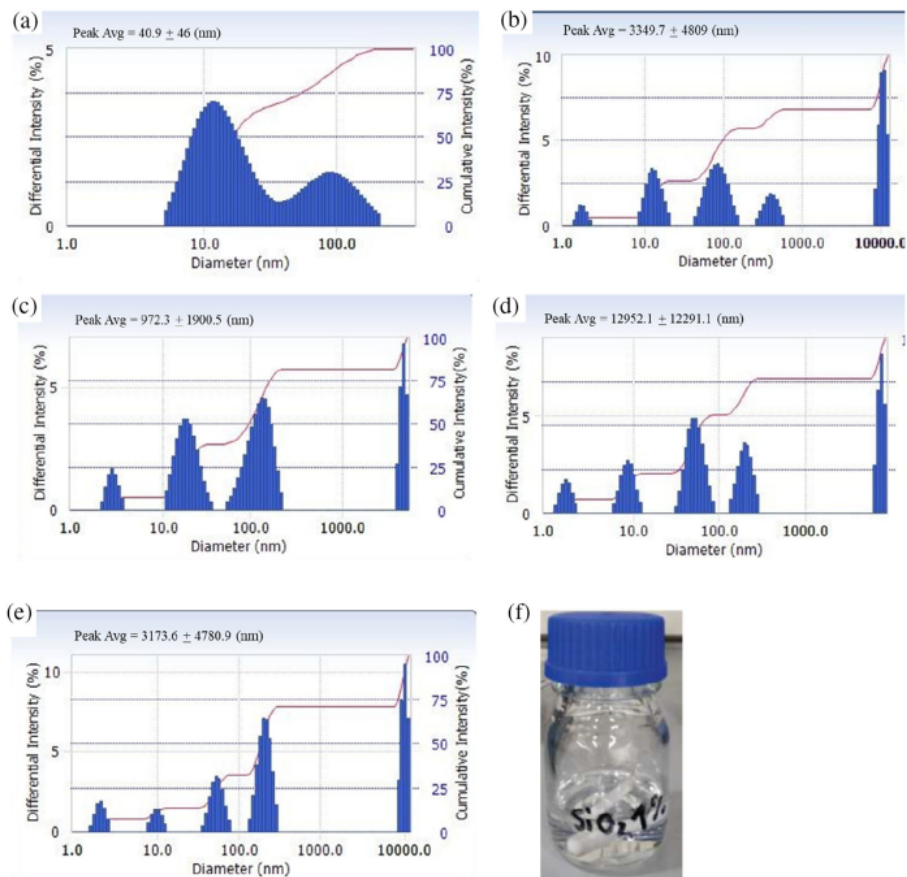


FIGURE 3 Particle size distributions, (a) initial SiO₂ (LUDOX AS-40); SiO₂ in DMSO at different concentrations (b) 1 wt% SiO₂, (c) 2 wt% SiO₂, (d) 3 wt% SiO₂, (e) 4 wt% SiO₂, and (f) photograph of the solution SiO₂ in DMSO [Color figure can be viewed at wileyonlinelibrary.com]

smallest mean particle size and the particle size distribution was more uniform compared to 1, 3, and 4 wt% (see Figure 3(b), (d), (e)). This indicates that 2 wt%-SiO₂ in DMSO has a higher intraparticle repulsive force, leading to less agglomeration. Nonetheless, all ludox-SiO₂ in DMSO dispersion has a transparent appearance (see Figure 3(f)).

3.3 | Morphological characterization

SEM images shown in Figure 4(a)-(e) suggest a dense membrane surface for all the fabricated membranes. The incorporation of SiO₂ in the CTA membrane can be seen as a white spot on the membrane surface (see Figure 4(b)-(e)). As shown in Figure 4(c), adding 2 wt% of SiO₂ nanoparticles results in numerous protrusions on the membrane surface, possibly due to the aggregation of

SiO₂. It can be seen in Figure 3(c) that the smallest mean particle size is obtained when 2 wt% SiO₂ was dispersed into DMSO; smaller particles have a higher interfacial area and potentially tend to aggregate,⁴⁰ which led to the highest roughness among all prepared membranes.⁴¹ Although there was some aggregation of nanoparticles on the membrane surface, the aggregation appeared homogeneous and uniform due the intrinsic characteristics of the colloidal SiO₂, which was dispersed well in the solution (Figure 3(f)). The cross-section image of the pristine membrane (Figure 4(f)) shows that it adopts a sponge-like structure with dense top and bottom layers. As the concentration of SiO₂ increased, the cross-section membrane morphology changes from porous middle layer to uniform dense structure (Figure 4(g)-(i)). It seems that the SiO₂ nanoparticles filled the pores in the sponge-like structure for CTA/SiO₂ nanoparticles membranes, resulting in a dense structure. Furthermore, increasing

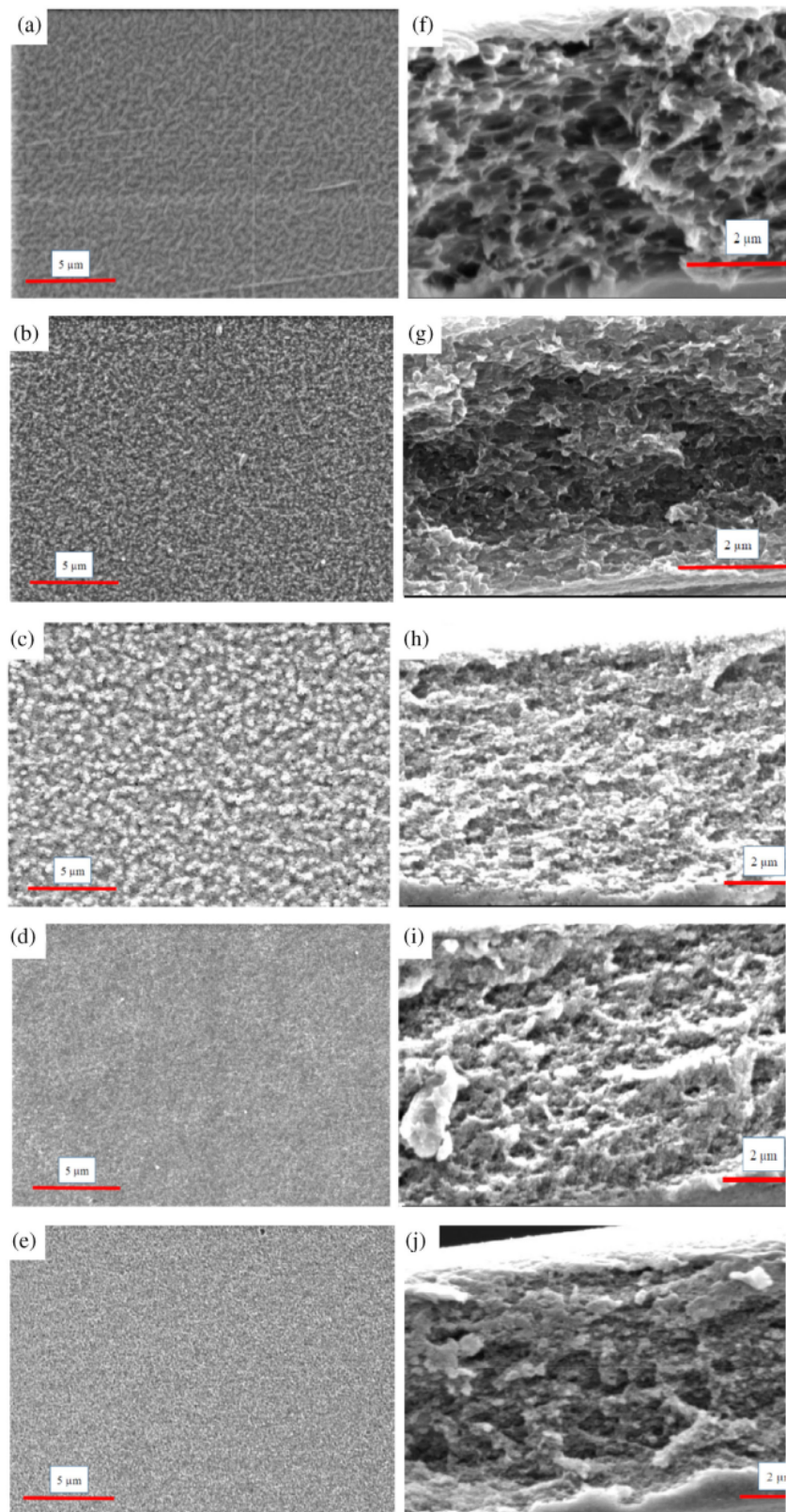


FIGURE 4 SEM images of membrane surface (a) CTA pristine, (b) CTA-1 wt% SiO₂, (c) CTA-2 wt% SiO₂, (d) CTA-3 wt% SiO₂, (e) CTA-4 wt% SiO₂ (magnification 5000×), the cross-section (f) CTA pristine, (g) CTA-1 wt% SiO₂, (h) CTA-2 wt% SiO₂, (i) CTA-3 wt% SiO₂, and (j) CTA-4 wt% SiO₂ (magnification 10 000×) of nanocomposite membrane [Color figure can be viewed at wileyonlinelibrary.com]

the SiO₂ loading leads to an increase in the final membrane thickness, as shown in Table 1.

3.4 | FTIR characterization

The surface functional group characterization of CTA/SiO₂ nanocomposite membranes by FTIR is shown in Figure 5. Most of the characteristic peaks in this figure are related to the pristine CTA membrane. The peak at 1370 cm⁻¹ is attributed to the asymmetric bending of C—H, the peak 1216 cm⁻¹ belongs to C—O stretching, and the peak at 1023 cm⁻¹ corresponds to pyranose ring C—O—C stretching (see Figure 5(a)). As Figure 5(b) shows, the characteristic peaks at 2963 and 3484 cm⁻¹ are corresponding to the stretching vibration of C—H and O—H, respectively.⁴² Compared with the pristine CTA membrane, the new peaks at 798 and 1121 cm⁻¹ (see Figure 5(a)) represents the Si—O bending and Si—O—Si symmetric stretching.^{43,44} The decreasing percentage of peak transmittance at 798 and 1121 cm⁻¹ correlates to the higher SiO₂ content in the membrane. The FTIR results confirm that SiO₂ nanoparticles are present in the fabricated nanocomposite membranes.

TABLE 1 Summary of different CTA/SiO₂ nanocomposite membrane thickness

% weight of SiO ₂	Modus (mm)	Average (mm)	Error
0	0.006	0.0066	0.00089
1	0.009	0.0088	0.00098
2	0.008	0.0084	0.00089
3	0.009	0.0092	0.0005
4	0.01	0.01	0.00081

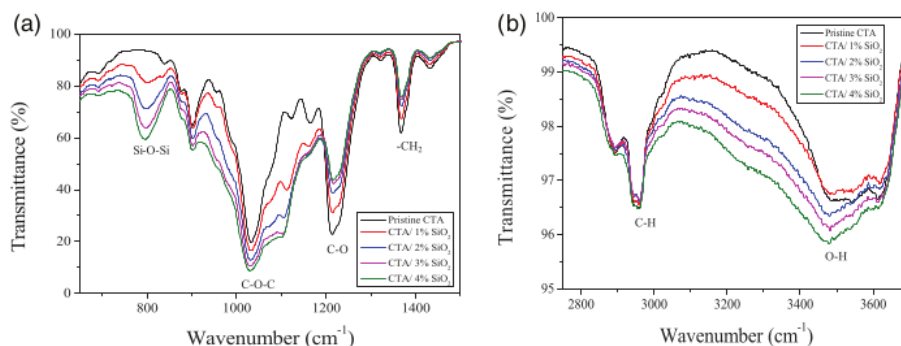


FIGURE 5 FTIR spectra of CTA/SiO₂ nanocomposite membranes fabricated in different content of SiO₂, (a) wavenumber range in 650 to 1500 cm⁻¹, and (b) wavenumber range in 2750 to 3700 cm⁻¹ [Color figure can be viewed at wileyonlinelibrary.com]

3.5 | Contact angle and mechanical properties analysis

Figure 6(a) presents the water contact angle values of the nanocomposite membranes with different SiO₂ content. All fabricated membranes are hydrophilic with a contact angle between 56.8–68.9° as shown in Figure 6(a). Increment of SiO₂ content does not have any significant impact on the surface hydrophilicity. However, loading 2 wt% SiO₂ in CTA membrane resulted in a hydrophilicity improvement due to roughness on the membrane surface (see Figure 4(c)). Generally, there are two wetting models, which suggested to explain the relationship between surface roughness and the contact angle of the surface, that is, the Wenzel⁴⁵ and Cassie-Baxter⁴⁶ models. Wenzel equation states that the surface roughness enhances both hydrophilicity and hydrophobicity, which is dependent on the nature of the material surface. CTA/SiO₂ is a hydrophilic membrane, hence with the increase in surface roughness will enhance the hydrophilicity of the membrane.

Figure 6(b) shows that the SiO₂ incorporation significantly enhances the membrane tensile strength. Salahshoori et al, noted that incorporating of SiO₂ nanoparticle in the membrane would enhance the tensile strength of the pristine membrane due to the uniform distribution of SiO₂ nanoparticles in the membranes.⁴⁷ This is in agreement with the morphological characterization in Figure 4, indicating that the uniform silica nanoparticle distribution increases nanocomposite membrane tensile strength. Besides, SiO₂ nanoparticles play a role as physical transfusion coupling between polymer parts, which reduces cracks or cavities at the membrane weak points.⁴⁸ However, increasing SiO₂ content beyond 3 wt% has an adverse effect on the membrane's tensile strength. Salahshoori reported that at percentages of SiO₂

above 15 wt% in polysulfone (PSF) membranes, the tensile strength decreased due to the accumulation of SiO₂ particles in PSF membrane.⁴⁷

These results imply that the presence of SiO₂ as inorganic nanoparticles strengthens the nanocomposite membrane due to the good dispersion of SiO₂ nanoparticles and the solid interaction between SiO₂ nanoparticles with the CTA matrix.⁴⁹ Therefore, the interfacial interaction between inorganic nanoparticles and polymer matrix should be considered an important factor affecting the tensile strength; however, excessive amounts of particles loaded would initiate the tensile strength to be decreased.⁵⁰

3.6 | Pervaporation desalination performance

Figure 7 shows the effect of SiO₂ content on the membrane permeability and NaCl rejection. The PV

performance of CTA/SiO₂ membranes in different SiO₂ content were investigated using a feed solution with a concentration of 30 g/L NaCl at a temperature of 70°C. Figure 7(a) shows that increasing the concentration of SiO₂ nanoparticles in the CTA membrane increases the water flux without sacrificing the NaCl rejection, as the NaCl removal stays above 99%. The highest water flux was obtained with a CTA/4 wt% SiO₂ nanocomposite membrane at 6.1 kg m⁻² h⁻¹. The water flux of the CTA/4% SiO₂ nanocomposite membrane can be increased by a factor 2.5 compared with the pristine

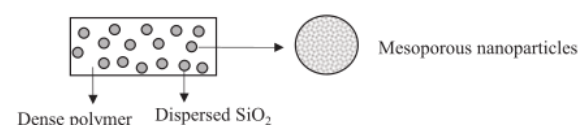


FIGURE 8 A schematic representation of SiO₂ in the dense polymer matrix

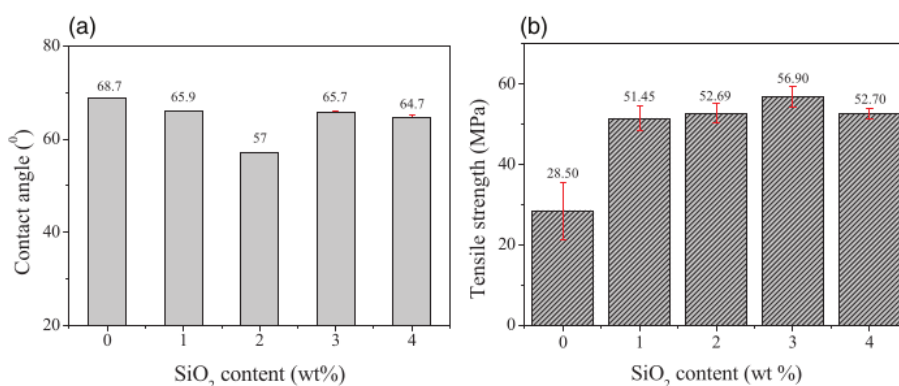


FIGURE 6 Contact angle of CTA/SiO₂ nanocomposite membranes (a), and tensile strength (b) with different SiO₂ content [Color figure can be viewed at wileyonlinelibrary.com]

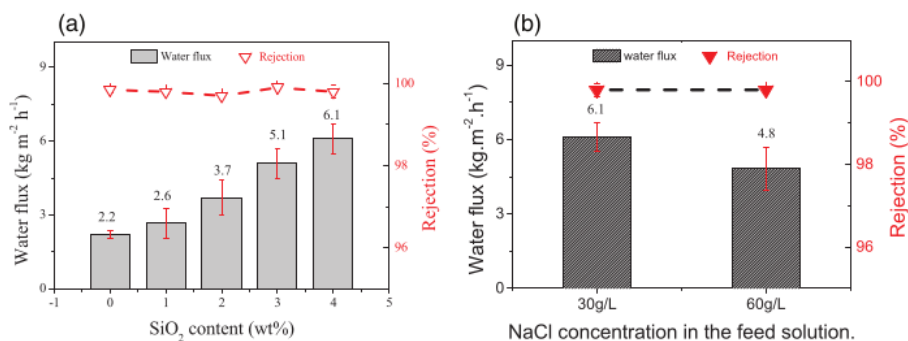


FIGURE 7 Pervaporation performance of CTA/SiO₂ nanocomposite membranes fabricated in different content SiO₂ (a), and pervaporation performance of CTA/4% SiO₂ nanocomposite membrane at different NaCl concentrations (b) [Color figure can be viewed at wileyonlinelibrary.com]

TABLE 2 Comparison of the performance of pervaporation desalination membranes

Membrane	Temperature in feed side (°C)	NaCl conc. (g/L)	Flux (kg/m ² h)	NaCl rejection (%)	References
Cellulose triacetate	50	100	2.3	99	35
Cellulose triacetate/Al ₂ O ₃	70	3090	6.85	99.8	20
Cellulose triacetate/CNCs	70	3090	11.677.6	99.7	42
Poly(vinyl alcohol)/maleic acid/TEOS	22	2	6.93	99.5	58
Poly(vinyl alcohol)/TEOS	Room temperature	2	96	99.9	59
Poly(vinyl alcohol)/TEOS/polysulfone	60	230	20.610.6	99.9	60
Cellulose triacetate/Ludox-SiO ₂	70	30	6.1	99.8	This study

CTA membrane. This increment is due to the addition of SiO₂ into the CTA membranes, which increases the hydrophilicity as described in FTIR spectra (see Figure 5(b)), as indicated by the hydroxyl group improvement. The membrane hydrophilic surface will enhance the water flux due to more water molecules being absorbed into the membrane.^{51,52} As shown in Figure 1(b) that diameter SiO₂ nanoparticles has diameter pore size is 2.9 nm. Hence, incorporating SiO₂ nanoparticles into CTA membrane can provide additional permeation pathways, which also contribute to the higher water flux. Figure 8 is a schematic representation of SiO₂ in the dense polymer matrix. Salt rejection can be maintained above 99% because of the role of the dense structure on the membrane surface of CTA/SiO₂, which acts as a selective layer. Besides, the high salt rejection was due to non-volatility and low diffusivity of NaCl.^{53–55}

Figure 7(b) shows the effect of the NaCl concentration in the feed on the performance of the CTA/4 wt% SiO₂ nanocomposite membrane at 70°C. The water flux decreased by 21% (6.1 to 4.8 kg m⁻² h⁻¹) when the NaCl concentration of the feed solution increased from 30 to 60 g/L NaCl; however, the NaCl rejection was independent of the feed concentration.

Increasing the feed concentration tends to an increase the concentration of species in the membrane. Feed concentration influences the sorption of species at the membrane interface.⁵⁶ Fick's law equation explains that flux (J) and diffusion (D) are concentration dependent (d_c).¹⁰

$$J = D \frac{d_c}{d_x} \quad (3)$$

While Antoine equation states that the vapor pressure (P) of water increased with temperature (T).⁵⁷

$$\log P = A - \frac{B}{T} \quad (4)$$

However, the decrease of water concentration at room temperature will not have significant effect on the water diffusivity in the membrane matrix. Hence, the difference in water vapor pressure at room temperature is negligible, while at temperature above 65°C the increasing temperature is more significant.⁵³ At high temperature (70°C), the vapor pressure enhances along with increasing the temperature. Differences in bulk feed water concentration will have an obvious influence on the water concentration in the membrane surface, and subsequently affect the diffusivity and flux.⁵³ Figure 7(b) reveals that the salt concentration increased from 3 wt% (30 g/L) to 6 wt% (60 g/L), hence the water concentration decreased from 97 to 94 wt%. The decreasing water concentration leads to a decrease in diffusivity in the membrane then water flux decreased. Table 2 summarizes several recent pervaporation membranes published in the literature.

4 | CONCLUSION

CTA/SiO₂ nanocomposite membranes were produced by solution casting for pervaporation desalination. The incorporation of SiO₂ in CTA membranes improved the mechanical strength of the membranes. The optimum SiO₂ added to CTA membrane was 4 wt% and increased the water flux by a factor 2.5 compared with pristine CTA (from 2.2 to 6.1 kg m⁻² h⁻¹), while the salt rejection was 99.8% using a feed solution of 30 g/L aqueous NaCl at 70°C. The water flux decreased by 21% (6.1 to 4.8 kg m⁻² h⁻¹) when the concentration of a feed solution rose from 30 to 60 g/L. It can be concluded that the

CTA/4 wt% SiO₂ nanocomposite membrane is a promising candidate for application in desalination by pervaporation.

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