ULTRA-THIN PVA MEMBRANES FOR CO_2 TRANSPORTATION

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Abstract

The main aim of the study is to investigate the performance of ultra-thin polymer composite nanofiber-embedded membranes for efficient CO_2 transport. To fabricate these membranes, a combination of polyvinyl alcohol (PVA) and a specially selected modifier that supports CO_2 transport was used in addition to polyamide 6 nanofiber layer. PVA has excellent film-forming properties, mechanical strength, and low toxicity, making it an ideal choice for sustainable applications. Two membranes with special modifiers were prepared. The material properties of the solution-cast membranes are discussed and compared. Surface morphology characterization was accomplished through scanning electron microscopy (SEM) analyses.

Experimental tests were performed to evaluate the CO_2 permeability of these new membranes. The data obtained from these tests provide evidence of the successful transport of CO_2 through the polymer membrane system. The CO_2 permeability was evaluated using special equipment designed specifically for these experiments. In addition, these ultra-thin membranes were characterized as robust, compact, and homogeneous. The development of these advanced vapor permeable non-porous systems with improved properties opens the way to interesting applications in gas separation and CO_2 capture processes. These advances are vital in reducing emissions and negative environmental impacts.

Keywords: Ultra-thin membranes, polymer composite nanofibers, polyvinyl alcohol (PVA), CO_2 transport, gas separation

1. INTRODUCTION

Growing concerns regarding climate change and greenhouse gas emissions, particularly CO_2, are driving rapid advancements in innovative solutions for capturing and storing this gas. Among these solutions, membrane technologies are gaining increasing significance. Using membranes for CO_2 capture presents an environmentally friendly, cost-effective, and energy-efficient approach, provided a membrane with high flux and selectivity is chosen [1]. Important factors for successful CO_2 capture are the porosity and pore size of the membrane since physical contact between the gas and liquid phases occurs only in these microscopic spaces. Furthermore, a proper chemical compatibility between the membrane material and the solvent used is essential, as the choice of the absorbent liquid has a major influence on the selectivity of the separation [2]. Polymer membranes excel in industrial separation processes due to their versatility, the feasibility of large-scale synthesis, and production capabilities. This is the primary reason for our focus on advancing polymer membranes for CO_2 separation [3].

When we focus on a specific material, we observe the importance of polyvinyl alcohol (PVA). PVA is characterized by its high mechanical stability, semi-crystalline structure, and the presence of 1,2-diol and 1,3-diol bonds. Particularly, PVA demonstrates remarkable resistance to chemicals and oils, complete biodegradability, outstanding adhesive, and film-forming properties, as well as the ability to act as a barrier against oxygen and aromas. This unique combination of attributes has resulted in a diverse range of practical applications for PVA [4]. The membrane used in non-porous membrane contactor can be an integrally dense membrane, skinned asymmetric membrane, or composite membrane consisting of a thin dense layer coated on a porous support. The integrally dense membrane logically imposes higher resistance to mass transfer than skinned asymmetric membrane or composite membrane [5]. One key requirement for a successful industrial gas separation membrane is the processability. Most CO_2 separation applications require reliable production of a thin selective layer of 0,1–10 µm. At such a scale, polymers are the preferable membrane materials and nearly all commercial membranes are made from polymers with good scalability and low cost [6].

2. MATERIALS AND METHODS

2.1 Materials

Polyamide 6 (PA6) nanofibrous materials were purchased from Nano Medical Ltd. A nanofibrous material with a weight per unit area of 3 g/m^2 was selected for this research. Polyvinyl alcohol (PVA), fully hydrolyzed (Mw. approx. 60000) was purchased from Sigma-Aldrich.

2.2 Preparation of samples

A selected amount of polyvinyl alcohol (PVA) was dissolved in distilled water. This dissolution was carried out on a magnetic stirrer at 85 °C for 30 minutes. A homogeneous PVA solution was thus prepared. The obtained PVA solution was then cooled to room temperature for at least 3-4 hours.

Different solutions were prepared separately for different experimental groups. Group A contained a PVA solution which was subsequently blended with a selected amount of glycerol. Group B included a PVA solution blended with various concentrations of sodium carbonate (Na_2CO_3), while group C contained a PVA solution blended with Na_2CO_3 and glycerol. This ensured variability in the composition of the materials for subsequent analysis. The prepared nanofibrous materials made of polyamide 6 (PA6) were then successively coated with each solution. This achieved the deposition of specific components on the surface of the nanofibers, which allowed the study of their properties and effect on CO_2 transport.

2.3 Surface characterization

Morphological analysis of the PVA membranes was performed by scanning electron microscopy (SEM) using a Tescan Vega 3 instrument. SEM was performed on the PA6 nanofibrous material and then on PA6 that was coated with a PVA membrane with modifiers.

2.4 CO_2 measurement

A CO_2 datalogger with built-in sensors was used for CO_2 measurements. Individual measurements were carried out over a period of 24 hours.

3. RESULTS AND DISCUSSION

CO_2 transport by PVA containing alkali (sodium carbonate) and humidifier (glycerol) polymeric membranes has been studied in this research paper.

3.1 Surface characterization

The prepared samples were subjected to SEM analysis. In the **Figure 1a**, the nanofibrous material PA6 is shown in its untreated material form. The **Figure 1b** was taken to visually illustrate the difference between untreated PA6 nanofibrous material and PA6 treated with a PVA membrane. The presence of a polyvinyl alcohol (PVA) membrane can be seen in the upper part of this image. The **Figure 1c** shows PA6 coated with polyvinyl alcohol along with Na_2CO_3 at the highest concentration. It is observed that the membrane coating exhibits a homogeneous structure and the nanofibrous structure remains clearly visible. The **Figure 1d** provides an analogous view to the **Figure 1c**, but under higher magnification. **Figures 1c** and **1d** depict PVA membrane samples with a high concentration of Na_2CO_3. Upon conducting SEM analysis, the other samples exhibited no significant differences compared to these.

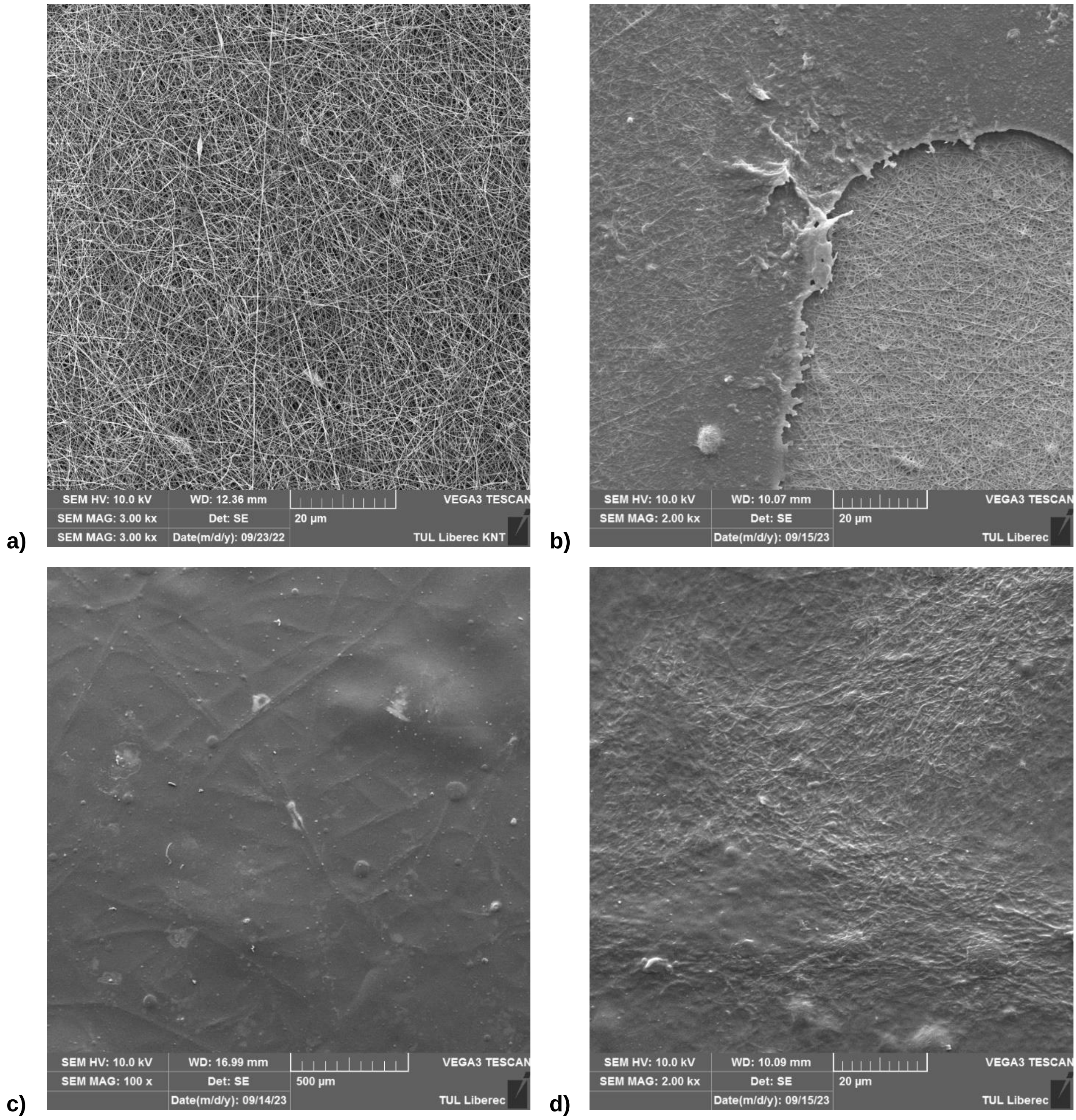

Figure 1 SEM Analysis of PA6 Nanofibrous material with PVA membrane: untreated PA6 Nanofibrous Material (1a), PA6 Nanofibrous Material with PVA membrane (1b), PA6 Nanofibrous Material Coated with PVA and Na_2CO_3 (1c), higher magnification of Figure 1c (1d)

3.2 CO_2 measurement

To evaluate CO_2 transport across different membranes, individual measurements were performed on prepared membranes. Each individual measurement session lasted 24 hours and was monitored using a special CO_2 datalogger. In this way, a systematic and reliable monitoring of CO_2 transport across the membranes was ensured and the recording of the data from these measurements allowed a thorough analysis of the influence of the different components on the permeability of these membranes to CO_2 molecules. An experiment was performed in which the effect of different combinations of substances on CO_2 transport was investigated. Data were collected for several different combinations of the substances PVA, glycerol, Na_2CO_3 and their different combinations. Data was collected using a CO_2 data logger with built-in sensors.

In the analysis of the **Figure 2a**, it can be observed that the PVA membrane itself does not show a significant effect on CO_2 transport. However, there is a slight improvement in transport when glycerol is incorporated into the PVA membrane. This finding suggests that the addition of glycerol may affect the permeability of the membrane to CO_2.

The **Figure 2b** focuses on the evaluation of CO_2 transport through the PVA membrane in which Na_2CO_3 was incorporated at different concentrations. The graph clearly shows that a low concentration of Na_2CO_3 tends to slightly increase CO_2 transport through the PVA membrane. As the concentration of Na_2CO_3 increases, the CO_2 transport through the membrane is increasingly improved. These results indicate a positive effect of Na_2CO_3 concentration on the permeability of the PVA membrane to CO_2 molecules.

In the **Figure 2c**, an experiment was performed with a PVA membrane containing incorporated sodium carbonate and glycerol was added simultaneously to investigate the effect of different concentrations of these components. **Figure 2c** presents results that are similar to the results in the **Figure 2b**. This suggests that the addition of glycerol does not show a significant individual effect on CO_2 transport.

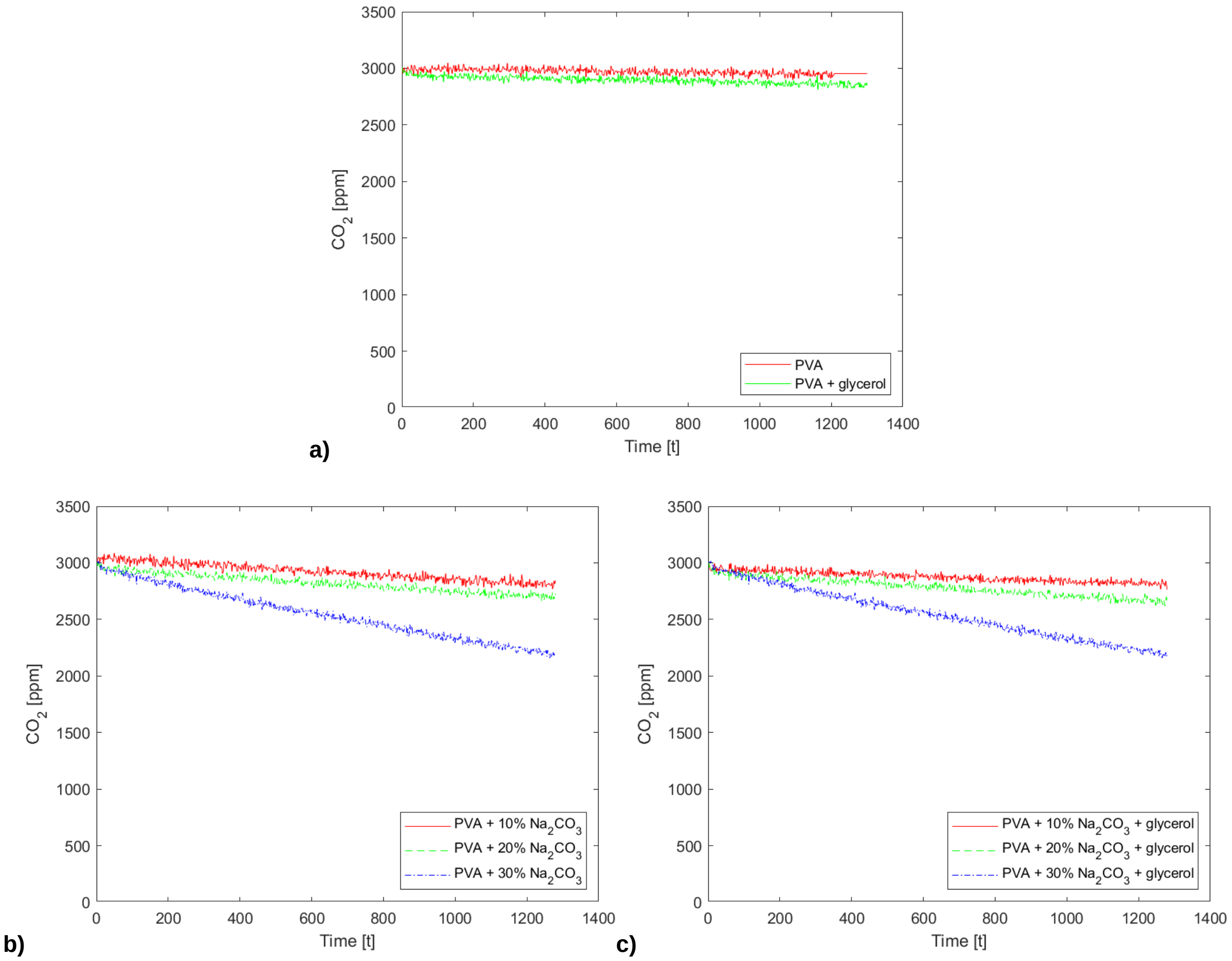

Figure 2 Graphs showing CO_2 transport through PVA membrane/PVA + glycerol (a), PVA with Na_2CO_3 (b) and PVA with Na_2CO_3 + glycerol (c)

These observations imply that the main enhancement of CO_2 transport was achieved by the incorporation of sodium carbonate into the PVA membrane, whereas glycerol did not show a significant impact on this membrane property.

CONCLUSION

In this experiment, the effect of different combinations of substances on CO_2 transport across PVA membranes was investigated. Data were carefully collected for different combinations of substances, including PVA, glycerol and Na_2CO_3, using a CO_2 datalogger with integrated sensors.

Overall, these observations suggest that the main increase in CO_2 transport was achieved by incorporation of Na_2CO_3 into the PVA membrane, whereas glycerol did not show a significant effect on this membrane property. These results have potential for use in a variety of applications, including separation and transfer of gaseous species, and open the door for further studies aimed at optimizing these membrane systems.

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