SUPEROLEOPHOBIC AND SUPERHYDROPHILIC NANOCOMPOSITE COATED HOLLOW FIBER CERAMIC MEMBRANE FOR TREATMENT OF OILY WASTEWATER

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ABSTRACT

Robust and efficient separation of emulsified oil and water mixtures is practically required as it still remains a global challenge. Existing conventional methods of oil-water separation using ceramic membranes still suffer some setbacks from membrane brittleness and fouling due to their innate inflexible ionic and covalent bonding and microfiltration pore size. Simultaneous superoleophobic and superhydrophilic surfaces are desired for various applications where emulsified oil separation is required. This study focused on improving the mechanical strength of the bare membrane (BM), addressing the prevailing fouling of membranes, and interactive effects of material properties and operating variables of the system. In the first stage, BM was successfully fabricated using phase inversion and sintering technique from kaolin-based ceramic material at different bore fluid flow rates (12.0-15.0 mL/min), kaolin content loadings (38-42 wt.%), and sintering temperatures (1300-1400 ^{o}C) and was examined for physicochemical properties. BM fabricated at 42 wt.% kaolin loading, 15 mL/min bore fluid flow rate and 1400 ^{o}C sintering temperature showed the best mechanical strength of 126.00 MPa, an average pore size of 3.50 µm, and pure water flux of 108.57 L/m^{2}.h. The result suggested an improvement in the mechanical strength and that BM was within range of microfiltration application. Due to its pore structures, it was prone to membrane fouling for oil-water separation. In the second stage, BM was modified through a simple dip-coating process with poly(diallyl dimethylammonium chloride)-alumina-perfluorooctanoic acid (PAP) and poly(diallyl dimethylammonium chloride)-perfluorooctanoic acid (PP) as interfacial materials. The interfacial materials were prepared using sol-gel method. Effects of coating layer cycles on BM were examined for surface wettability. Physicochemical properties of the PAP-BM and PP-BM including the surface morphologies and topologies were also studied. Highest average roughness, Ra of 1.042 was obtained for PAP-BM while BM with Ra of 0.665 showed the lowest. Oil contact angle (OCA) of PAP-BM was found at 155^{o} while water contact angle (WCA) displayed time dependence mode as values decreased from 25^{o} to 5^{o} after 10 min of penetration. The third stage involved the performance evaluation using statistical software Design-Expert 7.0.0 based on response surface methodology. Three independent parameters (feed concentration, pH, and pressure) were examined for interactive effects on the two dependent parameters (oil rejection and water flux). Prior to that, the results of the antifouling test showed the total fouling resistance of ~66% and ~73%, reversible fouling resistance of ~52% and ~26% and irreversible fouling resistance of ~14% and ~48% for PAP-BM and BM, respectively. The ANOVA results revealed that the optimum conditions of the emulsified oily wastewater separation were obtained to be 600 ppm, 3.0 bar, and 9.0 for feed concentration, pressure and pH, respectively. Under these conditions, 174.35 L/m^{2}.h of water flux and 98.63% of oil rejection were achieved experimentally. Oil rejection and water flux were found to be primarily affected by the feed concentration, pressure and pH. Hence, PAP-BM can tolerate and display intermittent superoleophobic and superhydrophilic surfaces, which was further evaluated based on its performance in a cross-flow filtration system.

ABSTRAK

Pemisahan campuran minyak dan air yang cekap diperlukan secara praktikal, kerana ia masih menjadi satu cabaran global. Kaedah konvensional sedia ada untuk rawatan air sisa berminyak menggunakan membran seramik, masih mengalami banyak kekurangan dari segi kerapuhan membran dan pengotoran membran berpunca dari ikatan ionik dan kovalen tidak stabil serta saiz liang mikropenurasan. Permukaan oliofobik lampau dan hidrofilik lampau secara serentak dikehendaki untuk pelbagai aplikasi di mana pemisahan emulsi minyak diperlukan. Kajian ini juga bertujuan untuk meningkatkan kekuatan mekanikal membran terdedah (BM), menangani kekotoran membran, dan mengkaji kesan saling tindak antara sifat bahan dan pembolehubah operasi sistem. Pada peringkat pertama, BM telah berjaya dihasilkan menggunakan penyongsangan fasa dan teknik sinteran dari bahan seramik berasaskan kaolin pada kadar aliran cecair jara yang berbeza (12.0-15.0 mL / min), beban kandungan kaolin (38-42 wt.%), dan suhu sinteran (1300-1400 ^{o}C) dan telah diperiksa untuk sifat-sifat fisikokimia. BM yang dihasilkan pada 42 wt.% kaolin, 15 mL / min kadar aliran cecair jara dan suhu sinteran 1400 ^{o}C menunjukkan kekuatan mekanikal terbaik pada 126.00 MPa, purata saiz liang 3.50 µm, dan fluks air tulen 108.57 L/m^{2}.h. Keputusan kajian menunjukkan peningkatan pada kekuatan mekanikal dan BM berada dalam julat aplikasi mikropenurasan. Oleh kerana struktur liangnya, ia terdedah kepada kekotoran membran bagi pemisahan air minyak. Pada peringkat kedua, BM diubahsuai menerusi proses lapisan celup mudah bersama asid poli (dialil dimetilammonium klorida)-alumina- perflorooktanoik) (PAP) dan poli (dialil dimetilammonium klorida)-perflorooktanoik) (PP) sebagai antara muka bahan. Bahan antara muka disediakan menggunakan kaedah sol-gel. Kesan kitaran salutan ke atas BM diperiksa untuk kelembapan permukaan. Ciri-ciri fisikokimia PAP-BM dan PP-BM termasuk morfologi permukaan dan topologi juga dikaji. Purata kekasaran tertinggi, Ra 1.042 diperoleh untuk PAP-BM manakala BM dengan Ra 0.665 menunjukkan nilai terendah. Sudut sentuhan minyak PAP-BM ditemui pada 155^{o} manakala sudut sentuhan air memaparkan mod bersandarkan masa kerana nilai menurun daripada 25^{o} kepada 5^{o} selepas 10 minit penembusan. Peringkat ketiga melibatkan penilaian prestasi menggunakan perisian statistik Design-Expert 7.0.0 berdasarkan kaedah sambutan permukaan. Tiga parameter tidak bersandar (kepekatan suapan, pH, dan tekanan) telah diperiksa untuk kesan interaktif pada kedua-dua parameter bersandar (penolakan minyak dan fluks minyak). Sebelum itu, keputusan ujian anti-kotoran menunjukkan jumlah kotoran sebanyak ~66% dan ~73%, kotoran berbalik sebanyak ~52% dan ~26% dan kekotoran yang tidak dapat dipulihkan masing-masing sebanyak ~14% dan ~48% untuk PAP-BM dan BM. Keputusan ANOVA menunjukkan bahawa keadaan optimum pemisahan air sisa berminyak diperoleh masing-masing bernilai 600 ppm, 3.0 bar, dan 9.0 untuk kepekatan suapan, tekanan dan pH. Di bawah syarat-syarat ini, 174.35 L/m^{2}.h fluks minyak dan 98.63% penolakan minyak telah dicapai secara eksperimen. Penolakan minyak dan fluks minyak didapati terjejas terutamanya oleh kepekatan makanan, tekanan dan pH. Oleh itu, PAP-BM boleh mentoleransi dan memaparkan permukaan oliofobik super dan hidrofilik super yang berselang-seli berdasarkan prestasi PAP-BM dalam sistem penapisan aliran silang.

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LIST OF ABBREVIATION

AFM	-	Atomic force microscopy
AG	-	Air gap
ASTM	-	American society for testing and materials
ANOVA	-	Analysis of variance
BBD	-	Box Behnken design
BOD	-	Biological oxygen demand
BM	-	Bare membrane
BN	-	Boron nitride
CA	-	Contact angle
CCD	-	Central composite design
COD	-	Chemical oxygen demand
CNTs	-	Carbon nanotubes
ED	-	Electrodialysis
EQR	-	Environmental quality regulations
EDX	-	Energy dispersive X-ray
FESEM	-	Field emission scanning microscopy
FTIR	-	Fourier transformation infrared
FO	-	Forward osmosis
GP	-	Gas permeation
GS	-	Gas separation
IF	-	Irreversible fouling
MB	-	Methylene blue
MIP	-	Mercury intrusion porosity
NMP	-	N-methylpyrrolidone
NP	-	Nanofiltration
NPs	-	Nanoparticles
OCA	-	Oil contact angle
OPS	-	Oil palm shell
PAM	-	Polyacrylamide

PAP	-	Poly(diallyldimethylammoniumchloride)-alumina-perfluorooctanoic acid
PEG	-	Polyethylene glycol
PFO	-	Perfluorooctanoate
PSA	-	Particle size analysis
PES	-	Polyethersulfone
FRP	-	Flux recovery percentage
POM	-	Palm oil mill
POME	-	Palm oil mill effluent
PP	-	Polypropylene
PS	-	Polystyrene
PTFE	-	Polytetrafluoroethylene
PVP	-	Polyvinylpyrrolidone
RF	-	Reversible fouling
RSM	-	Response surface methodology
Q_{AO}	-	Flow rate of the feed
Q_{AP}	-	Flow rate of the permeate
Q_{AR}	-	Flow rate of the retentate
RO	-	Reverse osmosis
RPM	-	Revolutions per minute
SDS	-	Sodium dodecyl sulfate
SEM	-	Scanning electron microscopy
TF	-	Total fouling
TEOS	-	Tetraethylorthosilicate
TGA	-	Thermogravimetric analysis
TiC	-	Titanium carbide
UF	-	Ultrafiltration
UTM	-	Universiti Teknologi Malaysia
WCA	-	Water contact angle
WHO	-	World Health Organization
XRD	-	X-ray diffraction
XPS	-	X-ray photoelectron spectroscopy

LIST OF SYMBOLS

Δt	-	Operating time (h)
A	-	Effective area of membrane (m^2)
Q_f	-	Bending strength (MPa)
γ	-	Surface tension mercury (N/m)
$C_d, final$	-	Final oil concentration
$C_d, initial$	-	Initial oil concentration (ppm)
C_f	-	Feed concentration (ppm)
C_P	-	Permeate concentration (ppm)
J_o	-	Flux determined at the beginning in the filtration ($L/m^2.h$)
J_t	-	Flux determined at every hour in the filtration ($L/m^2.h$)
R_{oil}	-	Oil rejection rate (%)
V	-	Volume of permeated water (mL)
$V_d, final$	-	Final volume of draw solution (mL)
$V_d, initial$	-	Initial volume of draw solution (mL)
Vp	-	Volume of permeate passing across the membrane (mL)
Wt %	-	Weight percentage (%)
D_i	-	Inner diameter of the membrane (mm)
D_o	-	Outer diameter of the membrane (mm)
F	-	Force at which the membrane fracture (N)
J_v	-	Permeate flux of the membrane ($L/m^2.h$)
L	-	Length of the membrane (cm)
Lp	-	Water permeability ($L/m^2.h.bar$)
P	-	Transmembrane pressure (bar)
Pa	-	Applied pressure (bar)
Ra	-	Surface roughness (μm)
Q	-	Volume of water permeate through the membrane (mL)
oC	-	Degree Celsius (^oC)
%	-	Percentage (%)

$\bar{X}$	-	Mean
S	-	Standard deviation
S^2	-	Variance
$S_{\bar{X}}$	-	Margin of error
N	-	Number of samples
K_{cost}	-	Cost of kaolin
Al_{cost}	-	Cost of alumina
P_{cost}	-	Cost of Polyethersulfone (PESf)
N_{cost}	-	Cost of N-methylpyrrolidone (NMP)
A_{cost}	-	Cost of Arlacel P135
A_{TF}	-	Surface area of tubular furnace (m^2)
λ_{TC}	-	Thermal conductivity of tubular furnace (W/m. K)
T_{TF}	-	Thickness of tubular furnace (m)
S_{TF}	-	Internal space surface area (m^2)
λ_{ITC}	-	Int. space thermal conductivity of tubular furnace (W/m. K)
T_{ITF}	-	Internal space thickness of tubular furnace (m)
C_p	-	Specific heat capacity (J/g. K)
ρ	-	Density of air (g/L)
T_{MTF}	-	Thickness of membrane tubular furnace (m)
$\dot{m}$	-	Mass flow rate of air (g/h)
t_{hr}	-	Heating time
$\Delta\theta$	-	Temperature difference (K)
AL_{mcost}	-	Material cost of alumina
$PDADMAC_{mcost}$	-	Material cost PDADMAC
$NaPFO_{mcost}$	-	Material cost NaPFO
$ETOH_{mcost}$	-	Material cost ethanol

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CHAPTER 1

INTRODUCTION

1.1 Background Introduction

Oily wastewater produced by industry has become a global issue affecting human and aquatic lives. Predominantly, oily wastewater contains different forms of oils such as stable emulsified oils, unstable dispersed oils and free-floating oils (Han *et al.*, 2015; Gohari *et al.*, 2015; Lu *et al.*, 2015; Zhu *et al.*, 2017). In contrast with free-floating oils that is the spilled oils on the deep-sea, dispersed oils are arbitrarily distributed in water. It has a strong propensity to amalgamate and instinctively develop into free-floating oils. Unlike, emulsified oils are relatively stable due to the existence of surfactant as in the case of asphaltenes in crude oil. Emulsified oils have small droplet sizes, usually not more than 10 μm (Dickhout *et al.*, 2017; Tummons *et al.*, 2017; Zhang *et al.*, 2017; Zhu *et al.*, 2017). Conventional approaches to the treatment and separation of oil from oily wastewater, such as coagulation, floatation, gravity settling, and ultrasonic separation have been found to be ineffective mainly due to low separation efficiency, process separation units of equipment are complex, and high energy cost and secondary pollution (Das *et al.*, 2017; Hua *et al.*, 2007a; Cheryan & Rajagopalan, 1998; Du *et al.*, 2017; Rubio *et al.*, 2002). Still, these approaches can be used for treating free-floating oils and dispersed oils, majority of them are not appropriate for treating emulsified oils for the reason that the emulsified oils have small droplet sizes, low bulk difference compared to H_2O (150 kg/m^3) and high stability (Han *et al.*, 2015; Li *et al.*, 2017; Motin *et al.*, 2015). For example, oily wastewater from industries such as palm oil mill effluent (POME) is extremely common pollutant worldwide as it affects the environment and aquatic life. Figure 1.1 shows the global research trends on POME. Malaysia is currently leading with about 61% in this regard, followed by Indonesia with 12% and closely followed by Thailand with 8.17% (Scopus, 2 January 2021).

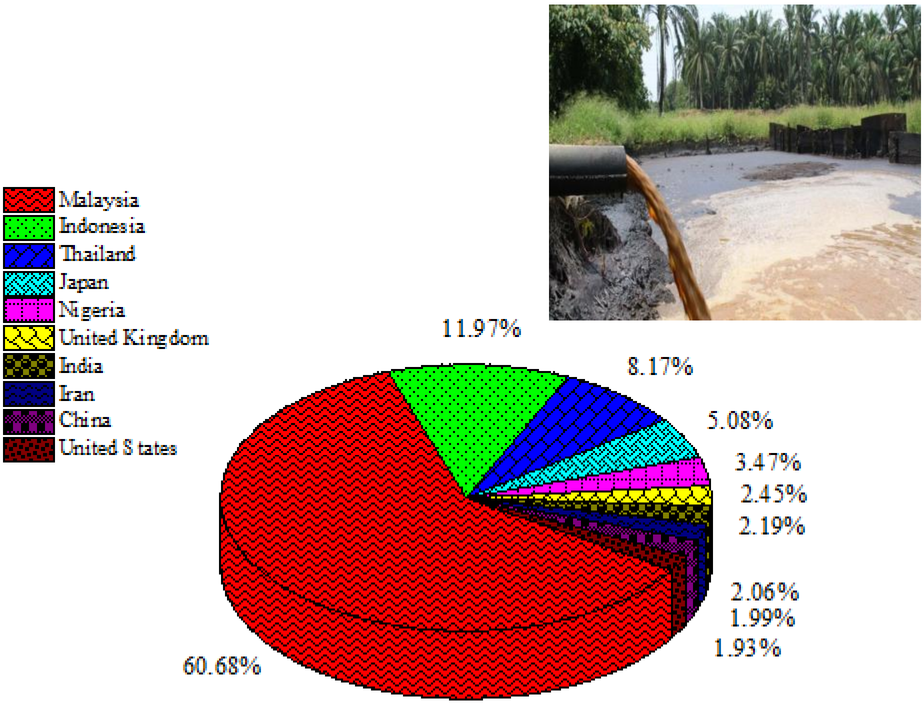

Figure 1.1 Global POME research output. Data were obtained from Scopus and accessed in January 2021

The effects can be attributed to the high demand for palm oil in the current market, globally. As shown in Figure 1.2, the production of palm oil increased more than double in the last one and half decades with an average growth of 6.8% per annum and accounted for 31% of the global oils and fats supply chain in 2018 (Ling, 2019). The effluent has a higher proportion of water (95 – 96%), with 0.6 – 0.7% oil, and the remaining 4.5% is total solid (Ahmad *et al.*, 2009; Azmi & Yunos, 2014; Chen & Xu, 2013; Kamyab *et al.*, 2018; Wang, 2006). This has generated tremendous concentration of biological oxygen demand (BOD), chemical oxygen demand (COD), oil and grease, as well as suspended solids; the level of this organic matter is due to the presence of unrecovered raw palm oil and its disposal to the water bodies without pre-treatment, posing threat to humans and the ecosystem (Ahmad *et al.*, 2005; Ahmad *et al.*, 2006; Jumadi *et al.*, 2021).

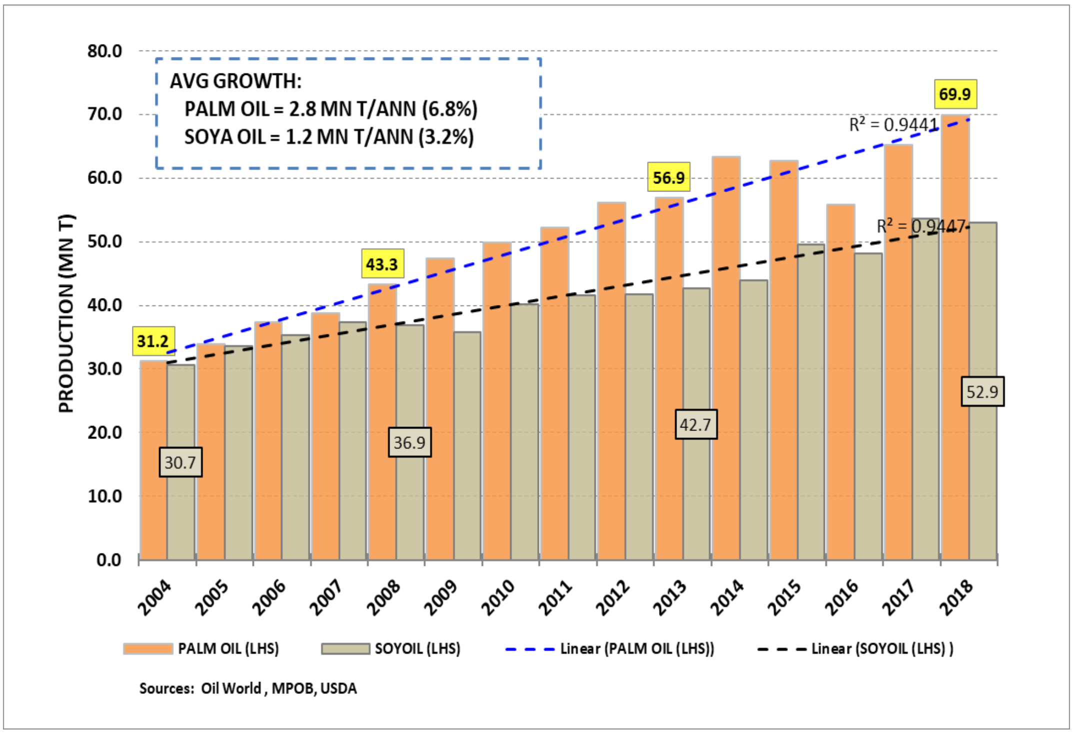

Figure 1.2 Global palm oil production with dynamic supply growth. An excerpt from Malaysia-China business forum, 4 March 2019, Kuala Lumpur and accessed in December 2020

However, the current strategy of using conventional biological anaerobic and aerobic systems, and faulty ponds treatment rely on the application of bacteria, which is unsafe, uneconomical, and unsustainable (Ahmad *et al.*, 2003), as it requires highly proper maintenance and assessment, and high labour and operational cost. Figure 1.3 gives insight into how rainfall patterns significantly influence BOD and SS concentration and how it affects quality of water. This is because water turbidity and TSS can be affected due to heavy rainfall during peak periods resulted in pond banks attrition, thereby resulting in SS suspension instead of settling at the bottom of the pond (Jumadi *et al.*, 2021). The current problems and challenges would require an advanced separation strategy such as microfiltration and ultrafiltration techniques to aid and reclaim a large proportion of water lost from palm oil production (Ahmad *et al.*, 2015). However, it is pertinent to protect the environment and develop systems that are economically viable and sustainable.

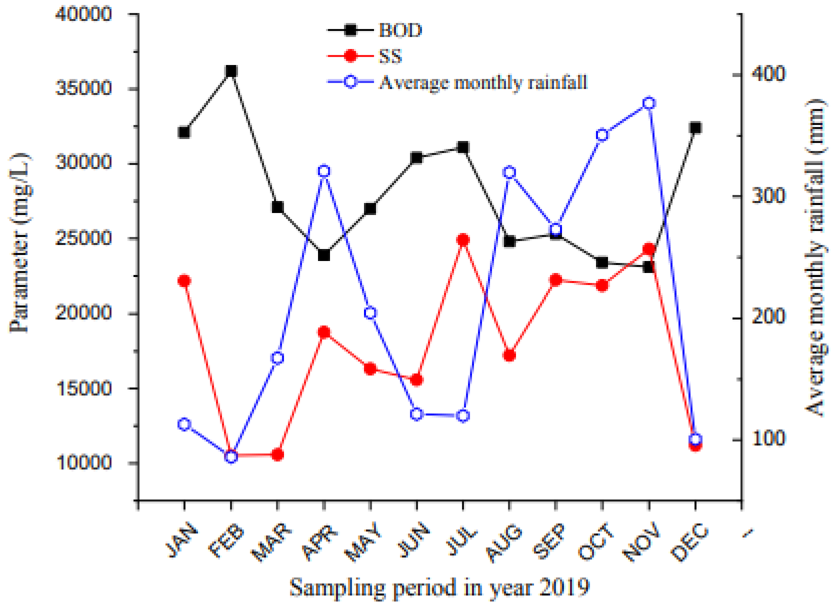

Figure 1.3 Raw palm oil mill effluent monitoring studies of BOD, SS and average monthly. 17th International symposium on solid oxide fuel cells. Digital meeting, July 18, 2021

One of the strategies that have been widely employed for oil-water separation with a different degree of oil concentration is the membrane separation technology. It is due to its efficiency and high selectivity structures. More of its merits are the high emulsion separation efficiency, no addition of chemicals and the ease of its operation. Inorganic (ceramic) membranes have been taken into consideration for presenting more advantages in terms of excellent solvent resistance, long lifetime, high thermal stability and exhibiting chemical inertness in the area of MF and UF processes (Xing, 2017). Other types of membranes from materials such as metal meshes, cotton, foams and nanofibers can be applied preferably as pre-treatment of oily wastewater (Du *et al.*, 2017; Han *et al.*, 2017; Li *et al.*, 2015; Obaid *et al.*, 2015; Wu *et al.*, 2017; Zhang *et al.*, 2015; Zhang *et al.*, 2017; Zhu & Chen, 2017).

Several articles have reported various strategies of oil and water separation, especially the use of ceramic membranes: alumina (Dong *et al.*, 2020), αAl_2O_3 (Abadi *et al.*, 2011), kaolin (Hubadillah *et al.*, 2018), sugarcane bagasse waste (Jamalludin *et al.*, 2019), kaolin/fly ash (Zou *et al.*, 2020), fly ash (Tai *et al.*, 2019), and ball clay (Abd Aziz *et al.*, 2019). Hence, a more robust, environmentally friendly and efficient oil and water separation system made from reusable and durable material is proposed. The oil and water separation systems that can treat and provide a volume of water in oily wastewater, with high effectiveness in the flux rates, also address the impediment and challenge of fouling in membranes should have the abovementioned characteristics. According to the report from Scopus 2nd January 2021 (Figure 1.4) over the last ten years (2010 -2020), the studies showed an increase in the researches related to oil and water separation technologies, and further studies revealed that the development of surface wettability remains the focus and of interest to the researchers as it involves the ability of a liquid to maintain contact with solid surface (Gupta *et al.*, 2017; Tuteja *et al.*, 2007; Yong *et al.*, 2017). Figure 1.4 reveals the country-wise distribution of oil-water separation researchers as obtained from Scopus. The chart demonstrated that the attraction in oil-water separation research is growing world recognition with the increase in the number of researchers across the globe.

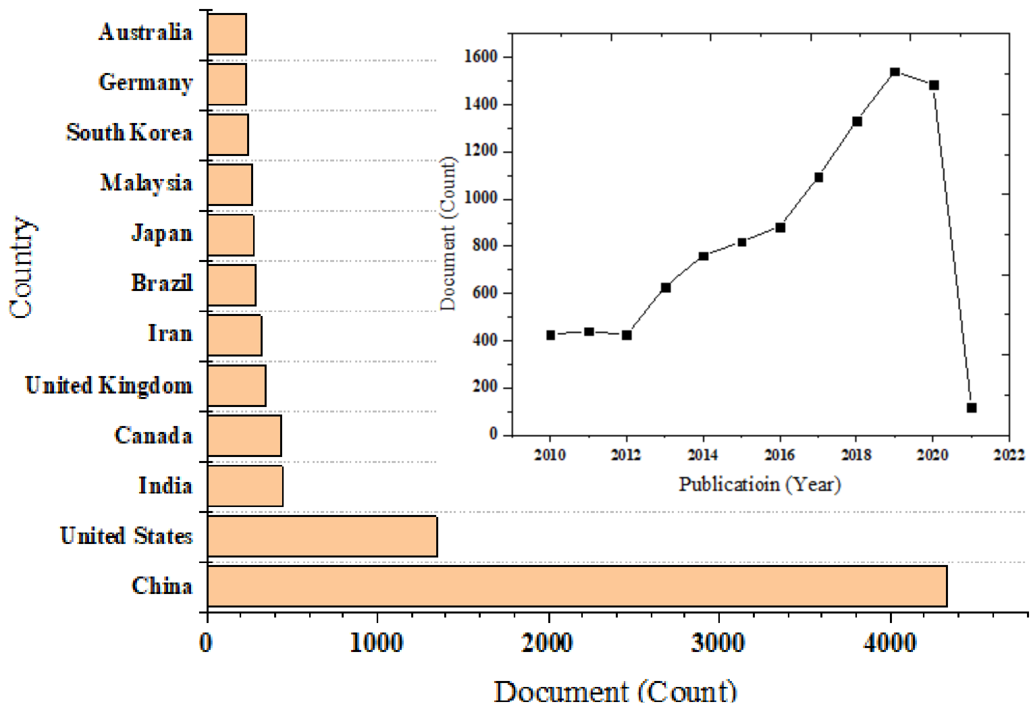

Figure 1.4 Research outlook on oil-water separation since 2010; output based on countries. Inset research publication on oil-water separation. Data were obtained from Scopus and accessed in February 2021

The application of ceramic membrane for oily water separation gives impetus to the physical structure and surface energy of membrane; in other words, it gave importance to the substrate with high surface roughness and suitable wettability (Gupta *et al.,* 2017). Both influence the concept of surface wettability behaviour, which usually expresses the ability of a material to get wetted when liquid encounters it. Super-wettability, such as for superhydrophilicity, has properties of water recovery from oily wastewater (Li *et al.*, 2011; Xue *et al.,* 2011; Jamaly *et al.,* 2015), whereas, superoleophobicity membrane material is still quite challenging to develop as oils with low surface tension tend to wet and spread across the membrane surfaces, and this leads to foulant generation, consequentially reduces flux rates, and ultimately leading to a decline in the operation and the performance of membrane (Liu *et al., 2014;* Li *et al.,* 2011; Pan *et al.,* 2013; Tuteja *et al.*, 2007; Zhang *et al.,* 2011). However, surface functionalization of membrane enables alteration of the membrane surface's wetting properties for proper oil and water separation. One of such functionalization materials is an inorganic material, which is the most common because of its unique capability to exhibit surface roughness and efficiently make membrane function for oil and water separation (Wang & Guo *et al.*, 2013a,b).

1.2 Problem Statement

Ceramic materials are very central to the numerous industrial applications involving severe conditions due to their unique properties such as thermal stability, chemical resistance, high mechanical strength and low surface area per unit volume, high permselectivity (Dai *et al.,* 2018; Tan *et al.,* 2001). Studies on inorganic membranes showed that hollow fibre membranes from such materials are comparatively scarce and too expensive as compared to ceramic materials (Liu *et al.*, 2001; Tan *et al.,* 2001). Hitherto, the intrinsic brittleness and fouling are the forestanding drawbacks of ceramic membranes importantly in the oil and water separation. Firstly, membrane fabricated from ceramic materials is susceptible to breakable and rupture during permeation process due to innate inflexible ionic and covalent bonding (Basu & Balani, 2011), and in addition to the inappropriate ratio of ratio ceramic material to a binder and small diameter of the hollow fibre during dope suspension preparation and fabrication process, respectively. This has many significant effects on the mechanical strength of ceramic membranes. Thus, high mechanical strength of ceramic membrane is very critical to membrane longevity (Xu *et al.,* 2014). For the stability and high efficiency of the membrane, 100 MPa is preferable (Abdulhameed *et al.,* 2017). However, most of the studies on the use of kaolin ceramic materials have not exceeded 100 MPa (Abdulhameed *et al.,* 2017; Hubadillah *et al.,* 2017, 2018; Mohtor *et al.,* 2017; Nandi *et al.,* 2008). But different studies suggested that varying the fabricating parameters will significantly improve the mechanical strength. Parameters such as ceramic material to the binder ratio (Liu *et al.*, 2001; Tan et al., 2001), bore fluid flow rate (Adam *et al.,* 2019; Alobaidy *et al.*, 2017; Jamalludin e*t al.,* 2018; Makhtar *et al.,* 2017a; Tai *et al.*, 2021), material content loading (Emani et al., 2013; L.-F. Han et al., 2011; Hubadillah, Harun, et al., 2016), sintering temperature (Alves et al., 2016; Chihi et al., 2019b; Makhtar et al., 2017b) are vital to the membrane structure and performance.

Secondly, ceramic membrane contains mineral oxides; its high surface energy (represents the equivalent attractive force between the liquid at the surface of a solid surface), makes it easily fouled by oil and other organic matter, which are quite challenging to remove, ruin membrane surfaces and block the membrane pores (Gao *et al.*, 2016). With such fouling, such surface hinders the smooth practical application of hydrophilic surface for oleophobicity. To address the challenges of the porogenic nature of ceramic membrane with respect to integrity with less resistance to fluid flow; by controlling the surface topology. Hence, this would require improving the surface structure and controlling the surface energy of ceramic membranes through surface modification of membranes' topology. The stimuli-responsive surface is accomplished by the simultaneous display of interaction between water as a polar phase and oil as a non-polar phase. In other words, water molecules would be able to penetrate the surface as a result of water-induced molecular rearrangement with the hydroxyl group of ceramic membrane attached to the interface.

On the other hand, oil at the interface of perfluoroalkyl group of the nanocomposite would experience low surface energy with oleophobicity because PFO has the tendencies to transforming the Al_2O_3 surface by lowering its surface energy. The PDADMAC prevents agglomeration of alumina nanoparticles, and surface cracking of membrane surface, thereby improving the oleophobicity of the coating.

To the best of my knowledge, superoleophobic and superhydrophilic stimuli-response surfaces from kaolin-based ceramic membrane coated with fumed alumina nanocomposite have not been reported and used in the literature for the fabrication of hollow fiber ceramic membrane for the oil-water separation. Therefore, the current study aimed at creating superoleophobic and superhydrophilic hollow fiber ceramic membrane for the separation of synthesized oily wastewater. Firstly, the fabrication of the bare membrane would be carried out using spinning process and sintering technique from commercial kaolin as a starting material. Bare membrane fabrication is carried out at different bore fluid flow rate, kaolin content loading and sintering temperature to improve the mechanical strength of the membrane. Secondly, the surface modification of the bare membrane is functionalized using different composites such as PDADMAC-PFO (PP) and PDADMAC-Al_2O_3/PFO (PAP) prepared by the sol-gel method using a simple dip-coating technique to address the prevailing fouling of ceramic membrane. The research problem is expected to solve by adhering to the research objectives outlined in Section 1.3. The development of ceramic membrane would be more rewarding and beneficial if the membrane obtained from the ceramic material fabrication is matched with the desired application to achieve excellent and efficient membrane performance. Hence, the research contributes to the field of knowledge and partly addresses the threats posed by oily wastewater to the environment.

1.3 Objectives of the Study

Based on the problem statement, the main objective of this thesis is to fabricate a superoleophobic and superhydrophilic hollow fiber ceramic membrane-based nanocomposite for treatment of oily wastewater. However, the specific objectives are:

(a) To correlate the effect of bore fluid flow rates, kaolin loadings, and sintering temperatures to achieve an improved mechanical strength hollow fiber ceramic membrane via extrusion and sintering techniques.

(b) To examine the superoleophobicity and superhydrophilicity of the bare membrane and Al_2O_3 incorporation on the PDADMAC-PFO based layer by simple dip-coating method at different coating cycles, heat treatment and chemical resistance treatment.

(c) To optimize the performance of the superoleophobic and superhydrophilic membranes through a cross-flow permeation with three independent parameters (feed concentration, pressure and pH) and two dependents parameters (oil rejection and water flux) using response surface methodology (RSM).

1.4 Scope of the Study

The following research activities have been selected as the scope of study to achieve the aforementioned specific objectives:

1. To correlate the effect of bore fluid flow rates, kaolin loadings, and sintering temperatures to achieve high mechanical strength hollow fiber ceramic membrane via extrusion and sintering techniques, the characterization of kaolin powder using PSA, XRD and FTIR, formulation of kaolin powder (KP) dope suspensions with the percentage by weight of KP1: 38 wt.%, KP2: 40 wt.%, KP3: 42 wt.% and the viscosity tests on the kaolin dope suspension loadings were conducted. Subsequently, the fabrication of bare membrane precursor via orifice spinneret using extrusion and a phase inversion technique with an air gap at 5 cm and

extrusion rates of 12 mL/min at different bore fluid flowrates: 12 mL/min, 13.5 mL/min, and 15 mL/min and the sintering process at different temperatures: 1300 ^{o}C, 1350 ^{o}C, 1400 ^{o}C to obtain the final bare membrane were investigated. In addition, the morphological studies and surface properties analyses: FESEM analysis for the surface area and cross-sectional area and pore size distribution and porosity test analysis of the bare membranes were examined. The Contact angle test for bare membranes 1300 ^{o}C, 1350 ^{o}C and 1400 ^{o}C was also conducted. The physical properties such as the mechanical strength analysis using three-point bending test analysis of the bare membranes was carried out and the permeability test to check for water flux capability was also investigated. The chemical properties such as FTIR analysis and XRD pattern of sintered bare membranes were examined.

2. To investigate the effect of coating cycle and Al_2O_3 incorporation on the PDADMAC-PFO based layer by simple dip-coating method, the synthesis of PDADMAC-Al_2O_3/PFO complex polymer nanocomposites and the investigation on the effect of surface wettability at 5 cycles of dip coating on the surface of bare membranes were carried out. While the morphologies and topologies were investigated via FESEM, SEM-EDX, and AFM analyses for membranes cross-sectional and surface area. The modified bare membranes were investigated and analysed for the porosity and pore size distribution using mercury intrusion porosimetry and as well XRD, FTIR, and XPS. Subsequently, the wettability test via water and oil contact angle on the membranes was conducted. Then, the investigation on the effect of chemical resistance and thermal treatment on the coated bare membrane was examined.

3. Lastly, to evaluate the performance of the superoleophobic and superhydrophilic kaolin-based hollow fiber membranes through a cross-flow permeation system, first and foremost, the preliminary evaluation on the uncoated and coated membranes were investigated for oil rejection and water flux. Secondly, the antifouling tests were performed on the membranes. Then lastly, for this objective, the design of experiment was performed based on a statistical software Design-Expert 7.0.0 (Stat-Ease, 2005) with respect to the following factors and percentage

of oil rejection and water flux were considered as the responses: (a) concentration of lower (10 ppm) and upper (10000 ppm) limit, (b) operating pressure at lower (0 bar) and upper (3.0 bar) limit, (c) pH at lower (4) and upper (10) limit, (d) ANOVA test, and (e) Optimization test. In addition, cost analysis for membrane materials and energy was estimated.

1.5 Significance of the Study

This study entails the process fabrication of superoleophobic and superhydrophilic hollow fiber ceramic membranes for oily wastewater treatment. One of the significances of this study is the use of local material that is readily available to produce ceramic membranes via spinning process and sintering technique. Another implication of this research is to overcome the limitation of conventional (biological and ponding) oily wastewater treatment with the use of hollow fiber ceramic ultrafiltration technology; water reclamation which would translate into a reduction in the use of chemical additives, lower operating cost and maintenance, and increase productivity. Outside these technical benefits, this study also promotes SDG 6 target 6.3 (2030), thereby improving water quality by reducing environmental pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recyclability and safe reusability globally. Lastly, the outcome of this study would contribute significantly towards knowledge-driven research and contribute to the environmental sustainability of current oily wastewater.

1.6 Organization of the Thesis

This thesis is divided into seven chapters including the preparation and characterization of high mechanical strength hollow fiber ceramic membranes via the spinning process and sintering technique at a high loading of kaolin and different sintering temperatures, the examination of the physicochemical characterization of fabricated hollow fiber ceramic membrane, the modification of bare membrane for the superoleophobicity and superhydrophilicity property by dip-coating using PDADMAC-Al_2O_3 /PFO nanocomposite, and lastly, the performance evaluation of modified membrane using synthesized oily-wastewater through a cross-flow permeation system.

Chapter 1 presents a brief background introduction on oily wastewater treatment using membrane technology. The statement of the problem, objectives, research scopes and significance of the study are highlighted.

Chapter 2 explicitly provides elaborated literature reviews of the research topics. This includes background literature on oily wastewater, treatment technologies, membrane materials, fabrication techniques and application, membrane fouling and control, process optimization and also the research gap.

Chapter 3 elaborates on the materials, techniques and working principles, characterization approaches and experimental step-up for the oily wastewater treatment.

Chapter 4 formulates and describes the detailed fabrication of kaolin-based hollow fiber ceramic membrane via phase inversion and sintering technique. The effect of kaolin content loading and sintering temperatures are examined and carefully characterized and discussed. It also describes the physicochemical characterization of the fabricated membrane to include mechanical strength, porosity test, water permeation test, and as well as determining the functional elements and groups.

Chapter 5 prepares and intercalates alumina-based NPs for the surface functionalization of kaolin-based membrane. Superoleophobic membrane obtained is characterized by contact angle, permeability test, and porosity test. Besides, surface morphologies and membrane antifouling processes are also studied.

Chapter 6 evaluates the performance of the modified membrane through a cross-flow filtration system for oil rejection and water flux. The antifouling properties of the membranes were also investigated. The effect of oil concentrations, the effect of pH and operating pressure based on the design of experiment using RSM are also elaborated.

Chapter 7 concludes each of the chapters contained in the thesis. The suggestions and recommendations for future work are also provided.

REFERENCES

Abadi, S. R. H., Sebzari, M. R., Hemati, M., Rekabdar, F., & Mohammadi, T. (2011). Ceramic membrane performance in microfiltration of oily wastewater. *Desalination*, *265*(1–3), 222–228.

Abbasi, M., Salahi, A., Mirfendereski, M., Mohammadi, T., & Pak, A. (2010). Dimensional analysis of permeation fl ux for micro fi ltration of oily wastewaters using mullite ceramic membranes. *DES*, *252*(1–3), 113–119.

Abd Aziz, M. H., Othman, M. H. D., Hashim, N. A., Adam, M. R., & Mustafa, A. (2019a). Fabrication and characterization of mullite ceramic hollow fiber membrane from natural occurring ball clay. *Applied Clay Science*, *177*, 51–62.

Abd Aziz, M. H., Othman, M. H. D., Hashim, N. A., Adam, M. R., & Mustafa, A. (2019b). Fabrication and characterization of mullite ceramic hollow fiber membrane from natural occurring ball clay. *Applied Clay Science*, *177*, 51–62.

Abdulhameed, M. A., Othman, M. H. D., Joda, H. N. A. Al, Ismail, A. F., Matsuura, T., Harun, Z., Rahman, M. A., Puteh, M. H., & Jaafar, J. (2017). Fabrication and characterization of affordable hydrophobic ceramic hollow fibre membrane for contacting processes. *Journal of Advanced Ceramics*, *6*(4), 330–340.

Abdullah, N., & Sulaim, F. (2013). The Oil Palm Wastes in Malaysia. In *Biomass Now - Sustainable Growth and Use*.

Abdullah, Norfazliana, Rahman, M. A., Ismail, A. F., Othman, M. H. D., & Jaafar, J. (2016). *Preparation of Ceramic Hollow Fiber Membrane Using Phase Inversion and Sintering Technique*. *1133*, 141–145.

Abdullah, Norfazliana, Rahman, M. A., Othman, M. H. D., Ismail, A. F., Jaafar, J., & Aziz, A. A. (2016). Preparation and characterization of self-cleaning alumina hollow fiber membrane using the phase inversion and sintering technique. *Ceramics International*, *42*(10), 12312–12322.

Adam, M. R., Matsuura, T., Othman, M. H. D., Puteh, M. H., Pauzan, M. A. B., Ismail, A. F., Mustafa, A., A. Rahman, M., Jaafar, J., & Abdullah, M. S. (2019). Feasibility study of the hybrid adsorptive hollow fibre ceramic membrane (HFCM) derived from natural zeolite for the removal of ammonia in wastewater. *Process Safety and Environmental Protection*.

Adam, M. R., Othman, M. H. D., Puteh, M. H., Ismail, A. F., Mustafa, A., Rahman, M. A., & Jaafar, J. (2020). Impact of sintering temperature and pH of feed solution on adsorptive removal of ammonia from wastewater using clinoptilolite based hollow fibre ceramic membrane. *Journal of Water Process Engineering*, *33*, 101063.

Ahmad, A., Ismail, S., & Bhatia, S. (2003a). Water recycling from palm oil mill effluent (POME) using membrane technology. *Desalination*, *157*(1–3), 87–95.

Ahmad, A., Ismail, S., & Bhatia, S. (2003b). Water recycling from palm oil mill effluent (POME) using membrane technology. *Desalination*, *157*(1–3), 87–95.

Ahmad, A. L., Chong, M. F., & Bhatia, S. (2009). A comparative study on the membrane based palm oil mill effluent (POME) treatment plant. *Journal of Hazardous Materials*, *171*, 166–174.

Ahmad, A. L., Chong, M. F., Bhatia, S., & Ismail, S. (2006). Drinking water reclamation from palm oil mill effluent (POME) using membrane technology. *Desalination*, *191*(1–3), 35–44.

Ahmad, A. L., Sumathi, S., & Hameed, B. H. (2005). Residual oil and suspended solid removal using natural adsorbents chitosan, bentonite and activated carbon: A comparative study. *Chemical Engineering Journal*, *108*(1–2), 179–185.

Ahmad Farid, M. A., Zakaria, M. R., Hassan, M. A., Mohd Ali, A. A., Othman, M. R., Ibrahim, I., Samsudin, M. H., & Shirai, Y. (2019). 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*.

Ahmad, M., Ahmed, E., Zafar, F., Khalid, N. R., Niaz, N. A., Hafeez, A., Ikram, M., Khan, M. A., & HONG, Z. (2015). Enhanced photocatalytic activity of Ce-doped ZnO nanopowders synthesized by combustion method. *Journal of Rare Earths*, *33*(3), 255–262.

Ait Taleb, A., El Baraka, N., Saffaj, N., Laknifli, A., Mamouni, R., Fatni, A., El Hammadi, A., & El Qacimi, N. (2018). New tubular ceramic membranes from natural moroccan clay for microfiltration application. *E3S Web of Conferences*.

Alftessi, S. A., Othman, M. H. D., Adam, M. R., Farag, T. M., Ismail, A. F., Rahman, M. A., Jaafar, J., Habib, M. A., Raji, Y. O., & Hubadillah, S. K. (2021). Novel silica sand hollow fibre ceramic membrane for oily wastewater treatment. *Journal of Environmental Chemical Engineering*, *9*(1), 104975.

Almojjly, A., Johnson, D. J., Mandale, S., & Hilal, N. (2019). Optimisation of the removal of oil in water emulsion by using ceramic microfiltration membrane and hybrid coagulation/sand filter-MF. *Journal of Water Process Engineering*, *27*, 15–23.

Alobaidy, A. A., Sherhan, B. Y., Barood, A. D., & Alsalhy, Q. F. (2017). Effect of bore fluid flow rate on formation and properties of hollow fibers. *Applied Water Science 2017 7:8*, *7*(8), 4387–4398.

Alves, H. P. A., Silva, J. B., Campos, L. F. A., Torres, S. M., Dutra, R. P. S., & Macedo, D. A. (2016). Preparation of mullite based ceramics from clay–kaolin waste mixtures. *Ceramics International*, *42*(16), 19086–19090.

Amirpoor, S., Siavash Moakhar, R., & Dolati, A. (2020). A novel superhydrophilic/superoleophobic nanocomposite PDMS-NH2/PFONa-SiO2 coated-mesh for the highly efficient and durable separation of oil and water. *Surface and Coatings Technology*, *394*, 125859.

Anuar, E., Saufi, S. M., & Yussof, H. W. (2019). Effects of air gap on membrane substrate properties and membrane performance for biomass processing. *Korean Journal of Chemical Engineering*, *36*(7), 1124–1130.

Arhin, S. G., Banadda, N., Komakech, A. J., Kabenge, I., & Wanyama, J. (2016). Membrane fouling control in low pressure membranes: A review on pretreatment techniques for fouling abatement. In *Environmental Engineering Research* (Vol. 21, Issue 2, pp. 109–120). Korean Society of Environmental Engineers.

Ariffin, K. S., Abdul Rahman, H., Hussin, H., & Abdul Hadi, K. A. (2008). The genesis and characteristics of primary kaolinitic clay occurrence at Bukit Lampas, Simpang Pulai, Ipoh. *Bulletin of the Geological Society of Malaysia*.

Azmi, N. S., & Yunos, K. F. M. (2014). Wastewater Treatment of Palm Oil Mill Effluent (POME) by Ultrafiltration Membrane Separation Technique Coupled with Adsorption Treatment as Pre-treatment. *Agriculture and Agricultural Science Procedia*, *2*, 257–264.

Baduel, C., Mueller, J. F., Rotander, A., Corfield, J., & Gomez-Ramos, M.-J. (2017). Discovery of novel per- and polyfluoroalkyl substances (PFASs) at a fire fighting training ground and preliminary investigation of their fate and mobility. *Chemosphere*, *185*, 1030–1038.

Bajpai, P. (2018). *Biermann's Handbook of Pulp and Paper: Volume 2: Paper and Board Making*. Elsevier.

Baker, R. W. (2004). *Membrane Technology and Applications*.

Bandaru, V. V. R., Somalanka, S. R., Mendu, D. R., Madicherla, N. R., & Chityala, A. (2006). Optimization of fermentation conditions for the production of ethanol from sago starch by co-immobilized amyloglucosidase and cells of Zymomonas mobilis using response surface methodology. *Enzyme and Microbial Technology*, *38*(1–2), 209–214.

Banik, A., Biswal, S. K., & Bandyopadhyay, T. K. (2020). Development of Box Behnken Design to Predict the Optimum Operating Condition of Rectangular Sheet Membrane to Increase Permeate Flux. In Joshua Thomas (Ed.), *Handbook of Research on Smart Technology Models for Business and Industry* (pp. 399–413). IGI Global.

Bao, Z., Chen, D., Li, N., Xu, Q., Li, H., He, J., & Lu, J. (2020). Superamphiphilic and underwater superoleophobic membrane for oil/water emulsion separation and organic dye degradation. *Journal of Membrane Science*, *598*, 117804.

Basu, B., & Balani, K. (2011). Advanced Structural Ceramics. *Advanced Structural Ceramics*.

Belgada, A., Charik, F. Z., Achiou, B., Ntambwe Kambuyi, T., Alami Younssi, S., Beniazza, R., Dani, A., Benhida, R., & Ouammou, M. (2021). Optimization of phosphate/kaolinite microfiltration membrane using Box–Behnken design for treatment of industrial wastewater. *Journal of Environmental Chemical Engineering*, *9*(1), 104972.

Belver, C., Bañares, M. A., & Vicente, M. A. (2002). *Preparation of Porous Silica by Acid Activation of Metakaolins*.

Bessiere, Y., Abidine, N., & Bacchin, P. (2005). Low fouling conditions in dead-end filtration: Evidence for a critical filtered volume and interpretation using critical osmotic pressure. *Journal of Membrane Science*, *264*(1–2), 37–47.

Bhatt, N., Prasad, R. K., Singh, K., & Panpalia, G. M. (2010). Stability study of O/W emulsions using zeta potential. *J. Chem. Pharm. Res*, *2*(1), 512–527.

Bouazizi, A., Breida, M., Achiou, B., Ouammou, M., Calvo, J. I., Aaddane, A., & Younssi, S. A. (2017). Removal of dyes by a new nano–TiO2 ultrafiltration membrane deposited on low-cost support prepared from natural Moroccan bentonite. *Applied Clay Science*, *149*, 127–135.

Boudaira, B., Harabi, A., Bouzerara, F., Condom, S., Zenikheri, F., Guechi, A., Foughali, L., & Karboua, N. (2016). Preparation and characterization of ZnO microfiltration membrane and its support using kaolin (DD3) and CaCO3. *Cerâmica*, *62*(362), 186–190.

Boumaza, A., Djelloul, A., & Guerrab, F. (2010). Specific signatures of α-alumina powders prepared by calcination of boehmite or gibbsite. *Powder Technology*, *201*(2), 177–180.

Bowen, W. R., Calvo, J. I., & Hernández, A. (1995). Steps of membrane blocking in flux decline during protein microfiltration. *Journal of Membrane Science*, *101*(1–2), 153–165.

Brown, P. S., & Bhushan, B. (2015a). Bioinspired, roughness-induced, water and oil super-philic and super-phobic coatings prepared by adaptable layer-by-layer technique. *Scientific Reports*, *5*(1), 1–16.

Brown, P. S., & Bhushan, B. (2015b). Mechanically durable, superomniphobic coatings prepared by layer-by-layer technique for self-cleaning and anti-smudge. *Journal of Colloid and Interface Science*, *456*, 210–218.

Buruga, K., Song, H., Jin, S., Bolan, N., Jagannathan, T. K., & Kim, K.-H. (2019). A review on functional polymer-clay based nanocomposite membranes for treatment of water. *Journal of Hazardous Materials*.

Cao, E. (2010). *Heat transfer in process engineering*. 568. https://books.google.com/books/about/Heat_Transfer_in_Process_Engineering.html?id=tMmlKyI4lvIC

Caro, J. (2016). Hierarchy in inorganic membranes. *Chem. Soc. Rev*, *45*, 3468.

Casanave, D., Ciavarella, P., Fiaty, K., & Dalmon, J.-A. (1999). Zeolite membrane reactor for isobutane dehydrogenation: Experimental results and theoretical modelling. *Chemical Engineering Science*, *54*(13–14), 2807–2815.

Chang, Q., Zhou, J., Wang, Y., Liang, J., Zhang, X., Cerneaux, S., Wang, X., Zhu, Z., & Dong, Y. (2014). Application of ceramic microfiltration membrane modified by nano-TiO2 coating in separation of a stable oil-in-water emulsion. *Journal of Membrane Science*, *456*, 128–133.

Chen, P.-C., & Xu, Z.-K. (2013). Mineral-coated polymer membranes with superhydrophilicity and underwater superoleophobicity for effective oil/water separation. *Scientific Reports*, *3*(1), 2776.

Chen, T., Duan, M., & Fang, S. (2016a). Fabrication of novel superhydrophilic and underwater superoleophobic hierarchically structured ceramic membrane and its separation performance of oily wastewater. *Ceramics International*, *42*(7), 8604–8612.

Chen, T., Duan, M., & Fang, S. (2016b). Fabrication of novel superhydrophilic and underwater superoleophobic hierarchically structured ceramic membrane and its separation performance of oily wastewater. *Ceramics International*, *42*(7), 8604–8612.

Cheryan, M., & Rajagopalan, N. (1998). Membrane processing of oily streams. Wastewater treatment and waste reduction. *Journal of Membrane Science*.

Chihi, R., Blidi, I., Trabelsi-Ayadi, M., & Ayari, F. (2019a). Elaboration and characterization of a low-cost porous ceramic support from natural Tunisian bentonite clay. *Comptes Rendus Chimie*, *xxxx*.

Chihi, R., Blidi, I., Trabelsi-Ayadi, M., & Ayari, F. (2019b). Elaboration and characterization of a low-cost porous ceramic support from natural Tunisian bentonite clay. *Comptes Rendus Chimie*, *22*(2–3), 188–197.

Chin, K. K., Lee, S. W., & Mohammad, H. H. (1996). A study of palm oil mill effluent treatment using a pond system. *Water Science and Technology*.

Chow, M. C., & Ho, C. C. (1996). Properties of palm-oil-in-water emulsions: Effect of mixed emulsifiers. *JAOCS, Journal of the American Oil Chemists' Society*.

Chung, T. S., Xu, Z. L., & Lin, W. (1999). Fundamental Understanding of the Effect of Air-Gap Distance on the Fabrication of Hollow Fiber Membranes. *Journal of Applied Polymer Science*.

Conesa, A., Gumí, T., & Palet, C. (2007). Membrane thickness and preparation temperature as key parameters for controlling the macrovoid structure of chiral activated membranes (CAM). *Journal of Membrane Science*, *287*(1), 29–40.

Cosgrove, T. (2005). Colloid Science. In T. Cosgrove (Ed.), *Colloid Science: Principles, Methods and Applications*. Blackwell Publishing Ltd.

da Silva Biron, D., dos Santos, V., & Zeni, M. (2018). Ceramic Membranes Preparation. *Springer International Publishing*, 31–48.

Dai, J., Singh, J., & Yamamoto, N. (2018). Fabrication and mechanical characterization of nanoporous ceramic composites for potential toughening. *AIAA/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, 2018, 210049.*

Das, B., Chakrabarty, B., & Barkakati, P. (2017). Separation of oil from oily wastewater using low cost ceramic membrane. *Korean Journal of Chemical Engineering*, *34*(10), 2559–2569.

de Pinho, M. N., & Minhalma, M. (2019). Introduction in Membrane Technologies. In *Separation of Functional Molecules in Food by Membrane Technology*. Elsevier Inc.

Debarros, S., Andrade, C., Mendes, E., & Peres, L. (2003). Study of fouling mechanism in pineapple juice clarification by ultrafiltration. *Journal of Membrane Science*, *215*(1–2), 213–224.

Del Colle, R., Fortulan, C. A., & Fontes, S. R. (2011). Manufacture and characterization of ultra and microfiltration ceramic membranes by isostatic pressing. *Ceramics International*, *37*(4), 1161–1168.

Dickhout, J. M., Moreno, J., Biesheuvel, P. M., Boels, L., Lammertink, R. G. H., & de Vos, W. M. (2017). Produced water treatment by membranes: A review from a colloidal perspective. In *Journal of Colloid and Interface Science*.

Djouadi Belkada, F., Kitous, O., Drouiche, N., Aoudj, S., Bouchelaghem, O., Abdi, N., Grib, H., & Mameri, N. (2018). Electrodialysis for fluoride and nitrate removal from synthesized photovoltaic industry wastewater. *Separation and Purification Technology*, *204*, 108–115.

Dong, S., Yun, Y., Wang, M., Li, C., Fu, H., Li, X., Yang, W., & Liu, G. (2020). Superhydrophobic alumina hollow ceramic membrane modified by TiO2 nanorod array for vacuum membrane distillation. *Journal of the Taiwan Institute of Chemical Engineers*.

Dong, Y., Li, J., Shi, L., Wang, X., Guo, Z., & Liu, W. (2014). Underwater superoleophobic graphene oxide coated meshes for the separation of oil and water. *Chemical Communications*, *50*(42), 5586.

Du, Xianjun, Shi, Y., Jegatheesan, V., & Ul Haq, I. (2020). A review on the mechanism, impacts and control methods of membrane fouling in MBR system. In *Membranes* (Vol. 10, Issue 2). MDPI AG.

Du, Xin, You, S., Wang, X., Wang, Q., & Lu, J. (2017). Switchable and simultaneous oil/water separation induced by prewetting with a superamphiphilic self-cleaning mesh. *Chemical Engineering Journal*, *313*, 398–403.

Du, Y., Li, Y., & Wu, T. (2017). A superhydrophilic and underwater superoleophobic chitosan-TiO2 composite membrane for fast oil-in-water emulsion separation. *RSC Advances*, *7*(66), 41838–41846.

Dunderdale, G. J., England, M. W., Sato, T., Urata, C., & Hozumi, A. (2016). Programmable Oil/Water Separation Meshes: Water or Oil Selectivity Using Contact Angle Hysteresis. *Macromolecular Materials and Engineering*, *301*(9), 1032–1036.

El Qacimi, N., El Baraka, N., Saffaj, N., Mamouni, R., Laknifli, A., Alami Younssi, S., Faouzi, A., & Zidouh, H. (2019). Preparation and characterization of flat membrane support based on Sahara Moroccan clay: application to the filtration of textile effluents. *Desalination and Water Treatment*, *143*, 111–117.

Emani, S., Uppaluri, R., & Purkait, M. K. (2013). Preparation and characterization of low cost ceramic membranes for mosambi juice clarification. *Desalination*.

Environmental Quality Regulations (EQR). (2014). *Oil Palm & The Environment (updated March 2014)*. Malaysian Palm Oil Board:

Fakhfakh, S., Baklouti, S., Baklouti, S., & Bouaziz, J. (2010). Elaboration and characterisation of low cost ceramic support membrane. *Advances in Applied Ceramics*, *109*(1), 31–38.

Fane, A. G., Fell, C. J. D., & Waters, A. G. (1981). The relationship between membrane surface pore characteristics and flux for ultrafiltration membranes. *Journal of Membrane Science*, *9*(3), 245–262.

Fang, Y., Xu, Z.-K., & Wu, J. (2013). Surface Modification of Membranes. In *Encyclopedia of Membrane Science and Technology* (pp. 1–15). John Wiley & Sons, Inc.

Fatemeh Rupani, P., Pratap Singh, R., Hakimi Ibrahim, M., & Esa, N. (2010). Review of Current Palm Oil Mill Effluent (POME) Treatment Methods: Vermicomposting as a Sustainable Practice. *World Applied Sciences Journal*, *11*(1), 70–81.

Feng, J., Fan, Y., Qi, H., & Xu, N. (2007). Co-sintering synthesis of tubular bilayer α-alumina membrane. *Journal of Membrane Science*, *288*(1–2), 20–27.

Forslind, E., & Jacobsson, A. (1975). Clay—Water Systems. In *Water in Disperse Systems* (pp. 173–248). Springer US.

Gao, C., Sun, Z., Li, K., Chen, Y., Cao, Y., Zhang, S., & Feng, L. (2013). Integrated oil separation and water purification by a double-layer TiO2-based mesh. *Energy & Environmental Science*, *6*(4), 1147.

Gao, N., Fan, Y., Quan, X., Cai, Y., & Zhou, D. (2016). Modified ceramic membranes for low fouling separation of water-in-oil emulsions. *Journal of Materials Science*, *51*(13), 6379–6388.

Gao, Q.-F., Jrad, M., Hattab, M., Fleureau, J.-M., & Ameur, L. I. (2020). Pore Morphology, Porosity, and Pore Size Distribution in Kaolinitic Remolded Clays under Triaxial Loading. *International Journal of Geomechanics*, *20*(6), 04020057.

Gao, Y., Hu, M., & Mi, B. (2014). Membrane surface modification with TiO2–graphene oxide for enhanced photocatalytic performance. *Journal of Membrane Science*, *455*, 349–356.

Garmsiri, E., Rasouli, Y., Abbasi, M., & Izadpanah, A. A. (2017). Journal of Water Process Engineering Chemical cleaning of mullite ceramic micro fi ltration membranes which are fouled during oily wastewater treatment. *Journal of Water Process Engineering*, *19*(March), 81–95.

Gondal, M. A., Sadullah, M. S., Dastageer, M. A., McKinley, G. H., Panchanathan, D., & Varanasi, K. K. (2014). Study of Factors Governing Oil–Water Separation Process Using TiO $_2$ Films Prepared by Spray Deposition of Nanoparticle Dispersions. *ACS Applied Materials & Interfaces*, *6*(16), 13422–13429.

Gorouhi, E., Sadrzadeh, M., & Mohammadi, T. (2006). Microfiltration of oily wastewater using PP hydrophobic membrane. *Desalination*, *200*(1–3), 319–321.

Guillotin, M., Lemoyne, C., Noel, C., & Monnerie, L. (1977). Physicochemical processes occurring during the formation of cellulose diacetate membranes. Research of criteria for optimizing membrane performance. IV. Cellulose diacetate-acetone-organic additive casting solutions. *Desalination*, *21*(2), 165–181.

Gunst, R. F., Myers, R. H., & Montgomery, D. C. (1996). Response Surface Methodology: Process and Product Optimization Using Designed Experiments. *Technometrics*, *38*(3), 285.

Gupta, R. K., Dunderdale, G. J., England, M. W., & Hozumi, A. (2017). Oil/water separation techniques: a review of recent progresses and future directions. *Journal of Materials Chemistry A*, *5*(31), 16025–16058.

Ha, J. H., Lee, S., Bukhari, S. Z. A., Lee, J., Song, I. H., Lee, S. J., & Choi, J. (2018). Effects of preparation conditions on the membrane properties of alumina-coated silicon carbide supports. *Journal of the Ceramic Society of Japan*.

Han, G., de Wit, J. S., & Chung, T. S. (2015). Water reclamation from emulsified oily wastewater via effective forward osmosis hollow fiber membranes under the PRO mode. *Water Research*.

Han, L.-F., Xu, Z.-L., Cao, Y., Wei, Y.-M., & Xu, H.-T. (2011). Preparation, characterization and permeation property of Al2O3, Al2O3–SiO2 and Al2O3–kaolin hollow fiber membranes. *Journal of Membrane Science*, *372*(1–2), 154–164.

Han, Z., Li, B., Mu, Z., Niu, S., Zhang, J., & Ren, L. (2017). Energy-Efficient Oil-Water Separation of Biomimetic Copper Membrane with Multiscale Hierarchical Dendritic Structures. *Small*, *13*(34), 1701121.

Harabi, A., Bouzerara, F., & Condom, S. (2009). Preparation and characterization of tubular membrane supports using centrifugal casting. *Desalination and Water Treatment*.

Harabi, Abdelhamid, Zenikheri, F., Boudaira, B., Bouzerara, F., Guechi, A., & Foughali, L. (2014). A new and economic approach to fabricate resistant porous membrane supports using kaolin and CaCO3. *Journal of the European Ceramic Society*, *34*(5), 1329–1340.

He, H., Li, Z., Ouyang, L., Liang, Y., & Yuan, S. (2021). Hierarchical WO3@Cu(OH)2 nanorod arrays grown on copper mesh with superwetting and self-cleaning properties for high-performance oil/water separation. *Journal of Alloys and Compounds*, *855*.

He, J., Li, J., Ma, L., Pang, Y., Liu, L., Liu, Q., Peng, L., & Qu, M. (2021). High-flux oil–water separation with superhydrophilicity and underwater superoleophobicity ZIF-67@Cu(OH)2 nanowire membrane. *Journal of Materials Science*, *56*(4), 3140–3154.

Hermia, J. (1982). Constant pressure blocking filtration laws - application to power-law non-Newtonian fluids. *Trans. Inst. Chem. Eng.*, *60*, 183–187.

Hofs, B., Ogier, J., Vries, D., Beerendonk, E. F., & Cornelissen, E. R. (2011). Comparison of ceramic and polymeric membrane permeability and fouling using surface water. *Separation and Purification Technology*, *79*(3), 365–374.

Hojjat, M., Mustapha, S., & Salleh, M. A. M. (2009). Optimization of POME Anaerobic Pond. *European Journal of Scientific Research*.

Holman, S. R., & Ohlinger, K. N. (2012). An Evaluation of Fouling Potential and Methods to Control Fouling in Microfiltration Membranes for Secondary Wastewater Effluent. *Proceedings of the Water Environment Federation*, *2007*(11), 6417–6444.

Howarter, J. A., Genson, K. L., & Youngblood, J. P. (2011). Wetting behavior of oleophobic polymer coatings synthesized from fluorosurfactant-macromers. *ACS Applied Materials and Interfaces*, *3*(6), 2022–2030.

Howarter, J. A., & Youngblood, J. P. (2007). Self-cleaning and anti-fog surfaces via stimuli-responsive polymer brushes. *Advanced Materials*, *19*(22), 3838–3843.

Howarter, J. A., & Youngblood, J. P. (2009). Amphiphile grafted membranes for the separation of oil-in-water dispersions. *Journal of Colloid and Interface Science*, *329*(1), 127–132.

Hsieh, H. P. (1997). Inorganic Membranes for Separation and Reaction. *Journal of the American Chemical Society*, *119*(44), 10876–10876.

Hu, M. X., Yang, Q., & Xu, Z. K. (2006). Enhancing the hydrophilicity of polypropylene microporous membranes by the grafting of 2-hydroxyethyl methacrylate via a synergistic effect of photoinitiators. *Journal of Membrane Science*, *285*(1–2), 196–205.

Hua, F. L., Tsang, Y. F., Wang, Y. J., Chan, S. Y., Chua, H., & Sin, S. N. (2007a). Performance study of ceramic microfiltration membrane for oily wastewater treatment. *Chemical Engineering Journal*.

Hua, F. L., Tsang, Y. F., Wang, Y. J., Chan, S. Y., Chua, H., & Sin, S. N. (2007b). Performance study of ceramic microfiltration membrane for oily wastewater treatment. *Chemical Engineering Journal*, *128*(2–3), 169–175.

Huang, H., Schwab, K., & Jacangelo, J. G. (2009). Pretreatment for Low Pressure Membranes in Water Treatment: A Review. *Environmental Science & Technology*, *43*(9), 3011–3019.

Huang, T., Zhang, L., Chen, H., & Gao, C. (2015). Sol–gel fabrication of a non-laminated graphene oxide membrane for oil/water separation. *Journal of Materials Chemistry A*, *3*(38), 19517–19524.

Hubadillah, S. K., Hafiz, M., Othman, D., Harun, Z., Ismail, A. F., Rahman, M. A., Jaafar, J., Jamil, S. M., & Mohtor, N. H. (2016). Superhydrophilic, low cost kaolin-based hollow fibre membranes for efficient oily-wastewater separation. *Materials Letters*.

Hubadillah, S. K., Harun, Z., Othman, M. H. D., Ismail, A. F., Salleh, W. N. W., Basri, H., Yunos, M. Z., & Gani, P. (2016). Preparation and characterization of low cost porous ceramic membrane support from kaolin using phase inversion/sintering technique for gas separation: Effect of kaolin content and non-solvent coagulant bath. *Chemical Engineering Research and Design*.

Hubadillah, S. K., Othman, M. H. D., Ismail, A. F., A. Rahman, M., & Jaafar, J. (2017). The feasibility of kaolin as main material for low cost porous ceramic hollow fibre membrane prepared using combined phase inversion and sintering technique. *Jurnal Teknologi*, *79*(1–2), 1–5. https://jurnalteknologi.utm.my/index.php/jurnalteknologi/article/view/10434

Hubadillah, S. K., Othman, M. H. D., Rahman, M. A., Ismail, A. F., & Jaafar, J. (2018). Preparation and characterization of inexpensive kaolin hollow fibre membrane (KHFM) prepared using phase inversion/sintering technique for the efficient separation of real oily wastewater. *Arabian Journal of Chemistry*, *13*(1), 2349–2367.

Hubadillah, S. K., Othman, M. H. D., Rahman, M. A., Ismail, A. F., & Jaafar, J. (2020). Preparation and characterization of inexpensive kaolin hollow fibre membrane (KHFM) prepared using phase inversion/sintering technique for the efficient separation of real oily wastewater. *Arabian Journal of Chemistry*, *13*(1), 2349–2367.

Hutton, S. J., Crowther, J. M., & Badyal, J. P. S. (2000). Complexation of fluorosurfactants to functionalized solid surfaces: Smart behavior. *Chemistry of Materials*, *12*(8), 2282–2286.

Hwang, K.-J., & Lin, T.-T. (2002). Effect of morphology of polymeric membrane on the performance of cross-flow microfiltration. *Journal of Membrane Science*, *199*(1–2), 41–52.

Ismail, A. F., Mustaffar, M. I., Illias, R. M., & Abdullah, M. S. (2006). Effect of dope extrusion rate on morphology and performance of hollow fibers membrane for ultrafiltration. *Separation and Purification Technology*, *49*(1), 10–19.

Ismail, N. J., Othman, M. H. D., Abu Bakar, S., Jaafar, J., & Rahman, M. A. (2020). Fabrication of ceramic, hollow-fibre membrane: The effect of bauxite content and sintering temperature. *Clays and Clay Minerals*, *68*(4), 309–318.

Issaoui, M., Limousy, L., Lebeau, B., Bouaziz, J., & Fourati, M. (2016). Design and characterization of flat membrane supports elaborated from kaolin and aluminum powders. *Comptes Rendus Chimie*, *19*(4), 496–504.

Izrin Mohamad Esham, M., Hafiz Dzarfan Othman, M., Fauzi Ismail, A., Abdul Rahman, M., Jaafar, J., & Jannah Ismail, N. (2019). Effect of sintering temperature on physical properties of bauxite-based hollow fiber membrane. In / *Malaysian Journal of Fundamental and Applied Sciences* (Vol. 15, Issue 2).

Jamalludin, M. R., Harun, Z., Othman, M. H. D., Hubadillah, S. K., Yunos, M. Z., & Ismail, A. F. (2018). Morphology and property study of green ceramic hollow fiber membrane derived from waste sugarcane bagasse ash (WSBA). *Ceramics International*, *44*(15), 18450–18461.

Jamalludin, M. R., Hubadillah, S. K., Harun, Z., Othman, M. H. D., & Yunos, M. Z. (2019). Novel superhydrophobic and superoleophilic sugarcane green ceramic hollow fibre membrane as hybrid oil sorbent-separator of real oil and water mixture. *Materials Letters*, *240*, 136–139.

Jamaly, S., Giwa, A., & Hasan, S. W. (2015a). Recent improvements in oily wastewater treatment: Progress, challenges, and future opportunities. *Journal of Environmental Sciences*, *37*, 15–30.

Jamaly, S., Giwa, A., & Hasan, S. W. (2015b). Recent improvements in oily wastewater treatment: Progress, challenges, and future opportunities. In *Journal of Environmental Sciences (China)* (Vol. 37, pp. 15–30). Chinese Academy of Sciences.

Jamshidi Gohari, R., Korminouri, F., Lau, W. J., Ismail, A. F., Matsuura, T., Chowdhury, M. N. K., Halakoo, E., & Jamshidi Gohari, M. S. (2015). A novel super-hydrophilic PSf/HAO nanocomposite ultrafiltration membrane for efficient separation of oil/water emulsion. *Separation and Purification Technology*.

Jana, S., Purkait, M. K., & Mohanty, K. (2010). Preparation and characterization of low-cost ceramic microfiltration membranes for the removal of chromate from aqueous solutions. *Applied Clay Science*, *47*(3–4), 317–324.

Jo, S., & Kim, Y. (2016). Superhydrophilic–underwater superoleophobic TiO2-coated mesh for separation of oil from oily seawater/wastewater. *Korean Journal of Chemical Engineering, 33*(11), 3203–3206.

Jumadi, J., Kamari, A., & Wong, S. T. S. (2021). Water quality assessment and a study of current palm oil mill effluent (POME) treatment by ponding system method. *IOP Conference Series: Materials Science and Engineering*, *980*, 012076.

Kamarudin, N. H., Harun, Z., Othman, M. H. D., Abdullahi, T., Syamsul Bahri, S., Kamarudin, N. H., Yunos, M. Z., & Wan Salleh, W. N. (2020). Waste environmental sources of metakaolin and corn cob ash for preparation and characterisation of green ceramic hollow fibre membrane (h-MCa) for oil-water separation. *Ceramics International*, *46*(2), 1512–1525.

Kamyab, H., Chelliapan, S., Din, M. F. M., Rezania, S., Khademi, T., & Kumar, A. (2018). Palm Oil Mill Effluent as an Environmental Pollutant. In *Palm Oil*. InTech.

Kang, Y., Jiao, S., Zhao, Y., Zhang, Z., Wang, B., & Pang, G. (2019). Stainless steel mesh supported TiO2 nanowires membrane with ultra-high flux for separation of oil-in-water mixtures and emulsions. *Surface and Coatings Technology*, *375,* 518–526.

Kaolin, S. (2019). *Industrial minerals solution provider*.

Khadijah, S., Ha, M., Othman, D., Matsuura, T., Ismail, A. F., Rahman, M. A., Harun, Z., Jaafar, J., & Nomura, M. (2018). *Fabrications and applications of low cost ceramic membrane from kaolin : A comprehensive review*. *44*(September 2017), 4538–4560.

Khalid, A. R., & Mustafa, W. A. W. (1992). External benefits of environmental regulation: Resource recovery and the utilisation of effluents. *The Environmentalist*.

Khayet, M. (2003). The effects of air gap length on the internal and external morphology of hollow fiber membranes. *Chemical Engineering Science*, *58*(14), 3091–3104.

Kingsbury, B. F. K., & Li, K. (2009a). A morphological study of ceramic hollow fibre membranes. *Journal of Membrane Science*, *328*(1–2), 134–140.

Kingsbury, B. F. K., & Li, K. (2009b). A morphological study of ceramic hollow fibre membranes. *Journal of Membrane Science*, *328*(1–2), 134–140.

Knudsen, F. P. (1959). Dependence of Mechanical Strength of Brittle Polycrystalline Specimens on Porosity and Grain Size. *Journal of the American Ceramic Society*, *42*(8), 376–387.

Koonaphapdeelert, S., & Li, K. (2007). Preparation and characterization of hydrophobic ceramic hollow fibre membrane. *Journal of Membrane Science*.

Kumar, A., & Lingfa, P. (2020). Sodium bentonite and kaolin clays: Comparative study on their FT-IR, XRF, and XRD. *Materials Today: Proceedings*, *22*, 737–742.

Kuroiwa, T., Ito, M., Okuyama, Y., Yamashita, K., & Kanazawa, A. (2020). Protein-Stabilized Palm-Oil-in-Water Emulsification Using Microchannel Array Devices under Controlled Temperature. *Molecules*, *25*(20), 4805.

Lampitt, R. A., Crowther, J. M., & Badyal, J. P. S. (2000). Switching liquid repellent surfaces. *Journal of Physical Chemistry B*, *104*(44), 10329–10331.

Lee, J., Chae, H. R., Won, Y. J., Lee, K., Lee, C. H., Lee, H. H., Kim, I. C., & Lee, J. min. (2013). Graphene oxide nanoplatelets composite membrane with hydrophilic and antifouling properties for wastewater treatment. *Journal of Membrane Science*.

Lee, K. S., Jang, K. S., Park, J. H., Kim, T. W., Han, I. S., & Woo, S. K. (2011). Designing the fiber volume ratio in SiC fiber-reinforced SiC ceramic composites under Hertzian stress. *Materials & Design*, *32*(8–9), 4394–4401.

Lee, S. J., & Kim, J. H. (2014). Differential natural organic matter fouling of ceramic versus polymeric ultrafiltration membranes. *Water Research*, *48*(1), 43–51.

Leenaars, A. F. M., & Burggraaf, A. J. (1985). The preparation and characterization of alumina membranes with ultra-fine pores. *Journal of Membrane Science*, *24*(3), 245–260.

Lemal, D. M. (2004). Perspective on Fluorocarbon Chemistry. *The Journal of Organic Chemistry*, *69*(1), 1–11.

Leong, S., Razmjou, A., Wang, K., Hapgood, K., Zhang, X., & Wang, H. (2014). TiO2 based photocatalytic membranes: A review. *Journal of Membrane Science*, *472*, 167–184.

Li, A., Sun, H.-X., Tan, D.-Z., Fan, W.-J., Wen, S.-H., Qing, X.-J., Li, G.-X., Li, S.-Y., & Deng, W.-Q. (2011). Superhydrophobic conjugated microporous polymers for separation and adsorption. *Energy & Environmental Science*, *4*(6), 2062.

Li, Beibei, Liu, X., Zhang, X., & Chai, W. (2015). Stainless steel mesh coated with silica for oil–water separation. *European Polymer Journal*, *73*, 374–379.

Li, Binrong, Meng, M., Cui, Y., Wu, Y., Zhang, Y., Dong, H., Zhu, Z., Feng, Y., & Wu, C. (2019). Changing conventional blending photocatalytic membranes (BPMs): Focus on improving photocatalytic performance of Fe3O4/g-C3N4/PVDF membranes through magnetically induced freezing casting method. *Chemical Engineering Journal*, *365*, 405–414.

Li, C., Sun, W., Lu, Z., Ao, X., & Li, S. (2020). Ceramic nanocomposite membranes and membrane fouling: A review. *Water Research*, *175*, 115674.

Li, H., Song, Z., Zhang, X., Huang, Y., Li, S., Mao, Y., Ploehn, H. J., Bao, Y., & Yu, M. (2013). Ultrathin, Molecular-Sieving Graphene Oxide Membranes for Selective Hydrogen Separation. *Science*, *342*(6154), 95–98.

Li, J.-J., Zhou, Y.-N., & Luo, Z.-H. (2015). Smart Fiber Membrane for pH-Induced Oil/Water Separation. *ACS Applied Materials & Interfaces*, *7*(35), 19643–19650.

Li, J., Xu, C., Guo, C., Tian, H., Zha, F., & Guo, L. (2018). Underoil superhydrophilic desert sand layer for efficient gravity-directed water-in-oil emulsions separation with high flux. *Journal of Materials Chemistry A*, *6*(1), 223–230.

Li, J., Yan, L., Hu, W., Li, D., Zha, F., & Lei, Z. (2016). Facile fabrication of underwater superoleophobic TiO2 coated mesh for highly efficient oil/water separation. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, *489*, 441–446.

Li, K. (2007). Ceramic Membranes for Separation and Reaction. In *Ceramic Membranes for Separation and Reaction*.

Li, Lei, Wang, Y., Gallaschun, C., Risch, T., & Sun, J. (2012). Why can a nanometer-thick polymer coated surface be more wettable to water than to oil? *Journal of Materials Chemistry*.

Li, Lingling, Chen, M., Dong, Y., Dong, X., Cerneaux, S., Hampshire, S., Cao, J., Zhu, L., Zhu, Z., & Liu, J. (2016). A low-cost alumina-mullite composite hollow fiber ceramic membrane fabricated via phase-inversion and sintering method. *Journal of the European Ceramic Society*.

Li, N. N., Fane, A. G., Ho, W. S. W., & Matsuura, T. (2008). Advanced Membrane Technology and Applications. In *Advanced Membrane Technology and Applications*.

Li, Y., Zhang, Z., Ge, B., Men, X., & Xue, Q. (2017). A versatile and efficient approach to separate both surfactant-stabilized water-in-oil and oil-in-water emulsions. *Separation and Purification Technology*, *176*, 1–7.

Lichtner, A., Roussel, D., Jauffrès, D., Martin, C. L., & Bordia, R. K. (2016). Effect of Macropore Anisotropy on the Mechanical Response of Hierarchically Porous Ceramics. *Journal of the American Ceramic Society*, *99*(3), 979–987.

Ling, A. H. (2019). *Global palm oil trade-prospects and outlook* (Issue March). http://www.mpob.gov.my/images/stories/pdf/2019/2019_1Palm

Liu, D., Šavija, B., Smith, G. E., Flewitt, P. E. J., Lowe, T., & Schlangen, E. (2017). Towards understanding the influence of porosity on mechanical and fracture behaviour of quasi-brittle materials: experiments and modelling. *International Journal of Fracture*, *205*(1), 57–72.

Liu, N., Zhang, M., Zhang, W., Cao, Y., Chen, Y., Lin, X., Xu, L., Li, C., Feng, L., & Wei, Y. (2015). Ultralight free-standing reduced graphene oxide membranes for oil-in-water emulsion separation. *Journal of Materials Chemistry A*, *3*(40), 20113–20117.

Liu, S., Li, K., & Hughes, R. (2003). Preparation of porous aluminium oxide (Al2O3) hollow fibre membranes by a combined phase-inversion and sintering method. *Ceramics International*, *29*(8), 875–881.

Liu, S., Tan, X., Li, K., & Hughes, R. (2001). Preparation and characterisation of SrCe0.95Yb0.05O2.975 hollow fibre membranes. *Journal of Membrane Science*, *193*(2), 249–260.

Liu, T. L., & Kim, C.-J. C. (2014). Turning a surface superrepellent even to completely wetting liquids. *Science*, *346*(6213), 1096–1100.

Liu, Y.-Q., Zhang, Y.-L., Fu, X.-Y., & Sun, H.-B. (2015). Bioinspired Underwater Superoleophobic Membrane Based on a Graphene Oxide Coated Wire Mesh for Efficient Oil/Water Separation. *ACS Applied Materials & Interfaces*, *7*(37), 20930–20936.

Lu, D., Zhang, T., & Ma, J. (2015). Ceramic Membrane Fouling during Ultrafiltration of Oil/Water Emulsions: Roles Played by Stabilization Surfactants of Oil Droplets. *Environmental Science & Technology*, *49*(7), 4235–4244.

Lu, L., & Ishiyama, O. (2015). Iron ore sintering. *Iron Ore: Mineralogy, Processing and Environmental Sustainability*, 395–433.

Ma, A. N., & Ong, A. S. H. (1985). Pollution control in palm oil mills in Malaysia. *Journal of the American Oil Chemists' Society*, *62*(2), 261–266.

Maarten Biesheuvel, P., & Verweij, H. (1999). Design of ceramic membrane supports: Permeability, tensile strength and stress. *Journal of Membrane Science*, *156*(1), 141–152.

MacCi, C., Masciandaro, G., & Ceccanti, B. (2010). Vermicomposting of olive oil mill wastewaters. *Waste Management and Research*.

Mahmoudi, E., Ng, L. Y., Ang, W. L., Chung, Y. T., Rohani, R., & Mohammad, A. W. (2019). Enhancing Morphology and Separation Performance of Polyamide 6,6 Membranes By Minimal Incorporation of Silver Decorated Graphene Oxide Nanoparticles. *Scientific Reports*.

Majouli, A., Tahiri, S., A. Younssi, S., Loukili, H., & Albizane, A. (2012). Elaboration of new tubular ceramic membrane from local Moroccan Perlite for microfiltration process. Application to treatment of industrial wastewaters. *Ceramics International*, *38*(5), 4295–4303.

Majouli, A., Younssi, S. A., Tahiri, S., Albizane, A., Loukili, H., & Belhaj, M. (2011). Characterization of flat membrane support elaborated from local Moroccan Perlite. *Desalination*, *277*(1–3), 61–66.

Makhtar, S. N. N. M., Rahman, M. A., Ismail, A. F., Othman, M. H. D., & Jaafar, J. (2017a). Preparation and characterization of glass hollow fiber membrane for water purification applications. *Environmental Science and Pollution Research*, *24*(19), 15918–15928.

Makhtar, S. N. N. M., Rahman, M. A., Ismail, A. F., Othman, M. H. D., & Jaafar, J. (2017b). Preparation and characterization of glass hollow fiber membrane for water purification applications. *Environmental Science and Pollution Research*, *24*(19), 15918–15928.

McEvoy, E., Donegan, S., Power, J., & Altria, K. (2007). Capillary electrophoresis | Microemulsion Electrokinetic Chromatography. In *Encyclopedia of Separation Science* (pp. 1–10). Elsevier.

Meng, S., Zhang, M., Yao, M., Qiu, Z., Hong, Y., Lan, W., Xia, H., & Jin, X. (2019). Membrane Fouling and Performance of Flat Ceramic Membranes in the Application of Drinking Water Purification. *Water*, *11*(12), 2606.

Meroufel, B., Benali, O., Benyahia, M., Zenasni, M. A., Merlin, A., & George, B. (2013). Removal of Zn (II) from Aqueous Solution onto Kaolin by Batch Design. *Journal of Water Resource and Protection*, *05*(07), 669–680.

Misaran, M. S., Sarbatly, R., Bono, A., & Rahman, M. M. (2016). Effect of extrusion rate on morphology of Kaolin/PolyEtherSulfone (PESf) membrane precursor. *IOP Conference Series: Materials Science and Engineering*, *160*(1), 012013.

Mohamed Bazin, M., Ahmad, N., & Nakamura, Y. (2019). Preparation of porous ceramic membranes from Sayong ball clay. *Journal of Asian Ceramic Societies*, *7*(4), 417–425.

Mohtor, N. H., Othman, M. H. D., Ismail, A. F., Rahman, M. A., Jaafar, J., & Hashim, N. A. (2017). Investigation on the effect of sintering temperature on kaolin hollow fibre membrane for dye filtration. *Environmental Science and Pollution Research*, *24*(19), 15905–15917.

Mollahosseini, A., Rahimpour, A., Jahamshahi, M., Peyravi, M., & Khavarpour, M. (2012). The effect of silver nanoparticle size on performance and antibacteriality of polysulfone ultrafiltration membrane. *Desalination*.

Motin, A., Tarabara, V. V., & Bénard, A. (2015). Numerical investigation of the performance and hydrodynamics of a rotating tubular membrane used for liquid-liquid separation. *Journal of Membrane Science*.

Moulik, S., Moulik, S., Moulik, S., Parakala, S., Parakala, S., Sridhar, S., Sridhar, S., & Sridhar, S. (2018). Vapor Permeation: Fundamentals, Principles and Applications. In *Membrane Processes*.

Murić, A., Petrinić, I., & Christensen, M. L. (2014). Comparison of ceramic and polymeric ultrafiltration membranes for treating wastewater from metalworking industry. *Chemical Engineering Journal*, *255*, 403–410.

Nakajima, A., Koizumi, S., Watanabe, T., & Hashimoto, K. (2000). Photoinduced Amphiphilic Surface on Polycrystalline Anatase TiO 2 Thin Films. *Langmuir*, *16*(17), 7048–7050.

Nandi, B. K., Uppaluri, R., & Purkait, M. K. (2008). Preparation and characterization of low cost ceramic membranes for micro-filtration applications. *Applied Clay Science*, *42*(1–2), 102–110.

Nawawi, M. G., Othman, N., Sadikin, A. N., Khalid, S. S., & Yusof, N. (2008). Development of empty fruit bunch filter with addition of chitosan for pre-treatment of palm oil mill effluent. *Journal of Chemical and Natural Resources Engineering*, *2*, 8–16.

Ng, W. J., Goh, A. C. C., & Tay, J. H. (1987). Palm oil mill effluent (POME) treatment-An assessment of coagulants used to aid liquid-solid separation. *Biological Wastes*.

Nicolaisen, B. (2003). Developments in membrane technology for water treatment. *Desalination*.

Nishihora, R. K., Rachadel, P. L., Quadri, M. G. N., & Hotza, D. (2018). Manufacturing porous ceramic materials by tape casting—A review. In *Journal of the European Ceramic Society*.

Obaid, M., Barakat, N. A. M., Fadali, O. A., Motlak, M., Almajid, A. A., & Khalil, K. A. (2015). Effective and reusable oil/water separation membranes based on modified polysulfone electrospun nanofiber mats. *Chemical Engineering Journal*.

Onyia CO, Uyu AM, Akunna JC, Norulaini NA, & AK., O. (2001). Increasing the fertilizer value of palm oil mill sludge: bioaugmentation in nitrification. *Water Science and Technology*.

Othman, N. H., Noor, A. M., Suria, M., Yusoff, A., Goh, P. S., Fauzi Ismail, A., Lau, W. J., & Ismail, N. (2017). Malaysian Journal of analytical sciences effect of bore fluid composition on composition on structural and performance of polyphenylsulfone hollow fiber membrane contactor for deacidfication of crude palm oil (Kesan Komposisi Cecair Lubang pada Struktur d. *Malaysian Journal of Analytical Sciences*, *21*, 633–642.

Paiman, S. H., Rahman, M. A., Othman, M. H. D., Ismail, A. F., Jaafar, J., & Aziz, A. A. (2015). Morphological study of yttria-stabilized zirconia hollow fibre membrane prepared using phase inversion/sintering technique. *Ceramics International*, *41*(10), 12543–12553.

Pan, S., Kota, A. K., Mabry, J. M., & Tuteja, A. (2013). Superomniphobic surfaces for effective chemical shielding. *Journal of the American Chemical Society*, *135*(2), 578–581.

Park, H., Park, Y., Kim, W., & Choi, W. (2013). Surface modification of TiO2 photocatalyst for environmental applications. *Journal of Photochemistry and Photobiology C: Photochemistry Reviews*, *15*, 1–20.

Perez, M., Romero, L. I., & Sales, D. (2001). Organic matter degradation kinetics in an anaerobic thermophilic fluidised bed bioreactor. *Anaerobe*.

Pesek, S. C., & Koros, W. J. (1994). Aqueous quenched asymmetric polysulfone hollow fibers prepared by dry/wet phase separation. *Journal of Membrane Science*.

Peshoria, S., Nandini, D., Tanwar, R. K., & Narang, R. (2020). Short-chain and long-chain fluorosurfactants in firefighting foam: a review. *Environmental Chemistry Letters*, *18*(4), 1277–1300.

Poh, P. E., & Chong, M. F. (2009). Development of anaerobic digestion methods for palm oil mill effluent (POME) treatment. In *Bioresource Technology*.

Puri, P. S. (1990). Fabrication of hollow fibre gas separation membranes. *Gas Separation and Purification*.

Raji, Y. O., Othman, M. H. D., Md Nordin, N. A. H., Ismail, A. F., A Rahman, M., Jaafar, J., Usman, J., & Momah, S. C. (2020). Preparation and characterization of bentonite-based ceramic hollow fibre membrane. *Journal of Membrane Science and Research*, *7*(2), 95–101.

Raji, Y. O., Othman, M. H. D., Nordin, N. A. H. S. M., Adam, M. R., Tai, Z. S., Usman, J., & Ismail, A. F. (2020). Surface matrix functionalization of ceramic-based membrane for oil-water separation: A mini-review. *Korean Journal of Chemical Engineering*, *37*(10), 1631–1641.

Raji, Y. O., Othman, M. H. D., Nordin, N. A. H. S. M., ShengTai, Z., Usman, J., Mamah, S. C., Ismail, A. F., Rahman, M. A., & Jaafar, J. (2020). Fabrication of magnesium bentonite hollow fibre ceramic membrane for oil-water separation. *Arabian Journal of Chemistry*, *13*(7), 5996–6008.

Rasouli, Y., Abbasi, M., & Hashemifard, S. A. (2019). A new combination of microfiltration, powdered activated carbon and coagulation for treatment of oily wastewater. *International Journal of Environmental Science and Technology*, *16*(10), 5595–5610.

Rasouli, Yaser, Abbasi, M., & Hashemifard, S. A. (2019). Fabrication, characterization, fouling behavior and performance study of ceramic microfiltration membranes for oily wastewater treatment. *Journal of Asian Ceramic Societies*, *7*(4), 476–495.

Raspati, G. S., & Leiknes, T. O. (2015). Applicability of blocking laws in non-Newtonian fluid membrane filtration. *Desalination and Water Treatment*, *54*(7), 1771–1781.

Ren, C., Fang, H., Gu, J., Winnubst, L., & Chen, C. (2015). Preparation and characterization of hydrophobic alumina planar membranes for water desalination. *Journal of the European Ceramic Society*, *35*(2), 723–730.

Richerson, D. W. (2005). Modern Ceramic Engineering. In *Modern Ceramic Engineering*. CRC press.

Rubio, J., Souza, M. L., & Smith, R. W. (2002). Overview of flotation as a wastewater treatment technique. *Minerals Engineering*.

Rugbani, A. (2009). *Investigating the influence of fabrication parameters on the diameter and mechanical properties of polysulfone ultrafiltration hollow-fibre membranes*. University of Stellenbosch.

Sabzi, M., Mirabedini, S. M., Zohuriaan-Mehr, J., & Atai, M. (2009). Surface modification of TiO2 nano-particles with silane coupling agent and investigation of its effect on the properties of polyurethane composite coating. *Progress in Organic Coatings*, *65*(2), 222–228.

Sahnoun, R. D., & Baklouti, S. (2013). Characterization of flat ceramic membrane supports prepared with kaolin-phosphoric acid-starch. *Applied Clay Science*, *83–84*, 399–404.

Salvini, V. R., Pandolfelli, V. C., & Spinelli, D. (2018). Mechanical Properties of Porous Ceramics. In *Recent Advances in Porous Ceramics*. InTech.

Sarbatly, R. (2011). Effect of Kaolin/pesf Ratio and Sintering Temperature on Pore Size and Porosity of the Kaolin Membrane Support. *Journal of Applied Sciences*, *11*(13), 2306–2312.

Schuchardt, F., Wulfert, K., Darnoko, & Herawan, T. (2008). Effect of new palm oil mill processes on the efb and pome utilization. *Journal of Oil Palm Research*.

Şener, T., Okumuş, E., Gürkan, T., & Yilmaz, L. (2010). The effect of different solvents on the performance of zeolite-filled composite pervaporation membranes. *Desalination*, *261*(1–2), 181–185.

Šereš, Z., Maravić, N., Takači, A., Nikolić, I., Šoronja-Simović, D., Jokić, A., & Hodur, C. (2016). Treatment of vegetable oil refinery wastewater using alumina ceramic membrane: Optimization using response surface methodology. *Journal of Cleaner Production*, *112*, 3132–3137.

Sharpe, I. D., Ismail, A. F., & Shilton, S. J. (1999). A study of extrusion shear and forced convection residence time in the spinning of polysulfone hollow fiber membranes for gas separation. *Separation and Purification Technology*, *17*(2), 101–109.

Sheikhi, M., Arzani, M., Mahdavi, H. R., & Mohammadi, T. (2019). Kaolinitic clay-based ceramic microfiltration membrane for oily wastewater treatment: Assessment of coagulant addition. *Ceramics International*, *45*(14), 17826–17836.

Shen, T. C., & Cabasso, I. (1982). Ethyl cellulose anisotropic membranes. In *Macromolecular Solutions* (pp. 108–119). Elsevier.

Shen, Z., Chen, W., Xu, H., Yang, W., Kong, Q., Wang, A., Ding, M., & Shang, J. (2019). Fabrication of a Novel Antifouling Polysulfone Membrane with in Situ Embedment of Mxene Nanosheets. *International Journal of Environmental Research and Public Health*, *16*(23), 4659.

Shieh, J.-J., & Chung, T. S. (1998). Effect of liquid-liquid demixing on the membrane morphology, gas permeation, thermal and mechanical properties of cellulose acetate hollow fibers. *Journal of Membrane Science*, *140*(1), 67–79.

Singh, S., Khulbe, K. C., Matsuura, T., & Ramamurthy, P. (1998). Membrane characterization by solute transport and atomic force microscopy. *Journal of Membrane Science*, *142*(1), 111–127.

Strathmann, H. (1985). Production of microporous media by phase inversion processes. *ACS Symposium Series*, *269*, 165–195.

Sulaiman, A., Zakaria, M. R., Hassan, M. A., Shirai, Y., & Busu, Z. (2009). Co-Digestion of Palm Oil Mill Effluent and Refined Glycerin Wash Water for Chemical Oxygen Demand Removal and Methane Production. *American Journal of Environmental Sciences*, *5*(5), 639–646.

Sun, J.-H., Dong, S.-Y., Wang, Y.-K., & Sun, S.-P. (2009). Preparation and photocatalytic property of a novel dumbbell-shaped ZnO microcrystal photocatalyst. *Journal of Hazardous Materials*, *172*(2), 1520–1526.

Suresh, K., Pugazhenthi, G., & Uppaluri, R. (2016). Fly ash based ceramic microfiltration membranes for oil-water emulsion treatment: Parametric optimization using response surface methodology. *Journal of Water Process Engineering*, *13*, 27–43.

Syväjärvi, M., & Yakimova, R. (2016). *Sublimation Growth of Hexagonal and Cubic SiC Layers BT - Reference Module in Materials Science and Materials Engineering*.

Tai, Z. S., Hafiz Dzarfan Othman, M., Mustafa, A., Mohamed Dzahir, M. I. H., Hubadillah, S. K., Koo, K. N., Azali, M. A., Alias, N. H., Seng Ooi, B., Kurniawan, T. A., & Ismail, A. F. (2021). Design and characterization of ceramic hollow fiber membrane derived from waste ash using phase inversion-based extrusion/sintering technique for water filtration. *Journal of Asian Ceramic Societies*, *9*(1), 341–358.

Tai, Z. S., Hubadillah, S. K., Othman, M. H. D., Dzahir, M. I. H. M., Koo, K. N., Tendot, N. I. S. T. I., Ismail, A. F., Rahman, M. A., Jaafar, J., & Aziz, M. H. A. (2019). Influence of pre-treatment temperature of palm oil fuel ash on the properties and performance of green ceramic hollow fiber membranes towards oil/water separation application. *Separation and Purification Technology, 222*(April), 264–277.

Tai, Z. S., Othman, M. H. D., Hubadillah, S. K., Ismail, A. F., Rahman, M. A., Jaafar, J., Koo, K. N., & Abd Aziz, M. H. (2018). Low cost palm oil fuel ash based ceramic membranes for oily water separation. *Malaysian Journal of Fundamental and Applied Sciences*, *14*(4), 419–424.

Tan, X., Liu, S., & Li, K. (2001). Preparation and characterization of inorganic hollow fiber membranes. *Journal of Membrane Science*, *188*(1), 87–95.

Tang, C. Y., Chen, W., Chen, W. Q., Fu, Q., Du, Z. L., Ye, Y., Onishi, M., & Abe, N. (2010). Effect of solution extrusion rate on morphology and performance of polyvinylidene fluoride hollow fiber membranes using polyvinyl pyrrolidone as an additive. *Chinese Journal of Polymer Science (English Edition)*.

Tang, H., Fu, Y., Yang, C., Zhu, D., & Yang, J. (2016a). A UV-driven superhydrophilic/superoleophobic polyelectrolyte multilayer film on fabric and its application in oil/water separation. *RSC Advances*, *6*(94), 91301–91307.

Tang, H., Fu, Y., Yang, C., Zhu, D., & Yang, J. (2016b). A UV-driven superhydrophilic/superoleophobic polyelectrolyte multilayer film on fabric and its application in oil/water separation. *RSC Advances*, *6*(94), 91301–91307.

Tingyi, L., & Changjin, K. (2014). Turning a surface superrepellent even to completely wetting liquids. *Science*.

Tsuru, T. (2001). Inorganic porous membranes for liquid phase separation. *Separation and Purification Methods*, *30*(2), 191–220.

Tummons, E. N., Chew, J. W., Fane, A. G., & Tarabara, V. V. (2017). Ultrafiltration of saline oil-in-water emulsions stabilized by an anionic surfactant: Effect of surfactant concentration and divalent counterions. *Journal of Membrane Science*.

Tuteja, A., Choi, W., Ma, M., Mabry, J. M., Mazzella, S. A., Rutledge, G. C., McKinley, G. H., & Cohen, R. E. (2007). Designing Superoleophobic Surfaces. *Science*, *318*(5856), 1618–1622.

Usman, J., Hafiz, M., Othman, D., Fauzi Ismail, A., Rahman, M. A., Jaafar, J., & Abdullahi, T. (2020). Comparative study of Malaysian and Nigerian kaolin-based ceramic hollow fiber membranes for filtration application. In */Malaysian Journal of Fundamental and Applied Sciences* (Vol. 16, Issue 2).

Usman, J., Othman, M. H. D., Ismail, A. F., A Rahman, M., Jaafar, J., & Abdullahi, T. (2020). Comparative study of Malaysian and Nigerian kaolin-based ceramic hollow fiber membranes for filtration application. *Malaysian Journal of Fundamental and Applied Sciences*, *16*(2), 182–185.

Usman, J., Othman, M. H., Ismail, A. F., Rahman, M. A., Jaafar, J., Raji, Y. O., El Badawy, T. H., Gbadamosi, A. O., & Kurniawan, T. A. (2020). Impact of organosilanes modified superhydrophobic-superoleophilic kaolin ceramic membrane on efficiency of oil recovery from produced water. *Journal of Chemical Technology & Biotechnology*, *95*(12), 3300–3315.

Vairappan, C. S., & Yen, A. M. (2008). Palm oil mill effluent (POME) cultured marine microalgae as supplementary diet for rotifer culture. *Journal of Applied Phycology*, *20*(5), 603–608.

Varga, G. (2007). The structure of kaolinite and metakaolinite. *Epitoanyag - Journal of Silicate Based and Composite Materials*, *59*(1), 6–9.

Vasanth, D., Suresh, K., & Pugazhenthi, G. (2014). Fabrication of circular shaped ceramic membrane using mixed clays by uniaxial compaction method for the treatment of oily wastewater. *International Journal of Nano and Biomaterials*, *5*(1), 75–88.

Vatanpour, V., Madaeni, S. S., Moradian, R., Zinadini, S., & Astinchap, B. (2012). Novel antibifouling nanofiltration polyethersulfone membrane fabricated from embedding TiO2 coated multiwalled carbon nanotubes. *Separation and Purification Technology*, *90*, 69–82.

Vela, M. C. V., Blanco, S. Á., García, J. L., & Rodríguez, E. B. (2008). Analysis of membrane pore blocking models applied to the ultrafiltration of PEG. *Separation and Purification Technology*, *62*(3), 489–498.

Vernaz, florian. (1999). *Industrial Process and the Environment- Crude Palm Oil Industry* (pp. 7–54).

Vinoth Kumar, R., Kumar Ghoshal, A., & Pugazhenthi, G. (2015a). Elaboration of novel tubular ceramic membrane from inexpensive raw materials by extrusion method and its performance in microfiltration of synthetic oily wastewater treatment. *Journal of Membrane Science*, *490*, 92–102.

Vinoth Kumar, R., Kumar Ghoshal, A., & Pugazhenthi, G. (2015b). Elaboration of novel tubular ceramic membrane from inexpensive raw materials by extrusion method and its performance in microfiltration of synthetic oily wastewater treatment. *Journal of Membrane Science*, *490*, 92–102.

Wang, B., & Guo, Z. (2013a). Superhydrophobic copper mesh films with rapid oil/water separation properties by electrochemical deposition inspired from butterfly wing. *Applied Physics Letters*, *103*(6), 063704.

Wang, B., & Guo, Z. (2013b). pH-responsive bidirectional oil–water separation material. *Chemical Communications*, *49*(82), 9416.

Wang, F., Lei, S., Xu, Y., & Ou, J. (2015). Green approach to the fabrication of superhydrophobic mesh surface for oil/water separation. *ChemPhysChem*, *16*(10), 2237–2243.

Wang, K., Abdala, A. A., Hilal, N., & Khraisheh, M. K. (2017). Mechanical Characterization of Membranes. In *Membrane Characterization* (pp. 259–306). Elsevier Inc.

Wang, L. K. (2006). Waste Chlorination and Stabilization. In *Advanced Physicochemical Treatment Processes* (pp. 403–440). Humana Press.

Wang, Y., & Gong, X. (2017a). Special oleophobic and hydrophilic surfaces: approaches, mechanisms, and applications. *Journal of Materials Chemistry A*, *5*(8), 3759–3773.

Wang, Y., & Gong, X. (2017b). Special oleophobic and hydrophilic surfaces: approaches, mechanisms, and applications. In *Journal of Materials Chemistry A*.

Wen, J., Li, X., Liu, W., Fang, Y., Xie, J., & Xu, Y. (2015). Photocatalysis fundamentals and surface modification of TiO2 nanomaterials. *Chinese Journal of Catalysis*, *36*(12), 2049–2070.

Wen, Q., Di, J., Jiang, L., Yu, J., & Xu, R. (2013). Zeolite-coated mesh film for efficient oil–water separation. *Chem. Sci.*, *4*(2), 591–595.

Weyten, H., Luyten, J., Keizer, K., Willems, L., & Leysen, R. (2000). Membrane performance: the key issues for dehydrogenation reactions in a catalytic membrane reactor. *Catalysis Today*, *56*(1–3), 3–11.

Wienk, I. M., Olde Scholtenhuis, F. H. A., van den Boomgaard, T., & Smolders, C. A. (1995). Spinning of hollow fiber ultrafiltration membranes from a polymer blend. *Journal of Membrane Science*, *106*(3), 233–243.

Williams, P. M. (2016). Zeta Potential. *Encyclopedia of Membranes*, 2063–2064.

Wu, J., Wei, W., Zhao, S., Sun, M., & Wang, J. (2017). Fabrication of highly underwater oleophobic textiles through poly(vinyl alcohol) crosslinking for oil/water separation: the effect of surface wettability and textile type. *Journal of Materials Science*.

Xing, W.-H. (2017). Ceramic Membranes. In *Membrane-Based Separations in Metallurgy*. Elsevier.

Xu, G., Wang, K., Zhong, Z., Chen, C.-S., Webley Bd, P. A., & Wang, H. (2014). *SiC nanofiber reinforced porous ceramic hollow fiber membranes*.

Xu, J., Singh, Y. B., Amy, G. L., & Ghaffour, N. (2016). Effect of operating parameters and membrane characteristics on air gap membrane distillation performance for the treatment of highly saline water. *Journal of Membrane Science*.

Xu, M., Xu, C., Rakesh, K. P., Cui, Y., Yin, J., Chen, C., Wang, S., Chen, B., & Zhu, L. (2020). Hydrophilic SiC hollow fiber membranes for low fouling separation of oil-in-water emulsions with high flux. *RSC Advances*, *10*(8), 4832–4839.

Xue, Z., Wang, S., Lin, L., Chen, L., Liu, M., Feng, L., & Jiang, L. (2011a). A Novel Superhydrophilic and Underwater Superoleophobic Hydrogel-Coated Mesh for Oil/Water Separation. *Advanced Materials*, *23*(37), 4270–4273.

Xue, Z., Wang, S., Lin, L., Chen, L., Liu, M., Feng, L., & Jiang, L. (2011b). A Novel Superhydrophilic and Underwater Superoleophobic Hydrogel-Coated Mesh for Oil/Water Separation. *Advanced Materials, 23*(37), 4270–4273.

Yakub, I., Du, J., & Soboyejo, W. O. (2012). Mechanical properties, modeling and design of porous clay ceramics. *Materials Science and Engineering A*, *558*, 21–29.

Yang, H., Pi, P., Cai, Z.-Q., Wen, X., Wang, X., Cheng, J., & Yang, Z. (2010). Facile preparation of super-hydrophobic and super-oleophilic silica film on stainless steel mesh via sol–gel process. *Applied Surface Science*, *256*(13), 4095–4102.

Yang, J., Song, H., Yan, X., Tang, H., & Li, C. (2014). Superhydrophilic and superoleophobic chitosan-based nanocomposite coatings for oil/water separation. *Cellulose*, *22*, 1851–1857.

Yang, J., Yin, L., Tang, H., Song, H., Gao, X., Liang, K., & Li, C. (2015). Polyelectrolyte-fluorosurfactant complex-based meshes with superhydrophilicity and superoleophobicity for oil/water separation. *Chemical Engineering Journal, 268*, 245–250.

Yang, J., Zhang, Z., Xu, X., Zhu, X., Men, X., & Zhou, X. (2012a). Superhydrophilic-superoleophobic coatings. *Journal of Materials Chemistry*, *22*(7), 2834–2837.

Yang, J., Zhang, Z., Xu, X., Zhu, X., Men, X., & Zhou, X. (2012b). Superhydrophilic-superoleophobic coatings. *Journal of Materials Chemistry*, *22*(7), 2834–2837.

Yang, S., Li, M., Fang, G., Xue, M., & Lu, Y. (2021). Flexible cement-sand coated cotton fabrics with superhydrophilic and underwater superoleophobic wettability for the separation of water/oil mixtures and oil-in-water emulsions. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, *608*.

Yeow, M. L., Liu, Y. T., & Li, K. (2004). Morphological study of poly(vinylidene fluoride) asymmetric membranes: Effects of the solvent, additive, and dope temperature. *Journal of Applied Polymer Science*, *92*(3), 1782–1789.

Yong, J., Chen, F., Yang, Q., Huo, J., & Hou, X. (2017). Superoleophobic surfaces. In *Chemical Society Reviews* (Vol. 46, Issue 14, pp. 4168–4217). Royal Society of Chemistry.

Yoon, Y., Hwang, Y., Kwon, M., Jung, Y., Hwang, T. M., & Kang, J. W. (2014). Application of O3 and O3/H2O2 as post-treatment processes for color removal in swine wastewater from a membrane filtration system. *Journal of Industrial and Engineering Chemistry*, *20*(5), 2801–2805.

Yu, Y., Chen, H., Liu, Y., Craig, V., Li, L. H., & Chen, Y. (2014). Superhydrophobic and Superoleophilic Boron Nitride Nanotube-Coated Stainless Steel Meshes for Oil and Water Separation. *Advanced Materials Interfaces*, *1*(1), 1300002.

Zeng, X., Lin, J., Cai, W., Lu, Q., Fu, S., Li, J., Yan, X., Wen, X., Zhou, C., & Zhang, M. (2021). Fabrication of superhydrophilic PVDF membranes by one-step modification with eco-friendly phytic acid and polyethyleneimine complex for oil-in-water emulsions separation. *Chemosphere*, *264*, 128395.

Zhang, Dawei, Wang, G., Zhi, S., Xu, K., Zhu, L., Li, W., Zeng, Z., & Xue, Q. (2018). Superhydrophilicity and underwater superoleophobicity TiO 2 /Al 2 O 3 composite membrane with ultra low oil adhesion for highly efficient oil-in-water emulsions separation. *Applied Surface Science*, *458*, 157–165.

Zhang, Dong-shuai, Abadikhah, H., Wang, J.-W., Hao, L.-Y., Xu, X., & Agathopoulos, S. (2019). β-SiAlON ceramic membranes modified with SiO2 nanoparticles with high rejection rate in oil-water emulsion separation. *Ceramics International*, *45*(4), 4237–4242.

Zhang, E., Cheng, Z., Lv, T., Qian, Y., & Liu, Y. (2015). Anti-corrosive hierarchical structured copper mesh film with superhydrophilicity and underwater low adhesive superoleophobicity for highly efficient oil–water separation. *Journal of Materials Chemistry A*, *3*(25), 13411–13417.

Zhang, J.-W., Fang, H., Wang, J.-W., Hao, L.-Y., Xu, X., & Chen, C.-S. (2014). Preparation and characterization of silicon nitride hollow fiber membranes for seawater desalination. *Journal of Membrane Science*, *450*, 197–206.

Zhang, J., Padmasiri, S. I., Fitch, M., Norddahl, B., Raskin, L., & Morgenroth, E. (2007). Influence of cleaning frequency and membrane history on fouling in an anaerobic membrane bioreactor. *Desalination*, *207*(1–3), 153–166.

Zhang, Jianqiang, Pan, X., Xue, Q., He, D., Zhu, L., & Guo, Q. (2017). Antifouling hydrolyzed polyacrylonitrile/graphene oxide membrane with spindle-knotted structure for highly effective separation of oil-water emulsion. *Journal of Membrane Science*, *532*, 38–46.

Zhang, Junping, & Seeger, S. (2011). Superoleophobic coatings with ultralow sliding angles based on silicone nanofilaments. *Angewandte Chemie International Edition*, *50*(29), 6652–6656.

Zhang, Lei, Gu, J., Song, L., Chen, L., Huang, Y., Zhang, J., & Chen, T. (2016). Underwater superoleophobic carbon nanotubes/core–shell polystyrene@Au nanoparticles composite membrane for flow-through catalytic decomposition and oil/water separation. *Journal of Materials Chemistry A*, *4*(28), 10810–10815.

Zhang, Luhong, Yang, X., Jiang, B., Sun, Y., Gong, Z., Zhang, N., Hou, S., Li, J., & Yang, N. (2020). Superhydrophilic and underwater superoleophobic Ti foam with robust nanoarray structures of TiO2 for effective oil-in-water emulsion separation. *Separation and Purification Technology*, *252*, 117437.

Zhang, X., Tian, J., Gao, S., Zhang, Z., Cui, F., & Tang, C. Y. (2017). In situ surface modification of thin film composite forward osmosis membranes with sulfonated poly(arylene ether sulfone) for anti-fouling in emulsified oil/water separation. *Journal of Membrane Science*, *527*, 26–34.

Zhao, J., Milanova, M., Warmoeskerken, M. M. C. G., & Dutschk, V. (2012). Surface modification of TiO2 nanoparticles with silane coupling agents. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, *413*, 273–279.

Zhao, X., Xuan, H., Chen, Y., & He, C. (2015). Preparation and characterization of superior antifouling PVDF membrane with extremely ordered and hydrophilic surface layer. *Journal of Membrane Science*, *494*, 48–56.

Zhao, Y. ying, Wang, X. mao, Yang, H. wei, & Xie, Y. feng F. (2018). Effects of organic fouling and cleaning on the retention of pharmaceutically active compounds by ceramic nanofiltration membranes. *Journal of Membrane Science*.

Zhou, H., Wang, H., Yang, W., Niu, H., Wei, X., Fu, S., Liu, S., Shao, H., & Lin, T. (2018). Durable superoleophobic-superhydrophilic fabrics with high anti-oil-fouling property. *RSC Advances*, *8*(47), 26939–26947.

Zhu, L., Chen, M., Dong, Y., Tang, C. Y., Huang, A., & Li, L. (2016a). A low-cost mullite-titania composite ceramic hollow fiber microfiltration membrane for highly efficient separation of oil-in-water emulsion. *Water Research*, *90*, 277–285.

Zhu, L., Chen, M., Dong, Y., Tang, C. Y., Huang, A., & Li, L. (2016b). A low-cost mullite-titania composite ceramic hollow fiber microfiltration membrane for highly efficient separation of oil-in-water emulsion. *Water Research*, *90*, 277–285.

Zhu, X., Dudchenko, A., Gu, X., & Jassby, D. (2017). Surfactant-stabilized oil separation from water using ultrafiltration and nanofiltration. *Journal of Membrane Science*.

Zhu, Y., & Chen, D. (2017). Novel clay-based nanofibrous membranes for effective oil/water emulsion separation. *Ceramics International*, *43*(12), 9465–9471.

Zou, D., Fan, W., Xu, J., Drioli, E., Chen, X., Qiu, M., & Fan, Y. (2020). One-step engineering of low-cost kaolin/fly ash ceramic membranes for efficient separation of oil-water emulsions. *Journal of Membrane Science*, 118954.

Zou, D., Qiu, M., Chen, X., Drioli, E., & Fan, Y. (2019). One step co-sintering process for low-cost fly ash based ceramic microfiltration membrane in oil-in-water emulsion treatment. *Separation and Purification Technology*, *210*, 511–520.

LIST OF PUBLICATIONS

Journal with Impact Factor

1. **Raji, Y. O.,** Othman, M. H. D*., Nordin, N. A. Md., Zhong, S. T., Usman, J; Mamah, S. C., Ismail, A. F., Rahman, M. A., Jaafar, J. (2020). Fabrication of magnesium bentonite hollow fibre ceramic membrane for oil-water separation. *Arabian Journal of Chemistry, 13*(7), 5996-6008 . https://doi.org/10.1016/j.arabjc.2020.05.001. **(Q2, IF:4.762)**

2. **Raji, Y. O.,** Othman, M. H. D*., Nordin, N. A. Md., Adam, M. R., Zhong, S. T., Usman, J; Ismail, A. F. (2020). Surface matrix functionalization of clay-based ceramic membrane for oily water treatment: A mini-review. *Korean Journal of Chemical Engineering, 37,*1631-1641. https://doi.org/10.1007/s11814-020-0575-5. **(Q2, IF:2.690)**

3. **Raji, Y.O.,** Othman, M. H. D*., Nordin, N. A. Md., Kurniawan T. A., Ismail, F. A., Rahman M., Jaafar J., Adam M. R., Alftessi S. A., El-badawy T., Farag, T. M. (2021). Wettability improvement of ceramic membrane by intercalating nano-Al_2O_3 for separation of oil and water. *Surfaces and Interfaces, 25,*101178. https://doi.org/10.1016/j.surfin.2021.101178. **(Q1, IF:3.724)**

4. **Raji, Y.O.,** Othman, M. H. D*., Nordin, N. A. Md., Adam, M. R., Ismail, F. A., Rahman M., Jaafar J., Said, K. A. M., Farag, T. M., Alftessi S. A., (2021). Synthesis and characterization of superoleophobic fumed alumina nanocomposite coated via the sol-gel process onto ceramic-based hollow fibre membrane for oil-water separation. *Ceramics International. 47(11)* 15367-15382. https://doi.org/10.1016/j.ceramint.2021.05.319. **(Q1, IF: 3.830)**

Indexed Journal

1. **Raji, Y. O.,** Othman, M. H. D*., Nordin, N. A. Md., Ismail, A. F., Rahman, M. A., Jaafar, Juhana, J., Usman, J; Mamah, S. C. (2020). Preparation and characterization of bentonite-based ceramic hollow fibre membrane, *Journal of Membrane Science and Research, 7(2),*95-101. https://doi.org/10.22079/JMSR.2020.121902.1346 (**Indexed by Scopus**)

2. **Raji, Y. O.,** Othman, M. H. D*., Nordin, N. A. Md., Ismail, A. F., Rahman, M. A., Jaafar, J., Ahmed, I., Mamah S. C., Usman J., Origomisan O. J. (2021). Effect of fluorosurfactant on alumina membrane for oil and water separation. *MaterialsToday: Proceedings.46,*1983-1989. https://doi.org/10.1016/ j.matpr.2021.02.596

Non-Indexed Conference Proceedings

1. **Raji, Y. O**; Othman, M. H. D*; Nordin, N. A. H; Ismail, A. F; Rahman, M. A; Jaafar, J; Usman, J; Mamah, S.C. (2019). Preparation and characterization of bentonite-based ceramic hollow fibre membrane for treatment of oily waste-water. *International Conference of Sustainable Environmental Technology,2019,* DoubleTree Hilton Hotel, Johor, Malaysia.

2. **Raji, Y. O**; Othman, M. H. D*; Nordin, N. A. H; Ismail, A. F; Rahman, M. A; Jaafar, J; Ahmed, I; Mamah, S. C; Usman, J; Origomisan, O.J. (2020). Effects of Fluorosurfactant on Nanocomposite Prepared by Sol-Gel Dip-Coating Process for Oil and Water Separation. Virtual- *Regional Conference on Membrane Technology,* Johor, Malaysia.