Cellulose Blended Membranes for High-Salinity Water Pervaporation Desalination [†]

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[†] Presented at the 1st International Conference on Energy, Power and Environment, Gujrat, Pakistan, 11–12 November 2021.

Abstract: In the current study, cellulose acetate (CA)/cellulose triacetate (CTA) nanocomposite membranes blended with zirconium dioxide (ZrO₂) are prepared via phase inversion for pervaporation desalination performance. ZrO₂ nanoparticles are added to enhance the hydrophilicity and porosity of the nanocomposite membranes. The fabricated nanocomposite membranes are characterized by SEM, FTIR, TGA, and DSC to study the surface morphology, chemical composition, thermal stability and strength. Nanocomposite membranes' performance for pervaporation desalination is assessed as a function of feed concentration. Pervaporation results revealed that the nanocomposite membrane consisting of 2% ZrO₂ achieved a maximum water flux of 6.5 kg/m²h, whereas the salt rejection was about 99.8%.

Keywords: cellulose acetate; desalination; nanocomposite membranes; pervaporation; zirconium dioxide (ZrO₂)

Citation: Fareed, J.; Zafar, M.;

Saleem, M.; Malik, R.A.; Ali, M.

Cellulose Blended Membranes for High-Salinity Water Pervaporation Desalination. *Eng. Proc.* **2021**, *12*, 57.

<https://doi.org/10.3390/engproc2021012057>

Academic Editor: Muhammad Nayyar

Published: 30 December 2021

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1. Introduction

Availability of fresh water is adversely affected by the declining quality of available natural water resources as a result of groundwater exploitation, water pollution, and rising living standards. It is expected that one-third of the entire population will be unable to access safe drinking water in the future [1]. Although the world has abundant water resources, nearly 97% of it is seawater; therefore, desalination is an evolving technology that can help solve these water crises. Over the last few years, unconventional desalination processes based on the membrane, such as pervaporation (PV), have been investigated as reverse osmosis (RO) desalination alternatives due to their excellent ability to handle highly salinity water. Furthermore, it is an environmentally benign process that can have minimal fouling effects. Unfortunately, current PV membrane processes have low permeability than other membrane-based desalination processes, particularly cellulose-based PV membranes [2].

Cellulose acetate (CA) has been mostly used material to fabricate PV membranes owing to its low proclivity for fouling, better mechanical stability, and exceptional durability. Another derivative of cellulose, cellulose triacetate (CTA), possesses several desirable properties for membrane-based separations, including an exceptional ability to reject salt and practical mechanical strength, as well as improved oxidant resistance. CTA-based

membranes tend to be more hydrophobic in comparison to CA membranes, results in better salt rejection but lower permeability [3]. Polymer nanocomposite membranes prepared by mixing hydrophilic nanofillers into polymer matrix have been used as a common strategy to improve membrane performance [4,5]. Zirconium oxide (ZrO_2) has recently attained greater attention due to its better stability, hydration, high porosity, low cost, and nontoxic nature. Accordingly, it is anticipated that nanocomposite CA/CTA membranes blended with ZrO_2 are most likely to improve the water flux and salt rejection during pervaporation desalination.

In the current study, the influence of ZrO_2 on the physiochemical characteristics of CA/CTA nanocomposite membranes is assessed during pervaporation desalination. Membrane physicochemical properties such as physical structure, chemical composition, and thermal strength are studied in detail to determine the influence of ZrO_2 . To comprehensively evaluate pervaporation performance for desalination in the case of nanocomposite CA/CTA membranes blended with ZrO_2 , the effects of salt concentration in feed are considered in this work.

2. Materials and Methods

Membrane Fabrication, Characterization, and Performance

First, a homogeneous polymer solution is prepared by stirring CA/CTA solid polymers in dimethyl sulfoxide (DMSO) solvent for 8 h at a constant temperature of 75 °C. Then, ZrO_2 nanoparticles are added to the polymer solution and sonication is carried out for 6 h at 70 °C to thoroughly disperse the ZrO_2 nanoparticles in the polymer solution. The suspension solution is spread onto the glass plates with the help of a hand-casting knife. Glass plates containing the solution are kept inside the fume hood for 24 h to evaporate the solvent thoroughly. Finally, the dried membrane is dipped inside a deionized water bath to remove excess solvent, and then the membrane is separated from the glass plates.

The surface and cross-sectional morphology of the fabricated nanocomposite membrane is analyzed through scanning electron microscopy (SEM). The chemical composition analysis of the fabricated membrane is examined using Fourier-transform infrared spectroscopy (FTIR). The thermal resistance of the fabricated membrane is studied using a thermogravimetric analyzer (TGA). The glass transition measurement for nanocomposite membrane is performed by differential scanning calorimetry (DSC). A laboratory-scale setup locally fabricated is used to carry out the pervaporation desalination performance of CA/CTA blended with ZrO_2 nanocomposite membranes.

3. Results and Discussion

3.1. Membrane Characterization

Fabricated nanocomposite membrane CA/CTA blended with ZrO_2 surface and cross-section morphologies are shown in Figure 1. The blending of ZrO_2 into the CA/CTA polymer matrix results in nanocomposite membranes with a surface consist of several protrusions, which are made up of ZrO_2 nanoparticles or their aggregates, as seen in Figure 1a. It can also be seen ZrO_2 particles are distributed evenly throughout the polymer matrix. Cross-section morphology shown in Figure 1b indicates that the nanocomposite membrane CA/CTA blended with ZrO_2 had a dense and compact structure.

Figure 1. Morphology of nanocomposite membranes: (a) surface; (b) cross-section.

The FTIR scan of a CA/CTA–ZrO₂ nanocomposite membrane is shown in Figure 2. The strong band appearing at 3078 cm^{−1} is attributed to the O–H bond stretching vibration. The aldehyde carbonyl group of the CA ring is responsible for the 1549 cm^{−1} peak. The C=C double bond stretching mode represents the peak showing up at 1447 cm^{−1}. Two distinctive peaks appearing at around 953 cm^{−1} and 685 cm^{−1} are ascribed to C–H vibration out-of-plane bending. The FTIR results show that the fabricated nanocomposite membrane contains ZrO₂ nanoparticles.

Figure 2. FTIR spectra of nanocomposite membrane.

Thermal characteristics of CA/CTA–ZrO₂ nanocomposite membrane are examined by TGA and DSC analysis, as presented in Figure 3. Figure 3a reveals that the thermal degradation (TGA analysis) of the fabricated membrane occurs in three steps. Figure 3b shows the obtained DSC thermogram of the fabricated membranes; it reveals that the glass transition temperature (T_g) is around 120 °C for the CA/CTA–ZrO₂ membrane. This demonstrated that the CA, CTA, and ZrO₂ have been blended together well.

Figure 3. Thermal stability of nanocomposite membrane: (a) TGA; (b) DSC.

3.2. Pervaporation Performance

Figure 4 depicts the influence of salt concentration in the feed on the performance of the CA/CTA–ZrO₂ nanocomposite membrane at 70 °C. When using 60 g/L salts in the feed solution, the water flux decreased by 21% (7.15 kg/m²h to 5.60 kg/m²h), while increasing the salt contents from 30 g/L to 60 g/L reduced the water flux by 14% (6.50 kg/m²h to 5.60 kg/m²h). It can also be seen that the water flux decreases as the salt concentration in the feed rises, but the salt rejection remains constant regardless of feed concentration.

Figure 4. Pervaporation performance of nanocomposite membrane for salt contents in feed solutions at 70 °C.

4. Conclusions

A phase inversion method is used to fabricate CA/CTA–ZrO₂ nanocomposite membranes for pervaporation desalination. It was found that adding 2% ZrO₂ to CA/CTA polymer matrix improved the water flux. Adding ZrO₂ to CA/CTA membranes improved the membranes' chemical composition, hydrophilicity, and thermal stability. The water flux of the nanocomposite membrane is enhanced by 21% at 30 g/L salt contents in the feed solution at 70 °C, with almost 99.8% salt rejection.

Author Contributions: Conceptualization, M.A. and R.A.M.; methodology, J.F. and M.A.; validation, M.Z., M.S. and M.A.; formal analysis, J.F.; investigation, J.F. and M.A.; resources, M.A.; data curation,

J.F.; writing—original draft preparation, J.F.; writing—review and editing, M.A.; visualization, M.A.; supervision, M.A.; project administration, R.A.M.; funding acquisition, M.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: The authors are thankful to the Department of Mechanical Engineering, University of Engineering and Technology, Taxila–Pakistan, for their cooperation with this research project.

Conflicts of Interest: The authors declare no conflict of interest.

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