NANOCOMPOSITE ULTRAFILTRATION MEMBRANE INCORPORATING ZINC-IRON OXIDE PHOTOCATALYST FOR DECOLOURISATION OF TREATED PALM OIL MILL EFFLUENT

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DEDICATION

This thesis is dedicated to my mother, who taught me that the best kind of knowledge to have is that which is learned for its own sake. It is also dedicated to my friends, who taught me that even the largest task can be accomplished if it is done one step at a time.

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ABSTRACT

Palm oil mill effluent (POME) is brownish, high organic loading effluent produced by palm oil industry. Conventionally used biological treatment has successfully reduced the biochemical oxygen demand of POME below 25 ppm, which is considered as clean effluent. However, chemical oxygen demand (COD) and colour of the aerobically treated palm oil mill effluent (AT-POME) are still high. Therefore, tertiary treatment such as membrane processes are used to further polish AT-POME in order to reduce its COD and colour to meet discharge standard. However, fouling becomes severe issue in restricting the membrane lifespan and usage in this application. This work aimed to develop hybrid photocatalytic membranes with self-cleaning properties to mitigate the membrane fouling and also photodegrades the chemical compounds in AT-POME. First, coupled zinc-iron oxide (ZIO) was synthesized from its precursor, i.e. zinc nitrate and iron (III) nitrate through solution combustion by varying the molar ratio between zinc and iron (ranging from 1:1 to 1:4 with respect to zinc to iron ratio). Second, the optimum molar ratio of ZIO was calcined at temperature ranging from 400°C to 800°C. Third, the self-synthesised ZIO was incorporated into polyvinylidene fluoride (PVDF) polymer matrix to produce mixed matrix photocatalytic ultrafiltration membrane (MMMs) for decolourisation of AT-POME. Five membranes were formulated by varying ZIO from 0.0 wt % to 2.0 wt%. The fabricated membranes were subjected to physico-chemical analysis, i.e. field emission scanning electron microscope, energy dispersive X-ray spectroscopy, X-ray diffraction, Brunauer-Emmett-Teller, ultraviolet-visible-near infrared, absorption test, filtration process, photodegradation test to identify the self-cleaning properties, separation performance and fouling mitigation properties. Based on the experimental results, ZIO with 1:4 zinc to iron ratio was the optimum ZIO which provided large surface area (30.9130 m^2/g), lowest band gap energy (2.07 eV), high photocatalytic activity (achieved 35% of mineralisation in 6.5 hours and 100% degradation in 3.5 hours). On the other hand, as calcination temperature increased, the particle size of ZIO increased gradually. This phenomenon led to the decrease of surface area of ZIO that reduced its performance in absorption and photodegradation of organic compounds. The results demonstrated that calcination temperature of 500°C was the optimum temperature to provide the highest photodegradation. For the MMMs, as the ZIO loading increased, the porosity decreased, and surface negativity increased. However, when higher loading of ZIO was used, the mechanical strength of the membrane structure deteriorated and cannot withstand long-term operation. Therefore, the optimum loading was identified as 0.5 wt% ZIO in which the membrane achieved 75% colour removal efficiency with flux of 20 – 25 LMH ($L.m^{-2}.hr^{-1}$). Furthermore, the self-fabricated MMMs photocatalytic ultrafiltration (UF) membrane possess the high flux recovery after ultraviolet and visible light cleaning, i.e. 92.3% and 90.3%, respectively. The addition of ZIO in polymeric matrix enabled the photodegradation of colour pigments in AT-POME. After 16 hours of operation, the colour of AT-POME reduced by 8%. In a nutshell, PVDF/ZIO photocatalytic UF membrane had successfully decolourised AT-POME and reduced its COD.

ABSTRAK

Efluen minyak kelapa sawit (POME) merupakan efluen berwarna perang dan mempunyai kandungan bahan organik yang tinggi yang dibebaskan dari kilang kelapa sawit. Secara lazimnya, rawatan biologi digunakan untuk merawat POME supaya keperluan oksigen biokimia di bawah 25 ppm, yang dikatakan sebagai efluen bersih. Walaubagaimanapun, keperluan oksigen kimia (COD) dan warna bagi efluen minyak kelapa sawit selepas rawatan anaerobik (AT-POME) masih tinggi. Jadi, rawatan tertier seperti proses membran digunakan untuk merawat AT-POME supaya COD dan warnanya dapat dikurangkan supaya mencapai tahap piawai. Pengotoran membran menjadi isu yang mengehadkan penggunaan proses membran dalam aplikasi ini. Kajian ini bertujuan untuk menghasilkan membran fotopemangkinan hibrid dengan ciri pencucian sendirian untuk meringankan pengotoran membran fotopemangkinan serta menguraikan sebatian organik dalam AT-POME. Pertama, zink-ferum oksida (ZIO) berganding diolah dengan menggunakan zink nitrat dan ferum (III) nitrat sebagai prekursor melalui kaedah pembakaran larutan dengan mengubah nisbah molar antara zink dengan ferum (julat dari 1:1 ke 1:4). Kedua, nisbah molar ZIO optimum dikalsinat pada suhu 400°C hingga 800°C. Ketiga, ZIO ditambah ke dalam matriks polimer polivinilidene difluorida (PVDF) untuk menghasilkan membran ultraturasan fotopemangkinan matriks bercampur (MMMs) untuk penyahwarnaan AT- POME. Lima membran diformulasi dengan mengubah kandungan ZIO dari 0.0 wt% ke 2.0 wt%. Membran yang dihasilkan dikaji dari segi analisis fisiko-kimia seperti mikroskop elektron imbasan pancaran medan, spektroskopi dispersif tenaga sinar-X, belauan sinar-X, Brunauer-Emmett-Teller dan ultraungu-nampak-dekat inframerah, ujian penyerapan, ujian penurasan dan ujian fotopemangkinan untuk menentukan keupayaan membran untuk pembersihan sendirian, penurasan dan pengurangan pengotoran membran. Daripada keputusan eksperimen, ZIO dengan nisbah 1:4 zink kepada ferum merupakan ZIO optimum yang menunjukkan luas permukaan yang besar (30.9130 m^2/g), tenaga sela jalur yang rendah (2.07 eV), aktiviti fotopemangkinan yang tinggi (35% mineralisasi dalam 6.5 jam dan 100% degradasi dalam 3.5 jam). Di samping itu, peningkatan suhu kalsinasi menyebabkan saiz partikel ZIO bertambah. Fenomena ini menyebabkan penurunan luas permukaan ZIO dan menurunkan prestasi penyerapan dan fotodegradasi sebatian organik. Keputusan eksperimen menunjukkan suhu 500°C adalah suhu kalsinasi optimum yang memberikan fotodegradasi yang tertinggi. Untuk MMMs, apabila ZIO bertambah, keliangan dan cas permukaan semakin negatif. Walaubagaimanapun, semakin tinggi kandungan ZIO yang digunakan, kekuatan mekanikal bagi struktur membran termusnah dan tidak dapat menahan operasi jangka masa panjang. Oleh itu, optimal telah ditentukan iaitu 0.5 % berat ZIO di mana membran mencapai 75 % penyahwarnaan dengan flux 20 – 25 LMH ($L.m^{-2}.j^{-1}$). Selain itu, MMMs fotopemangkinan ultraturasan menunjukkan perolehan fluks yang tinggi selepas pencucian ultraungu dan cahaya nampak, iaitu masing-masing 92.3 % dan 90.3 %. Penambahan ZIO dalam matriks PVDF dapat menguraikan pigmen warna dalam AT-POME. Selepas 16 jam operasi, warna AT-POME diturunkan sebanyak 8 %. Kesimpulannya, membran ultraturasan fotopemangkinan PVDF/ZIO telah berjaya menyahwarnakan AT-POME dan mengurangkan CODnya.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ABE	–	Acetone-butanol-ethanol
AC	–	Activated carbon
ADMI	–	American Dye Manufacturers Institute
AFM	–	Atomic force microscopy
AN	–	Ammoniacal nitrogen
AOPs	–	Advanced oxidation processes
AT-POME	–	Aerobically treated palm oil mill effluent
BET	–	Brunauer-Emmett-Teller analysis
BOD	–	Biochemical oxygen demand
BPA	–	Bis-phenol A
CPO	–	Crude palm oil
CNT	–	Carbon nanotube
COD	–	Chemical oxygen demand
CV	–	Crystal violet
DOE	–	Department of Environment
EDX	–	Energy dispersive X-ray analaysis
EFB	–	Empty fruit bunch
FESEM	–	Field emission scanning electron microscope
4-HBZ	–	Para-hydrobenzoic acid
HPLC	–	High performance liquid chromatography
HRT	–	Hydraulic retention time
HS	–	Helmholts-Smoluchowski
JAS	–	National Environment Agency/ Department of Environment
MB	–	Methyl blue
MMMs	–	Mixed matrix membranes
MR	–	Methyl red
MWCO	–	Molecular weight cut off
NF	–	Nanofiltration
NMP	–	N-methyl-2-pyrrolidone
OECD	–	Organisation for Economic Co-operation and Development

OMW	–	Olive oil mill wastewater
PEG	–	Polyethylene glycol
PHA	–	Polyhydroxyalkanoates
POME	–	Palm oil mill effluent
PVDF	–	Polyvinylidene fluoride
PVP	–	Polyvinylpyrrolidone
PWP	–	Pure water permeation
RO	–	Reactive orange 16
SCA	–	Static contact angle
SRT	–	Solid retention time
SS	–	Suspended solids
TN	–	Total nitrogen
TOC	–	Total organic carbon
TS	–	Total solids
TSS	–	Total suspended solids
TVS	–	Total volatile solids
UF	–	Ultrafiltration
UV	–	Ultraviolet
UV-Vis-NIR	–	Ultraviolet-visible-near infrared spectrophotometer
WWF	–	World Wildlife Fund
XRD	–	X-ray diffraction
ZIO	–	Coupled zinc-iron oxide

LIST OF SYMBOLS

°C	–	Degree Celsius
L	–	Litre
LMH	–	Litre per meter square per hour
m	–	meter
mg	–	miligram
ppm	–	Part per million
%	–	Percent

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Research Background

Oil palm (*Elaeis guineensis*) is one of the most versatile crops in the tropical region, notably in Malaysia and Indonesia. As reported by World Wildlife Fund (WWF), more than 65 per cent of all vegetable oil traded internationally is palm oil. Also, this number is expected to be increased double by 2020 [1]. In Malaysia, the palm oil production grows 12 per cent annually based on the statistics by United States Department of Agriculture [2]. Despite the benefits of palm oil industries to the social and economic growth, the processing of oil palm generates huge quantity of solid waste and wastewater. The solid waste of palm oil mill includes empty fruit bunch (EFB) and kernel seed. These wastes can be used to produce energy through combustion. Besides, some studies showed that the EFB can be used as the culture medium for microorganism growth. The wastewater from palm oil mill is known as palm oil mill effluent (POME) which is a brownish liquid with unpleasant smell and low pH. The POME is known as one of the major water pollutants in Malaysia due to its high organic content [3, 4]. These organic substances that loaded into source water may cause the eutrophication and eventually cause death of the aquatic organisms. The colour pigment presents in the aerobically or anaerobically treated POME (AT-POME) which arise from the biodegradation of lignocellulosic compound in POME. The brown colour pigment majorly come from tannin, lignin and carotene [5]. These colour pigment prevent the use of AT-POME in the palm oil extraction process because it colourises the pipeline and reduces the lifetime of the pipe. The conventional handling method of these AT-POME is discharge into point and source water instead of reusing it into the process line. AT-POME is dark brownish in colour. In fact, the darkness of the AT-POME is higher than POME due to the degradation of lignocellulose product and carotenoid compound in the POME into lignin and tannin. This will further increase the acidity, turbidity and colour of the AT-POME. This restrict the reclamation of the treated POME for further reuse.

Generally, there are several technologies available for the removal of colour and COD from POME. For instance, ion exchange [6], coagulation [7], adsorption [8], and membrane processes [9]. Coagulation is a process that uses chemicals to destabilize the impurities (especially macromolecules and suspended solids) in POME. Coagulation has been proven to be capable to remove the suspended impurities that contribute to the high COD and dark brown colour of POME [7]. For instance, Zahrim et al. [10] showed that the use of dual-coagulants, i.e. ferric chloride-anionic polyacrylamide managed to achieve higher than 90% colour removal in POME treatment. The attractiveness of coagulation process is its simplicity in design and operation, low energy consumption and high versatility. However, coagulation process alone could not attain complete decolourization and treatment of POME due to its failure to remove dissolved organic substances in POME. In order to achieve higher removal of colour and reduction of COD, adsorption has been proposed for POME treatment. Adsorption process utilizes adsorbents (with the most widely used is activated carbon) to adsorb and capture the dissolved organic impurities in wastewater for decolourization purpose [11]. Mohammed et al. [8] reported that the use of activated carbon adsorbent could reduce the colour intensity of POME with removal efficiency of 96.46%. Though the high decolourization efficiency is quite encouraging, the widespread of adsorption for POME treatment and decolourization has not been well accepted by industry due to the high expenditure associated with the regeneration of activated carbon for reuse and the replacement cost of spent activated carbon. On the other hand, membrane technologies such as NF and RO could be used to remove both suspended and dissolved organic substances in POME [9]. Both NF and RO membranes could reduce the COD down to less than 10 mg/L and colour intensity to less than 5 Pt.Co. The performance of membrane technologies is very convincing yet it is not employed in POME treatment due to membrane fouling issue, where impurities will deposit on the membrane surface and block the passage of water from passing through the membrane. Hence, unless membrane fouling could be resolved or minimized, the fouling issue will continue to hinder the application of membrane in POME treatment and decolourization.

Another emerging technology for colour removal is photocatalysis [12]. Photocatalyst is a semiconductor nanoparticle that can generate electrons and holes through the excitation by solar or light energy. Photocatalyst can photodegrade most of the organic molecules into less hazardous molecules. Thus, it is widely applied in wastewater and water treatment. However, using photocatalyst directly will cause the suspension of nanoparticles in the treated solution. This requires additional unit operation to recover the nanoparticles for the subsequent usage. Therefore, the footprint of the plant will increase, and more construction and maintenance cost will be involved. In order to enhance the photocatalysis, nanosized photocatalyst has been normally used. However, it is very tedious to separate nanoparticles with low cost process.

In order to harness the advantages of both membrane technology and photocatalysis, also to mitigate their undesired limitations, nanocomposite ultrafiltration (UF) membrane with photocatalytic properties is developed. UF membrane is a membrane technology that is able to separate macromolecule of 10^3 to 10^6 Da. Therefore, UF can give relatively high flux with lower operating pressure. Yet, UF cannot remove colour pigment since they are too small. Therefore, a new configuration of UF that incorporate with photocatalytic nanoparticles is fabricated to overcome this limitation. Nanoparticles with photocatalytic properties are incorporated into membrane matrix to enhance it hydrophilicity and also render photocatalytic properties to achieve the synergistic effects.

In this study, nanocomposite UF membrane with coupled zinc-iron oxide nanoparticles was fabricated to enhance the AT-POME colour removal. The coupled zinc-iron oxide nanoparticles (ZIO) were synthesised by solution combustion technique. The nanoparticles were then incorporated with the polymer dope solution to form a flat sheet membrane via phase inversion process. The resultant photocatalytic nanocomposite membrane demonstrates the ability of self-cleaning, prolonged operation duration and also enhanced performance in colour removal of AT-POME.

1.2 Problem Statements

The high pollutant content of the POME hampers the direct discharge into the water source. Therefore, proper and systematic treatments are highly desired to prevent the pollution of water by the palm oil waste. However, the conventional treatment method, i.e. biological degradation method is ineffective for colour removal. This is due to the dependency of the microorganism on the weather and environment. Besides, the biodegradation of lignocellulosic compounds produces tannin and lignin that increase the brownness of AT-POME [13]. This raises the public concern about the level of toxicity or pollutant in the AT-POME. Besides, the build-up of brown colour pigment restricts the reclamation of AT-POME in palm oil industry. Thus, membrane-based separation holds very promising potential to address this issue as this technology can be used to reclaim the water for the plant reuse and reduce the chemical oxygen demand (COD) significantly.

NF has been widely used in decolourization of wastewater [9, 14, 15]. The major drawback of the process is utilization of high pressure and low permeation rate, i.e. approximate 11.3 LMH [16, 17]. Therefore, it is not feasible for the palm oil industry to handle high output rate of AT-POME. Thus, UF with bigger pore size need to be customized so that it can cope the AT-POME production rate. Another drawback of NF process is the high fouling tendency. The foulant (i.e. colour pigment) tends to block the pore on the membrane and reduce the flux drastically. Therefore, nanocomposite membrane is an attractive candidate to solve these problems. Photocatalysts can serve as nanoparticles that alter the membrane physical properties and also act as antifouling agent. Ideally, photocatalyst in the membrane matrix can work in two ways, which are photodegrade foulant that block the membrane pores and photodegrade the colour pigment in the AT-POME that close to the membrane surface. This can further enhance the membrane separation efficiency by mitigating the fouling problem.

In this study, UF with near NF properties can be incorporated with bimetallic photocatalyst to filter the AT-POME. The photocatalyst in polymeric matrix can tailor the surface charge of membrane so that the desired charge can be obtained. Besides, the photocatalyst that embedded into the membrane can give self-cleaning property to the membrane and extend it lifespan. Furthermore, when the photocatalytic membrane is irradiated under visible light, it can carry out photocatalysis and filtration simultaneously. Thus, recycle of photocatalyst can be easily achieved. Figure 1.1 shows the working mechanism of membrane with photocatalyst. Upon excited by UV light source, TiO_2 photocatalyst will produce hydroxyl radicals from water molecules. These hydroxyl radicals will then degrade the organic impurities (either present on the membrane surface or suspended close to the membrane surface) into harmless compounds such as CO_2 and H_2O. This can help to minimize membrane fouling propensity and enhance the separation efficiency since membrane blocking issue by impurities will be mitigated through photocatalytic degradation. The photodegradation of the colour pigment in the AT-POME can dilute the brownish colour of the AT-POME and reduce the concentration of colour pigment in AT-POME so that the membrane separation can be carried out easily. Another advantage of embedding photocatalyst in the membrane matrix is that it can avoid the secondary treatment of photocatalyst in heterogenous system. Membrane serves as the binder or holder of the photocatalyst to enable the recycle and reuse of the photocatalyst for long term usage.

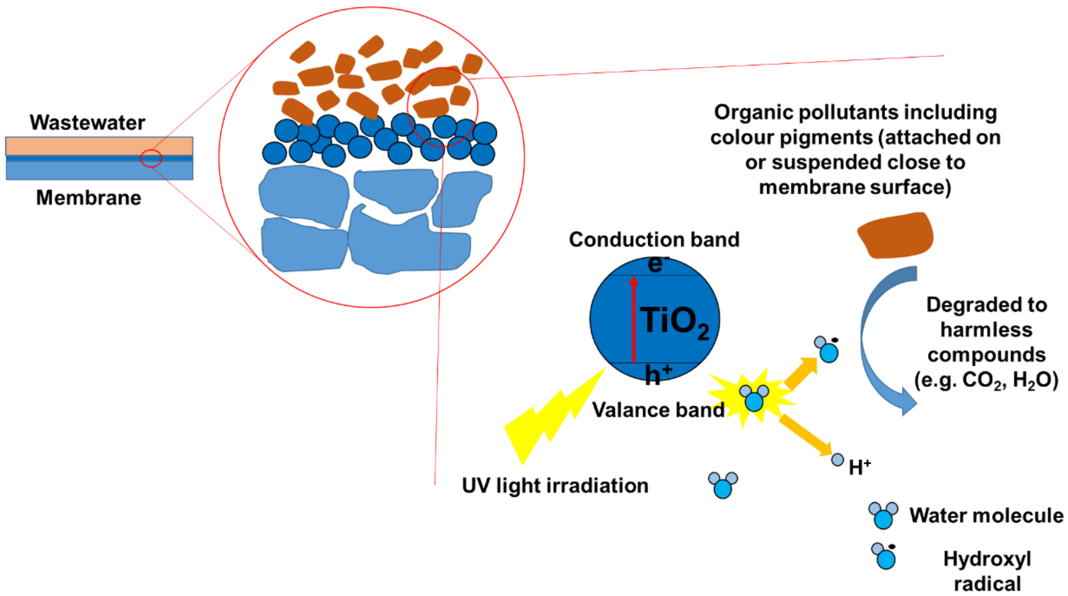

Figure 1.1 Working mechanism of membrane embedded with photocatalyst [12]

The rate of photocatalysis are depending on the concentration of photogenerated holes and electrons and their rate of recombination. Currently, titanium dioxide has been employed as commercial photocatalyst as its high photocatalytic activity. However, the use of titanium dioxide requires high photoenergy, thus, it can only be activated by ultraviolet (UV) light. Therefore, photocatalytic reactor must be properly enclosed to prevent the exposure of ultraviolet light to operator. Reducing the band gap energy of photocatalyst can be one of the methods to shift the activation light from ultraviolet to visible region. But, this will indirectly increase the rate of recombination between the photoexcited holes and electrons. This phenomenon could result in the low photocatalytic activity. Hence, bimetallic oxide photocatalyst is developed to solve these two mentioned problems above. By constructing bimetallic oxide with different characteristics, a p-n junction can be formed. p-n junction will help to hold the photoexcited holes and electrons at its respective matrixes. As a result, the rate of recombination could be minimised.

1.3 Objectives of Study

The main focus of this study is to develop a photocatalytic nanocomposite membrane for AT-POME colour removal. In order to achieve this main goal, several sub-objectives have been identified:

(i) To synthesize and characterize coupled zinc-iron oxide (ZIO) photocatalyst that can be activated in both UV and visible light range.

(ii) To fabricate and characterize nanocomposite UF membrane which embedded with ZIO.

(iii) To evaluate the performance of the photocatalytic nanocomposite UF membrane which embedded with different loading of ZIO in terms of AT-POME colour removal efficiency, flux, anti-fouling properties, photodegradation and separation performance of the nanocomposite UF membrane.

(iv) To study the photocatalytic properties of hybrid membrane.

1.4 Scopes of Study

The objective of this study can be accomplished by the following scopes:

(i) Characterising the average particle size of AT-POME with commercial NF and UF membranes.

(ii) Synthesising ZIO with different zinc to iron molar ratio 1:1, 1:2, 1:3 and 1:4 via solution combustion method using zinc nitrate and iron (III) nitrate as precursor

(iii) Studying the effect of zinc to iron molar ratio to the reduction in band gap energy and AT-POME photocatalytic activity.

(iv) Synthesising ZIO with optimum molar ratio by varying calcination temperature ranging from 400°C to 800°C.

(v) Studying the effect of calcination temperature to the surface area of coupled ZIO and its absorption capacity.

(vi) Fabricating nanocomposite UF membrane by polyvinylidene fluoride (PVDF) (18.0 wt%), polyvinylpyrrolidone (PVP) (1.0 wt%), lithium chloride (LiCl) (0.5 wt%), ZIO (0.0 – 2.0 wt%) and n-methyl-2-pyrrolidone (NMP) (78.5 – 80.5 wt%).

(vii) Studying the effect of ZIO loading to the morphology of membrane by field emission scanning electron microscope (FESEM), atomic force microscope (AFM) and X-ray diffraction (XRD).

(viii) Evaluating the performance of photocatalyst ZIO in terms of photodegradation in visible and UV light.

(ix) Evaluating the performance of photocatalysis via COD, colour removal and total organic carbon (TOC) analysis.

(x) Investigating the self-cleaning properties of nanocomposite UF membrane by membrane-flux recovery ratio over 4 hours continuous operation in 4 cycles.

(xi) Studying the effect of ZIO loading to the membrane performance via pure water permeation, colour removal of AT-POME and fouling analysis.

1.5 Significance of Study

This study aims to decolourise brownish AT-POME which is high in COD, colour and TOC. Therefore, through the well study and the control of the synthesis parameters, it is believed that the ZIO is able to photodegrade colour pigment and other organic substances in AT-POME to produce clear water. Besides, ZIO oxide is believed can move the activation photon of photocatalyst from UV light region to visible light region. Thus, photocatalytic reaction can be easily activated with the presence of natural light (i.e. sunlight).

Besides, this is the first attempt by incorporating bimetallic oxide into polymeric membrane matrix to produce mixed matrix photocatalytic membrane. By developing such nanocomposite photocatalytic membrane, the photocatalysis and UF of AT-POME can be carried out simultaneously. Thus, the efficiency of decolourization will greatly improve and mitigate the water pollution problems. Furthermore, the treated AT-POME which is free from colour pigment can be reclaimed into the palm oil mill for other purposes. This will further enhance the water sustainability in plant and help to mitigate the excessive water use. In a broader text, water shortage problem can be mitigated.

1.6 Thesis Outline

This thesis consists of 5 chapters which are introduction, literature review, methodology, results and discussion and conclusion and recommendation. Besides, raw data for the membrane performance results are attached in the appendices. The thesis was written based on UTM Thesis Manual 2018.

Chapter 1 discussed the problem statement of the current AT-POME treatment for the colour removal and some drawback of the technologies used currently. Besides, objectives and scopes of the research are mentioned. Chapter 2 discussed the literature review which are the recent development for POME and AT-POME treatment, advanced oxidation processes and membrane technologies used in decolourisation. Chapter 3 discussed the research methodology for the study and chemical and analysis used to determine the performance of the membrane. Chapter 4 discussed the results based on the experimental and analysis. Chapter 5 concluded the research based on the quantitative and qualitative of the experimental results.

REFERENCES

1. Teoh, C.H., Key sustainability issues in the palm oil sector. 2010, A discussion paper for multi-stakeholders consultations (Commissioned by the World Bank Group).
2. Wahab, A.G. and J. Dong, Malaysia Oilseeds and Products Annual. 2017, Global Agricultural information network.
3. Cheng, C.K., et al., Preparation of titania doped argentum photocatalyst and its photoactivity towards palm oil mill effluent degradation. *Journal of Cleaner Production*, 2016. 112: p. 1128-1135.
4. Zahrim, A., A. Nasimah, and N. Hilal, Pollutants analysis during conventional palm oil mill effluent (POME) ponding system and decolourisation of anaerobically treated POME via calcium lactate-polyacrylamide. *Journal of Water Process Engineering*, 2014. 4: p. 159-165.
5. Ng, K.H., et al., Photocatalytic degradation of recalcitrant POME waste by using silver doped titania: Photokinetics and scavenging studies. *Chemical Engineering Journal*, 2016. 286: p. 282-290.
6. Wawrzkiewicz, M., Anion Exchange Resins as Effective Sorbents for Acidic Dye Removal from Aqueous Solutions and Wastewaters. *Solvent Extraction and Ion Exchange*, 2012. 30(5): p. 507-523.
7. Lee, Z.S., et al., Treatment technologies of palm oil mill effluent (POME) and olive mill wastewater (OMW): A brief review. *Environmental Technology & Innovation*, 2019. 15: p. 100377.
8. Mohammed, R.R. and M.F. Chong, Treatment and decolorization of biologically treated Palm Oil Mill Effluent (POME) using banana peel as novel biosorbent. *Journal of environmental management*, 2014. 132: p. 237-249.
9. Ghani, M.S.H., et al., Fouling assessment of tertiary palm oil mill effluent (POME) membrane treatment for water reclamation. *Journal of Water Reuse and Desalination*, 2018. 8(3): p. 412-423.
10. Zahrim, A.Y., et al., Effective coagulation-flocculation treatment of highly polluted palm oil mill biogas plant wastewater using dual coagulants:

Decolourisation, kinetics and phytotoxicity studies. *Journal of Water Process Engineering*, 2017. 16: p. 258-269.

11. Verma, V.K. and A.K. Mishra, Kinetic and isotherm modeling of adsorption of dyes onto rice husk carbon. *Global NEST Journal*, 2010. 12(2): p. 190-196.
12. Riaz, S. and S.-J. Park, An overview of TiO2-based photocatalytic membrane reactors for water and wastewater treatments. *Journal of Industrial and Engineering Chemistry*, 2019. Article in press.
13. Ratpukdi, T., Decolorization of anaerobically treated palm oil mill wastewater using combined coagulation and vacuum ultraviolet-hydrogen peroxide. *International Journal of Chemical Engineering and Applications*, 2012. 3(5): p. 333.
14. Lu, Z., et al., Composite nanofiltration membrane with asymmetric selective separation layer for enhanced separation efficiency to anionic dye aqueous solution. *Journal of Hazardous Materials*, 2019. 368: p. 436-443.
15. Ong, Y.K., et al., Nanofiltration hollow fiber membranes for textile wastewater treatment: Lab-scale and pilot-scale studies. *Chemical Engineering Science*, 2014. 114: p. 51-57.
16. Tang, C. and V. Chen, Nanofiltration of textile wastewater for water reuse. *Desalination*, 2002. 143(1): p. 11-20.
17. Lau, W.J., et al., Performance Evaluation of Hybrid Coagulation/Nanofiltration Process for AT-POME Treatment. *International Journal of Engineering*, 2018. 31(8): p. 1430-1436.
18. M.P.O.B., Malaysian Palm Oil Statistics. 2012, Malaysian Palm Oil Board (M.P.O.B.).
19. Szydłowska-Czerniak, A., et al., Effect of refining processes on antioxidant capacity, total contents of phenolics and carotenoids in palm oils. *Food Chemistry*, 2011. 129(3): p. 1187-1192.
20. Azlan, A., et al., Comparison of fatty acids, vitamin E and physicochemical properties of Canarium odontophyllum Miq. (dabai), olive and palm oils. *Journal of Food Composition and Analysis*, 2010. 23(8): p. 772-776.
21. Sulaiman, F., et al., An outlook of Malaysian energy, oil palm industry and its utilization of wastes as useful resources. *Biomass and Bioenergy*, 2011. 35(9): p. 3775-3786.
22. OECD/FAO, OECD0FAO Agricultural Outlook 2011-2020. 2011.

23. Levin, J., Profitability and Sustainability in Palm Oil Production - Analysis of Incremental Financial Costs and Benefits of RSPO Compliance. 2012, World Wide Fund for Nature (WWF): Malaysia. p. 1-60.
24. Guha, A., Market Outlook - Palm Oil. 2010, ARABIS: Malaysia. p. 1-57.
25. Malaysia, E.U.D.t., The Malaysian Palm Oil Sector - Overview. 2011, Trade and Economic Section of EU: Europe. p. 1-21.
26. Shinoj, S., et al., Oil palm fiber (OPF) and its composites: A review. *Industrial Crops and Products*, 2011. 33(1): p. 7-22.
27. Hamzah, F., A. Idris, and T.K. Shuan, Preliminary study on enzymatic hydrolysis of treated oil palm (Elaeis) empty fruit bunches fibre (EFB) by using combination of cellulase and β 1-4 glucosidase. *Biomass and Bioenergy*, 2011. 35(3): p. 1055-1059.
28. Rozman, H.D., K.R. Ahmadhilmi, and A. Abubakar, Polyurethane (PU)—oil palm empty fruit bunch (EFB) composites: the effect of EFBG reinforcement in mat form and isocyanate treatment on the mechanical properties. *Polymer Testing*, 2004. 23(5): p. 559-565.
29. Ahmadzadeh, A., S. Zakaria, and R. Rashid, Liquefaction of oil palm empty fruit bunch (EFB) into phenol and characterization of phenolated EFB resin. *Industrial Crops and Products*, 2009. 30(1): p. 54-58.
30. Ahmad, A.L., S. Ismail, and S. Bhatia, Water recycling from palm oil mill effluent (POME) using membrane technology. *Desalination*, 2003(157): p. 8.
31. Ahmad, A.L., M.F. Chong, and S. Bhatia, Mathematical modelling of multiple solutes system for reverse osmosis process in palm oil mill effluent (POME) treatment. *Chemical Engineering Journal*, 2007(132): p. 11.
32. Ahmad, A.L., M.F. Chong, and S. Bhatia, A comparative study on the membrane based palm oil mill effluent (POME) treatment plant. *Journal of Hazardous Materials*, 2009. 171(1-3): p. 166-174.
33. Mumtaz, T., et al., Turning waste to wealth-biodegradable plastics polyhydroxyalkanoates from palm oil mill effluent - a Malaysian perspective. *Journal of Cleaner Production*, 2010. 18: p. 10.
34. Chong, M.L., et al., Biohydrogen production by Clostridium butyricum EB6 from palm oil mill effluent. *International Journal of Hydrogen Energy*, 2009. 34: p. 8.

35. (DOE), D.o.E., Industrial Processes & The Environment (Handbook No. 3) Crude Palm Oil Industry. 1999, Swigravis Advertising: Selangor, Malaysia. p. 102.
36. Lam, M.K. and K.T. Lee, Renewable and sustainable bioenergies production from palm oil mill effluent (POME): Win–win strategies toward better environmental protection. *Biotechnology Advances*, 2011. 29(1): p. 124-141.
37. Wu, T.Y., et al., Pollution control technologies for the treatment of palm oil mill effluent (POME) through end-of-pipe processes. *Journal of Environmental Management*, 2010(91): p. 24.
38. Alrawi, R.A., et al., Characterization of Oily and Non-Oily Natural Sediments in Palm Oil Mill Effluent. *Journal of Chemistry*, 2013. 2013: p. 11.
39. Gamaralalage, D., O. Sawai, and T. Nunoura, Degradation behavior of palm oil mill effluent in Fenton oxidation. *Journal of Hazardous Materials*, 2019. 364: p. 791-799.
40. Rupani, P.F., et al., Review of Current Palm Oil Mill Effluent (POME) Treatment Methods: Vermicomposting as a Sustainable Practice. *World Applied Sciences Journal*, 2010. 11(1): p. 12.
41. Sumathi, S., S.P. Chai, and A.R. Mohamed, Utilization of oil palm as a source of renewable energy in Malaysia. *Renewable and Sustainable Energy Reviews*, 2008. 12(9): p. 2404-2421.
42. Wu, T.Y., et al., Palm oil mill effluent (POME) treatment and bioresources recovery using ultrafiltration membrane: Effect of pressure on membrane fouling. *Biochemical Engineering Journal*, 2007. 35(3): p. 309-317.
43. Borja R and B. CJ., Anaerobic digestion of palm oil mill effluent using an up-flow anaerobic sludge blanket reactor. *Biomass Bioenergy*, 1994. 6: p. 9.
44. M.P.O.B. A summary on the performance of the Malaysian oil palm industry-2008. 2008; Available from: http:// econ.mpob.gov.my/economy/ Performance-130109.htm.
45. Malaysia, Environmental Quality Act 1974 [ACT 127] - Environmental Quality (Sewage and Industrial Effluents) Regulation 1979, in P. U. (A) 12/79. 2009.
46. Liew, W.L., et al., Conventional methods and emerging wastewater polishing technologies for palm oil mill effluent treatment: a review. *Journal of Environmental Management*, 2015. 149: p. 222-35.

47. Zainuri, N.Z., et al., Palm oil mill secondary effluent (POMSE) treatment via photocatalysis process in presence of ZnO-PEG nanoparticles. *Journal of Water Process Engineering*, 2018. 26: p. 10-16.
48. Othman, M.R., et al., Treatment of effluents from palm oil mill process to achieve river water quality for reuse as recycled water in a zero emission system. *Journal of Cleaner Production*, 2014. 67: p. 58-61.
49. Chin, K.K., S.W. Lee, and H.H. Mohammad, A study of palm oil mill effluent treatment using a pond system. *Water Science and Technology*, 1996. 34(11): p. 119-123.
50. Chan, Y.J., M.F. Chong, and C.L. Law, Biological treatment of anaerobically digested palm oil mill effluent (POME) using a Lab-Scale Sequencing Batch Reactor (SBR). *Journal of Environmental Management*, 2010. 91(8): p. 1738-46.
51. Zahrim, A.Y., et al., Decolourisation of anaerobic palm oil mill effluent via activated sludge granular activated carbon. *World Applied Sciences Journal 5 (Special Issue for Environment)*, 2009: p. 126-129.
52. Rana, S., et al., A Recent Overview of Palm Oil Mill Effluent Management via Bioreactor Configurations. *Current Pollution Reports*, 2017. 3(4): p. 254-267.
53. Poh, P.E. and M.F. Chong, Development of anaerobic digestion methods for palm oil mill effluent (POME) treatment. *Bioresource Technology*, 2009. 100(1): p. 1-9.
54. Yacob, S., et al., Baseline study of methane emission from anaerobic ponds of palm oil mill effluent treatment. *Science of The Total Environment*, 2006. 366(1): p. 187-196.
55. Yacob, S., et al., Baseline study of methane emission from open digesting tanks of palm oil mill effluent treatment. *Chemosphere*, 2005. 59(11): p. 1575-1581.
56. Khadaroo, S.N.B.A., et al., Applicability of various pretreatment techniques to enhance the anaerobic digestion of Palm oil Mill effluent (POME): A review. *Journal of Environmental Chemical Engineering*, 2019. 7(5): p. 103310.
57. Demirel, B. and P. Scherer, The roles of acetotrophic and hydrogenotrophic methanogens during anaerobic conversion of biomass to methane: a review. *Review Environmental Science Biotechnology*, 2008(7): p. 18.

58. Chan, Y.J., et al., A review on anaerobic–aerobic treatment of industrial and municipal wastewater. *Chemical Engineering Journal*, 2009. 155(1–2): p. 1-18.
59. Ugoji, E.O., Anaerobic digestion of palm oil mill effluent and its utilization as fertilizer for environmental protection. *Renewable Energy*, 1997. 10(2/3): p. 291-294.
60. Shammas, N.K. and L.K. Wang, Aerobic Digestion, in Handbook of Environmental Engineering, L.K. Wang, Y.-T. Hung, and N.C. Pereira, Editors. 2009, Humana Press: New York, USA.
61. Shavandi, M.A., et al., Removal of Fe(III), Mn(II) and Zn(II) from palm oil mill effluent (POME) by natural zeolite. *Journal of Taiwan Institute of Chemical Engineers*, 2012(43): p. 10.
62. Mudhoo, A. and S. Kumar, Effects of heavy metals as stress factors on anaerobic digestion processes and biogas production from biomass. *International Journal of Environmental Science and Technology*, 2013. 10(6): p. 1383-1398.
63. Wong, Y.-S., et al., Anaerobic Acidogenesis Biodegradation of Palm Oil Mill Effluent Using Suspended Closed Anaerobic Bioreactor (SCABR) at Mesophilic Temperature. *Procedia Environmental Sciences*, 2013. 18: p. 433-441.
64. Saidu, M., et al., Influence of palm oil mill effluent as inoculum on anaerobic digestion of cattle manure for biogas production. *Bioresource Technology*, 2013. 141: p. 174-6.
65. Ahmad, A.L., S. Sumathi, and B.H. Hameed, Coagulation of residue oil and suspended solid in palm oil mill effluent by chitosan, alum and PAC. *Chemical Engineering Journal*, 2006. 118(1-2): p. 99-105.
66. Wong, Y.S., M.O.A.B. Kadir, and T.T. Teng, Biological kinetics evaluation of anaerobic stabilization pond treatment of palm oil mill effluent. *Bioresource Technology*, 2009. 100(21): p. 4969-4975.
67. Omar, A.K.M., et al., Implementation of the supercritical carbon dioxide technology in oil palm fresh fruits bunch sterilization: A review. *Journal of CO2 Utilization*, 2018. 25: p. 205-215.

68. Fujihira, T., et al., High-rate anaerobic treatment system for solid/lipid-rich wastewater using anaerobic baffled reactor with scum recovery. *Bioresource Technology*, 2018. 263: p. 145-152.
69. Chan, Y.J., M.F. Chong, and C.L. Law, Effects of Temperature on Aerobic Treatment of Anaerobically Digested Palm Oil Mill Effluent (POME). *Industrial and Engineering Chemistry Research*, 2010. 49: p. 7093-7101.
70. Gozan, M., et al., Techno-Economic Analysis of Biogas Power Plant from POME (Palm Oil Mill Effluent). *International Journal of Applied Engineering Research*, 2018. 13(8): p. 6151-6157.
71. Hosseini, S.E., et al., Clean fuel, clean energy conversion technology: experimental and numerical investigation of palm oil mill effluent biogas flameless combustion. *BioResources*, 2015. 10(4): p. 6597-6609.
72. Nigam, P.S.n. and A. Pandey, Biotechnology for Agro-Industrial Residues Utilisation. Springer, 2009.
73. Raposo, F., et al., Anaerobic digestion of solid organic substrates in batch mode: An overview relating to methane yields and experimental procedures. *Renewable and Sustainable Energy Reviews*, 2012. 16(1): p. 861-877.
74. Horan, N., A.Z. Yaser, and N. Wid, Anaerobic digestion processes Applications and effluent treatment. Springer, 2018.
75. Hasanudin, U., et al., Palm oil mill effluent treatment and utilization to ensure the sustainability of palm oil industries. *Water Science and Technology*, 2015. 72(7): p. 1089-95.
76. Bello, M.M. and A.A. Abdul Raman, Trend and current practices of palm oil mill effluent polishing: Application of advanced oxidation processes and their future perspectives. *Journal of Environmental Management*, 2017. 198: p. 170-182.
77. A Aziz, M.M., et al., Recent advances on palm oil mill effluent (POME) pretreatment and anaerobic reactor for sustainable biogas production. *Renewable and Sustainable Energy Reviews*, 2019: p. 109603.
78. Yacob, S., et al., Start-up operation of semi-commercial closed anaerobic digester for palm oil mill effluent treatment. *Process Biochemistry*, 2006. 41(4): p. 962-964.

79. Li, C., S. Tabassum, and Z. Zhang, An advanced anaerobic expanded granular sludge bed (AnaEG) for the treatment of coal gasification wastewater. *RSC Advances*, 2014. 4(101): p. 57580-57586.
80. Tabassum, S., Y. Zhang, and Z. Zhang, An integrated method for palm oil mill effluent (POME) treatment for achieving zero liquid discharge – A pilot study. *Journal of Cleaner Production*, 2015. 95: p. 148-155.
81. Kheang, L.S., et al., An integrated anaerobic-aerobic treatment of palm oil mill effluent to achieve zero discharge. *Palm Oil Engineering Bulletin*, 2015. 117: p. 11-17.
82. Jain, M., Anaerobic Membrane Bioreactor as Highly Efficient and Reliable Technology for Wastewater Treatment—A Review. *Advances in Chemical Engineering and Science*, 2018. 08(02): p. 82-100.
83. Ylitervo, P., J. Akinbomia, and M.J. Taherzadeha, Membrane bioreactors' potential for ethanol and biogas production: a review. *Environmental Technology*, 2013. 34(13-16): p. 1711-23.
84. Abdurahman, N.H., Y.M. Rosli, and N.H. Azhari, Development of a membrane anaerobic system (MAS) for palm oil mill effluent (POME) treatment. *Desalination*, 2011. 266(1-3): p. 208-212.
85. Poh, P.E. and M.F. Chong, Upflow anaerobic sludge blanket-hollow centered packed bed (UASB-HCPB) reactor for thermophilic palm oil mill effluent (POME) treatment. *Biomass and Bioenergy*, 2014. 67: p. 231-242.
86. Divya, D., L.R. Gopinath, and P. Merlin Christy, A review on current aspects and diverse prospects for enhancing biogas production in sustainable means. *Renewable and Sustainable Energy Reviews*, 2015. 42: p. 690-699.
87. B., D., S. V., and J. S., Biogas Generation through Anaerobic Digetsion Process – An Overview. *Research Journal of Chemistry and Environment*, 2014. 18(5): p. 80-93.
88. Hagos, K., et al., Anaerobic co-digestion process for biogas production: Progress, challenges and perspectives. *Renewable and Sustainable Energy Reviews*, 2017. 76: p. 1485-1496.
89. Dvořák, L., et al., Anaerobic membrane bioreactors—a mini review with emphasis on industrial wastewater treatment: applications, limitations and perspectives. *Desalination and Water Treatment*, 2015. 57(41): p. 19062-19076.

90. Abdulsalam, M., et al., Treatment of Palm Oil Mill Effluent Using Membrane Bioreactor: Novel Processes and Their Major Drawbacks. *Water*, 2018. 10(9): p. 1165.
91. Ahmed, Y., et al., Production of biogas and performance evaluation of existing treatment processes in palm oil mill effluent (POME). *Renewable and Sustainable Energy Reviews*, 2015. 42: p. 1260-1278.
92. Uddin, W., et al., Biogas potential for electric power generation in Pakistan: A survey. *Renewable and Sustainable Energy Reviews*, 2016. 54: p. 25-33.
93. Qin, X., et al., The Advanced Anaerobic Expanded Granular Sludge Bed (AnaEG) Possessed Temporally and Spatially Stable Treatment Performance and Microbial Community in Treating Starch Processing Wastewater. *Frontiers in Microbiology*, 2018. 9: p. 589.
94. Chaiprapat, S. and T. Laklam, Enhancing digestion efficiency of POME in anaerobic sequencing batch reactor with ozonation pretreatment and cycle time reduction. *Bioresource Technology*, 2011. 102(5): p. 4061-8.
95. Abd Nasir, M.A., et al., The use of acidified palm oil mill effluent for thermophilic biomethane production by changing the hydraulic retention time in anaerobic sequencing batch reactor. *International Journal of Hydrogen Energy*, 2019. 44(6): p. 3373-3381.
96. Khemkhao, M., S. Techkarnjanaruk, and C. Phalakornkule, Effect of chitosan on reactor performance and population of specific methanogens in a modified CSTR treating raw POME. *Biomass and Bioenergy*, 2016. 86: p. 11-20.
97. Choong, Y.Y., K.W. Chou, and I. Norli, Strategies for improving biogas production of palm oil mill effluent (POME) anaerobic digestion: A critical review. *Renewable and Sustainable Energy Reviews*, 2018. 82: p. 2993-3006.
98. Khemkhao, M., S. Techkarnjanaruk, and C. Phalakornkule, Simultaneous treatment of raw palm oil mill effluent and biodegradation of palm fiber in a high-rate CSTR. *Bioresource Technology*, 2015. 177: p. 17-27.
99. Mao, C., et al., Review on research achievements of biogas from anaerobic digestion. *Renewable and Sustainable Energy Reviews*, 2015. 45: p. 540-555.
100. Gobi, K. and V.M. Vadivelu, By-products of palm oil mill effluent treatment plant – A step towards sustainability. *Renewable and Sustainable Energy Reviews*, 2013. 28: p. 788-803.

101. Borja, R. and C.J. Banks, Treatment of Palm Oil Mill Effluent by upflow anaerobic filtration. *Journal of Chemical Technology and Biotechnology*, 1994. 61: p. 103-109.

102. Zinatizadeh, A.A.L., et al., Optimization of pre-treated palm oil mill effluent digestion in an up-flow anaerobic sludge fixed film bioreactor: A comparative study. *Biochemical Engineering Journal*, 2007. 35(2): p. 226-237.

103. Khemkhao, M., et al., UASB performance and microbial adaptation during a transition from mesophilic to thermophilic treatment of palm oil mill effluent. *Journal of Environmental Management*, 2012. 103: p. 74-82.

104. Zinatizadeh, A.A. and M. Mirghorayshi, Effect of Temperature on the Performance of an Up-flow Anaerobic Sludge Fixed Film (UASFF) Bioreactor Treating Palm Oil Mill Effluent (POME). *Waste and Biomass Valorization*, 2017. 10(2): p. 349-355.

105. Chan, Y.J., et al., Fuzzy optimisation approach on the treatment of palm oil mill effluent (POME) via up-flow anaerobic sludge blanket–hollow centered packed bed (UASB–HCPB) reactor. *Journal of Water Process Engineering*, 2015. 5: p. 112-117.

106. Choi, W.H., et al., Anaerobic treatment of palm oil mill effluent using combined high-rate anaerobic reactors. *Bioresource Technology*, 2013. 141: p. 138-44.

107. Mamimin, C., et al., Trace metals supplementation enhanced microbiota and biohythane production by two-stage thermophilic fermentation. *International Journal of Hydrogen Energy*, 2019. 44(6): p. 3325-3338.

108. Sidik, U.H., et al., Biogas production through Co-digestion of palm oil mill effluent with cow manure. *Nigerian Journal of Basic and Applied Sciences*, 2013. 21(1).

109. Khemkhao, M., et al., Effect of chitosan on UASB treating POME during a transition from mesophilic to thermophilic conditions. *Bioresource Technology*, 2011. 102(7): p. 4674-81.

110. Bala, J.D., J. Lalung, and N. Ismail, Palm Oil Mill Effluent (POME) Treatment ‘‘Microbial communities in an anaerobic digester": A review. International *Journal of Scientific and Research Publications*, 2014. 4(6): p. 1-24.

111. Fang, C., et al., Comparison of UASB and EGSB reactors performance, for treatment of raw and deoiled palm oil mill effluent (POME). *Journal of Hazardous Materials*, 2011. 189(1-2): p. 229-34.
112. Budych-Gorzna, M., M. Smoczynski, and P. Oleskowicz-Popiel, Enhancement of biogas production at the municipal wastewater treatment plant by co-digestion with poultry industry waste. *Applied Energy*, 2016. 161: p. 387-394.
113. Baharuddin, A.S., et al., Effects of Palm Oil Mill Effluent (POME) Anaerobic Sludge From 500m3 of closed anaerobic methane digested tank on pressed-shredded empty fruit bunch (EFB) composting process. *African Journal of Biotechnology*, 2010. 9(16): p. 2427-2436.
114. Prasertsan, P., et al., Direct hydrolysis of palm oil mill effluent by xylanase enzyme to enhance biogas production using two-steps thermophilic fermentation under non-sterile condition. *International Journal of Hydrogen Energy*, 2017. 42(45): p. 27759-27766.
115. Saifuddin, Effect of Microwave and Ultrasonic Pretreatments on Biogas Production from Anaerobic Digestion of Palm Oil Mill Effleunt. *American Journal of Engineering and Applied Sciences*, 2009. 2(1): p. 139-146.
116. Suzana, C.u.S.M., et al., Immobilization of microbial cells: A promising tool for treatment of toxic pollutants in industrial wastewater. *African Journal of Biotechnology*, 2013. 12(28): p. 4412-4418.
117. Ayu, E.D., et al., The effect of natural zeolite as microbial immobilization media in anaerobic digestion at various concentrations of palm oil mill effluent (POME). *AIP Conference Proceedings*, 2017. 1840: p. 110005.
118. Ahmad, A., A novel application of red mud-iron on granulation and treatment of palm oil mill effluent using upflow anaerobic sludge blanket reactor. *Environmental Technology*, 2014. 35(21-24): p. 2718-26.
119. Elliott, A. and T. Mahmood, Pretreatment technologies for advancing anaerobic digestion of pulp and paper biotreatment residues. *Water Research*, 2007. 41(19): p. 4273-86.
120. Vijayaraghavan, K., D. Ahmad, and M. Ezani Bin Abdul Aziz, Aerobic treatment of palm oil mill effluent. *Journal of Environmental Management*, 2007. 82(1): p. 24-31.
121. Li, Z., et al., Electricity generation using a baffled microbial fuel cell convenient for stacking. *Bioresource Technology*, 2008. 99(6): p. 1650-5.

122. Back, J., et al., Erratum to "Construction of bacterial artificial chromosome library from electrochemical microorganisms" [FEMS Microbiol. Lett. 238 (2004) 65?70]. *FEMS Microbiology Letters*, 2004. 239(1): p. 203-203.
123. Cheng, J., et al., Palm oil mill effluent treatment using a two-stage microbial fuel cells system integrated with immobilized biological aerated filters. *Bioresource Technology*, 2010. 101(8): p. 2729-34.
124. Rismani-Yazdi, H., et al., Cathodic limitations in microbial fuel cells: An overview. *Journal of Power Sources*, 2008. 180(2): p. 683-694.
125. Adeleke, A.O., et al., Optimization of operating parameters of novel composite adsorbent for organic pollutants removal from POME using response surface methodology. *Chemosphere*, 2017. 174: p. 232-242.
126. Chew, C.M., et al., Evaluation of ultrafiltration and conventional water treatment systems for sustainable development: an industrial scale case study. *Journal of Cleaner Production*, 2016. 112: p. 3152-3163.
127. Cheng, C.K., M. Rizauddin Derahman, and M.R. Khan, Evaluation of the photocatalytic degradation of pre-treated palm oil mill effluent (POME) over Pt-loaded titania. *Journal of Environmental Chemical Engineering*, 2015. 3(1): p. 261-270.
128. Cheng, C.K., et al., Preparation of titania doped argentum photocatalyst and its photoactivity towards palm oil mill effluent degradation. *Journal of Cleaner Production*, 2016. 112, Part 1: p. 1128-1135.
129. Huzir, N.M., et al., Optimization of coagulation-flocculation process for the palm oil mill effluent treatment by using rice husk ash. *Industrial Crops and Products*, 2019. 139: p. 111482.
130. Ahmad, A.L., et al., Drinking water reclamation from palm oil mill effluent (POME) using membrane technology. *Desalination*, 2006. 191(1-3): p. 35-44.
131. Ahmad, A.L., S. Ismail, and S. Bhatia, Membrane treatment for palm oil mill effluent: effect of transmembrane pressure and crossflow velocity. *Desalination*, 2005. 179(1-3): p. 245-255.
132. Ahmad, A.L., S. Ismail, and S. Bhatia, Ultrafiltration behavior in the treatment of agro-industry effluent: Pilot scale studies. *Chemical Engineering Science*, 2005. 60(19): p. 5385-5394.
133. Idris, A., I. Ahmed, and M.A. Limin, Influence of lithium chloride, lithium bromide and lithium fluoride additives on performance of polyethersulfone

membranes and its application in the treatment of palm oil mill effluent. *Desalination*, 2010. 250(2): p. 805-809.

134. Wu, T.Y., et al., Palm oil mill effluent (POME) treatment and bioresources recovery using ultrafiltration membrane: Effect of pressure on membrane fouling. *Biochemical Engineering Journal*, 2007. 35(3): p. 309-317.

135. Idris, A., I. Ahmed, and H.W. Jye, Performance of cellulose acetate - polyethersulphone blend membrane prepared using microwave heating for palm oil mill effluent treatment. *Water Science and Technology*, 2007. 56(8): p. 169-177.

136. Shamsuddin, M.R., I. Abdullah, and R. Othaman. Celluloses Filled ENR/PVC Membranes for Palm Oil Mill Effluent (POME) Treatment. in Universiti-Kebangsaan-Malaysia, Faculty-of-Science-and-Technology Postgraduate Colloquium. 2013. Univ Kebangsaan Malaysia, Fac Sci & Technol, Bangi, MALAYSIA.

137. Subramaniam, M.N., et al., Hydrophilic hollow fiber PVDF ultrafiltration membrane incorporated with titanate nanotubes for decolourization of aerobically-treated palm oil mill effluent. *Chemical Engineering Journal*, 2017. 316: p. 101-110.

138. Nasrullah, M., et al., High performance electrocoagulation process in treating palm oil mill effluent using high current intensity application. *Chinese Journal of Chemical Engineering*, 2019. 27(1): p. 208-217.

139. Mod, N. and R. Othaman. Preparation and Pre-Characterization of Epoxidized Natural Rubber (ENR) / Poly(vinylidene fluoride) (PVDF) (ENR/PVDF) Thin Film Composite Membrane. in UKM FST Postgraduate Colloquium. 2015. Univ Kebangsaan Malaysia, Fac Sci & Technol, Selangor, MALAYSIA.

140. Amosa, M.K., Towards sustainable membrane filtration of palm oil mill effluent: analysis of fouling phenomena from a hybrid PAC-UF process. *Applied Water Science*, 2017. 7(6): p. 3365-3375.

141. Ho, K.C., et al., Novel GO/OMWCNTs mixed-matrix membrane with enhanced antifouling property for palm oil mill effluent treatment. *Separation and Purification Technology*, 2017. 177: p. 337-349.

142. Badawy, M.I., et al., Enhancement of olive mill wastewater biodegradation by homogeneous and heterogeneous photocatalytic oxidation. *Journal of Hazardous Materials*, 2009. 169(1–3): p. 673-679.

143. Idris, M.A., M.S. Jami, and S.A. Muyibi, Tertiary Treatment of Biologically Treated Palm Oil Mill Effluent (POME) Using UF Membrane System: Effect of MWCO and Transmembrane Pressure. *International Journal of Chemical and Environmental Engineering*, 2010. 1(2): p. 1-5.
144. Sulong, M., et al., Membrane bioreactor technology for tertiary treatment of palm oil mill effluent (POME). MPOB Information Series, 2007.
145. Sulong, M. and N.A. Wahab, Compact tertiary plant for the treatment of POME. MPOB Information Series, 2008.
146. Kongnoo, A., et al., Decolorization and Organic Removal from Palm Oil Mill Effluent by Fenton's Process. *Environmental Engineering Science*, 2012. 29(9): p. 855-859.
147. Neoh, C.H., et al., Optimization of decolorization of palm oil mill effluent (POME) by growing cultures of Aspergillus fumigatus using response surface methodology. *Environmental Science and Pollution Research*, 2013. 20(5): p. 2912-23.
148. Oswal, N., et al., Palm oil mill effluent treatment by a tropical marine yeast. *Bioresource Technology*, 2002. 85: p. 35-37.
149. Abdullah, N. and F. Sulaim, The Oil Palm Wastes in Malaysia. Biomass Now - Sustainable Growth and Use, 2013.
150. Neyens, E. and J. Baeyens, A review of classic Fenton's peroxidation as an advanced oxidation technique. *Journal of Hazardous Materials*, 2003. 98(1-3): p. 33-50.
151. Saeed, M.O., et al., Application of CCD in RSM to obtain optimize treatment of POME using Fenton oxidation process. *Journal of Water Process Engineering*, 2015. 8: p. e7-e16.
152. Nazhif Mohd Nohan, M.A., et al., Highly stable binder free CNTs/rGO aerogel electrode for decolouration of methylene blue & palm oil mill effluent via electro-Fenton oxidation process. *RSC Advances*, 2019. 9(29): p. 16472-16478.
153. Bashir, M.J.K., et al., Electro persulphate oxidation for polishing of biologically treated palm oil mill effluent (POME). *Journal of Environmental Management*, 2017. 193: p. 458-469.
154. Bashir, M.J., et al., Post treatment of Palm Oil Mill Effluent Using Electro-coagulation-peroxidation (ECP) technique. *Journal of Cleaner Production*, 2019. 208: p. 716-727.

155. Alhaji, M.H., et al., Photo-oxidation of pre-treated palm oil mill Effluent using cylindrical column immobilized photoreactor. *Process Safety and Environmental Protection*, 2018. 117: p. 180-189.
156. Lv, K., et al., Fabrication of TiO 2 nanorod assembly grafted rGO (rGO@TiO 2 -NR) hybridized flake-like photocatalyst. *Applied Surface Science*, 2017. 391: p. 218-227.
157. Luo, M.-L., et al., Hydrophilic modification of poly(ether sulfone) ultrafiltration membrane surface by self-assembly of TiO2 nanoparticles. *Applied Surface Science*, 2005. 249(1-4): p. 76-84.
158. Zangeneh, H., A.A.L. Zinatizadeh, and M. Feyzi, Degradation of Linear Alkyl Benzene Using an Immobilized Nano TiO2Photocatalytic Reactor: Process Analysis and Modeling. *CLEAN - Soil, Air, Water*, 2016. 44(1): p. 78-88.
159. Sotto, A., et al., Doping of polyethersulfone nanofiltration membranes: antifouling effect observed at ultralow concentrations of TiO2 nanoparticles. *Journal of Materials Chemistry*, 2011. 21(28): p. 10311.
160. Ghaemi, N., et al., Fabrication and modification of polysulfone nanofiltration membrane using organic acids: Morphology, characterization and performance in removal of xenobiotics. *Separation and Purification Technology*, 2012. 96: p. 214-228.
161. Safarpour, M., V. Vatanpour, and A. Khataee, Preparation and characterization of graphene oxide/TiO2 blended PES nanofiltration membrane with improved antifouling and separation performance. *Desalination*, 2016. 393: p. 65-78.
162. Zangeneh, H., et al., A novel photocatalytic self-cleaning PES nanofiltration membrane incorporating triple metal-nonmetal doped TiO2 (K-B-N-TiO2) for post treatment of biologically treated palm oil mill effluent. *Reactive and Functional Polymers*, 2018. 127: p. 139-152.
163. Ahmad Farid, M.A., et al., A holistic treatment system for palm oil mill effluent by incorporating the anaerobic-aerobic-wetland sequential system and a convective sludge dryer. *Chemical Engineering Journal*, 2019. 369: p. 195-204.
164. Black and C. Veatch, Advanced Oxidation Processes, in White's Handbook of Chlorination and Alternative Disinfectants. 2010, John Wiley & Sons, Inc. p. 976-1002.

165. Choi, H., et al., Chapter 8 TiO2-Based Advanced Oxidation Nanotechnologies for Water Purification and Reuse, in Sustainability Science and Engineering, C.E. Isabel and I.S. Andrea, Editors. 2010, Elsevier. p. 229-254.

166. Zaw, M. and M.T. Emett, Arsenic removal from water using advanced oxidation processes. *Toxicology Letters*, 2002. 133(1): p. 113-118.

167. Oller, I., S. Malato, and J.A. Sánchez-Pérez, Combination of Advanced Oxidation Processes and biological treatments for wastewater decontamination—A review. *Science of The Total Environment*, 2011. 409(20): p. 4141-4166.

168. Hernandez, R., et al., Comparing the performance of various advanced oxidation processes for treatment of acetone contaminated water. *Journal of Hazardous Materials*, 2002. 92(1): p. 33-50.

169. Glauner, T., et al., Elimination of Swimming Pool Water Disinfection By-products with Advanced Oxidation Processes (AOPs). *Acta hydrochimica et hydrobiologica*, 2005. 33(6): p. 585-594.

170. Kestioğlu, K., T. Yonar, and N. Azbar, Feasibility of physico-chemical treatment and Advanced Oxidation Processes (AOPs) as a means of pretreatment of olive mill effluent (OME). *Process Biochemistry*, 2005. 40(7): p. 2409-2416.

171. Matilainen, A. and M. Sillanpää, Removal of natural organic matter from drinking water by advanced oxidation processes. *Chemosphere*, 2010. 80(4): p. 351-365.

172. Klavarioti, M., D. Mantzavinos, and D. Kassinos, Removal of residual pharmaceuticals from aqueous systems by advanced oxidation processes. *Environment International*, 2009. 35(2): p. 402-417.

173. Zamaraev, K.I., Photocatalysis: State of the art and perspectives, in Studies in Surface Science and Catalysis, W.N.D.E.I. Joe W. Hightower and T.B. Alexis, Editors. 1996, Elsevier. p. 35-50.

174. Gordon, T., et al., Synthesis and characterization of zinc/iron oxide composite nanoparticles and their antibacterial properties. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 2011. 374(1–3): p. 1-8.

175. Pradhan, G.K., S. Martha, and K.M. Parida, Synthesis of Multifunctional Nanostructured Zinc-Iron Mixed Oxide Photocatalyst by a Simple Solution-Combustion Technique. *Applied Materials and Interfaces*, 2012. 4: p. 7.

176. Tong, H., et al., Nano-photocatalytic Materials: Possibilities and Challenges. *Advanced Materials*, 2012. 24(2): p. 229-251.

177. Song, H., et al., Natural organic matter removal and flux decline with PEG–TiO2-doped PVDF membranes by integration of ultrafiltration with photocatalysis. *Journal of Membrane Science*, 2012. 405–406(0): p. 48-56.

178. El Hajjouji, H., et al., Photochemical UV/TiO2 treatment of olive mill wastewater (OMW). *Bioresource Technology*, 2008. 99(15): p. 7264-7269.

179. Zhang, X., et al., Preparation, performance and adsorption activity of TiO2 nanoparticles entrapped PVDF hybrid membranes. *Applied Surface Science*, 2012. 263(0): p. 660-665.

180. Rahimpour, A., et al., Structural and performance properties of UV-assisted TiO2 deposited nano-composite PVDF/SPES membranes. *Desalination*, 2012. 285(0): p. 31-38.

181. Ollis, D.F., E. Pelizzetti, and N. Serpone, Photocatalyzed destruction of water contaminants. *Environmental Science & Technology*, 1991. 25(9): p. 1522-1529.

182. Liu, S., et al., A novel preparation of highly active iron-doped titania photocatalysts with a p–n junction semiconductor structure. *Journal of Alloys and Compounds*, 2010. 506(2): p. 877-882.

183. Shifu, C., et al., Preparation, characterization and activity evaluation of p–n junction photocatalyst p-CaFe2O4/n-ZnO. *Chemical Engineering Journal*, 2009. 155(1): p. 466-473.

184. Chen, S., et al., Preparation, characterization and activity evaluation of p–n junction photocatalyst p-ZnO/n-TiO2. *Applied Surface Science*, 2008. 255(5, Part 1): p. 2478-2484.

185. Rashid, J., et al., InVO 4/TiO 2 composite for visible-light photocatalytic degradation of 2-chlorophenol in wastewater. *Environmental Technology*, 2014. 35(17): p. 2153-2159.

186. Pradhan, G.K., S. Martha, and K.M. Parida, Synthesis of Multifunctional Nanostructured Zinc–Iron Mixed Oxide Photocatalyst by a Simple Solution-Combustion Technique. *ACS Applied Materials & Interfaces*, 2012. 4(2): p. 707-713.

187. Saeed, K., I. Khan, and M. Sadiq, Synthesis of graphene-supported bimetallic nanoparticles for the sunlight photodegradation of Basic Green 5 dye in

aqueous medium. *Separation Science and Technology*, 2016. 51(8): p. 1421-1426.

188. Zhao, W., et al., A simple method for fabricating p–n junction photocatalyst $CuFe_2O_4/Bi_4Ti_3O_{12}$ and its photocatalytic activity. *Materials Chemistry and Physics*, 2014. 143(3): p. 952-962.

189. Riaz, N., et al., Photodegradation of Orange II under visible light using Cu–Ni/TiO_2: Effect of calcination temperature. *Chemical Engineering Journal*, 2012. 185-186: p. 108-119.

190. Castro, C.L.D. and B.S. Mitchell, Chapter 1 Nanoparticles from Mechanical Attrition, in Synthesis, Functionalization and Surface Treatment of Nanoparticles, M.-I. Baraton, Editor. 2002, American Scientific Publishers. p. 1-15.

191. Shifu, C., et al., The preparation of coupled WO_3/TiO_2 photocatalyst by ball milling. *Powder Technology*, 2005. 160(3): p. 198-202.

192. Aruna, S.T. and A.S. Mukasyan, Combustion synthesis and nanomaterials. *Current Opinion in Solid State and Materials Science*, 2008. 12(3–4): p. 44-50.

193. Moussaoui, R., et al., Sol–gel synthesis of highly TiO_2 aerogel photocatalyst via high temperature supercritical drying. *Journal of Saudi Chemical Society*, 2017. 21(6): p. 751-760.

194. Anderson, C. and A.J. Bard, An Improved Photocatalyst of TiO_2/SiO_2 Prepared by a Sol-Gel Synthesis. *The Journal of Physical Chemistry*, 1995. 99(24): p. 9882-9885.

195. González-Cortés, S.L. and F.E. Imbert, Fundamentals, properties and applications of solid catalysts prepared by solution combustion synthesis (SCS). *Applied Catalysis A: General*, 2013. 452(0): p. 117-131.

196. Zhang, Z. and W. Wang, Solution combustion synthesis of $CaFe_2O_4$ nanocrystal as a magnetically separable photocatalyst. *Materials Letters*, 2014. 133: p. 212-215.

197. Hossain, M.K., et al., Solution Combustion Synthesis, Characterization, and Photocatalytic Activity of $CuBi_2O_4$ and Its Nanocomposites with CuO and α-Bi_2O_3. *The Journal of Physical Chemistry C*, 2017. 121(15): p. 8252-8261.

198. Rauf, M.A., M.A. Meetani, and S. Hisaindee, An overview on the photocatalytic degradation of azo dyes in the presence of TiO2 doped with selective transition metals. *Desalination*, 2011. 276(1–3): p. 13-27.

199. Yang, L. and Z. Liu, Study on light intensity in the process of photocatalytic degradation of indoor gaseous formaldehyde for saving energy. *Energy Conversion and Management*, 2007. 48(3): p. 882-889.

200. Shiragami, T., et al., Semiconductor photocatalysis: effect of light intensity on nanoscale cadmium sulfide-catalyzed photolysis of organic substrates. *The Journal of Physical Chemistry*, 1993. 97(49): p. 12882-12887.

201. Akpan, U.G. and B.H. Hameed, Parameters affecting the photocatalytic degradation of dyes using TiO2-based photocatalysts: A review. *Journal of Hazardous Materials*, 2009. 170(2–3): p. 520-529.

202. Piscopo, A., D. Robert, and J.V. Weber, Influence of pH and chloride anion on the photocatalytic degradation of organic compounds: Part I. Effect on the benzamide and para-hydroxybenzoic acid in TiO2 aqueous solution. *Applied Catalysis B: Environmental*, 2001. 35(2): p. 117-124.

203. Zhang, G., et al., Effects of organic acids and initial solution pH on photocatalytic degradation of bisphenol A (BPA) in a photo-Fenton-like process using goethite (α-FeOOH). *Photochemical & Photobiological Sciences*, 2016. 15(8): p. 1046-1053.

204. Shaban, Y.A., et al., Photocatalytic degradation of phenol in natural seawater using visible light active carbon modified (CM)-n-TiO2 nanoparticles under UV light and natural sunlight illuminations. *Chemosphere*, 2013. 91(3): p. 307-313.

205. Saratale, R.G., et al., Influence of parameters on the photocatalytic degradation of phenolic contaminants in wastewater using TiO2/UV system. *Journal of Environmental Science and Health, Part A*, 2014. 49(13): p. 1542-1552.

206. Chin, Y.-H., J.-C. Sin, and S.-M. Lam, A facile route for fabrication of hierarchical porous Nb2O5/ZnO composites with enhanced photocatalytic degradation of palm oil mill effluent. *Materials Letters*, 2018. 216: p. 8-11.

207. Membrane Separation Operations, in Multistage Separation Processes, Third Edition. 2004, CRC Press.

208. Membranes, in The Physical Chemistry of Materials. 2009, CRC Press. p. 467-490.

209. Membrane selection — more than material properties alone. Membrane Technology, 1998. 1998(97): p. 7-10.
210. Lalia, B.S., et al., A review on membrane fabrication: Structure, properties and performance relationship. *Desalination*, 2013. 326(0): p. 77-95.
211. Hamza, A., et al., Development of membranes with low surface energy to reduce the fouling in ultrafiltration applications. *Journal of Membrane Science*, 1997. 131(1–2): p. 217-227.
212. Polyakov, Y.S. and A.L. Zydney, Ultrafiltration membrane performance: Effects of pore blockage/constriction. *Journal of Membrane Science*, 2013. 434(0): p. 106-120.
213. Hofmann, T., Studies on the Relationship between Molecular Weight and the Color Potency of Fractions Obtained by Thermal Treatment of Glucose/Amino Acid and Glucose/Protein Solutions by Using Ultracentrifugation and Color Dilution Techniques. *Journal of Agricultural and Food Chemistry*, 1998. 46(10): p. 3891-3895.
214. Marcucci, M., et al., Treatment and reuse of textile effluents based on new ultrafiltration and other membrane technologies. *Desalination*, 2001. 138(1): p. 75-82.
215. Ochoa, N.A., M. Masuelli, and J. Marchese, Development of charged ion exchange resin-polymer ultrafiltration membranes to reduce organic fouling. *Journal of Membrane Science*, 2006. 278(1–2): p. 457-463.
216. Veerasamy, D., A. Supurmaniam, and Z.M. Nor, Evaluating the use of in-situ ultrasonication to reduce fouling during natural rubber skim latex (waste latex) recovery by ultrafiltration. *Desalination*, 2009. 236(1–3): p. 202-207.
217. Asatekin, A., et al., Anti-fouling ultrafiltration membranes containing polyacrylonitrile-graft-poly(ethylene oxide) comb copolymer additives. *Journal of Membrane Science*, 2007. 298(1–2): p. 136-146.
218. Aroon, M.A., et al., Performance studies of mixed matrix membranes for gas separation: A review. *Separation and Purification Technology*, 2010. 75(3): p. 229-242.
219. Hassan, K.P., et al., Influence of copper oxide nanomaterials in a poly(ether sulfone) membrane for improved humic acid and oil–water separation. *Journal of Applied Polymer Science*, 2016. 133(36).

220. Sotto, A., et al., Binary metal oxides for composite ultrafiltration membranes. *Journal of Materials Chemistry A*, 2014. 2(19): p. 7054-7064.
221. Kwon, G., E. Post, and A. Tuteja, Membranes with selective wettability for the separation of oil–water mixtures. *MRS Communications*, 2015. 5(3): p. 475-494.
222. Li, Y., et al., The effects of polymer chain rigidification, zeolite pore size and pore blockage on polyethersulfone (PES)-zeolite A mixed matrix membranes. *Journal of Membrane Science*, 2005. 260(1–2): p. 45-55.
223. Petsi, A.J. and V.N. Burganos, Interphase layer effects on transport in mixed matrix membranes. *Journal of Membrane Science*, 2012. 421–422(0): p. 247-257.
224. Widjojo, N., T.-S. Chung, and S. Kulprathipanja, The fabrication of hollow fiber membranes with double-layer mixed-matrix materials for gas separation. *Journal of Membrane Science*, 2008. 325(1): p. 326-335.
225. Kango, S., et al., Surface modification of inorganic nanoparticles for development of organic–inorganic nanocomposites—A review. *Progress in Polymer Science*, 2013. 38(8): p. 1232-1261.
226. Kockmann, A., et al., Impact of nanoparticle surface modification on the mechanical properties of polystyrene-based nanocomposites. *RSC Advances*, 2018. 8(20): p. 11109-11118.
227. Bian, X., et al., Effect of Nano-TiO2 Particles on the Performance of PVDF, PVDF-g-(Maleic anhydride), and PVDF-g-Poly(acryl amide) Membranes. *Industrial & Engineering Chemistry Research*, 2011. 50(21): p. 12113-12123.
228. Noble, R.D., Perspectives on mixed matrix membranes. *Journal of Membrane Science*, 2011. 378(1–2): p. 393-397.
229. Ngang, H.P., et al., Preparation of PVDF–TiO2 mixed-matrix membrane and its evaluation on dye adsorption and UV-cleaning properties. *Chemical Engineering Journal*, 2012. 197(0): p. 359-367.
230. Jamshidi Gohari, R., et al., Adsorptive removal of Pb(II) from aqueous solution by novel PES/HMO ultrafiltration mixed matrix membrane. *Separation and Purification Technology*, 2013. 120: p. 59-68.
231. Jamshidi Gohari, R., et al., Fabrication and characterization of novel PES/Fe–Mn binary oxide UF mixed matrix membrane for adsorptive removal of As(III)

from contaminated water solution. *Separation and Purification Technology*, 2013. 118: p. 64-72.

232. Zhang, Y., et al., Investigation of phosphorylated TiO2–SiO2 particles/polysulfone composite membrane for wastewater treatment. *Desalination*, 2013. 324(0): p. 118-126.

233. Zhang, H., et al., Ag nanocrystals decorated g-C3N4/Nafion hybrid membranes: One-step synthesis and photocatalytic performance. *Materials Letters*, 2018. 213: p. 218-221.

234. Yu, S., et al., Novel mpg-C3N4/TiO2 nanocomposite photocatalytic membrane reactor for sulfamethoxazole photodegradation. *Chemical Engineering Journal*, 2018. 337: p. 183-192.

235. Subramaniam, M.N., et al., AT-POME colour removal through photocatalytic submerged filtration using antifouling PVDF-TNT nanocomposite membrane. *Separation and Purification Technology*, 2018. 191: p. 266-275.

236. Zhu, C., et al., One-step facile synthesis of graphene oxide/TiO2 composite as efficient photocatalytic membrane for water treatment: Crossflow filtration operation and membrane fouling analysis. *Chemical Engineering and Processing: Process Intensification*, 2017. 120: p. 20-26.

237. Kuvarega, A.T., et al., Polysulfone/N,Pd co-doped TiO2 composite membranes for photocatalytic dye degradation. *Separation and Purification Technology*, 2018. 191: p. 122-133.

238. Dzinun, H., et al., Photocatalytic degradation of nonylphenol by immobilized TiO2 in dual layer hollow fibre membranes. *Chemical Engineering Journal*, 2015. 269: p. 255-261.

239. Ali Amat, N.A., et al., Tackling colour issue of anaerobically-treated palm oil mill effluent using membrane technology. *Journal of Water Process Engineering*, 2015. 8: p. 221-226.

240. Ismail, A.F. and W.J. Lau, Influence of feed conditions on the rejection of salt and dye in aqueous solution by different characteristics of hollow fiber nanofiltration membranes. *Desalination and Water Treatment*, 2009. 6(1-3): p. 281-288.

241. Lau, W.-J. and A.F. Ismail, Polymeric nanofiltration membranes for textile dye wastewater treatment: Preparation, performance evaluation, transport

modelling, and fouling control — a review. *Desalination*, 2009. 245(1): p. 321-348.

242. An, J.-H. and S. Dultz, Adsorption of tannic acid on chitosan-montmorillonite as a function of pH and surface charge properties. *Applied Clay Science*, 2007. 36(4): p. 256-264.

243. Lin, J., et al., Adsorption of tannic acid from aqueous solution onto surfactant-modified zeolite. *Journal of Hazardous Materials*, 2011. 193: p. 102-111.

244. Ong, C.S., W.J. Lau, and A.F. Ismail, Treatment of dyeing solution by NF membrane for decolorization and salt reduction. *Desalination and Water Treatment*, 2012. 50(1-3): p. 245-253.

245. Pradhan, G.K., S. Martha, and K.M. Parida, Synthesis of Multifunctional Nanostructured Zinc–Iron Mixed Oxide Photocatalyst by a Simple Solution-Combustion Technique. *ACS Applied Materials & Interfaces*, 2011. 4(2): p. 707-713.

246. Maya-Treviño, M.L., et al., Activity of the ZnO–Fe2O3 catalyst on the degradation of Dicamba and 2,4-D herbicides using simulated solar light. *Ceramics International*, 2014. 40(6): p. 8701-8708.

247. Buttersack, C., Modeling of type IV and V sigmoidal adsorption isotherms. *Physical Chemistry Chemical Physics*, 2019. 21(10): p. 5614-5626.

248. Gordon, T., et al., Synthesis and characterization of zinc/iron oxide composite nanoparticles and their antibacterial properties. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 2011. 374(1): p. 1-8.

249. Tsai, W.-T., et al., Photodegradation of bisphenol-A in a batch TiO2 suspension reactor. *Journal of Hazardous Materials*, 2009. 168(1): p. 269-275.

250. Molkenthin, M., et al., Photo-Fenton-like treatment of BPA: Effect of UV light source and water matrix on toxicity and transformation products. *Water Research*, 2013. 47(14): p. 5052-5064.

251. Vatanpour, V., M.E. Yekavalangi, and M. Safarpour, Preparation and characterization of nanocomposite PVDF ultrafiltration membrane embedded with nanoporous SAPO-34 to improve permeability and antifouling performance. *Separation and Purification Technology*, 2016. 163: p. 300-309.

252. Alpatova, A., et al., Composite polyvinylidene fluoride (PVDF) membrane impregnated with Fe2O3 nanoparticles and multiwalled carbon nanotubes for

catalytic degradation of organic contaminants. *Journal of Membrane Science*, 2015. 490: p. 227-235.

253. Wang, J., et al., Fabrication of hydrophobic flat sheet and hollow fiber membranes from PVDF and PVDF-CTFE for membrane distillation. *Journal of Membrane Science*, 2016. 497: p. 183-193.

254. Pezeshk, N., et al., Novel modified PVDF ultrafiltration flat-sheet membranes. *Journal of Membrane Science*, 2012. 389: p. 280-286.

255. Dlamini, D.S., B.B. Mamba, and J. Li, The role of nanoparticles in the performance of nano-enabled composite membranes – A critical scientific perspective. *Science of The Total Environment*, 2019. 656: p. 723-731.

256. Zhao, J.Q., et al., Development of mesoporous titanium dioxide hybrid poly(vinylidene fluoride) ultrafiltration membranes with photocatalytic properties. *Journal of Applied Polymer Science*, 2016. 133(19).

257. Daraei, P., et al., Novel polyethersulfone nanocomposite membrane prepared by PANI/Fe3O4 nanoparticles with enhanced performance for Cu(II) removal from water. *Journal of Membrane Science*, 2012. 415: p. 250-259.

258. Hwang, T., et al., Ultrafiltration using graphene oxide surface-embedded polysulfone membranes. *Separation and Purification Technology*, 2016. 166: p. 41-47.

259. Mukherjee, R., P. Bhunia, and S. De, Impact of graphene oxide on removal of heavy metals using mixed matrix membrane. *Chemical Engineering Journal*, 2016. 292: p. 284-297.

260. Rajabi, H., et al., Nano-ZnO embedded mixed matrix polyethersulfone (PES) membrane: Influence of nanofiller shape on characterization and fouling resistance. *Applied Surface Science*, 2015. 349: p. 66-77.

261. Said, M., et al., Blocking mechanism of PES membrane during ultrafiltration of POME. *Journal of Industrial and Engineering Chemistry*, 2015. 21: p. 182-188.

262. Li, X., et al., Characterization and antifouling performance of negatively charged PES/mesoporous silica ultrafiltration membrane for raw water filtration. *Desalination and Water Treatment*, 2016. 57(24): p. 10980-10987.

APPENDIX I

Raw data for Experiment of Nanocomposite UF membrane incorporating ZIO (PWP, COD Removal and Colour Removal)

(a) Pure water permeation

Sample	Flux (mL)					Time (min)	Pressure (bar)	PWP (LMH)	PWP (LMH Bar)	Std Dev
	1	2	3	Average	Std Dev.					
M0	4.10	4.10	4.00	4.07	0.05	2.00	1.00	85.92	85.92	1.00
M0.1	5.40	5.20	5.30	5.30	0.08	1.00	1.00	223.94	223.94	3.45
M0.5	4.00	3.90	4.00	3.97	0.05	1.00	1.00	167.61	167.61	1.99
M1.0	3.80	3.80	3.90	3.83	0.05	1.00	1.00	161.97	161.97	1.99
M2.0	3.00	2.90	3.00	2.97	0.05	1.00	1.00	125.35	125.35	1.99
MZ	2.80	2.70	2.80	2.77	0.05	10.00	5.00	11.69	2.34	0.20
MF	4.90	5.00	4.90	4.93	0.05	30.00	1.00	6.95	6.95	0.07

(b) AT-POME permeation

Sample	Flux (mL)	Time (min)	Pressure (bar)	PWP (LMH)
M0	7.5	10	1	31.69
M0.1	9.8	10	1	41.41
M0.5	9.5	10	1	40.14
M1.0	9.8	10	1	41.41
M2.0	7.5	10	1	31.69
MZ	2.6	10	5	10.99
MF	3.1	30	1	4.37

(c) Colour and COD removal efficiency

Sample	ADMI Rejection (%)	COD Rejection
M0	59.25	51.37
M0.1	64.46	60.77
M0.5	69.53	60.16
M1.0	66.35	61.14
M2.0	70.97	62.73
MZ	59.32	48.66
MF	53.77	47.39

(d) Colour and COD removal efficiency

		COD	COD REDUCTION	TOC	TOC REDUCTION	ADMI	ADMI REDUCTION
		ppm	%	ppm	%		%
	AT-POME	468		160.8		2770	
ABSORBENT (0.5 WT%)	ZIO (1:1) 500C	328	29.91	117.5	26.93	1923	30.58
	ZIO (1:2) 500C	343	26.71	110.5	31.28	1643	40.69
	ZIO (1:3) 500C	321	31.41	105.8	34.20	1538	44.48
	ZIO (1:4) 400C	310	33.76	110.5	31.28	1348	51.34
	ZIO (1:4) 500C	335	28.42	111.1	30.91	1506	45.63
	ZIO (1:4) 600C	301	35.68	114.6	28.73	1894	31.62
	ZIO (1:4) 700C	375	19.87	117.2	27.11	2062	25.56
	ZIO (1:4) 800C	373	20.30	123.4	23.26	2056	25.78