MIST BASED INTERFACIAL POLYMERIZATION TECHNIQUE FOR GRAPHENE OXIDE MODIFIED THIN FILM COMPOSITE NANOFILTRATION MEMBRANE

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DEDICATION

This thesis is dedicated to my family, who provided me with financial and emotional support to complete this journey.

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ABSTRACT

Among the major issues faced by thin film composite membrane used in nanofiltration (NF) application are the fouling behaviour and the trade-off effect between water permeability and salt rejection. This study aimed to develop a new type of nanomaterials-modified thin film nanocomposite (TFN) membrane with enhanced surface characteristics by employing a new interfacial polymerization (IP) technique based on the mist method. Particularly, the objectives of this work are to investigate the effects of different mist-based interfacial polymerization conditions on the polyamide (PA) selective layer properties of membranes, to evaluate the impacts of plasma-enhanced chemical vapour deposition (PECVD)-modified graphene oxide (GO) interlayer on the characteristics of TFN membrane made of optimized mist-based IP conditions, and to investigate the influences of organic solution temperature during IP process on the properties of GO-modified TFN membrane for NF applications. The results show that in addition to forming thinner and looser PA structure, the piperazine (PIP) solution required in the mist-based IP (MIP) reaction was significantly reduced, i.e., 17 times lower than conventional IP. The microdroplet dispersion approach in MIP could form a higher crosslinked PA due to the high polymerization interface, besides forming a higher free volume selective layer due to the disruption in the PA repeat structure. The newly developed membrane could achieve 9.08 $L/m^2\cdot h\cdot bar$ pure water permeability (PWP) and 97.2% Na_2SO_4 rejection coupled with complete flux recovery rate. Following this, a new TFN membrane incorporating GO was fabricated using the developed MIP technique. GO was surface-functionalized using greener PECVD approach to improve its dispersibility. Compared to the control GO, acrylic acid-modified GO (AA/GO) was able to improve PWP of TFN membrane by 6.6%, reaching 11.34 $L/m^2\cdot h\cdot bar$. Its PWP was also higher compared to TFC membrane (~25% enhancement) owing to enhanced membrane hydrophilicity coupled with formation of thin yet highly crosslinked PA upon AA/GO incorporation. By varying the temperature of organic solvent (0 to 55 °C) during IP, the TFN 0 membrane with the thinnest and smoothest PA layer was able to be produced, recording 12.14 $L/m^2\cdot h\cdot bar$ PWP, 93% Na_2SO_4 rejection and 16% NaCl rejection. This membrane with the smoothest surface aided in its low protein adsorption, demonstrating great antifouling potential. Meanwhile, the TFN 55 membrane achieved a water-salt permselectivity ratio of 11.0, which was found to be >2 folds compared to the commercial NF3 membrane (4.88) owing to its enhanced crosslinking. Both TFN 55 and TFN 0 membrane showed great short-term (12 h) stability and retained more than 95% of the AA/GO nanosheets after a 5-day agitation period. Overall, the mist-based IP fabrication of TFN membrane at low temperature can overcome the limitations of the conventional IP technique to produce a smooth and defect-free TFN membrane with improved filtration performance and reduced protein adsorption.

ABSTRAK

Antara isu utama yang dihadapi oleh membran komposit filem nipis yang digunakan dalam aplikasi nano turasan (NF) adalah tingkah laku pengotoran dan kesan pertukaran antara kebolehtelapan air dan penolakan garam. Kajian ini bertujuan untuk membangunkan sejenis membran nanokomposit filem nipis (TFN) terubahsuai bahan nano baharu dengan ciri permukaan yang dipertingkatkan dengan menggunakan teknik pempolimeran antara muka (IP) baharu berdasarkan kaedah kabus. Khususnya, objektif kerja ini adalah untuk menyiasat kesan keadaan pempolimeran antara muka berasaskan kabus yang berbeza pada sifat lapisan selektif membran poliamida (PA), untuk menilai kesan pemendapan wap kimia dipertingkatkan plasma (PECVD) grafin oksida (GO) terubahsuai pada ciri-ciri membran TFN yang diperbuat daripada keadaan IP berasaskan kabus yang dioptimumkan, dan untuk menyiasat pengaruh suhu larutan organik semasa proses IP ke atas sifat membran TFN terubahsuai GO untuk aplikasi NF. Keputusan mendapati bahawa selain membentuk struktur PA yang lebih nipis dan longgar, larutan piperazin (PIP) yang diperlukan dalam tindak balas IP berasaskan kabus (MIP) telah berkurangan dengan ketara, iaitu, 17 kali lebih rendah daripada IP lazim. Pendekatan penyebaran mikrotitisan dalam MIP boleh membentuk PA terpaut silang yang lebih tinggi disebabkan oleh antara muka pempolimeran yang tinggi, selain membentuk lapisan selektif isipadu bebas yang lebih tinggi akibat gangguan dalam struktur ulangan PA. Membran yang baharu dibangunkan boleh mencapai 9.08 $L/m^2 \cdot h \cdot bar$ kebolehtelapan air tulen (PWP) dan 97.2% penolakan Na_2SO_4 ditambah dengan kadar perolehan fluks sepenuhnya. Berikutan itu, membran TFN baharu yang menggabungkan GO telah direka menggunakan teknik MIP yang dibangunkan. GO telah difungsikan permukaan menggunakan pendekatan PECVD yang lebih hijau untuk meningkatkan keterserakannya. Berbanding dengan kawalan GO, GO (AA/GO) yang terubahsuai asid akrilik dapat meningkatkan PWP membran TFN sebanyak 6.6%, mencapai 11.34 $L/m^2 \cdot h \cdot bar$. PWPnya juga lebih tinggi berbanding dengan membran TFC (~25% peningkatan) disebabkan oleh sifat hidrofilik membran yang dipertingkatkan ditambah dengan pembentukan PA terpaut silang yang nipis apabila digabungkan dengan AA/GO. Dengan mengubah suhu pelarut organik (0 hingga 55 °C) semasa IP, membran TFN 0 dengan lapisan PA paling nipis dan licin merekodkan 12.14 $L/m^2 \cdot h \cdot bar$ PWP, 93% penolakan Na_2SO_4 dan 16% penolakan NaCl. TFN 0 dengan permukaan membran paling licin membantu dalam penjerapan proteinnya yang rendah, menunjukkan potensi antikotoran yang hebat. Sementara itu, membran TFN 55 mencapai nisbah permkememilihan air-garam sebanyak 11.0, yang didapati >2 kali ganda berbanding membran NF3 komersial (4.88) disebabkan oleh pemautsilangan yang dipertingkatkan. Kedua-dua membran TFN 55 dan TFN 0 menunjukkan kestabilan jangka pendek (12 jam) yang hebat dan mengekalkan lebih daripada 95% helaian nano AA/GO selepas tempoh pengadukan selama 5 hari. Secara keseluruhannya, fabrikasi IP membran TFN berasaskan kabus pada suhu rendah boleh mengatasi batasan teknik IP lazim untuk menghasilkan membran TFN yang licin dan bebas kecacatan dengan prestasi penapisan yang lebih baik dan penjerapan protein yang berkurangan.

TABLE OF CONTENTS

TITLE PAGE

DECLARATION iii
DEDICATION iv
ACKNOWLEDGEMENT v
ABSTRACT vi
ABSTRAK vii
LIST OF ABBREVIATIONS xviii
LIST OF SYMBOLS xx
LIST OF APPENDICES xxi

CHAPTER 1 INTRODUCTION 1
- 1.1 Research Background 1
- 1.2 Problem Statement 3
- 1.3 Objectives of Study 5
- 1.4 Scopes of Study 6
- 1.5 Significance of Study 8

CHAPTER 2 LITERATURE REVIEW 11
- 2.1 Water Scarcity 11
- 2.2 Overview of Nanofiltration Membrane Process and Its Applications 12
  - 2.2.1 Brief History of Nanofiltration Membranes 14
  - 2.2.2 Applications of Nanofiltration Membranes 15
- 2.3 Development of Nanofiltration Membranes 16
  - 2.3.1 Integrally Asymmetric Nanofiltration Membrane 18
  - 2.3.2 Thin Film Composite Nanofiltration Membrane 20
  - 2.3.3 Comparison between Asymmetric and Thin Film Composite Membranes 22
- 2.4 New Generation of Nanofiltration Membrane – Thin Film Nanocomposite Membrane 23

2.4.1 Conventional Interfacial Polymerization Technique for Thin Film Composite/Nanocomposite Membrane Fabrication 25

2.4.2 Nanomaterials in Thin Film Nanocomposite Membrane 27

2.5 Modified Interfacial Polymerization Techniques for Thin Film Composite/Nanocomposite Membranes Fabrication 31

2.5.1 Modified Interfacial Polymerization Techniques 32

2.5.2 Mist-based Interfacial Polymerization Technique 35

2.5.3 Temperature-controlled Interfacial Polymerization Technique 37

2.6 Impacts of Graphene Oxide on Thin Film Nanocomposite Membranes 38

2.6.1 Characteristics of Graphene Oxide 38

2.6.2 Properties of Membrane incorporated with Graphene Oxide 40

2.6.3 Challenges of Thin Film Nanocomposite Membrane incorporated with Unmodified Graphene Oxide 42

2.6.4 Plasma-enhanced Chemical Vapour Deposition as a Nanomaterial Surface Modification Technique 45

2.7 Summary of literature review 47

CHAPTER 3 RESEARCH METHODOLOGY 49

3.1 Research Design 49

3.2 Materials 51

3.3 Thin Film Composite Membrane Fabrication 51

3.3.1 Conventional Interfacial Polymerization Technique – Rubber rolling 52

3.3.2 Development of Mist-based Interfacial Polymerization Technique 53

3.4 Thin Film Nanocomposite Membrane Fabrication 54

3.4.1 Synthesis of Graphene Oxide 55

3.4.2 Plasma-enhanced Chemical Vapour Deposition Modification of Graphene Oxide 56
3.4.3 Incorporation of Modified-Graphene Oxide as an Interlayer 57
3.4.4 Thin Film Nanocomposite Membrane Fabrication at Varying Temperature 57
3.5 Characterization of Graphene Oxide 58
3.5.1 Chemical Composition of Graphene Oxide 58
3.5.2 Crystallinity of Graphene Oxide 58
3.5.3 Dispersibility of Graphene Oxide 59
3.5.4 Structural Morphology of Graphene Oxide 59
3.6 Characterization of Thin Film Composite/Nanocomposite Membrane 59
3.6.1 Structural Morphology of Composite Membranes 60
3.6.2 Wettability Analysis 60
3.6.3 Membrane Chemical Composition 61
3.6.4 Membrane Crosslinking Degree 61
3.7 Nanofiltration Performance Evaluation 62
3.7.1 Pure Water Permeability Test 62
3.7.2 Salt Rejection Test 63
3.7.3 Water/Salt Permselectivity 64
3.7.4 Stability Test 64
3.7.5 Leaching Test 64
3.7.6 Antifouling Test 65

CHAPTER 4 RESULTS AND DISCUSSION 67
4.1 Development of Mist-based Interfacial Polymerization Approach 67
4.1.1 Fundamental Mechanism of Mist-based Interfacial Polymerization Driving Force: Interfacial Free Energy 67
4.1.2 Misting Time – Membrane Structure 69
4.1.3 Misting Time – Membrane Chemical Properties 73
4.1.4 Misting Time – Membrane Performance 76

4.1.5 TMC Concentration – Membrane Structure 77
4.1.6 TMC Concentration – Membrane Performance 78
4.1.7 Findings Summary of Objective 1 80
4.2 Incorporation of Functionalized-Graphene Oxide in Thin Film Nanocomposite Membrane 81
4.2.1 Graphene Oxide Functionalization – Physicochemical Properties 81
4.2.2 Thin Film Nanocomposite – Membrane Structure 86
4.2.3 Thin Film Nanocomposite – Membrane Chemical Properties 88
4.2.4 Thin Film Nanocomposite – Membrane Performance 90
4.2.5 Findings Summary of Objective 2 93
4.3 Varying Interfacial Polymerization Temperature in Mist-based Thin Film Nanocomposite Membrane Fabrication 93
4.3.1 TMC Solution Temperature – Membrane Structure 93
4.3.2 TMC Solution Temperature – Membrane Chemical Properties 95
4.3.3 TMC Solution Temperature – Membrane Performance 97
4.3.3.1 Short-term Stability Test using High Salt Concentration 98
4.3.3.2 Nanomaterial Leaching Potential from Membrane 99
4.3.3.3 Static protein adsorption 100
4.3.4 Findings Summary of Objective 3 101

CHAPTER 5 GENERAL CONCLUSION AND RECOMMENDATIONS 103
5.1 General Conclusion 103
5.2 Recommendations for Future Work 105

REFERENCES 107

APPENDIX A **125**

LIST OF PUBLICATIONS **126**

LIST OF TABLES

TABLE NO.	TITLE	PAGE
Table 2.1	Summary of nanomaterial-modified TFN membrane	29
Table 2.2	Comparison of TFN membranes fabricated using conventional IP and modified IP	34
Table 2.3	Advantages and disadvantages of novel IP techniques	35
Table 2.4	Summary of TFN membranes incorporated with functionalized/modified GO nanofillers	44
Table 3.1	Membrane name and parameters invovled	54
Table 3.2	PECVD parameters of GO surface modification	56
Table 3.3	Respective GO loadings for TFN membrane fabricated	57

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
Figure 2.1	Comparison of energy consumption (kWh) by RO and NF process (Wafi *et al.*, 2019)	13
Figure 2.2	Solute rejection mechanism of NF membrane	14
Figure 2.3	Conventional IP Process using m-phenylenediamine (MPD) and TMC	17
Figure 2.4	Simplified diagram for plasma grafting process (Mohammad *et al.*, 2015)	18
Figure 2.5	Phase separation processes (Tasselli, 2014)	19
Figure 2.6	(a) Cross-sectional scanning electron microscopy (SEM) images of membrane prepared with solvent/co-solvent (NMP/THF) of a mass ratio of 3:1 (Xu *et al.*, 2019) and (b) Cross-section FESEM image of ISA PBI membrane (Abadi Farahani and Chung, 2019)	19
Figure 2.7	(a) Schematic illustration of TFC NF membrane by addition of acyl chloride (Zhao *et al.*, 2019), (b) Cross-section SEM image of TFC NF membranes mediated by rapid co-deposition of PDA/PIP (Zhu *et al.*, 2018b) and (c) Cross-section image of membrane fabricated with the addition of sericin as co-reactant (Pan *et al.*, 2017)	21
Figure 2.8	Typical structures of TFN membranes showing nanomaterial position, (a) within PA layer, (b) coated on top of PA layer, (c) within substrate and (d) interlayer between substrate and PA layer (Akther *et al.*, 2019).	24
Figure 2.9	(a) Typical lab-scale IP process for TFC flat sheet membrane fabrication and (b) the most common cross-linked PA structures for commercial TFC NF membranes and their respective FESEM and AFM surface images (Zhang *et al.*, 2020; Lai, Lau, Goh, *et al.*, 2016)	26
Figure 2.10	TEM cross-sectional images of (a) neat dense membrane and (b) GO-modified membrane (Lai *et al.*, 2018)	28
Figure 2.11	SEM images showing agglomeration of modified-GO [47] and MWCNT [69] in the PA layer of membrane	32
Figure 2.12	Commercially available humidifier	36
Figure 2.13	Ultrasonic humidifier forming water mist (Shehata *et al.*, 2019)	37

Figure 2.14 2D-honeycomb lattice structure of GO which acts as a precursor for all graphene-based materials (Geim and Novoselov, 2007) 39

Figure 2.15 (a) TEM images of fractionated GO (Chae *et al.*, 2015) and (b) Interaction of PA monomers (MPD and TMC) with GO during IP process (Ali *et al.*, 2016) 41

Figure 2.16 Cross-sectional FESEM images of (a) TFC and (b) TFN membranes (Lai *et al.*, 2016a) and SEM images of TFN membrane (c) optimum GO loading of 100 ppm and (d) aggregation which occurs at GO loading of 300 ppm (Ali *et al.*, 2016) 42

Figure 2.17 Addition of more hydrophilic functional groups on GO after maleic anhydride modification (Xie *et al.*, 2017) 43

Figure 2.18 Schematic representation of polymers formed via plasma and conventional polymerization (Nisol and Reniers, 2015) 46

Figure 3.1 Research Methodology Design and Planning 50

Figure 3.2 Formation of semi-aromatic PA layer 52

Figure 3.3 Fabrication of TFC membrane via MIP and CIP 52

Figure 3.4 Mist-based IP lab-scale apparatus setup 54

Figure 3.5 Oxidation of graphite using $KMnO_4$ and H_2SO_4 for GO synthesis 55

Figure 3.6 Chemical structure of monomers used in GO functionalization 56

Figure 4.1 Mechanism of PA formation through CIP and MIP explained using interfacial free energy driving force (A: aqueous; O: organic and AS: aqueous-substrate) 68

Figure 4.2 Surface (left) and cross-sectional (right) FESEM images of different TFC membranes, (a) CIP, (b) MIP-1-0.2, (c) MIP-2-0.2, (d) MIP-3-0.2 and (e) MIP-4-0.2 70

Figure 4.3 (a) Comparison of EDX surface mapping of N element on different PIP deposition methods and (b) Volume of PIP solution required for CIP- and MIP-made membranes based on fabrication size of 121 cm^2 70

Figure 4.4 3D AFM images and roughness value of (a) CIP, (b) MIP-1-0.2, (c) MIP-2-0.2, (d) MIP-3-0.2 and (e) MIP-4-0.2 72

Figure 4.5 TEM cross-sectional images of (a) MIP-3-0.2 and (b) CIP membrane 73

Figure 4.6 (a) Comparison of the ATR-FTIR spectra of MIP membranes with CIP membrane and (b) CA for MIP membranes. Dotted line shows the CA of CIP membrane (32°) 74

Figure 4.7 (a)(i) XPS wide scan, (a)(ii) O/N ratio of different membranes and C1s core level spectra of (b) MIP-1-0.2, (c) MIP-2-0.2, (d) MIP-3-0.2 and (e) MIP-4-0.2 membrane 75

Figure 4.8 Pure water permeability and salt rejection of CIP and MIP membranes measured at 8 bar. 77

Figure 4.9 Surface and cross-sectional FESEM images of (a) MIP-3-0.05, (b) MIP-3-0.10, (c) MIP-3-0.15 and (d) MIP-3-0.20 78

Figure 4.10 The impact of TMC concentration on membrane properties, (a) Pure water permeability and rejection of MIP membranes at 8 bar and (b) CA of MIP membranes. The misting time is fixed at 3 min. 79

Figure 4.11 (a) Normalized permeability and (b) FRR of CIP, MIP-3-0.2 and MIP-3-0.05 membrane measured at 8 bar using 1500 ppm BSA solution 80

Figure 4.12 (a) FTIR of AA and MMA monomer and their respective polymeric films, (b,c) FTIR and XRD spectra of GO nanosheets with and without surface functionalization and (d) Photographs of different GO (Loading: 0.0033%) dispersed in 15-mL aqueous solution before and after ultrasonication (Note: Tyndall effect is demonstrated by passing red light through the dispersion). 83

Figure 4.13 TEM images of (a,b) GO and (c,d) AA/GO. Inset image in (b) and (d) shows the SAED pattern of respective nanosheet. 84

Figure 4.14 (a) Wide scan XPS survey spectra of three different GO nanosheets (Inset: Elemental composition table of GO nanosheets) and high resolution XPS spectra of C1s of (b) GO, (c) AA/GO and (d) MMA/GO 85

Figure 4.15 Surface properties of composite membranes in terms of FESEM (i) cross-sectional and (ii) surface images, (iii) AFM morphology and (iv) water droplet image and its angle, (a) TFC, (b) TFN-GO, (c) TFN-AA/GO and (d) TFN-MMA/GO. 88

Figure 4.16 Membrane surface properties, (a) ATR-FTIR (Inset: enlarged image for wavelength of 3500–3300 cm^{-1}), (b) XPS wide scan spectra, (c) elemental breakdown and O/N ratio and (d) PA cross-linking degree 90

Figure 4.17 (a) Pure water permeability (PWP) and single salt rejection and (b) flux and thickness-normalized flux of composite membranes measured at 8 bar. 92

Figure 4.18 (a) PWP and salt rejection of TFN-AA/GO membrane with different loadings and (b) zeta potential of TFC and optimized TFN-AA/GO membrane 92

Figure 4.19 3D AFM (top), FESEM surface (middle) and cross-sectional (bottom) images of (a) TFN 0, (b) TFN 25, (c) TFN 35 and (d) TFN 55 membranes. 94

Figure 4.20 (a) ATR-FTIR spectra of membranes, (b-e) deconvoluted O1s XPS spectra of TFN membranes fabricated at different organic solution temperature and (f) surface water contact angle of different TFN membranes. 96

Figure 4.21 (a) Nanofiltration performance and (b) water-salt permselectivity ratio (A/B) of TFC and TFN membranes fabricated using different organic solution temperature. Data for the NF3 membrane was obtained from in-lab testing. 98

Figure 4.22 (a) Stability performance of TFN 0 and TFN 55 membranes tested using 10,000 ppm Na_2SO_4 salt solution for 12 hours, (b) concentration of AA/GO leachate (in 50 mL RO water) and the percentage of AA/GO leached from TFN membrane during 4-day agitation, and (c,d) TEM images of TFN 0 membrane before and after a 12-h testing period. (Note: The AA/GO loading on each TFN membrane is 0.03 g/m^2, corresponding to 6.5×10^{-5} g per membrane coupon). 100

Figure 4.23 CLSM images using fluorescently-labelled protein (BSA-FITC) on (a) NF3 (commercial), (b) TFN 0 and (c) TFN 55 membrane with (i) 2D bottom surface (substrate bottom) image and (ii, iii) 2D and 3D top surface (polyamide surface) images generated by LAS AF Leica software. 101

LIST OF ABBREVIATIONS

2D	-	2-Dimension
AA	-	Acrylic Acid
AFM	-	Atomic Force Microscopy
ATR-FTIR	-	Attenuated Total Reflectance-FTIR
BSA	-	Bovine Serum Albumin
CA	-	Contact Angle
CNT	-	Carbon Nanotube
CVD	-	Chemical Vapour Deposition
FESEM	-	Field Emission Scanning Electron Microscopy
FO	-	Forward Osmosis
FRR	-	Flux Recovery Ratio
FTIR	-	Fourier-Transform Infrared Spectroscopy
GO	-	Graphene Oxide
GP	-	Graft Polymerization
HEMA	-	Hydroxyethyl Methacrylate
HFBA	-	Hexafluorobutyl Acrylate
HMO	-	Hydrous Manganese Oxide
IP	-	Interfacial Polymerization
ISA	-	Integrally Skinned Asymmetric
MF	-	Microfiltration
MOF	-	Metal Organic Framework
MPD	-	*M*-Phenylenediamine
MWCNT	-	Multi-Walled Carbon Nanotube
MWCO	-	Molecular Weight Cut-Off
NF	-	Nanofiltration
NMP	-	1-Methyl-2-Pyrrolidone
NTSC	-	Naphthalene-1,3,6-Trisufonylchloride
o-POP	-	*O*-Hydroxy Porous Organic Polymer
PA	-	Polyamide
PBI	-	Polybenzimidazole

PDA - Polydopamine
PECVD - Plasma-Enhanced Chemical Vapour Deposition
PEI - Polyethylenimine
PES - Polyethersulfone
PIP - Piperazine
PRO - Pressure-Retarded Reverse Osmosis
PSA - Polysulfonamide
PSf - Polysulfone
PVA - Polyvinyl Alcohol
PVDF - Polyvinylidene Difluoride
PWP - Pure Water Permeability
RO - Reverse Osmosis
SEM - Scanning Electron Microscopy
TAC - Trimellitic Anhydride Chloride
TCSP - Tris(Chlorosulfonyl)Phenol
TEM - Transmission Electron Microscopy
TFC - Thin Film Composite
TFN - Thin Film Nanocomposite
TFPTCS - (3,3,3-Trifluoropropyl)Trichlorosilane
THF - Tetrahydrofuran
TMC - Trimesoyl Chloride
TNT - Titania Nanotubes
UF - Ultrafiltration
XPS - X-Ray Photoelectron Spectroscopy
XRD - X-Ray Diffraction

LIST OF SYMBOLS

A_0	-	Initial water permeability
A	-	Water permeability
A_m	-	Effective membrane area
C_f	-	Feed solute concentration
C_p	-	Permeate solute concentration
J	-	Water flux
ΔP	-	Transmembrane pressure difference
R	-	Salt rejection rate
R_a	-	Mean roughness
R_{max}	-	Mean difference between the highest peaks and the lowest valleys
R_{ms}	-	Root mean square of Z value
Δt	-	Permeate collection time
V	-	Permeate volume

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
Appendix A	Commercial NF3 membrane characterization	127

CHAPTER 1

INTRODUCTION

1.1 Research Background

Fresh water is vital for human consumption and sanitary purposes. However, the access to fresh water is limited, giving rise to a major issue known as water scarcity (NAE, 2017). In the 2015 Global Risk Report, water scarcity is determined to be the most high-impact risk issue of current times (WEF, 2015). Although water is available in many forms such as ice, glaciers, rivers and lakes, natural fresh water only makes up to 0.5 percent of the entire water supply on the Earth (Kucera, 2014). Some major factors that exacerbate water scarcity are climate change, uneven distribution of freshwater as well as man-made and natural contamination (Gude, 2017). Desalination technology is one of the emerging water treatment methods due to its unlimited raw supply and relatively simple operation.

Membrane desalination is one of the highly focused research areas owing to its lower operating cost and increased efficiency, compared to other desalination technologies. Fane *et al.* (2011) categorized membrane technology into microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO). RO is generally used in the desalination technology while NF membranes acts as a pre-treatment for RO to reduce fouling problems. Thus, NF membranes with high water permeability, solute/salt rejection and antifouling ability are highly sought after.

For application in water purification or water desalination systems, the most prominent NF membranes are thin film composite (TFC) and thin film nanocomposite (TFN) membranes (Xie *et al.*, 2017). TFC membranes are made up of two or more distinct layers. It generally consists of bottom substrate layer which acts as a support and top selective polyamide (PA) layer which determines the membrane performance. On the other hand, TFN membranes are nanomaterial modified-TFC membranes. In general, TFN membrane exhibits better surface properties and filtration performance compared to the counterpart TFC membranes as a result of embedment of advanced nanomaterials. Some desirable characteristics of TFN are high pure water permeability (PWP) and salt rejection, chlorine resistance, antifouling and antibacterial properties (Zhao *et al.*, 2019; Tajuddin *et al.*, 2019; Li *et al.*, 2019; Gholami *et al.*, 2019; Wu, Xie and Mao, 2020).

To date, most TFN or TFC membranes are fabricated using the conventional interfacial polymerization (IP) technique. The conventional IP method uses a rubber roller or airbrush to remove any excess aqueous and/or organic solution. Recent studies have shown novel techniques such as filtration IP (Wu *et al.*, 2017; Lai *et al.*, 2019a), spin-assisted IP (Jimenez-Solomon *et al.*, 2016) and spray-assisted IP (Shan *et al.*, 2017; Morales-Cuevas *et al.*, 2019) method to replace the rubber rolling step. These studies have shown that novel techniques indeed are more advantageous compared to conventional IP method. As such, the mist-based IP technique in this study works by distributing monomer solutions as fine mist particles using ultrasonic atomization technology (Shehata *et al.*, 2019). The method is also able to significantly reduce chemical wastage. The physicochemical property of PA layer is largely affected by its reaction temperature. Ali *et al.* (2019) reported that a lower reaction temperature could form a smoother membrane surface in TFC RO membrane fabrication. Therefore, besides the use of mist-based IP technique, the temperature of organic solution will be varied in this study to investigate its effect on PA layer properties in a bid to produce TFC/TFN NF membrane with enhanced filtration and antifouling performance.

Some of the nanomaterials that have been incorporated in TFC NF membranes are carbon-based nanomaterials such as graphene oxide (GO) (Shao *et al.*, 2019; Kang *et al.*, 2019), metal oxide such as titanium oxide (TiO_2) (Ng *et al.*, 2019; Ahmad *et al.*, 2020) and hybrid nanomaterials such as ZIF-8/CNT and TiO_2/GO (Sirinupong *et al.*, 2017; Lee *et al.*, 2019b). In particular, GO is an attractive nanomaterial to study due to its high hydrophilicity and negative charge owing to the presence of multiple oxygen-containing functional groups. Additionally, the high aspect ratio could increase the active surface area as well as minimise leaching issues. Incorporation of this nanomaterial has been shown to improve membrane pure water permeability

(PWP) while maintaining high salt rejection (Lai *et al.*, 2018; Zhao *et al.*, 2018; Abbaszadeh, Krizak and Kundu, 2019; Saeedi-Jurkuyeh *et al.*, 2020). However, nanomaterial agglomeration and compatibility issues are still the major concerns of TFN membrane fabrication.

GO modified by hydrophilic functional groups or coatings can help reduce agglomeration in TFN membranes (Shukla *et al.*, 2018). However, current liquid-based surface modification methods are less likely to produce uniform layer on the surface of nanomaterials and are associated with the use of hazardous solvents (Lai *et al.*, 2019b). As such, the rapid yet solvent-free plasma-enhanced chemical vapour deposition (PECVD) is selected in this study. PECVD technique used in this study will form pure thin films on a substrate through the vaporization and polymerization of monomers without any carrier gas, eliminating any contaminants. There are several studies which performed nanomaterial modification using PECVD method (Subramaniam *et al.*, 2019; Ng *et al.*, 2019; Lai *et al.*, 2019b). Nevertheless, hydrophilic acrylic acid (AA) and hydrophobic methyl methacryate (MMA) are yet to be used to modify GO. In this study, two different monomers (AA and MMA) will be coated on the GO to examine its effect on membrane properties.

Here, the characterization of GO nanosheets will be carried out to determine their chemical composition, crystallinity, dispersibility and structural morphology. Then, the resultant composite membranes will be analysed based on their structural morphology, wettability, chemical composition and cross linking degree. Finally, the evaluation of membrane performance will be conducted with respect to water permeability, salt rejection, water-salt permselectivity, stability, leaching and antifouling properties.

1.2 Problem Statement

The commonly used methods to fabricate TFC NF membranes are phase inversion for microporous substrate fabrication and IP technique for selective PA layer synthesis. However, there are difficulties in forming membranes with good monomer distribution using these conventional techniques. As such, modified IP techniques have been implemented in fabricating TFC/TFN membranes with superior performance (Morales-Cuevas *et al.*, 2019; Shen *et al.*, 2019; Kang *et al.*, 2020). Although many innovative IP approaches have been discovered, they typically involve complex fabrication procedures and are difficult to implement into existing manufacturing process. Additionally, they face major the chemical wastage issues, not unlike the conventional IP procedure, which presents itself in the form of contaminated aqueous and organic monomers. Therefore, this study proposes a novel mist-based IP technique which has not been reported in any work. Compared to conventional IP, the chemical used in mist-based IP will be dramatically reduced through the deposition of fine mist on the substrate surface.

Another concern is the trade-off relationship between water permeability and membrane selectivity that have halted the advancement of conventional TFC NF membranes for industrial applications (Akther *et al.*, 2019). In terms of performance, the commercial TFC NF membranes (e.g., NF3 and NF270) were reported to exhibit ~15 $L/m^2 \cdot h \cdot bar$ PWP and ~97% $MgSO_4$ rejection. To resolve this complication, research on the integration of nanomaterials or nanofillers have been conducted on TFC membranes. The incorporation of nanomaterials can help to alter the membrane's physicochemical properties such as its hydrophilicity, surface charge, structure and strength. Therefore, the suggestion of incorporating GO into NF membrane to minimize this trade-off effect is a valid approach owing to its high aspect ratio and hydrophilic characteristics.

Although GO is highly hydrophilic, it is difficult to fully disperse the nanomaterial without prior modification. As such, many studies have performed modification to increase the hydrophilic functional groups on GO (Li *et al.*, 2017; Kang *et al.*, 2019). However, these methods typically involve multi-step synthesis procedures and hazardous chemicals. Therefore, this study suggests to modify GO nanosheets using hydrophilic AA and hydrophobic MMA via surface coating by a rapid approach based on PECVD method. Besides being able to form uniform and thin layer to improve GO dispersability, PECVD technique is also more environmentally friendly compared to other coating methods as it does not require any organic solvents during synthesis and post-treatment.

Previous studies on RO membranes have shown that a lower organic solution temperature results in a smoother, looser and thinner PA layer due to the lowered reaction volatility (Ali *et al.*, 2019). The thinner PA layer could enhance water permeability while membrane smoothness have been closely regarded as a desirable property for good antifouling performance, since foulants would not be entrapped on the membrane surface (Zhu *et al.*, 2020; Le *et al.*, 2021). Importantly, temperature-controlled IP process could be integrated into existing manufacturing processes with ease. However, there is limited literature on the effect of IP reaction temperature for TFC/TFN NF membranes in particular. As such, the fabrication of PA layer at low temperature for TFN NF membrane in this study is most likely to obtain a smoother membrane that could significantly improve its antifouling property.

This study aims to improve the performance of nanomaterial-modified membrane in terms of separation performance and antifouling ability. To the best of my knowledge, no study has shown the performance of PECVD-modified GO TFN membrane that is fabricated using mist-based IP method for NF applications.

1.3 Objectives of Study

The aim of this research is to develop a novel PECVD-modified TFN GO NF membrane with high performance using mist-based IP technique for NF process. In particular, the objectives of this work are:

1. To determine the filtration performance of TFC NF membranes made of novel mist-based IP technique by varying fabrication conditions including piperazine (PIP) misting time and trimesoyl chloride (TMC) concentration.
2. To evaluate the impact of different coatings (hydrophilic AA and hydrophobic MMA) on the surface of GO and its loading on the surface properties and

filtration performance of TFN NF membranes made via optimized mist-based IP conditions obtained from Objective 1.

3. To analyse the effects of organic solution temperature during IP process on the surface properties and separation performance of TFN NF membranes.

1.4 Scopes of Study

In order to successfully achieve the objectives of this research, the following scopes are determined:

Scopes for Objective 1

a) Determining the fundamental mechanism of conventional IP and mist-based IP PA formation based on interfacial free energy driving force.
b) Developing a novel IP technique based on misting to optimize the performance of TFC membrane using commercial PS20 substrate [aqueous phase: 2 w/v% PIP; organic phase: 0.2 w/v% TMC] by varying misting time of aqueous solution only (1, 2, 3 and 4 min).
c) Developing novel IP technique based on obtained optimum misting time [aqueous phase: 2 w/v% PIP; aqueous misting time: 3 min] by varying concentration of organic solution (0.05, 0.10, 0.15 and 0.20 w/v% TMC).
d) Characterizing morphological and chemical properties of TFC membranes through field emission scanning electron microscopy (FESEM), energy dispersive X-ray spectroscopy (EDX), atomic force microscopy (AFM), transmission electron microscopy (TEM), attenuated total reflectance-Fourier transform infrared spectroscopy (ATR-FTIR), contact angle (CA) measurement and X-ray photoelectron spectroscopy (XPS).
e) Performing filtration performance tests at 8 bar pressure to measure PWP and salt rejection using Na_2SO_4 and NaCl at 1000 ppm.
f) Performing antifouling tests using 1500 ppm bovine serum albumin (BSA) solution for 3.5 h to measure normalized permeability and flux recovery ratio (FRR)

g) Identifying the best mist-based IP conditions based on the filtration performance of TFC membrane with respect to the optimum PIP misting time and TMC concentration.

Scopes for Objective 2

a) Synthesizing poly-AA and poly-MMA films using PECVD method.
b) Performing FTIR analysis on poly-AA and poly-MMA films.
c) Synthesizing GO using modified-Hummers' method.
d) Performing 5-min PECVD modification using AA and MMA on synthesized GO nanosheets.
e) Determining physicochemical properties of PECVD-modified GO using FTIR, X-ray diffraction (XRD), Tyndall effect, TEM and XPS.
f) Fabricating TFN membranes by incorporating 0.03 g/m^2 of GO, AA/GO or MMA/GO as an interlayer using vacuum filtration method, followed by PA synthesis via optimized mist-based IP conditions.
g) Characterizing the morphology and chemical properties of fabricated membranes through FESEM, AFM, CA measurement, ATR-FTIR, and XPS
h) Performing filtration performance tests at 8 bar pressure to measure PWP, and salt rejection using $NaSO_4$ and NaCl at 1000 ppm.
i) Identify the best TFN membrane based on the filtration performance with respect to the surface modification of GO.
j) Fabricating TFN membranes by incorporating 0, 0.02, 0.03 and 0.04 g/m^2 of AA/GO as an interlayer using vacuum filtration method, followed by PA synthesis via optimized mist-based IP conditions.
k) Characterizing the morphology and chemical properties of fabricated membranes through FESEM.
l) Performing filtration performance tests at 8 bar pressure to measure PWP and salt rejection using $NaSO_4$ and NaCl at 1000 ppm.
m) Identifying the best TFN membrane based on the filtration performance with respect to type of GO functionalization and its loading.

Scopes for Objective 3

a) Varying IP reaction temperature of the best TFN NF membrane fabricated using optimized mist-based IP conditions by varying the organic TMC solution temperature (0, 25, 35 and 55 °C).
b) Characterizing morphological and chemical properties of TFC membranes through AFM, FESEM, ATR-FTIR, XPS and CA measurement.
c) Performing filtration performance tests at 8 bar pressure to measure PWP, and salt rejection using Na_2SO_4 and NaCl at 1000 ppm.
d) Performing short-term stability test up to 12 h for selected TFN membranes using concentrated salt (Na_2SO_4) solution.
e) Analyzing the AA/GO leachate from TFN membranes for a 5-day agitation period.
f) Determining the antifouling performance of selected TFN membranes using static protein adsorption test and imaging membrane after 12 h fouling with confocal laser scanning microscope (CLSM, Leica TCS SP5 II). 3D images of the surface adhesion were generated using LAS AF Leica software.
g) Benchmarking the performance of self-developed TFN membranes with commercial NF membrane (NF3).
h) Identifying the best TFN membrane based on its filtration, stability, leaching and antifouling performance.

1.5 Significance of Study

Previous literature has shown that TFC/TFN membranes play a major role in desalination processes. Developing novel fabrication techniques is still crucial as it can further improve the structural morphology of TFC/TFN NF which leads to enhanced separation performance. Thus, a novel method to form looser PA layer with high free volume is highly sought after to enhance the membrane water permeability while maintaining high salt rejection. Although GO is a highly studied nanomaterial, there is still limited research on the surface modification of GO nanosheets using AA or MMA coating, in particular using rapid yet environmentally friendly PECVD approach. GO nanosheets with enhanced dispersibility could lead to enhanced filtration performance by preventing nanomaterial agglomeration issues. Finally, there is limited study on the effect of IP temperature in TFN NF membrane fabrication. By understanding the effect of temperature on membrane physical and chemical properties, NF membranes with desired properties could be fabricated by simply fine-tuning its fabrication temperature. The results from this study proved that a new technique can be used to overcome the disadvantages brought by conventional IP fabrication method to form TFN NF membrane with superior membrane integrity.

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LIST OF PUBLICATIONS

Publications

1. **Seah, M. Q**., Lau, W. J., Goh, P. S., Tseng, H., Wahab, R. A. and Ismail, A. F. (2020) Progress of Interfacial Polymerization Techniques for Polyamide Thin Film (Nano)Composite Membrane Fabrication : A Comprehensive Review, *Polymers (Basel).*, 12, 2817 **(Impact Factor: 4.329, Q1)**
2. **Seah, M. Q**., Khoo, Y. S., Lau, W. J., Goh, P. S. and Ismail, A. F. (2021) New Concept of Thin-Film Composite Nanofiltration Membrane Fabrication Using a Mist-Based Interfacial Polymerization Technique, *Ind. Eng. Chem. Res.*, 60(25), 9167–9178. **(Impact Factor: 3.720, Q2)**
3. **Seah, M. Q**., Lau, W. J., Goh, P. S. and Ismail, A. F. (2022) Greener synthesis of functionalized-GO incorporated TFN NF membrane for potential recovery of saline water from salt / dye mixed solution, *Desalination*, 523, 115403 **(Impact Factor: 9.501, Q1)**

Conferences

1. Regional Congress on Membrane Technology 2020 & Regional Conference Environmental Engineering 2020 (RCOM 2020 & RCENVE 2020) on 16-17th January 2021 in Johor Bahru, Malaysia (virtual)
2. Climate Change E-Colloquium 2021 on 3rd August 2021 in Putrajaya, Malaysia (virtual).
3. The 2nd International Conference of Sustainable Environmental Technology 2021 on 9-10th November 2021 in Johor Bahru, Malaysia (virtual)

Patents

1. Method of fabricating thin fim nanocomposite membrane having improved free volume and nanomaterials distribution for water treatment and article thereof. Application No.: PI2021003144. Filing Date: 4 June 2021 (Malaysia). Inventors: Lau Woei Jye, **Seah Mei Qun**, Goh Pei Sean, Ahmad Fauzi Ismail, Farhana Aziz, Mustafa Karaman, Mehmet Gürsoy

2. Method of preparing modified thin film composite membrane having improved surface hydrophilicity and antifouling properties for use in water treatment and assembly thereof. Application No.: PI2020007224. Filing Date: 31 Dec 2020 (Malaysia). Inventors: Lau Woei Jye, Khoo Ying Siew, **Seah Mei Qun**, Goh Pei Sean, Ahmad Fauzi Ismail, Mustafa Karaman, Mehmet Gürsoy, Ting Teo Ming