UNIVERSITI PUTRA MALAYSIA

SYNTHESIS AND CHARACTERIZATION OF POLYETHER SULFONE/ POLYETHYLENE GLYCOL / MONTMORILLONITE NANO MIXEDMATRIX MEMBRANE FOR REMOVAL OF PHOSPHATE FROM WATER

ALI BADERLDIN ABDELMILK ALANSARI

FS 2017 27

SYNTHESIS AND CHARACTERIZATION OF POLYETHER SULFONE/ POLYETHYLENE GLYCOL / MONTMORILLONITE NANO MIXED-MATRIX MEMBRANE FOR REMOVAL OF PHOSPHATE FROM WATER

By

ALI BADERLDIN ABDELMILK ALANSARI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science

May 2017

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the Degree of Master of Science

SYNTHESIS AND CHARACTERIZATION OF POLYETHER SULFONE/ POLYETHYLENE GLYCOL / MONTMORILLONITE NANO MIXED-MATRIX MEMBRANE FOR REMOVAL OF PHOSPHATE FROM WATER

By

ALI BADERLDIN ABDELMILK ALANSARI

May 2017

Chairman : Associate Professor Abdul Halim Abdullah, PhD
Faculty : Science

Eutrophication is one of the most problematic water pollution, caused by the high level of nutrients in water, mainly phosphate, which is due to the fertilizers runoff from the agricultural areas, as well as the untreated disposal of domestic and industrial wastewater into the environments. Besides, consuming high concentration of phosphate from drinking water can lead to various types of health diseases. Considering the adverse effects of phosphate pollution to human and environment, scientists and researchers had done numerous studies using different methods to remove phosphate from water, such as adsorption, extraction, flotation, precipitation, ion exchange, electro dialysis, membrane filtration and electrocoagulation.

Phosphate removal using membranes based on polyether sulfone (PES), with different ratios of organically modified montmorillonite (OMMT) nanoparticles and polyethylene glycol (PEG), prepared by phase inversion method was investigated. The hydrophilicity of prepared PES membranes was studied by water content and porosity measurements. FTIR and FESEM-EDX was used to study the chemical composition as well as to ensure the phosphate absorption by the membranes. Thermal properties of the membranes were investigated by TGA and DSC. While the morphology of the membrane investigated by FESEM. Performance of prepared membranes was determined in terms of the water flux and removal by changing conditions of pressure range 1 to 3 bar and pH form 2 to 10 as well as OMMT nanoparticles concentration 1 to 7 wt.%. It was observed that increase in pressure and OMMT nanoparticles loading is inversely proportional to the removal, and directly proportional to the water flux. Eleven different membranes, containing different ratios of PES, OMMT nanoparticles and PEG were sampled in order to prepare optimum membrane. At 1 bar pressure and 50 ppm phosphate concentration the neat PES membrane successfully achieved rejection of phosphate up to 97.6 % and water flux up to 2.26 L/m^2. h whereas the optimum membrane achieved rejection of phosphate up to 94.70%, water flux up to

49.2 L/m^2. h, and the optimum pH was pH 4. The experimental results revealed that the PES/OMMT/PEG could have a promising performance for the phosphate removal in wastewater treatment technology.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Master Sains

SINTESIS DAN PENCIRIAN MEMBRAN CAMPURAN NANO POLIETERSULFON/POLIETILENA GLIKOL/MONTMORILONIT DIUBAH SUAI SECARA ORGANIK BAGI PENGGUNAAN BERPOTENSI DALAM PENYINGKIRAN FOSFAT DARI AIR

Oleh

ALI BADERLDIN ABDELMILK ALANSARI

Mei 2017

Pengerusi : Profesor Madya Abdul Halim Abdullah, PhD
Fakulti : Sains

Eutrofikasi adalah salah satu punca pencemaran air yang paling bermasalah, oleh kerana kandungan nutrient yang tinggi, terutamanya fosfat, dimana ia disebabkan oleh tumpahan baja daripada kawasan pertamian, dan juga pembuangan sisa air tidak terawat daripada pihak industri dan tempatan ke alam sekitar. Tambahan lagi, pengambilan fosfat berkepekatan tinggi daripada air minuman boleh menjurus kepada pelbagai jenis penyakit pada kesihatan. Memandangkan kesan buruk pencemaran fosfat terhadap manusia dan alam sekitar, ahli-ahli sains dan para penyelidik telah menjalankan banyak kajian menggunakan kaedah yang berbeza untuk menyingkirkan fosfat dari air, seperti penjerapan, pengekstrakan, pengapungan, pemendakkan, pertukaran ion, dialisis elektro, penapisan membran dan pembekuan elektro.

Penyingkiran fosfat menggunakan membran berasaskan Polietersulfon (PES), dengan nisbah yang berbeza daripada partikel nano montmorrilonite terubasuai dergon bahan organik (OMMT) dan Polietilena glikol (PEG), yang disediakan dengan kaedah fasa penyongsangan telah dikaji. Kehidrofilikan membran PES yang disediakan telah dikaji menggunakan ukuran keliangan dan kandungan air. FTIR dan FESEM-EDX telah digunakan untuk mengkaji komposisi kimia dan juga untuk memastikan penyerapan fosfat oleh membran tersebut. Sifat haba membran telah dikaji menggunakan TGA dan DSC. Sementara itu morfologi membran telah dikaji menggunakan FESEM. Prestasi membran yang disediakan telah ditentukan dari segi penolakan dan fluks air dengan menukar tekanan dan keadaan pH serta kandungan partikel nano OMMT. Ia dapat diperhatikan bahawa peningkatan tekanan dan kandungan partikel nano OMMT adalah berkadar songsang dengan penolakan, dan berkadar terus dengan fluks air. Sebelas membran yang berbeza, yang mengandungi nisbah PES yang berbeza, partikel nano OMMT dan PEG telah disampel untuk menyediakan membran optimal. Pada tekanan 1 bar dan kepekatan fosfat 50 ppm,

membran PES kosong berjaya mencapai penyingkiran fosfat sehingga 97.6% dan fluks air sehingga 2.26 L/ m^2.h, manakala membran optimal mencapai penyingkiran fosfat sehingga 94.70%, fluks air sehingga 49.2 L/m^2.h, dan pH optimal adalah pH 4. Keputusan eksperimen menunjukkan bahawa PES/OMMT/PEG mampu menjanjikan prestasi yang baik untuk penyingkiran fosfat dalam teknologi rawatan air sisa.

ACKNOWLEDGEMENTS

At the beginning, all praise due to Allah, Lord of the worlds. Only by his Grace and Mercy this work has been completed and Insha Allah, it will be successful.

Throughout my research period, there are so many people who deserve appreciation and credit for their direct or indirect contribution to this work. First of all, the person who I respect most and deserve the most reverence expression is my supervisor, Associate Professor Dr. Abdul Halim Abdullah without his guidance; I cannot reach and achieve what I did. I appreciatively thank him for his kind help, great support, beneficial advice and valuable contributions during this project. I also highly appreciate his understanding, patience and motivation throughout my research period.

I also want to give my warm appreciation to my committee members. Associate Professor Dr. Nor Azowa Ibrahim and Associate Professor Dr Zurina Binti Zainal Abidin for their worthwhile suggestions, insights and great comments.

I wish to thank all the staffs of Faculty of Science for sharing their valued knowledge, and rigorous attitude toward scientific research and single out DR. Jaafar Abdullah, Ms. Zaidina Mohd Daud and Ms. Nurhidayu Jamaluddin. I also would like to thank all my beloved friends and lab mates for their unparalleled help, kindness and moral support, Zul Adlan Mohd Hir, Pourya Moradihamedani, Marliyn yuen , Ainisah bt Md Yunus, Mohd hazani mat zaid , Abubaker Umar, Pam Aloysius , Chan Siew Ling , Fozy Alfortas , Mohamed Ahmed and Nayma Asalmi .

I want to express my very sincere thanks and love to my wonderful family members for their support and prayers.

I certify that a Thesis Examination Committee has met on 2 May 2017 to conduct the final examination of Ali Baderldin Abdelmilk Alansari on his thesis entitled "Synthesis and Characterization of Polyether Sulfone/Polyethylene Glycol/Montmorillonite Nano Mixed-Matrix Membrane for Removal of Phosphate from Water" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

Members of the Thesis Examination Committee were as follows:

Thahira Begum, PhD
Senior Lecturer
Faculty of Science
Universiti Putra Malaysia
(Chairman)

Jaafar bin Abdullah, PhD
Senior Lecturer
Faculty of Science
Universiti Putra Malaysia
(Internal Examiner)

Lau Woei Jye (W.J. Lau), PhD
Senior Lecturer
Universiti Teknologi Malaysia
Malaysia
(External Examiner)

NOR AINI AB. SHUKOR, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 6 July 2017

This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

Abdul Halim Abdullah, PhD
Associate Professor
Faculty of Science
Universiti Putra Malaysia
(Chairman)

Nor Azowa Ibrahim, PhD
Associate Professor
Faculty of Science
Universiti Putra Malaysia
(Member)

Zurina Binti Zainal Abidin, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

____

ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software

Signature: ________________________________ Date: __________________

Name and Matric No: Ali Baderldin Abdelmilk Alansari, GS39831

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) were adhered to.

Signature: ______________________________
Name of Chairman of Supervisory Committee: Associate Professor Dr. Abdul Halim Abdullah

Signature: ______________________________
Name of Member of Supervisory Committee: Associate Professor Dr. Nor Azowa Ibrahim

Signature: ______________________________
Name of Member of Supervisory Committee: Associate Professor Dr. Zurina Binti Zainal Abidin

TABLE OF CONTENTS

		Page
ABSTRACT		i
ABSTRAK		iii
ACKNOWLEDGEMENTS		v
APPROVAL		vi
DECLARATION		viii
LIST OF TABLES		xii
LIST OF FIGURES		xiii
LIST OF ABBREVIATIONS		xv
CHAPTER		
1	**INTRODUCTION**	1
	1.1 Background of research	1
	1.2 Problem statement	3
	1.3 Objectives	5
2	**LITERATURE REVIEW**	6
	2.1 Biological method	6
	2.2 Electrocoagulation method	7
	2.3 Adsorption	8
	2.4 Chemical precipitation	9
	2.5 Membrane processes	11
	2.5.1 Ultrafiltration by polymeric membranes	11
	2.5.2 Reverse osmosis (RO)	11
	2.5.3 Electro dialysis ion exchange membrane	12
	2.5.4 Donnan dialysis	14
	2.6 Membrane process	15
	2.6.1 Classification of membranes	16
	2.6.2 Classification based on membrane materials	17
	2.6.3 Classification based on morphology and structure	17
	2.6.4 Classification depending on manufacturing process	19
	2.6.4.1 Tubular Form Membranes	19
	2.6.4.2 Flat Sheet Membranes	19
	2.6.5 Membrane separation process	22
	2.6.5.1 Other membrane separation process	24
	2.6.6 Preparation of membrane	25
	2.6.6.1 Phase inversion	26
	2.7 Polyether sulfone nanocomposites membranes	28
	2.7.1 Preparation and Application of Polyether sulfone and Polyethersulfone Nanocomposites Membranes in water treatment	29
	2.8 Membrane fouling	31
3	**METHODOLOGY AND EXPERIMENTAL SET-UP**	34
	3.1 Materials	34
	3.2 Instrumentation	35

	3.3	Membrane preparation	36
	3.4	Membrane Characterization	40
		3.4.1 Water flux	40
		3.4.2 Membrane water content Porosity	40
		3.4.3 Morphology Field Emission Scanning Electron Microscope (FESEM)	40
		3.4.4 Fourier Transform Infrared Spectroscopy (FT-IR)	41
		3.4.5 Thermogravimetric Analysis (TGA) and Differential Scanning Calorimetry Analysis (DSC)	41
		3.4.6 Removal of phosphate	41
4	**RESULTS AND DISCUSSION**		43
	4.1	Initial water flux and removal percentage	43
	4.2	Effect of transmembrane pressure	46
	4.3	Effect of membrane thickness	47
	4.4	Removal of Phosphate	52
		4.4.1 Effect of phosphate concentration	52
		4.4.2 Effects of pH	53
		4.4.3 Effect of operating time	54
	4.5	Characterization of the membrane	56
		4.5.1 Fourier Transform Infrared Spectroscopy (FTIR)	56
		4.5.2 Thermogravimetric Analysis (TGA)	57
		4.5.3 Differential Scanning Calorimetry Analysis (DSC)	58
		4.5.4 Water content and porosity	59
		4.5.5 Field Emission Scanning Electron Microscopy (FESEM)	60
		4.5.6 Energy dispersive X-ray analysis (EDX)	63
5	**CONCLUSION AND RECOMMENDATIONS**		64
	5.1	Conclusions	64
	5.2	Recommendations	65
REFERENCES			66
APPENDICES			77
BIODATA OF STUDENT			79

LIST OF TABLES

Table		Page
2.1	Characteristic values, applications, advantages and disadvantages of module types with tubular membranes	21
2.2	Characteristic values, applications, advantages disadvantages of module types with flat sheet membranes.	22
2.3	Comparison between Hollow Fiber membranes and flat sheet membranes	22
2.4	Overview of membrane separation processes	23
2.5	Classification of pressure driven membrane processes	23
2.6	Characteristic features of pressure driven membrane separation processe	24
2.7	Membrane preparation techniques	25
2.8	commonly preparation methods used to prepare polymeric membranes for water treatment processes.	26
3.1	Compositions of the casting solutions for the preparation of the membrane.	37
4.1.a	Effect membrane thickness on the water flux and the removal percentage of phosphate	49
4.1.b	Effect membrane thickness on the water flux and the removal percentage of phosphate	50
4.2	The effect of feed concentration on phosphate removal	52
4.3	DSC analyses data of the prepared Membranes	59

LIST OF FIGURES

Figure		Page
1.1	The phosphorus cycle	2
2.1	The principle of electrodialysis	13
2.2	Schematic diagram of the lab of scale selective ion exchange membranes ED system	14
2.3	Schematic diagram of phosphate removal by Donnan dialysis with anion.exchange membrane (AEM).	15
2.4	Illustration of a membrane process	16
2.5	Detailed classifications of membranes.	17
2.6	Demonstrates two different types of membrane strucutres, symmetric and asymmetric.	18
2.7	Morphological and structural classification of membranes	19
2.8	Illustration of membrane preparation process via phase inversion method	27
2.9	Schematic representation of three dry.wet separation processes.	27
2.10	Ternary phase diagram for the phase inversion process through immersion precipitation	28
2.11	Illustration of concentration polarization, which leads to the first phase of flux loss during membrane filtration.	32
3.1	The structures of chemicals used for the preparation of membrane.	34
3.2	Schematic diagram of the experimental setup for phosphate removal	36
3.3(A)	Schematic diagram for the preparation of PES, PES-PEG and PES-OMMT	38
3.3(B)	Schematic diagram for the preparation of PES-PEG-OMMT membrane.	39
3.4	Illustration of the research framework	42

4.1	Water fluxes of 80 µm thick neat PES and PES membranes containing various amount of OMMT	44
4.2	Water fluxes of 80 µm thick neat PES and PES membranes containing various amount of PEG	45
4.3	Phosphate removal by neat PES and PES/OMMT membranes	46
4.4	Phosphate removal by neat PES and PES/PEG membranes	46
4.5	Percentage of phosphate removal by PES/PEG 2%/OMMT5% membrane compared with Percentage of phosphate removal by previous prepared membranes	51
4.6	PES/PEG 2%/OMMT5% membranes water fluxes compared with previous prepared membranes	51
4.7	pH effect on Phosphate removal by PES/PEG 2%/OMMT 5% membrane	53
4.8	The dependence of the concentrations for different ionic components and the ionic strength on the pH.	54
4.9	Effect of operating time on water flux	55
4.10	Effect of operating time on phosphate removal	55
4.11	Fourier transform infrared spectra of selected fresh membranes and used PES membrane (PES*) after filtration.	57
4.12	TGA graph of PES five prepared membranes.	58
4.13	Water content and porosity of all prepared membranes	60
4.14	FESEM analysis of prepared membranes with different ratio of OMMT and PEG in casting solution	62
4.15	Energy dispersive X-ray analysis (EDX)	63

LIST OF ABBREVIATIONS

ABPBI	Poly (2, 5-benzimidazole)
AM	anion exchange membranes
ASP	Activated Sludge Process
BPA	bisphenol A
CA	cellulose acetate
CM	standard cation exchange membranes
COD	Chemical Oxygen Demand
Da	Dalton
DETA	Diethylenetriamine
DMF	N, N-dimethyl formamide
DNP	dinitrophenol
DNSA	dinitrosalicylic acid
DSC	Calorimetry Analysis
EBPR	Enhanced Biological Phosphorus Removal
EC	Electro-coagulation
EDX	dispersive X-ray analysis
EPS	Extracellular Polymeric Substances
FESEM	Field Emission Scanning Electron Microscopy
FTIR	Fourier Transform Infrared Spectroscopy
HNT	halloysite nanotube
HSA	human serum albumin
MMMs	mixed matrix membranes
MMT	Na-montmorillonite

MVA	monovalent selective anion exchange membranes
NA	Nafion
NMP	N-methyl-2-pyrrolidone
NP	nitro phenol
OLR	organic loading rates
OMMT	organically modified montmorillonite
OSP	oyster shell powder
PA	polyamide
PAN	polyacrylonitrile
PBI	Polybenziimidazoline
PC	polycarbonate
PE	Polyethylene
PEEK	Polyetheretherketone
PEG	polyethylene glycol
PEI	polyetherimide
PES	Polyether sulfone
PLSN	Polyether sulfone layered silicate nanocomposites
PMMA	polymethyl methacrylate
PP	Polypropylene
PPO	polydimethyl phenylene oxide
PPSu	polyphenylsulfone
PSf	Polysulfone
PTFE	Poly(tetrafluorethylene)
PVA	Poly vinyl alcohol
PVDF	polyvinylidene fluoride

PVP	polyvinylpyrrolidone
RO	Reverse Osmosis
SED	selectrodialysis
TFNC	Thin-film nanofiltration composite
TGA	Thermogravimetric Analysis
UF	ultrafiltration
ZCB	Zirconium-Modified Chitosan

CHAPTER 1

INTRODUCTION

1.1 Background of research

Increased in human population has triggered food demand globally, and this influences productivity in agro-allied industries for food supply in meeting the demand of the populace. Hence, untreated industrial waste is released to the environment as a result of urbanization, industrialization, and agricultural activities which enhance environmental pollution and disrupt ecosystem. Polluted water when consumed may cause hormonal imbalance which depends greatly on physiochemical characteristics and quantity of pollutants discharged. Two types of water pollution were identified, the point and non-point source pollution. When comparing both types of pollution, the point source pollution is known to have fixed sources of pollutants which are emitted in large amount, while the non-point pollution consists of mobile sources of contaminants which are discharged in low quantity. The pollution from the point sources is often detected and treated easily. Meanwhile, the emission of the pollutants from the non-point sources is difficult to be traced and controlled such as discharge of untreated municipal waste water from factories and the domestic wastes like human and animal excretion, food bodies and household garbage are sources of phosphates respectively *(*Sharpley *et al.,*1999) .

Phosphate is among lethal pollutants which affects surface and groundwater, the phosphate pollutants spread easily within ecosystem.

Phosphorus is found as phosphate (PO_4^{3-}) in nature and present as orthophosphate, polyphosphate and organic phosphate in water. Orthophosphates are usually applied to agricultural or residential land as fertilizer, which will then be carried into surface waters with storm runoff and melting snow. In addition, phosphates can also be found in various consumer products such as water softeners, baking powders, pharmaceuticals, cured meats, toothpastes, soft drinks, processed cheeses and evaporated milk. In addition, phosphate is also found abundantly in the wastewater from laundering agents for examples shampoo and detergents (Köhler, 2006).

The three main sources of phosphorus are livestock waste, human waste and agricultural fertilizers. Phosphates can be effectively removed by the restriction of phosphates in household detergents, the installation of sewage collection and the treatment of waste water in sewage plants (Köhler, 2006) . Phosphorus is typically the constraining supplements in the environment. The phosphorus cycle as shown in Figure 1-1.

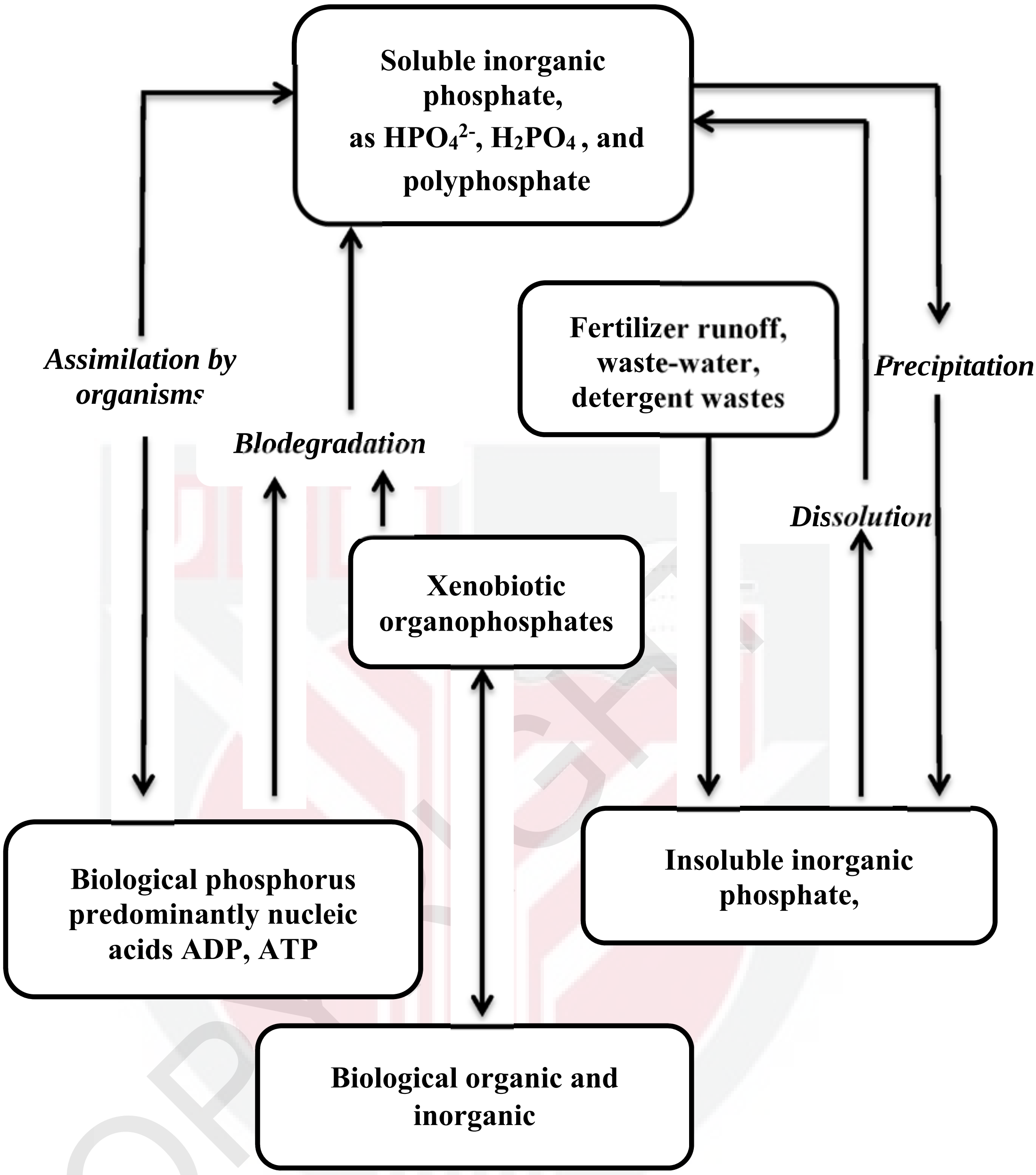

Figure 1.1 : The phosphorus cycle

The phosphorus cycle is endogenic, as there are no common stable gaseous forms of phosphorus in nature. In the geosphere, phosphorus exists in insoluble inorganic form such as hydroxyapatite (calcium salts) or iron phosphates. Following that, the soluble phosphorus from phosphate minerals and fertilizers is absorbed by the plant roots and incorporated into nucleic acid which is an essential component of genetic materials. Subsequently, the phosphorus is returned to soil by mineralization of biomass through microbial decay process and atmospheric precipitation of soluble inorganic phosphate.

Malaysian researchers were concern on issues arise from the phosphate and nitrate pollution as a results of agricultural activities, ten years ago (2006) there was a study conducted to determine the concentration of both nitrate and phosphate in rivers and wells of nine (9) states in Peninsular of Malaysia (Ikhtiar et al., 2007).

The experimental data established that the states other than Kedah, Selangor and Terengganu have river waters which are slightly contaminated phosphate. Based on Department of Environment in national water quality standard in Malaysia, the level measurement to discharge phosphate is 0.2 mg/L.

1.2 Problem statement

Water is an invaluable natural asset crucial to guarantee the satisfactory advancement of human life. However, some number of factors can lead to readily lack of accessible safe drinking water in various regions globally (van Rooijen *et al.,* 2010; Postel *et al.,* 1996). These factors can mostly be placed into one of two main groups – factors related to changes in the earth's climate and factors related to pollution. Moreover, worldwide 80% of the used water is neither collected nor treated (Corcoran *et al.,*2010).

It has been proposed that the changes in the earth's climate (due to mostly combustion of fossil fuels) have a negative impact on water resources around the world (Lockwood *et al.,* 2010; Gambhir *et al.,* 2010). These changes have led to a change in chemistry water and increasing in drought periods, water temperatures and floods, an approximately 29% decrease in annual maximum daily stream-flow has been reported to be due to increased temperatures and increased evaporation (Smith *et al.,* 2011; Rieman *et al.,* 2007; Regonda *et al.,* 2005). Ground water recharge rates and depths have also been greatly affected. Floods have been shown to have negative influences on the contamination of surface and ground water and water shortage (Legates *et al.,* 2005; Lettenmaier *et al.,* 1999).

Poor water quality is a close crisis notwithstanding the general water deficiency in numerous parts in the world. Almost 2.2 million people are dying, mostly children under the age of five due to scarcity of clean water for drinking (Corcoran *et al.,* 2010).

Although the reasons for why there is water shortages in various regions of the world vary, the one thing that a number of towns and/or cities located in such regions have in common is the lack of adequate processes for generating sufficient quantities of safe drinking water. Meeting of the growing demands for safe drinking water imposes a huge requirement to develop effective and economic technologies for water treatment (Butt *et al.*,2005).

The potential sources identified for reuse are industrial effluents, domestic waste water and rain water, numerous applications for domestic waste water reuse are toilet flushing, car washing, green landscapes irrigation, firefighting and cooling operations carried out by water (Asano *et al.,* 1996).

There is a large amount of phosphate, which is extracted from the phosphate compounds form industrial chemicals, fertilizer, and food additives. Phosphorus is also a constituent to highly degree poisonous compounds , such as military poison nerve gaze and insecticides (Manahan, 2000). Phosphorus is key to the development of natural life forms, including both their metabolic and photosynthetic processes. Phosphates is essential nutrients for plant growth, hence it is widely used in the manufacture of fertilizers. The high concentration of phosphate in wastewater effluents and from agricultural runoff will result in the increase of nutrients levels in water. This will stimulate extensive phytoplankton growth and causes algal blooms, which then disrupts the normal aquatic ecosystem functioning. The huge population of algae will use up all the dissolved oxygen in the water, disturb any flora and fauna to live. Besides, the massive lumps of algae also block sunlight from penetrate through the water for the photosynthesis of aquatic plants. This is called the eutrophication phenomenon. Eutrophication destroy water quality such as high turbidity, low oxygen concentration, unpleasant odour and bad flavour (Sharpley *et al.,* 1999).

A wide range of water treatment methods have been used for wastewater treatment Including phosphate removal. They can be divided into mechanical, thermal, biological, chemical and physical processes. A selection of a certain wastewater treatment technique depends on many aspects, such as type of wastewater, cost, available space, lifetime, and the need for chemical additive(s)(Sarkar *et al.,* 2006). Examples of mechanical wastewater treatments are the use of settlers, filters and sieves. Settlers for example are used to separate components on the basis of a difference in density between the components and water (e.g. sedimentation of sand, degumming of oil). This technique is sometimes supported by adding chemical compounds (coagulants, flocculants) to increase the rate of settling. Examples of thermal treatments are evaporation and distillation techniques. A drawback of these techniques is their very high energy consumption, which is required to evaporate the water. Biological treatment is carried out by using biological aerated filters, sequencing batch reactors and rotating biological contractors. The main drawbacks of these conventional processes are: treatment process time, extensive testing before treatment, monitoring throughout treatment, difficulties in controlling the processes and high operating and capital costs.

Physical water treatment processes, which essentially consist mostly of membrane based processes, have received significantly increased interest over the last few decades.

Membrane technology differentiate mixtures of membranes labour-like filter. Hence, materials filtered were not physically, chemically or biologically affected (Humpert *et al.,* 2016). Globally, the domain of application of membrane technology became more and more wide, this increase can be assigned to stringency of water quality that inefficiently met by conventional treatment methods which can intensify retention of coagulates and micro-organisms removal. Membrane processes has been used in drinking water treatment. Membranes are available in different forms for wastewater treatment which include biological oxidation as a hybrid system called Membrane Bioreactor (MBR) (Vincenzo, 2012). Some of the advantages of membrane is that, low-pressure membrane filtration processes highly effective in removal of suspended matters and smaller footprints such as microfiltration (MF) and ultrafiltration (UF), these are widely used in portable water purification of suspended solids and pathogens (Guo *et al.,* 2014).

The pressure difference between feed side and permeate side, produce driving force for the separation process which called transmembrane pressure (Wijmans & Baker, 1995). Membrane selectivity and capacity are essential in ensuring effectiveness of membrane. Selectivity of membrane clarifies its ability in separation of elements and compounds of a mixture also differentiate phases. Effectiveness of a membrane can be described by calculating permeate flow under specific operational conditions. Permeability is an important factor of a membrane which can be determined by calculating flow of permeate, it is described as quotient of flow and transmembrane pressure the quotient from flow and the accompanying transmembrane pressure. The main drawback of polymeric membrane is fouling. To mitigate the fouling of membrane and to make the membrane anti-fouling or fouling resistant, various inorganic metal/metal oxide or carbon-based nanoparticles have been used in polymeric membranes because of the properties such as hydrophilicity, anti-fouling, self-cleaning, photocatalytic, photodegradation, etc. Different membranes can be tailored with some or all of these properties but the overall effect should be prevention in fouling. Inorganic materials like alumina, zirconia, silica, etc. mostly used as fillers, improved the performance of membrane process by enhancing the permeate flux, increasing the salt removal and improving the thermal, chemical and mechanical stability. However, due to large size of these particles, their use was limited to MF and UF, which requires membranes of pore size 0.1 micron and 0.01 micron, respectively. With the development in the field of novel materials with at least one dimension in nano-range, the scope of application of inorganic materials was extended to NF as well as RO. Nanoparticles used for membrane modification are mostly metal and metal oxide. (Jhaveri *et al.,* 2015).

1.3 Objectives

The main objective of this research is to employ PES/PEG/OMMT matrix membrane for the removal of phosphate from water.

The specific objectives include:

1- To prepare and characterize Neat PES membrane
2- To modify neat PES membrane with OMMT and PEG
3- To study the removal of phosphate from the wastewater using the PES, PES-OMMT, PES-PEG and PES-PEG-OMMT nanocomposites membranes.

REFERENCES

Ahmad, M. Bin, Gharayebi, Y., Salit, M. S., Hussein, M. Z., & Shameli, K. (2011). Comparison of In Situ polymerization and solution-dispersion techniques in the preparation of Polyimide/Montmorillonite (MMT) Nanocomposites. *International Journal of Molecular Sciences*, 12(9), 6040–6050.

Ali, N., Mohammad, A. W., Jusoh, A., Hasan, M. R., Ghazali, N., & Kamaruzaman, K. (2005). Treatment of aquaculture wastewater using ultra-low pressure asymmetric polyethersulfone (PES) membrane. *Desalination*, 185(1–3), 317–326.

Amirilargani, M., & Mohammadi, T. (2009). Effects of PEG on Morphology and Permeation Properties of Polyethersulfone Membranes. *Separation Science and Technology*, 44(16), 3854–3875.

Amirilargani, M., Sadrzadeh, M., & Mohammadi, T. (2010). Synthesis and characterization of polyethersulfone membranes. *Journal of Polymer Research*, 17(3), 363–377.

Anadão, P., Sato, L. F., Wiebeck, H., & Valenzuela-díaz, F. R. (2010). Applied Clay Science Montmorillonite as a component of polysulfone nanocomposite membranes. *Applied Clay Science*, 48(1–2), 127–132.

Arkhangelsky, E., & Gitis, V. (2008). Effect of transmembrane pressure on rejection of viruses by ultrafiltration membranes. *Separation and Purification Technology*, 62(3), 619–628.

Asano, T., Maeda, M., & Takaki, M. (1996). Wastewater reclamation and reuse in Japan: Overview and implementation examples. *Water Science and Technology*, 34(11), 219–226.

Basri, H., Ismail, A. F., & Aziz, M. (2011). Polyethersulfone (PES)-silver composite UF membrane: Effect of silver loading and PVP molecular weight on membrane morphology and antibacterial activity. *Desalination*, 273(1), 72–80.

Buonomenna, M. G., Macchi, P., Davoli, M., & Drioli, E. (2007). Poly(vinylidene fluoride) membranes by phase inversion: the role the casting and coagulation conditions play in their morphology, crystalline structure and properties. *European Polymer Journal*, 43(4), 1557–1572.

Butt, M. S., Sharif, K., Bajwa, B. E., & Aziz, A. (2005). Hazardous effects of sewage water on the environment: Focus on heavy metals and chemical composition of soil and vegetables. *Management of Environmental Quality: An International Journal*, 16(4), 338–346.

Cao, F., Bai, P., Li, H., Ma, Y., Deng, X., & Zhao, C. (2009). Preparation of polyethersulfone-organophilic montmorillonite hybrid particles for the removal of bisphenol A. *Journal of Hazardous Materials*, 162(2), 791–798.

Chakrabarty, B., Ghoshal, A. K., & Purkait, M. K. (2008). Effect of molecular weight of PEG on membrane morphology and transport properties. *Journal of Membrane Science*, 309(1–2), 209–221.

Chen, S. Y., Shi, Z., Song, Y., Li, X. R., & Hu, Y. L. (2014). Phosphate removal from aqueous solution by Donnan dialysis with anion-exchange membrane. *Journal of Central South University*, 21(5), 1968–1973.

Corcoran, E., Nellemann, C., Baker, E., Bos, R., Osborn, D., Savelli, H. (2010). Sick water? The central role of wastewater management in sustainable development: a rapid response assessment. *United Nations Environment Programme,UN-HABITAT, GRID-Arendal. www.grida.no Page:* 88

Dalla Costa, R. F., Klein, C. W., Bernardes, A. M., & Ferreira, J. Z. (2002). Evaluation of the electrodialysis process for the treatment of metal finishing wastewater. *Journal of the Brazilian Chemical Society*, 13(4), 540–547.

Davey, C.J.; Leak, D.; Patterson, D.A.(2016).Hybrid and Mixed Matrix Membranes for Separations from Fermentations. *Membranes*, 6(1), 17.

El-gendi, A. T. A. E. (2015). Phase Diagram and Membrane Desalination book edited by Robert Y. Ning, ISBN 978-953-51-2189-3, Published: October 28, 2015 under CC BY 3.0 license.

El-Naas, M. H., Al-Zuhair, S., Al-Lobaney, A., & Makhlouf, S. (2009). Assessment of electrocoagulation for the treatment of petroleum refinery wastewater. *Journal of Environmental Management*, 91(1), 180–185.

Elahi, S. H., & Escobar, I. C. (2011). Investigation of the Effects of Thickness and Presence of Pore Formers on Tailor-Made. *Modern Applications in Membrane Science and Technology* , 16(1), 271-283.

Eren, B., Aydin, R., & Eren, E. (2013). Synthesis, characterization, and performance of a benzimidazole-based membrane in removal of phosphate: First lab-scale experimental results. *Journal of Materials Science*, 48(21), 7456–7465.

Erniza, M. J. J., & Low, S. C. (2014). Chromium (III) removal by epoxy-cross-linked polyethersulfone ultrafiltration membrane. *Jurnal Teknologi (Sciences and Engineering)*, 70(2), 19–22.

Fan, Y. (2016). A new route for the fabrication of TiO_2 ultrafiltration membranes with suspension derived from a wet chemical synthesis suspension derived from a wet chemical synthesis, *Journal of Membrane Science*. 270 (1), 179–186.

Fernandes, K. S., Alvarenga, E. A., Brandão, P. R. G., & Lins, V. F. C. (2011). Infrared-spectroscopy analysis of zinc phosphate and nickel and manganese modified zinc phosphate coatings on electrogalvanized steel. *Rem: Revista Escola de Minas*, 64(1), 45–49

Gambhir, A., Dixit, S., Toro, V., Singh, V., Ramachandra, T. V., Jain,. (2010). A Guide to PV System Design and Installation. *Solar Energy*, 44(5), 1–5.

Ghaemi, N., Madaeni, S. S., Alizadeh, A., Rajabi, H., & Daraei, P. (2011). Preparation , characterization and performance of polyethersulfone / organically modified montmorillonite nanocomposite membranes in removal of pesticides. *Journal of Membrane Science*, 382(2), 135–147.

Ghernaout, D., Badis, A., Kellil, A., & Ghernaout, B. (2008). Application of electrocoagulation in Escherichia coli culture and two surface waters. *Desalination*, 219 (3), 118–125.

Griffioen, J., Anthony, C. (1993). Nature and extent of carbonate precipitation during aquifer thermal energy storage. *Applied Geochemistry* ,8 (1) ,161–176.

Guillen, G. R., Pan, Y., Li, M., & Hoek, E. M. V. (2011). Preparation and characterization of membranes formed by nonsolvent induced phase separation: A review. *Industrial and Engineering Chemistry Research*, 50(7), 3798–3817.

Guo, H., Wyart, Y., Perot, J., Nauleau, F., & Moulin, P. (2010). Low-pressure membrane integrity tests for drinking water treatment: A review. *Water Research*, 44(1), 41–57.

Hir, Z. A. M., Moradihamedani, P., Abdullah, A. H., & Mohamed, M. A. (2017). Immobilization of TiO_2 into polyethersulfone matrix as hybrid film photocatalyst for effective degradation of methyl orange dye. *Materials Science in Semiconductor Processing*, 57, 157–165.

Hoon, C. H. U. I.(2013). The removal methods of phosphorus/phosphate and nitrogen/nitrate from water and wastewater. (Master's thesis, school of arts and science tunku abdul rahman college kuala lumpur). Retrieved from : *http://www.researchgate.net/publication/235898906*

Huang, J., Zhang, K., Wang, K., Xie, Z., Ladewig, B., & Wang, H. (2012). Fabrication of polyethersulfone-mesoporous silica nanocomposite ultrafiltration membranes with antifouling properties. *Journal of Membrane Science*, 423(1), 362–370.

Hui, B., Zhang, Y., & Ye, L. (2014). Preparation of PVA hydrogel beads and adsorption mechanism for advanced phosphate removal. *Chemical Engineering Journal* 235 (1), 207–214.

Humpert, D., Ebrahimi, M., & Czermak, P. (2016). Membrane Technology for the Recovery of Lignin: A Review. *Membranes*, *6* (3), 42.

Idris, A., Mat, N., & Noordin, M. Y. (2007). Synthesis , characterization and performance of asymmetric polyethersulfone (PES) ultrafiltration membranes with polyethylene glycol of different molecular weights as additives. *Desalination*, 207(1), 324–339.

Ikhtiar, K., Hidayat, U., & Mohammad, I. (2007). Nitrate and phosphate pollution in surface and ground water in Western Malaysia. *Journal of the Chemical Society of Pakistan*, 29(4), 315–320.

Ismail, A. F., & Hassan, A. R. (2007). Effect of additive contents on the performances and structural properties of asymmetric polyethersulfone (PES) nanofiltration membranes. *Separation and Purification Technology* ,55 (1), 98–109.

Jhaveri, J. H., Murthy, Z. V. P., Jhaveri, J. H., & Murthy, Z. V. P. (2015). Nanocomposite membranes Nanocomposite membranes, *Desalination and Water Treatment* ,3994, 1–17.

Kc, K., Cy, F. Membrane Characterisation. *Water and Wastewater Treatment Technologies, in Encyclopedia of Life Support Systems (EOLSS), Developed under the Auspices of the UNESCO*. Retrieved from http://www.eolss.net

Keating, C., Chin, J. P., Hughes, D., Manesiotis, P., Cysneiros, D., Mahony. (2016). Biological phosphorus removal during high-rate, low-temperature, anaerobic digestion of wastewater. *Frontiers in Microbiology*, 1–14.

John W O'Flaherty, Vincent. (2016). Biological phosphorus removal during high-rate, low-temperature, anaerobic digestion of wastewater. *Frontiers in Microbiology*, 7(1), 1–14.

Khulbe, K. C., Feng, C. Y., Matsuura, T., Mosqueada-Jimenaez, D. C., Rafat, M., Kingston, D., Khayet, M. (2007). Characterization of surface-modified hollow fiber polyethersulfone membranes prepared at different air gaps. *Journal of Applied Polymer Science*, 104(2), 710–721.

Kim, H. J., Phenrat, T., Tilton, R. D., & Lowry, G. V. (2012). Effect of kaolinite, silica fines and pH on transport of polymer-modified zero valent iron nano-particles in heterogeneous porous media. *Journal of Colloid and Interface Science*, 370(1), 1–10.

Kim, T. H., Park, C., Shin, E. B., & Kim, S. (2002). Decolorization of disperse and reactive dyes by continuous electrocoagulation process. *Desalination*, 150(2), 165–175.

Köhler, J. (2006). Detergent phosphates: an EU policy assessment. *Journal of Business Chemistry*, *3*(2), 15–30.

Kools, W. F. C. (1998). Membrane Formation By Phase Inversion in Multicomponent Polymer Systems. *Ph.D. Thesis* , 4–195.

Koppineni Praneeth (2014). Synthesis and Characterization of Novel Polymeric Membranes for Water Purification and Effluents Treatment. (phD thesis School of Applied Sciences ,College of Science, Engineering and Health RMIT University, Australia) , Retrieved from http:// researchbank.rmit.edu.au /view/rmit :161037

Kumar, N. S., & Goel, S. (2010). Factors influencing arsenic and nitrate removal from drinking water in a continuous flow electrocoagulation (EC) process. *Journal of Hazardous Materials*, *173*(1–3), 528–533.

Kuokkanen, V., Kuokkanen, T., Rämö, J., & Lassi, U. (2013). Recent Applications of Electrocoagulation in Treatment of Water and Wastewater—A Review. *Green and Sustainable Chemistry*, *3*(2), 89–121.

Kwankhao, B. (2013). Microfiltration membranes via electrospinning of polyethersulfone solutions (Doctoral dissertation, Universität Duisburg-Essen, Fakultät für Chemie) .

Lalia, B. S., Kochkodan, V., Hashaikeh, R., & Hilal, N. (2013a). A review on membrane fabrication: Structure, properties and performance relationship. *Desalination*, 326 (1), 77–95.

Lecouvet, B., Sclavons, M., Bourbigot, S., & Bailly, C. (2013). Thermal and flammability properties of polyethersulfone/halloysite nanocomposites prepared by melt compounding. *Polymer Degradation and Stability*, *98*(10), 1993–2004.

Lee, H. B., Khang, G., & Lee, J. H. (2007). Polymeric biomaterials. *Acta Materialia*,48 (1), 263–277.

Legates, D. R., Lins, H. F., & McCabe, G. J. (2005). Comments on "Evidence for global runoff increase related to climate warming" by Labat et al. *Advances in Water Resources*, *28*(12), 1310–1315.

Lettenmaier, D. P., Wood, A. W., Palmer, R. N., Wood, E. F., & Stakhiv, E. Z. (1999). Water resources implications of global warming: A U.S. regional perspective. *Climatic Change*, *43*(3), 537–579.

Li, C., Ma, J., Shen, J., & Wang, P. (2009). Removal of phosphate from secondary effluent with Fe^{2+} enhanced by H_2O_2 at nature pH/neutral pH. *Journal of Hazardous Materials*, 166 (2–3), 891–896.

Li, W.-W., Zhang, H.-L., Sheng, G.-P., & Yu, H.-Q. (2015). Roles of extracellular polymeric substances in enhanced biological phosphorus removal process. *Water Research*, 86 (1), 85–95.

Liang, C. Y., Uchytil, P., Petrychkovych, R., Lai, Y. C., Friess, K., Sipek, S. Y. (2012a). A comparison on gas separation between PES (polyethersulfone)/MMT (Na-montmorillonite) and PES/TiO_2 mixed matrix membranes. *Separation and Purification Technology*, 92, 57–63.

Liu, X., & Zhang, L. (2015). Removal of phosphate anions using the modified chitosan beads: Adsorption kinetic, isotherm and mechanism studies. *Powder Technology*, 277 (1), 112–119.

Lockwood, M. (2010). Solar change and climate: an update in the light of the current exceptional solar minimum. *Proceedings of the Royal Society A*, 466 , 303–329.

Ma, Y., Shi, F., Zhao, W., Wu, M., Zhang, J., Ma, J., & Gao, C. (2012). Preparation and characterization of PSf/clay nanocomposite membranes with LiCl as a pore forming additive. *Desalination*, 303 (1), 39–47.

Manahan, S. E. (2000). *Environmental chemistry*. Boca Raton, FL: Lewis Publishers. Retrieved from https:// www.academia.edu /7241736 / Environmental _Chemistry-Manahan_7th_Edition_-Ebook

Marshall, A. D., Munro, P. A., & Trägårdh, G. (1993). The effect of protein fouling in microfiltration and ultrafiltration on permeate flux, protein retention and selectivity: A literature review. *Desalination*, 91(1), 65–108.

Maximous, N., Nakhla, G., Wan, W., & Wong, K. (2009). Preparation, characterization and performance of Al_2O_3/PES membrane for wastewater filtration. *Journal of Membrane Science*, 341(1–2), 67–75.

Azry, B., Muhammad ,M. (2014). Removal of Monoethanolamine from Wastewater by Composite Reverse . *Jurnal Teknologi*, 5, 53–58.

Mierzwa, J. C., Arieta, V., Verlage, M., Carvalho, J., & Vecitis, C. D. (2013). Effect of clay nanoparticles on the structure and performance of polyethersulfone ultrafiltration membranes. *Desalination*, 314, 147–158.

Moradihamedani, P., & Abdullah, A. H. Bin. (2016). Phosphate removal from water by polysulfone ultrafiltration membrane using PVP as a hydrophilic modifier. *Desalination and Water Treatment*, 57(53), 25542-25550

Motawie, a. M., Madany, M. M., El-Dakrory, a. Z., Osman, H. M., Ismail, E. a., Badr, M. M., Abulyazied, D. E. (2014). Physico-chemical characteristics of nano-organo bentonite prepared using different organo-modifiers. *Egyptian Journal of Petroleum*, 23(3), 331–338.

Najib, N., & Christodoulatos, C. (2013). Phosphate removal from aqueous solution using a quaternized electrospun cellulose nanofiber as an anion exchange resin. *Proceedings of the 13th International Conference of Environmental Science and Technology*, 5–7.

Namasivayam, C., Sakoda, A., & Suzuki, M. (2005). Removal of phosphate by adsorption onto oyster shell powder - Kinetic studies. *Journal of Chemical Technology and Biotechnology*, 80(3), 356–358.

Nguyen, T., Roddick, F. A., & Fan, L. (2012). Biofouling of water treatment membranes: A review of the underlying causes, monitoring techniques and control measures. *Membranes*, 2(4), 804–840.

Oztekin, E., & Altin, S. (2016). Wastewater Treatment By Electrodialysis System and Fouling Problems. *Journal of Science and Technology* 6(1), 91–99.

Pesek, S. C., & Koros, W. J. (1993). Aqueous quenched asymmetric polysulfone membranes prepared by dry / wet phase separation. *Journal of Membrane Science*, 81(1-2), 71-88.

Petcu, C., Purcar, V., Radu, A. L., Ianchis, R., Elvira, A., Sarbu, A.,Ciobotaru, A. I. (2015). Removal of zinc ions from model wastewater system using bicopolymer membranes with fumed silica. *Journal of Water Process Engineering*, 8, 1–10.

Phalakornkule, C., Polgumhang, S., Tongdaung, W., Karakat, B., & Nuyut, T. (2010). Electrocoagulation of blue reactive, red disperse and mixed dyes, and application in treating textile effluent. *Journal of Environmental Management*, 91(4), 918–926.

Postel, S. L., Daily, G. C., & Ehrlich, P. R. (1996). Human Appropriation of Renewable Fresh Water. *Science*, 271(5250), 785–788.

Rajeswari, A., Amalraj, A., & Pius, A. (2015). Removal of phosphate using chitosan-polymer composites. *Journal of Environmental Chemical Engineering*, 3(4), 2331–2341.

Regonda, S. K., Rajagopalan, B., Clark, M., & Pitlick, J. (2005). Seasonal cycle shifts in hydroclimatology over the western United States. *Journal of Climate*, 18(2), 372–384.

Rieman, B. E., Isaak, D., Adams, S., Horan, D., Nagel, D., Luce, C., & Myers, D. (2007). Anticipated Climate Warming Effects on Bull Trout Habitats and Populations Across the Interior Columbia River Basin. *Transactions of the American Fisheries Society*, 136(6), 1552–1565.

Roy, P. K. (1995). *Nanofiltration as a Tertiary Treatment for Phosphate Removal from Wastewater*. (Master's thesis, Asian Institute of Technology Bangkok, Thailand). Retrieved from http:// *faculty.ait.ac.th/visu/public/uploads/images /.../PritishKumarRoy.pdf*

Rzayev, Z. M. O. (2011a). Functional Copolymer/Organo-MMT Nanoarchitectures. VIII. Synthesis, Morphology and Thermal Behavior of Poly(maleic anhydride-alt-acrylamide)-Organo-MMT Clays Nanohybrids. *Engineering*, 3(1), 73–82.

Rzayev, Z. M. O. (2011b). Functional Copolymer/Organo-MMT Nanoarchitectures. VIII. Synthesis, Morphology and Thermal Behavior of Poly(maleic anhydride-alt-acrylamide)-Organo-MMT Clays Nanohybrids. *Engineering*, 3(1), 73–82.

Sarkar, B., Chakrabarti, P. P., Vijaykumar, A., & Kale, V. (2006). Wastewater treatment in dairy industries - possibility of reuse. *Desalination*, 195(1), 141–152.

Sarparastzadeh, H., Saeedi, M., Naeimpoor, F., & Aminzadeh, B. (2007). Pretreatment of municipal wastewater by enhanced chemical coagulation. *International Journal of Environmental Research*, 1(2), 104–113.

Şengil, I. A., Kulaç, S., & Özacar, M. (2009). Treatment of tannery liming drum wastewater by electrocoagulation. *Journal of Hazardous Materials*, 167(3), 940–946.

Shameli, K., Ahmad, M. Bin, Jazayeri, S. D., Sedaghat, S., Shabanzadeh, P., Jahangirian, H.,Abdollahi, Y. (2012). Synthesis and characterization of polyethylene glycol mediated silver nanoparticles by the green method. *International Journal of Molecular Sciences*, 13(6), 6639–6650.

Shang, R., Verliefde, A. R. D., Hu, J., Zeng, Z., Lu, J., Kemperman, A. J. B. Rietveld, L. C. (2013). Tight ceramic UF membrane as RO pre-treatment : The role of electrostatic interactions on phosphate rejection. *Water Research*, 48 , 498-507.

Sharpley, A. N., Gburek, W. J., Folmar, G., & Pionke, H. B. (1999). Sources of phosphorus exported from an agricultural watershed in Pennsylvania. *Agricultural Water Management*, 41(2), 77–89.

Sikder, J., Pereira, C., Palchoudhury, S., Vohra, K., Basumatary, D., & Pal, P. (2009). Synthesis and characterization of cellulose acetate-polysulfone blend microfiltration membrane for separation of microbial cells from lactic acid fermentation broth. *Desalination*, 249(2), 802–808.

Smith, S. J., Van Aardenne, J., Klimont, Z., Andres, R. J., Volke, A., & Delgado Arias, S. (2011). Anthropogenic sulfur dioxide emissions: 1850-2005. *Atmospheric Chemistry and Physics*, 11(3), 1101–1116.

T. Balamurali, B. Preetha Suchitra, M. (2014). Effect of organic additive (PEG 600) on ultrafiltration performance of pes membranes. *International Journal of Advanced Research in Engineering and Technology (IJARET)*, 5(8), 132–138.

Suryanarayan, S., Mika, A. M., & Childs, R. F. (2007). The effect of gel layer thickness on the salt rejection performance of polyelectrolyte gel-filled nanofiltration membranes. *Journal of Membrane Science*, 290(1), 196–206.

Sun, M., Su, Y., Mu, C., & Jiang, Z. (2009). Improved antifouling property of PES ultrafiltration membranes using additive of silica- PVP nanocomposite. Industrial & Engineering Chemistry Research, 49(2), 790–796.

Tchobanoglous, G., Burton, F. L., S. (2003). *Wastewater Engineering: Treatment, Disposal, and Reuse*. (M. & Eddy, Ed.) (4th edition). New York: McGrawHill.

Arthanareeswaran, G., Thanikaivelan, P., Raguime, J. A., Raajenthiren, M., & Mohan, D. (2007). Metal ion separation and protein removal from aqueous solutions using modified cellulose acetate membranes: role of polymeric additives. *Separation and purification technology*, 55(1), 8-15.

Tilková, A., Majorová, P., & Seidlerová, J. (2013). Using Montmorillonite for Phosphate Removal. *Advanced Science Focus*, 1(4), 351–353.

Ulbricht, M. (2006). Advanced functional polymer membranes. *Polymer*, 47(7), 2217–2262.

Unnikrishnan, L., Nayak, S. K., Mohanty, S., & Sarkhel, G. (2010). Polyethersulfone membranes: the effect of sulfonation on the properties. *Polymer-Plastics Technology and Engineering*, 49(14), 1419-1427.

Van Rooijen, D. J., Biggs, T. W., Smout, I., & Drechsel, P. (2010). Urban growth, wastewater production and use in irrigated agriculture: A comparative study of Accra, Addis Ababa and Hyderabad. *Irrigation and Drainage Systems*, 24(2), 53–64.

Vincenzo, N. (2012). Membrane Technology in Wastewater Treatments. *Journal of Hydrogeology & Hydrologic Engineering*,1,1,0-1.

Wang, L., Wang, J., Gao, X., Liang, Z., Zhu, B.-K. B., Zhu, L. L., & Xu, Y. Y.-Y. (2014). A Facile Transetherification Route to Polysulfone-Poly(ethylene glycol) Amphiphilic Block Copolymers with Improved Protein Resistance. *Polymer Chemistry*, 5(8), 2836.

Wang, X., Song, L., Yang, F., & He, J. (2016). Investigation of phosphate adsorption by a polyethersulfone-type affinity membrane using experimental and DFT methods membrane using experimental and DFT methods, 57(52), 25036-25056.

Wang, Z., Fan, Y., Li, Y., Qu, F., Wu, D., & Kong, H. (2016). Synthesis of zeolite/hydrous lanthanum oxide composite from coal fly ash for efficient phosphate removal from lake water. Microporous and Mesoporous Materials, 222, 226-234. Wijmans, J. G., & Baker, R. W. (1995). The solution-diffusion model : a review. *Journal of Membrane Science* , 107, 1–21.

Xiong, Y., Strunk, P. J., Xia, H., Zhu, X., & Karlsson, H. T. (2001). Treatment of dye wastewater containing acid orange II using a cell with three-phase three-dimensional electrode. *Water Research*, 35(17), 4226–4230.

Yan-jun, Z. H. A. O., Kai-fen, W. U., Zheng-jun, W. A. N. G., Liang, Z. H. A. O., & Shu-shen, L. I. (2000). Fouling and cleaning of membrane–a literature review. Environmental Science, 12(2), 241-251.

Yan, Y., Sun, X., Ma, F., Li, J., Shen, J., Han, W., Wang, L. (2014). Removal of phosphate from etching wastewater by calcined alkaline residue: Batch and column studies. *Journal of the Taiwan Institute of Chemical Engineers*, 45(4), 1709–1716.

Yang, Y., Lohwacharin, J., & Takizawa, S. (2014). Hybrid ferrihydrite-MF/UF membrane filtration for the simultaneous removal of dissolved organic matter and phosphate. *Water Research*, 65, 177–185.

Yin, J., & Deng, B. (2015). Polymer-matrix nanocomposite membranes for water treatment. *Journal of Membrane Science*, 479, 256–275.

You, X., Farran, A., Guaya, D., Valderrama, C., Soldatov, V., & Luis, J. (2016). Phosphate removal from aqueous solutions using a hybrid fibrous exchanger containing hydrated ferric oxide nanoparticles. *Journal of Environmental Chemical Engineering*, 4, 388–397.

Zaroual, Z., Chaair, H., Essadki, A. H., El Ass, K., & Azzi, M. (2009). Optimizing the removal of trivalent chromium by electrocoagulation using experimental design. *Chemical Engineering Journal*, 148(2–3), 488–495.

Zeng, Z. (2012). Phosphorus removal by ceramic tight ultra-filtration (CTUF) membranes for RO pre-treatment. (Master's thesis,Sanitary Engineering Section, Department of Water Management, Faculty of Civil Engineering and Geosciences , Delft University of Technology, Delf) , Retrieved from http:// *www.citg.tudelft.nl/fileadmin/.../doc/.../Zheyi_Zeng_Final_thesis.pdf*

Zhang, J., Zhang, Y., Chen, Y., Du, L., Zhang, B., Zhang, H.,Wang, K. (2012). Preparation and characterization of novel polyethersulfone hybrid ultrafiltration membranes bending with modified halloysite nanotubes loaded with silver nanoparticles. *Industrial and Engineering Chemistry Research*, 51(7), 3081–3090.

Zhang, Y., Desmidt, E., Van Looveren, A., Pinoy, L., Meesschaert, B., & Van Der Bruggen, B. (2013). Phosphate separation and recovery from wastewater by novel electrodialysis. *Environmental Science and Technology*, 47(11), 5888–5895.

Zhao, C., Xue, J., Ran, F., & Sun, S. (2013). Modification of polyethersulfone membranes - A review of methods. *Progress in Materials Science*, 58(1), 76–150.

Zhou, H., & Smith, D. W. (2002). Advanced technologies in water and wastewater treatment. *Journal of Environmental Engineering and Science*, 1(4), 247–264.

Zhu, S., Shi, M., Zhao, S., Wang, Z., Wang, J., & Wang, S. (2015). Preparation and characterization of a polyethersulfone/polyaniline nanocomposite membrane for ultrafiltration and as a substrate for a gas separation membrane. RSC Advances, 5(34), 27211-27223.

Zvinowanda, C. M., Okonkwo, J. O., Shabalala, P. N., & Agyei, N. M. (2009). A novel adsorbent for heavy metal remediation in aqueous environments. *International Journal of Environmental Science and Technology*, 6(3), 425–434.