MULTIFUNCTIONAL IRON OXIDE SUPPORTED ALUMINA/YTTRIA STABILIZED ZIRCONIA HOLLOW FIBER ADSORPTIVE MEMBRANE FOR WATER TREATMENT

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ABSTRACT

Ceramic membrane offers high thermal, mechanical and chemical resistance. It also has been regarded as an alternative membrane for water separation application. In this study, a composite aluminium oxide/yttria-stabilized zirconia (Al_2O_3/YSZ) hollow fiber membrane was fabricated via the combined dry-wet phase inversion spinning method and sintering process. The findings had observed an asymmetrical membrane structure consisting of the finger-like voids and sponge-like voids. The addition of YSZ had improved the mechanical strength of the membrane produced despite the porous structure and thin wall thickness. The findings had concluded that the Al_2O_3/YSZ hollow fiber membrane prepared using the composite of 0.3 µm YSZ particle and sintered at 1350 ^oC (HF0.3-1350 membrane) was selected as the substrate for iron oxide (Fe_2O_3) deposition. This is due to the HF0.3-1350 measured to be having the highest water flux. Next, the deposition of Fe_2O_3 on the Al_2O_3/YSZ hollow fiber membrane was carried out using the hydrothermal process. The hydrothermal process is a facile process and the Fe_2O_3 particles can be simultaneously synthesized and deposited. For the application of an adsorptive membrane for lead (Pb) removal, the Fe_2O_3 particles were deposited onto the porous structure of the membrane. The performance showed high Pb (II) removal at pH 7, with fast removal within the first 10 min of the filtration process and had reached the equilibrium at 60 min. Moreover, the kinetic isotherm of pristine, F005-24 and F02-24 membrane followed the pseudo-second-order kinetics model. This study proved that the Fe_2O_3 deposition played an indispensable role in improving the adsorption capability of the pristine membrane towards Pb (II) ions. For the application of oil emulsion separation, the Fe_2O_3 particles were deposited on the outer surface of the Al_2O_3/YSZ hollow fiber membrane. Then, depositing at the hydrothermal concentration above 0.2 M, Fe_2O_3 layer was formed. The findings have shown that the Fe_2O_3 layer gave increment to the water flux and oil rejection of the membrane. Then, the property of Fe_2O_3 itself as a photocatalyst gave other functionalities of the membrane for the photocatalytic process. Therein, the stimulated photo-induced separation system was operated for the Fe_2O_3 supported Al_2O_3/YSZ hollow fiber membrane to highlight the self-cleaning mechanism of the membrane. The finding recorded was that the flux and oil rejection increases with the light assisted throughout the separation process. Lastly, the polymer coating of UV curable resin (UVR) on the outer membrane surface had preserved the Fe_2O_3 layer from the delamination. The UVR layer formed had changed the surface properties of the membrane from hydrophilic to hydrophobic. The existence of the UVR layer had highlighted the potential of the hydrophobic UVR-coated ceramic hollow fiber membrane for water separation using the sweeping liquid filtration system. The F02-UVR membrane was able to remove 94% of humic acid with a flux of 46.53 $kg/m^2.h$. The outcome of this study was the multifunctional Fe_2O_3 supported Al_2O_3/YSZ hollow fiber adsorptive membrane can be used for the treatment of different water pollutant.

ABSTRAK

Membran seramik telah menawarkan rintangan terma, mekanik dan kimia yang tinggi. Membran ini juga telah dianggap sebagai membran alternatif untuk aplikasi pemisahan air. Kajian ini membran gentian berongga alumina/yttria-stabil zirkonia (Al_2O_3/YSZ) komposit dibuat melalui gabungan teknik pemejaman kering-basah dan proses pensinteran. Pemerhatian terhadap hasil kajian mendapati membran yang terhasil mempunyai struktur yang terdiri dari lompang seperti jari dan lompang seperti span. Kajian juga mendapati campuran partikel YSZ telah berjaya meningkatkan kekuatan mekanikal membran walaupun struktur membran yang terhasil mempunyai ketebalan dinding yang nipis dan berongga. Hasil kajian merumuskan bahawa membran gentian berongga Al_2O_3/YSZ yang dihasilkan menggunakan campuran partikel YSZ bersaiz 0.3 µm dan disinter pada suhu 1350 °C (HF0.3-1350) telah dipilih untuk digunakan sebagai substrat untuk pemendapan ferik oksida (Fe_2O_3). Hal ini kerana membran HF0.3-1350 merekodkan fluks air yang paling tinggi. Seterusnya, pemendapan ferik oksida (Fe_2O_3) di atas membran gentian berongga Al_2O_3/YSZ dilakukan dengan menggunakan proses hidroterma. Proses ini mudah dan membolehkan penghasilan dan pemendapan partikel Fe_2O_3 dijalankan secara serentak. Untuk penggunaan membran sebagai membran penjerap untuk penyingkiran plumbum (Pb), partikel Fe_2O_3 dimendapkan di dalam membran gentian berongga Al_2O_3/YSZ. Prestasi membran mencatatkan penyingkiran Pb (II) yang tinggi dan cepat pada pH 7 dalam masa 10 minit pertama proses pemisahan dan mencapai keseimbangan pada minit ke-60. Tambahan lagi, kinetik isoterma bagi membran kosong, membran F005-24 dan membran F02-24 telah mengikuti model kinetik pseudo-tertib kedua. Kajian ini juga membuktikan bahawa pemendapan Fe_2O_3 memainkan peranan dalam meningkatkan kebolehupayaan membran kosong untuk proses penjerapan ion Pb (II). Untuk aplikasi membran bagi tujuan pemisahan emulsi minyak, partikel Fe_2O_3 telah dimendapkan di atas permukaan luar membran gentian berongga Al_2O_3/YSZ. Proses pemendapan menggunakan cecair hidroterma dengan kelikatan di atas 0.2 M telah menghasilkan lapisan Fe_2O_3. Hasil kajian mendapati kehadiran lapisan Fe_2O_3 telah meningkatkan fluks air dan penyingkiran minyak oleh membran. Kemudian, sifat partikel Fe_2O_3 sebagai fotomangkin telah memberikan fungsi baharu kepada membran untuk proses foto pemangkinan. Justeru, sistem pemisahan dengan rangsangan cahaya telah dikendalikan untuk membran gentian berongga Al_2O_3/YSZ yang menyokong Fe_2O_3 untuk menonjolkan fungsi kebolehan pembersihan-sendiri oleh membran. Hasil kajian menunjukkan peningkatan terhadap fluks dan penyingkiran minyak dengan kehadiran cahaya di sepanjang proses pemisahan berlaku. Akhir sekali, salutan polimer resin UV yang boleh diubah (UVR) di atas permukaan luar membran telah memelihara lapisan Fe_2O_3 daripada tanggal. Selain itu, lapisan UVR juga telah mengubah sifat membran daripada hidrofilik kepada hidrofobik. Kehadiran lapisan UVR telah menonjolkan keupayaan membran gentian berongga seramik hidrofobik untuk proses pemisahan air menggunakan sistem pemisahan sapuan cecair. Membran F02-UVR berjaya menyingkirkan 94% asid humik dengan jumlah fluks 46.53 kg/m^2.h. Kajian mendapati penjerapan membran multifungsi Fe_2O_3 yang disokong di atas gentian berongga Al_2O_3/YSZ boleh digunakan untuk merawat pencemar air yang berbeza.

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LIST OF ABBREVIATIONS

AA	-	Acetic acid
Al_2O_3	-	Aluminium oxide
As	-	Arsenic
Cd	-	Cadmium
COOH	-	Carboxyl
CeO_2	-	Cerium dioxide
CTAB	-	Cetyltrimethylammonium bromide
Cr	-	Chromium
Cu	-	Copper
CuO	-	Copper oxide
EDX	-	Energy dispersive x-ray spectroscopy
EtOH	-	Ethanol
EA	-	Ethanol amine
ED	-	Ethylene diamine
EG	-	Ethylene glycol
FESEM	-	Field emission electron microscopy
FTIR	-	Fourier transform infrared spectroscopy
HA	-	Humic acid
HCl	-	Hydrochloric acid
OH	-	Hydroxyl
Fe_2O_3	-	Iron oxide
Pb	-	Lead
MCL	-	Maximum concentration level
MD	-	Membrane distillation
Hg	-	Mercury
MOF	-	Metal organic framework
MF	-	Microfiltration
MoS_2	-	Molybdenum disulphide
MWCO	-	Molecular weight cut-off
NF	-	Nanofiltration

Ni	-	Nickel
NiO	-	Nickel oxide
NMP	-	N-Methylpyrrolidone
NMR	-	Nuclear magnetic resonance
PESf	-	Polyethersulfone
PTFE	-	Polytetrafluoroethylene
RO	-	Reverse osmosis
SEM	-	Scanning electron microscopy
NaOH	-	Sodium hydroxide
TiO_2	-	Titanium dioxide
UF	-	Ultrafiltration
UV	-	Ultraviolet
UVR	-	UV curable resin
H_2O	-	Water
WHO	-	World Health Organization
XRD	-	X-ray diffraction
YSZ	-	Yttria-stabilized zirconia
Zn	-	Zinc

LIST OF SYMBOLS

A	-	Area of hollow fiber membrane
nm	-	Nanometre
µm	-	Micrometre
cm	-	Centimetre
mm	-	Millimetre
m	-	Meter
t	-	Time
s	-	Second
min	-	Minute
h	-	Hour
g	-	Gram
wt	-	Weight
T	-	Temperature
°C	-	Degree Celsius
Pa.s	-	Viscosity
W	-	Watt
D_i	-	Inner diameter
D_o	-	Outer diameter
D_{cry}	-	Crystallite size
kN	-	Kilo newton
%	-	Percentage
θ	-	Degree
λ	-	Wavelength
M	-	Molar concentration
B_F	-	3P bending strength
F_M	-	Maximum load at which the fracture occurs
L_h	-	Span length
J_W	-	Flux
V	-	Volume
qt	-	Adsorption capacity at time

qm	-	Adsorption capacity at equilibrium
C_i	-	Concentration at initial
C_f	-	Concentration at final
C_e	-	Concentration at equilibrium
C_p	-	Concentration at permeate
Wg	-	Weight of adsorbent
W_{HF}	-	Weight of membrane
$\Delta W_{M,feed}$	-	Weight change
W_D	-	Weight of dry membrane
W_S	-	Weight of suspended saturated membrane
W_{SS}	-	Weight of saturated membrane
R	-	Percentage rejection

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CHAPTER 1

INTRODUCTION

1.1 Research Background

The global issue on the water scarcity is driven by the growth of the human population. The necessity and the increasing demand for high-quality water supply rise from the fact of the contaminated water caused by the human activities that are responsible for such a drastic decrease in water quality. Human activities such as in the industrial process, in the agricultural sector and daily activities with the improper disposal of waste material has been the major anthropogenic sources of the water contaminants. The contaminants such as heavy metal ions, organic compounds and natural organic compounds which having the excess into the food chains can cause to the waterborne illness. Hence, treating the contaminated water before safely channeled for consumption is primely important to protect environmental safety, aquatic life and human's health from intoxication.

Numbers of research study had introduced methods to treat the contaminated water that meets with the strict water quality standard. Such methods are the adsorption, separation and photocatalytic process. The adsorption process is an attractive method and widely used to remove water contaminants such as heavy metal ions due to its low cost, the availability of different adsorbents and simple operation. The photocatalytic process having the ability to decompose the organic water pollutants and enhanced the water quality. Then, the rising membrane technology had gathered a wide interest as an alternative method for water separation. The interesting part of membrane technology is that the advanced membranes can be fabricated with stimuli-responsive either by depositing the responsive materials into the membrane. These responsive materials, such as adsorbent and photocatalyst, to respond to the adsorption and photocatalytic process, respectively. The material deposition also response to the physical changes of the membrane properties, such as pore size of the membranes, hydrophilicity and surface roughness. Therefore, the advanced membranes are capable of bringing a mammoth change and opportunities as a multifunctional membrane for water treatment.

In membrane technology, the development of the ceramic membrane has been extensively studied over the past few years due to the properties of the ceramic membrane that can overcome the limitation in the polymeric membrane [1]. The ceramic membrane is having a high resistance to high-temperature operation, high pressure and harsh chemical conditions. These properties are benefited to the ceramic membrane recovery to allow for the physical and chemical cleaning process [2,3]. Besides, the ceramic membrane is also having a lower fouling effect as compared to the polymeric membrane due to the hydrophilic properties of ceramic material [4]. In this study, a multifunctional ceramic hollow fiber membrane is highlighted. The membrane offers water separation for a different type of contaminants removal. As an adsorptive ceramic hollow fiber membrane, the membrane is beneficial for the removal of even low-concentration of heavy metal ions from aqueous water. Thus, the membrane can be a wise choice to replace the adsorbents in powder form for the adsorption process. Then, the photocatalytic process of the membrane is beneficial to reduce the membrane fouling effect by the degradation of organic pollutants. Thus, self-cleaning of the membrane surface membrane for oil emulsion separation can be done. Overall, the multifunctional properties of the membrane can assure plant simplicity.

1.2 Problem Background

Phase inversion technique is reported mostly in fabricating the ceramic hollow fiber membrane with a porous asymmetrical structure. The porous asymmetrical structure consisting of the sponge-like, and finger-like pores is favorable for a high flux membrane. The development of the combined alumina and YSZ particles for the ceramic hollow fiber membrane is not extensively studied yet. The phase inversion condition to achieve the desired membrane morphology is interesting to be studied. However, the concern related to the fabrication of ceramic hollow fiber membrane is the membrane pore sizes produced. It was reported that the ceramic membranes produced via the phase inversion technique are having large membrane pore sizes. Normally in microfiltration (MF) and ultrafiltration (UF) range. The pore size of the ceramic membrane can be reduced to a nanofiltration (NF) or reverse osmosis (RO) range through the sintering process by increasing the sintering temperature. However, the densification of the sponge-like voids as prone to the sintering process leading to a formation of dense membrane structure and the formation of the non-interconnecting pores. Thus, reducing the membrane permeability by preventing or reducing the water pathways across the membrane. Besides, sintering at a high temperature can cause the elimination of the hydroxyl group from the membrane surface and reduced the hydrophilic property of the ceramic membrane.

The separation mechanism of a membrane is based on the size exclusion. The capability in retaining the small ionic size of water contaminants such as heavy metal ions (Pb^{2+}) using MF and UF type membrane is not possible. The Pb^{2+} ions dissociate in water is having a radius of 0.119 nm. Then, the relative difference between the membrane pore size and Pb^{2+} ions size it can pass through the membrane pore to the permeate side. Hence, advancing the adsorptive properties to the ceramic membrane can give a solution to this issue when using MF or UF type membrane for heavy metal ions removal. Using inorganic particles as an adsorbent for wastewater treatment had prone to the agglomeration of the inorganic particles due to the Van der Waals forces when dispersed in a solution for the adsorption process. Depositing or embedded the inorganic particles on a substrate can overcome the issue of particles agglomeration. For this purpose, the MF and UF membrane range can be used as the substrate for the development of an advance ceramic membrane. This can be done by undergoing modification to the ceramic substrate with an inorganic material. Hence, the deposition of inorganic material with the adsorptive properties allow the membrane to act as an adsorptive membrane. Thus, the small sizes of the monovalent ions which cannot be retained by the MF or UF membrane range through size exclusion mechanism can be adsorbed by the membrane during the filtration process. Therein, provide a single solution to overcome the issues of porous ceramic membrane range to separate small sizes of particulates by separative and inorganic particles agglomeration for adsorption process.

Another issue that arises from the membrane separation process is the membrane fouling phenomenon. There is no exception for the ceramic membrane even though the fouling rate is lower than the polymeric membrane. The ceramic membrane will loss of its nature of the hydrophilic properties efficacy over time to resist the membrane fouling. The fouling phenomenon occurs due to the accumulation of foulants on the membrane surface and pores. Thus, increasing the mass transfer and reducing the membrane flux. The previous study had reports oily type wastewater had caused to the great membrane fouling. This type of wastewater also can be separated using MF or UF type membrane as the oil droplets associate in water is within the membrane range.As a solution to the ceramic hollow fiber membrane fouling issue for the oil type wastewater separation, the membrane surface modification with the hydrophilic coating was introduced. The hydrophilic coating by depositing an inorganic material helps in increasing the membrane flux. Owing to the properties of the inorganic material which also response as a photocatalyst can mitigate oil degradation. Thus, creating a self-cleaned membrane process to prevent the formation of foulants layer on the membrane surface. Considering the opaque ceramic hollow fiber membrane, depositing the inorganic material on the outer surface of the ceramic hollow fiber membrane is favored to activate the inorganic material with light irradiation.

From the above problems stated and the solutions proposed, the iron oxide (Fe_2O_3) was chosen as the depositing inorganic material as it can response both as an adsorbent and as a photocatalyst. The deposition can realize the aim of the study to develop a multifunctional ceramic hollow fiber membrane for a different type of water separation. Thus, embedding and depositing the Fe_2O_3 particles within the porous ceramic membrane can provide the adsorptive and photocatalytic properties to the membrane. However, a possibility prone to the detachment of the depositing Fe_2O_3 is concerned to resolve. The polymer coating approached as a protective film or layer can give a solution to secure the deposited Fe_2O_3. Thus, it is interesting to study the feasibility of the composite polymer-ceramic hollow fiber membrane for the water separation process.

1.3 Objectives

This study aims to develop a multifunctional ceramic hollow fiber membrane for water separation. To highlight the multi-function of the membrane and to solve the problem issued at sub-chapter 1.2, the specific objectives of the study were listed as below:

1. To study the effect of fabrication condition on the Al_2O_3/YSZ hollow fiber morphology as substrate via dry-wet phase inversion and sintering process
2. To evaluate the effect of iron oxide dispersed across the Al_2O_3/YSZ hollow fiber substrate on the structural properties, physical properties and the adsorptive membrane performance
3. To evaluate the effect of iron oxide deposited on the surface of Al_2O_3/YSZ hollow fiber on the structural properties, physical properties and the performance for oil emulsion separation and self-cleaning membrane properties
4. To study the feasibility of polymer coating on the iron oxide supported Al_2O_3/YSZ hollow fiber membrane

1.4 Scope of the Study

To achieve the objectives in this study, the following scope of the study was performed:

Scope objective 1: fabricating the asymmetric Al_2O_3/YSZ hollow fiber substrate via dry-wet phase inversion spinning process and followed by the sintering process.

1. The composition of the ceramic suspension was varied by using two different particle size of the YSZ particles at 0.3 and 0.01 µm.
2. The sintering temperature was also varied at 1350 and 1400 ^{o}C.

3. The structural properties of the hollow fibers produced were observed using scanning electron microscopy (SEM), and the distribution between alumina and YSZ particles was observed with the assistance of the energy-dispersive x-ray spectroscopy (EDX).
4. The physical properties of the hollow fiber produced were characterized using mercury intrusion porosimetry (MIP) to measure the pore size distribution of the hollow fibers. The mechanical strength was also measured using the 3P bending strength test. Then, flux properties of the hollow fibers were measured using pure water by using crossflow pressure-driven filtration system.

Scope objective 2: depositing Fe_2O_3 particles within the Al_2O_3/YSZ hollow fiber substrate via an in-situ hydrothermal process

1. The hydrothermal solution was varied by varying the concentration of iron precursor at 0.05 and 0.2 M to determine the Fe_2O_3 deposition within the Al_2O_3/YSZ hollow fiber substrate. During the hydrothermal-deposition process, both ends of the hollow fiber substrate were not closed or capped.
2. The hydrothermal duration was also varied at 24 h and 48 h to evaluate the effect on the deposited Fe_2O_3 particles within the Al_2O_3/YSZ hollow fiber substrate.
3. The structural properties of the Fe_2O_3 deposited within the Al_2O_3/YSZ hollow fiber substrate were examined using field emission scanning electron microscopy (FESEM) and energy-dispersive x-ray spectroscopy (EDX).
4. The physical properties of the Fe_2O_3 deposited were characterized using Fourier-transform infrared spectroscopy (FTIR), using x-ray diffraction (XRD) and N_2 adsorption-desorption. The flux properties of the hollow fibers were measured using pure water by using crossflow pressure-driven filtration system.
5. The Fe_2O_3 supported Al_2O_3/YSZ hollow fiber membrane performance as an adsorptive membrane were evaluated for lead (Pb) removal. The effect of the pH value of Pb (II) solution, time contact, and initial concentration of Pb (II) solution was studied. The concentration of the Pb (II) ions was measured using atomic absorption spectroscopy (AAS).

Scope objective 3: depositing Fe_2O_3 on the surface of the Al_2O_3/YSZ hollow fiber via an in-situ hydrothermal process.

1. The hydrothermal solution was varied by varying the concentration of iron precursor at 0.05, 0.2 and 0.5 M. For this deposition process, both ends of the hollow fiber were capped with polytetrafluoroethylene (PTFE) tape to avoid the penetration of the hydrothermal solution into the hollow fiber substrate through the lumen.
2. The structural properties of the Fe_2O_3 deposited on top of the hollow fiber were examined using field emission scanning electron microscopy (FESEM). The surface properties of the membrane were examined using atomic force microscopy (AFM).
3. The physical properties of the Fe_2O_3 supported on Al_2O_3/YSZ hollow fiber membrane were characterized by the contact angle. The flux properties of the membranes were measured using pure water by using crossflow pressure-driven filtration system.
4. The performance of the Fe_2O_3 supported on Al_2O_3/YSZ hollow fiber membrane was evaluated for oil emulsion separation. The crossflow pressure-driven filtration system was used to carry out the separation of 1000 mg/L oil emulsion solution. The concentration of the oil emulsion was measured using Uv-vis spectroscopy. The particle size distribution of oil droplets was measure using zeta sizer (DLS Malvern).
5. The self-cleaning properties of the Fe_2O_3 supported on Al_2O_3/YSZ hollow fiber membrane were evaluated by a photo-induced filtration process, where the light was illuminated during the filtration process. The oil fluxes and rejections were measured.

Scope objective 4: coating polymer layer on Fe_2O_3 supported Al_2O_3/YSZ hollow fiber membrane

1. Coating the Fe_2O_3 supported on Al_2O_3/YSZ hollow fiber membrane with UV curable resin via dip coating and UV curing process.
2. The structural properties of the UV curable resin coating were observed using field emission scanning electron microscopy (FESEM). The surface properties of the membrane were examined using atomic force microscopy (AFM) and contact angle.
3. The interaction between UV curable resin towards the membrane was analyzed using x-ray diffraction (XRD) and Fourier-transform infrared spectroscopy (FTIR) analysis.
4. The feasibility of the coated membrane with the UV curable resin was evaluated for 1000 mg/L of humic acid removal using sweeping liquid crossflow filtration system. The concentration of the humic acid solution was determined using Uv-vis.

1.5 Significant of Study

This study contributed to the knowledge of the development of multifunctional ceramic hollow fiber membrane for water separation. The different water pollutants in aqueous water can be treated using the same Fe_2O_3 supported Al_2O_3/YSZ hollow fiber membrane. The simultaneous synthesis and deposition of inorganic material via in-situ hydrothermal process within the ceramic hollow fiber substrate are exposed in this study. With the different setup and hydrothermal conditions during the hydrothermal process, the inorganic material can be deposited on top or within across the porous hollow fiber substrate in one-pot. Also, the knowledge on the polymeric coating on the ceramic membrane via UV curing process is defined in this study as the topic regarding this process is not well reported in previously. Then, the feasibility of the membrane for a different type of wastewater treatment is enclosed in this study. First, for the treatment of heavy metal solution, the deposition of inorganic material (adsorbent) within the porous structure of the ceramic membrane had improved the adsorptive properties of the membrane. Second, as for the oily wastewater treatment, the deposition of inorganic material (photocatalyst) on top of the membrane enables for improving the membrane’s flux by improving the hydrophilicity properties of the membrane surface and also enable for the self-cleaning membrane process with the assisted of light irradiation. Third and last, the polymer coating had made the porous ceramic membrane feasible for forward osmosis (FO) application.

The morphology of the ceramic membrane can be categorized into a symmetric and asymmetric structure. The symmetric structure is having the homogeneous pore size distribution across the membrane cross-sectional. Meanwhile, an asymmetrical structure possesses a change in pore size distribution across the membrane cross-sectional. As illustrates in Figure 2.2, the asymmetric membrane consists of a thin as an active layer on the top, an intermediate porous layer and more porous layer as the support at the bottom part. The outer active layer plays a key role in the separation process and the substrate provides the mechanical support to the membrane. Moreover, all layers can be made of the same material or different materials (called a composite ceramic membrane). Where, in a composite ceramic membrane, the properties of the membrane can be tailored depending on the material used in each layer with multi-step of fabrication process [5]. Furthermore, the membrane process can be further classified into microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO) according to the pore sizes of the membrane in the pressure-driven membrane processes.

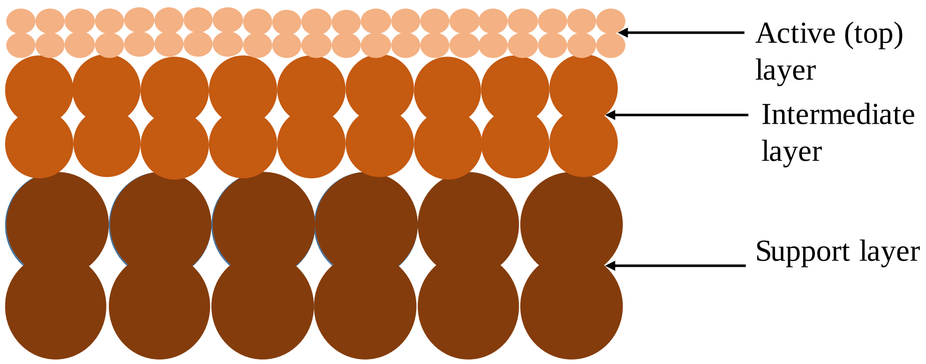

Figure 2.2 The illustration of an asymmetric ceramic membrane.

2.2 Fabrication of an Asymmetric Ceramic Hollow Fiber Membrane

Fabrication of ceramic membrane involves with three main steps: (1) preparation of a homogeneous ceramic suspension containing ceramic powder, solvent, polymer binder and additive; (2) packing and shaping the ceramic suspension into a specific geometry; and (3) consolidation of the ceramic particles by the sintering

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LIST OF PUBLICATIONS

Journal with Impact Factor

1. **Syafikah Huda Paiman**, Mukhlis A Rahman, Tetsuo Uchikoshi, Norfadhilatuladha Abdullah, Mohd Hafiz Dzarfan Othman, Juhana Jaafar, Khairul Hamimah Abas and Ahmad Fauzi Ismail (2020). Functionalization effect of Fe-type MOF for methylene blue adsorption. *Journal of Saudi Chemical Society, 24, 896–905*. https://doi.org/10.1016/j.jscs.2020.09.006. **(Q2, IF: 3.517).**
2. **Syafikah Huda Paiman**, Mukhlis A Rahman, Tetsuo Uchikoshi, Nik Abdul Hadi Md Nordin, Nur Hashimah Alias, Norfadhituladha Abdullah, Khairul Hamimah Abas, Mohd Hafiz Dzarfan Othman, Juhana Jaafar and Ahmad Fauzi Ismail (2020). In situ growth of α-Fe_2O_3 on Al_2O_3/YSZ Hollow Fiber Membrane for Oily Wastewater. *Separation and Purification Technology, 23, 115250.* https://doi.org/10.1016/j.seppur.2019.116250. **(Q1, IF: 5.774)**.
3. **Syafikah Huda Paiman**, Mukhlis A Rahman, Khairul Hamimah Abas, Azian Abd Aziz, Ahmad Fauzi Ismail, Mohd Hafiz Dzarfan Othman, Juhana Jaafar, Mohammad Noorul Anam Mohd Norddin (2019). Al_2O_3/YSZ Hollow Fiber Membrane Incorporated with Iron Oxide for Pb (II) Removal. *Chemical Engineering & Technology, 42, 1321–1329*. https://doi.org/10.1002/ceat.201800065. **(Q2, IF: 3.742)**.
4. Nur Hashimah Alias, Juhana Jaafar, Sadaki Samitsu, T Matsuura, AF Ismail, MHD Othman, Mukhlis A Rahman, Nur Hidayati Othman, Norfazliana Abdullah, **Syafikah Huda Paiman**, N Yusof, F Aziz (2018). Photocatalytic nanofiber-coated alumina hollow fiber membranes for highly efficient oilfield produced water treatment. *Chemical Engineering Journal, 360, 1437–1446*. https://doi.org/10.1016/j.cej.2018.10.217. **(Q1, IF: 10.652)**.

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