**Carbon Nanotube Incorporated Nanocomposite Membranes for Carbon Dioxide Removal** *(Times New Roman, Font 14)*

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**ABSTRACT**

Thin-film nanocomposite (TFN) membranes that consist of multi-walled carbon nanotube (MWNT) incorporated polyamide selective layer formed on polysulfone substrate were developed. The resultant TFN membranes were used for CO2 gas removal. For inclusion into these active layers, a grafting procedure for CNT was established in this study to enhance their hydrophobicity. MWNTs grafted with poly (methyl methacrylate) (PMMA) were synthesized via a micro emulsion polymerization of methyl methacrylate (MMA) in the presence of acid-modified multi-walled carbon nanotubes (c-MWNTs). Subsequently, polyamide TFN membranes containing PMMA–MWNTs were prepared via interfacial polymerization reaction between aqueous and organic phases. The resultants TFN were characterized by using FTIR and SEM. Morphology studies demonstrate that MWNTs have been successfully embedded into the active polyamide layer. The gas selectivity increased about 6.6 times compared to the thin-film composite membrane when using 0.35 w/v% amine in the aqueous phase, 0.28 w/v% trimesoyl chloride (TMC) in organic phase and 0.50g/L PMMA–MWNTs in coating layer.

*Keywords: carbon nanotubes; membrane; gas; CO2; selective layer (3-5 keywords)*

1. **INTRODUCTION** *(Times New Roman, Font 12)*

Global warming is mainly caused by the combustion of fossil fuels and other human activities, leading to carbon dioxide (CO2) emissions. Application of polymeric membranes in gas separation processes like natural gas sweetening, CO2 capture from fuel gas and removal of volatile organic compounds from effluent streams, is growing rapidly. However, the trade-off between permeability and selectivity is one of the most important challenges which prominently limit their industrial application [1].

Recent studies have demonstrated that thin film nanocomposite (TFN) membranes formed by embedding porous nanoparticle materials such as pure metals, metal oxides, silicon nanoparticles and carbon nanoparticles into a polyamide matrix layer may significantly improve membrane properties such as permeability, selectivity, stability, surface area, or catalytic activity in various membrane separation processes [2]. Figure 1 illustrates the process of synthesizing TFN membranes via interfacial polymerization technique.

The water permeability of the zeolite polyamide TFN membranes was improved without a significant loss of salt rejection under high pressure in reverse osmosis (RO)or forward osmosis (FO) [3-4]. This, however, has rarely been explored for CNTs, mainly due to the difficulties in synthesis of the polyamide layer because the dispersion of CNTs in polymer matrices is always a key issue to achieve high performance, especially when CNTs are added through dispersion from the organic phase.

A screenshot of a video game

AI-generated content may be incorrect.

**Figure 1**. The schematic process of TFN membrane synthesis

Therefore, in this study, multi-walled carbon nanotubes (MWNT) will be functionalized with poly (methyl methacrylate) (PMMA) to facilitate the dispersion of the PMMA-MWNT in organic solvent for the preparation of a more uniform nanocomposite film. PMMA has been studied as the polymer for synthesizing membranes (such as ultrafiltration membranes [5] or gas separation membranes [6]) because it is amorphous, which can prevent the membrane formation being complicated by crystallization [7]. PMMA based membranes are membranes with good solute permeability and a high degree of biocompatibility, which is thought to be related to the hydrophobic nature of the polymer [8].

Different techniques have been applied for the preparation of TFN membranes, e.g. plasma-initiated polymerization, photo-initiated polymerization, photo-grafting, electron beam irradiations, dip-coating, interfacial polymerization (IP) [9]. Among all these, IP is the most followed technique for preparing such composite membrane. The interfacial polymerization technique is based on a polymerization reaction that forms a polymer film at the interface between two immiscible phases (aqueous and organic phases), each of which has a highly reactive monomer dissolved in it. The polymer film formed at the interface usually grows from the aqueous phase toward the organic phase. This concept of polymer film growth at the interface has been proven by Morgan [10].

Interfacial polymerization is an effective technique for the preparation of a composite membrane consisting of an interfacial polymerized selective thin layer on the surface of a porous membrane support. The interfacial membrane formed by Cadotte at Northstar Research in 1977 consists of a combination of aromatic amines polymer such as *m*-phenyldiamine as the aqueous phase and triacyl chloride such as trimesoyl chloride as the organic phase. Further studies on TFC membranes have also been studied by Roh [11,12] and Samuel [13] regarding various polyamides prepared by interfacial polymerization. Roh [11,12] studied the effect of polyamide molecular structure on the performance of reverse osmosis membrane and the influence of rupture strength of TFC membrane structure whilst Samuel [13] investigated the structure and properties relationship of the thin film composite membrane.

In some cases, porous polysulfone or polyethersulfone membranes have been widely used as a substrate due to their superior chemical and mechanical stability and relatively low price. While polyamide TFC membranes have been extensively deployed for nanofiltration and reverse osmosis, they have also been trialed for gas separation applications. Recent results have shown that polyamide reverse osmosis membranes and their derivatives are possible candidates for CO2/N2 or CO2/CH4 separation purposes [14-20]. Thus, in this work, we report on TFN membranes composed of polyamide and PMMA functionalized MWNTs for CO2 gas removal. The loading of PMMA-MWNT is manipulated to obtain an optimum TFN for the acidic gas separation.

**2.0 Experimental** *(Times New Roman, Font 12)*

**2.1 Materials**

**2.2 XXX**

***IMPORTANT NOTE:*** *All equations used in the experiment must be clearly presented, with a complete description of each symbol. To insert an equation in* ***Word,*** *go to the* ***Insert*** *tab, click the* ***Equation*** *button and choose from built-in options or select* ***Insert New Equation*** *to build your own using the special tools for structures like fractions, scripts and symbols that appear in the Design tab.*

*Example:*

To determine the gas permeance, (*Pi*/*l*), the following equation was used:

(1)

where ( *Pi*/*l* ) represents the gas permeance of a membrane which is expressed in GPU (1 GPU = 1 10-6 cm3 (STP)/cm2 s cmHg), *i* is the penetrating gas *i*, Q*i* is the volumetric flow rateof gas permeated through the membrane at a standard temperature and pressure (cm3/s, STP), Δ*P* is the trans-membrane pressure difference (cmHg), *T* is the temperature of ambient environment at which the permeation experiment is performed and *A* is the effective membrane surface area.

**2.3 XXX**

**2.4 XXX**

**2.5 XXX**

**3.0 RESULTS AND DISCUSSION**

**3.1 Membrane Characterization**

Figure 2 compares the surface properties of two types of TFN membranes………..

***IMPORTANT NOTES:***

1. *All figures, including photographs and schematic diagrams, must be properly arranged and presented in high resolution (at least 300 DPI (Dots Per Inch)).*
2. *Each figure must be accompanied by a full caption and explicitly mentioned in the main text.*
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*Example:*

A collage of images of a piece of metal

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**Fig. 2.** Surface properties of (a) PA TFN and (b) PE TFN membranes, (i) surface morphology, (ii) cross-sectional view, (iii) TEM image and (iv) 3D AFM morphology

**3.2 XXX**

**3.3 XXX**

**3.4 Membrane Performance**

Table 1 compares the CO2/CH4 selectivity of the best performing TFN membrane with other TFN membranes reported in the literature……

***IMPORTANT NOTES:***

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*Example:*

**Table 1.** Selectivity of CO2/CH4 of different CNTs-based TFN membranes

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| TFN Membranes | Types of filler (CNTs or MWCNTs) | Testing conditions | Selectivity | Ref. |
| A | 1 wt% MWCNTs | 26°C, 10 bar | 55 | This work |
| B | 1 wt% MWCNTs | 25°C, 2 bar | 34 | [13] |
| C | 1 wt% CNTs | 30°C, 1 bar | 54 | [14] |
| D | 1 wt% CNTs | 27°C, 5 bar | 13 | [15] |

**4.0 CONCLUSION**

*XXXXX*

**DECLARATION OF GENERATIVE AI & AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS *(Optional)***

*XXXXX*

**DECLARATION OF COMPETING INTEREST**

*XXXXX*

**ACKNOWLEDGEMENT**

*XXXXX*

**AUTHOR CONTRIBUTIONS *(Optional)***

*XXXXX*

**APPENDIX: SUPPLEMENTRY DATA *(Optional)***

*XXXXX*

**REFERENCES**

***IMPORTANT NOTES:*** *All references cited in this journal must adhere to the APA 7th Edition referencing style.*

*Examples:*

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