COPPER OXIDE INCORPORATED POLYVINYLIDENE FLUORIDE DUAL LAYER HOLLOW FIBER PHOTOCATALYTIC MEMBRANE FOR BISPHENOL A REMOVAL

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DEDICATION

This thesis is dedicated to my late father [Mohamed Noor Abdul Kadir], my mother [Siti Jaminah Samian], parents in-law [Ramlan Abu Bakar & Nora Abdul Wahab], my siblings, in-laws, nieces and nephews who taught me that the best kind of knowledge to have been that which is learned for its own sake and encouraged me to further study to the next step. Lastly, dedicated to my beloved husband and daughter [Mohd Hairil Nizam Ramlan & Hayla Yasmin Mohd Hairil Nizam] who supports me in every aspect and always been there through thick and thin.

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ABSTRACT

Bisphenol A (BPA) is grouped under endocrine disrupting compound (EDC), which accumulating in most Southeast Asia rivers from 8 ng/L to 36.9 ng/L. It is a common plasticizer have been in plastic bottles, water pipes, and toys and enters our household water after being exposed to heat, acid, or base. Continuous exposure to BPA may lead to myocardial infraction, cardiac hypertrophy, preterm birth, and neuro-behavioral disturbances. This study developed a novel photocatalytic membrane to remove BPA from water body efficiently. The photocatalysis process was chosen to be a hybrid with membrane in this work as it is safe and has no secondary by-product. Copper (I) oxide (Cu_2O), also known as cuprous oxide, is a type of semiconductor which is nontoxic and able to work under visible light with its low band gap of 2.2 eV. In this study, Cu_2O was incorporated into polyvinylidene fluoride (PVDF) based dual-layer hollow fiber membrane at different Cu_2O to PVDF ratios, namely 0.25, 0.50, and 0.75. The outer dope layer flowrate was also varied at 3, 6, and 9 ml/min. The membranes were analyzed for scanning electron microscope, contact angle, porosity, tensile strength test, atomic force microscopy, X-ray diffraction, dispersive energy X-ray, Fourier-transform infrared spectroscopy, and water flux measurement. Based on the finding, a higher outer dope flowrate increased the outer layer finger like structure and thickness. 6 ml/min outer dope flowrate had the highest porosity (63.13% ± 5.09), and water flux (4919.02 ± 42.52 L/m^{2}h). Meanwhile, the increase in photocatalyst loading had increased the Cu_2O agglomeration in the outer layer membrane, copper mapping in the outer layer membrane, and surface roughness. The DLHF membrane with a Cu_2O/PVDF ratio of 0.5 possessed the highest water flux (13890.99 ± 164.96 L/m^{2}h) and the lowest contact angle (58.90° ± 1.72). Thus, the selected membranes were observed for their performance to degrade BPA with 10, 20, and 30 mg/L concentrations under visible light irradiation for 360 minutes. The treated water sample was analysed for the leaching test. The best membrane configuration as photocatalytic membrane is 0.50 Cu_2O/PVDF ratio with 6 ml/min outer dope flowrate with the ability to remove 75 % of 10 mg/L BPA, 69.23 % of 20 mg/L BPA and 68.42 % of 30 mg/L BPA in 360 minutes under visible light irradiation. In conclusion, Cu_2O/PVDF DLHF membrane is able to remove BPA under visible light irradiation.

ABSTRAK

Bisphenol A (BPA) tergolong di dalam kumpulan sebatian yang mengganggu endokrin (EDC) yang semakin terkumpul di kebanyakan sungai di Asia Tenggara dari 8 ng/L ke 36.9 ng/L. Ia merupakan pemplastik lazim dalam botol plastik, paip air dan permainan kanak-kanak dan berupaya memasuki sumber air rumah selepas terdedah pada haba, asid dan alkali. Pendedahan berterusan terhadap BPA boleh menyebabkan infraksi miokardium, hipertrofi jantung, kelahiran pramatang dan gangguan tingkah-laku neuro. Dalam kajian ini, satu membran fotomangkin novel telah dibangunkan untuk menyingkirkan BPA dari sumber air secara efisien. Proses fotomangkin telah dipilih untuk dihibridkan bersama membran kerana ianya selamat dan tiada hasil sampingan sekunder terhasil. Kuprum (I) oksida (Cu_2O) atau dikenali sebagai kuprus oksida adalah sejenis semikonduktor yang tidak bertoksik dan berupaya bekerja di bawah cahaya tampak dengan sela jalurnya yang rendah, 2.2 eV. Melalui kajian ini, Cu_2O telah digabungkan bersama membran dua lapis gentian berongga polivinilidena flourida (PVDF) dengan nisbah Cu_2O kepada PVDF yang berbeza, 0.25, 0.50 dan 0.75. Kadar aliran lapisan luar juga telah divariasikan pada 3, 6 dan 9 ml/min. Membran telah dianalisa menggunakan mikroskop elektron imbasan, sudut sentuh, keliangan, ujian kekuatan tegangan, mikroskopi daya atom, pembelauan sinar-X, sinar-X sebaran tenaga, spektroskopi inframerah transformasi Fourier dan pengukuran fluks air. Berdasarkan keputusan kajian, struktur kadar air dop luar tinggi meningkatkan struktur jari lapisan luar dan ketebalan. Kadar aliran lapisan luar 6 ml/min mempunyai keliangan paling tinggi (63.13% ± 5.09) dan fluks air (4919.02 ± 42.52 L/m^2h). Manakala, peningkatan muatan fotomangkin meningkatkan pengaglomeratan Cu_2O pada lapis luar membran, pemetaan kuprum pada lapis luar membran dan kekasaran permukaan membran. Membran DLHF dengan nisbah Cu_2O/PVDF 0.5 mempunyai fluks air paling tinggi (13890.99 ± 164.96 L/m^2h) dan sudut sentuh paling rendah (58.90° ± 1.72). Membran terpilih telah dicerap untuk prestasinya untuk penurunan BPA dengan kepekatan 10, 20 dan 30 mg/L dibawah sinaran cahaya tampak selama 360 minit. Sampel air terawat telah dianalisa untuk ujian larut lesap. Konfigurasi membran fotomangkin terbaik adalah nisbah Cu_2O/PVDF 0.5 dengan kadar aliran lapisan luar 6 ml/min berupaya mendegradasi 75% BPA 10 mg/L, 69.23% BPA 20 mg/L dan 68.42% BPA 30 mg/L dalam 360 minit dibawah sinaran cahaya tampak. Kesimpulannya, membran DLHF Cu_2O/PVDF berjaya menyingkirkan BPA di bawah sinaran cahaya tampak.

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LIST OF ABBREVIATIONS

SEM	-	Scanning Electron Microscopy
XRD	-	X-ray Diffraction
FTIR	-	Fourier-transform Infrared Spectroscopy
AFM	-	Atomic Force Microscopy
EDX	-	Energy Dispersive X-ray
DLHF	-	Dual Layer Hollow Fibre
PVDF	-	Polyvinylidene fluoride
DMAc	-	Dimethylacetamide
PEG	-	Polyethylene glycol
Cu_2O	-	Copper (I) oxide
PVC	-	Polyvinyl chloride
EDC	-	Endocrine Disrupting Compound
BPA	-	Bisphenol A
WWTP	-	Wastewater Treatment Plant
MSN-CTAB	-	Hexadecyltrimetgylammonium
ANMWC	-	Antimony Nanoparticle Multi-Walled Carbon
MWCNT	-	Multi-Walled Carbon Nanotube
NF	-	Nanofiltration
TiO_2	-	Titanium dioxide
WO_3	-	Tungsten trioxide
Ag_3PO_4	-	Silver phosphate
UV	-	Ultraviolet
CdS	-	Cadmium sulfide
$BiVO_4$	-	Bismuth vanadate
$g\text{-}C_3N_4$	-	Graphitic carbon nitride
PPCP	-	Pharmaceuticals and Personal Care Products
CuO	-	Copper (II) oxide
ZnO	-	Zinc Oxide

LIST OF SYMBOLS

kV	-	Kilo Volt
mA	-	Milli Ampere
N	-	Newton
pa	-	Pascal
ε	-	Porosity
ρp	-	Polymer Density
ρw	-	Water Density

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CHAPTER 1

INTRODUCTION

1.1 Background of study

According to the World Health Organization (2019), by 2025, half of the world's population will face significant challenges with access to safe drinking water. Even now, 2 billion people use faeces-contaminated water as drinking water (Shakya *et al.*, 2021). Contaminated water transmits diseases such cholera, hepatitis A, polio, diarrhea and dysentery. According to Environmental Protection Agency (2016), compounds that labelled as contaminants in water are nitrogen, salts, metals, toxins, bleach, microorganisms, uranium, cesium, human drugs, animal drugs and endocrine disrupting compounds (EDCs). Thus, more efforts need to start from now to prepare the world for water crisis in 2025. Contaminants from water need to remove so it can be use as drinking water.

Because of estrogenic effect, toxicity, durability, and bioaccumulation, EDCs, a collection of organic compounds, have garnered worldwide interest. Humans' exposure to EDC through drinking water and tap water leads to the risk of health issues (Wee and Aris, 2017). Bisphenol A (BPA) is a member of EDCs found in each house, as it is one of food and beverages packaging composition. It demands also increasing annually worldwide (Corrales *et al.*, 2015). BPA can be detected in municipal and industrial wastewater due to leaching, domestic waste combustion, or plastic degradation (Santhi *et al.*, 2012). It affects not only human health but also animals. Reproduction problems such as fertility, miscarriage, and premature deliveries, human development problems such as neurodevelopment and birth weight, and metabolic problems such as cardiovascular disease, obesity, and hypertension are the main target of BPA as it is an endocrine disruptor compound (Rochester, 2013). BPA also disturbs animals' reproduction systems and hormone signals (Larsen, 2015).

BPA is widely used in various industries. The concentration of BPA found in the environment is also quite high, but there is less concern to remove it extensively (Rochester, 2013). Surface water in Asia itself exceeded 80 % of Canadian Predicted No Effect Concentrations of BPA, which is 750 ng/L. Meanwhile, Europe exceeded 63.4 %, North America exceeded 56.3 %, and Asia exceeded 52.4 % for effluent water (Corrales *et al.*, 2015). BPA has been removed by several methods, including adsorption, nanofiltration, biological method, and emulsion liquid membrane (A Boukhelkhal *et al.*, 2016; Abdel-Fatah, 2018; Iosob *et al.*, 2016; Kumar *et al.*, 2019). However, these methods still have limitations to remove BPA optimally without producing secondary compounds, green process, less fouling, short time duration of treatment, and good stability.

The Photocatalysis concept was first discovered in 1911 by Dr Alexander Eibner, originally from Germany (Coronado *et al.*, 2013). He found that zinc oxide could bleach Prussian blue, a dark blue pigment, under the presence of illumination (Nawaz *et al.*, 2021). The photocatalysis process is low in cost, but it is also reusable, eco-friendly, and able to degrade completely compared to other treatment processes (Kumar *et al.*, 2014). This process can activate when the photocatalyst is irradiated with visible light or UV light, depending on its bandgap energy. Few factors affect the photocatalysis process; light intensity, amount of catalyst, temperature, structure, size, pH, surface area, and pollutants concentration. This process has been used in organic pollutant degradation, especially in wastewater, hydrogen production, air purification, and disinfectant (Saravanan *et al.*, 2017). It removed contaminants in water, including organic compounds, textile dyes, EDCs, and pharmaceutical drugs (Ismail *et al.*, 2019; Kamaludin *et al.*, 2018; Wang *et al.*, 2018).

A chemically stable, photocorrosion stable, low cost, safe, and can get activated when exposed under visible light irradiation photocatalyst is needed. Copper (I) oxide (Cu_2O) is chosen because of its narrow band gap semiconductor. It has a 2.0 – 2.4 eV of band gap value, which can get activated after being exposed under visible light, which is cost effective as solar light is also considered as a visible light source (Koiki and Arotiba, 2020). Besides, it also has a lower recombination rate (Imtiaz *et al.*, 2019). It is chemically stable and can be found abundant naturally. Cu_2O is also applied in various areas such as sensor application, solar cells, photocatalysis, and water splitting (Koiki and Arotiba, 2020). Cu_2O also has a high affinity towards organic contaminants (Jing *et al.*, 2014). Based on a previous study, Cu_2O is capable of removing up to 95% of 45 mg/L of BPA (Losada-Garcia *et al.*, 2020). A visible light photocatalyst is needed as it can fully utilized 45% of the visible light solar spectrum rather than only 5% of the UV solar spectrum. Visible light photocatalysis advantages on its clean, use low-cost visible light as driving force, and renewable (Chen *et al.*, 2016).

Cooperating photocatalytic technology and membrane technology maintains the advantages of photocatalytic technology to degrade high concentrations of organic pollutants in wastewater and benefits from rapid reaction speed and extensive degradation (Wang, 2018). Other than that, the photocatalytic membrane is the hybrid of the filtration and photocatalysis process, no recovery treatment is needed for the photocatalyst as it is immobilized on the membrane and has a longer membrane lifetime as it has self-cleaning properties (Nascimbén Santos *et al.*, 2020).

DLHF membrane is a hollow fiber membrane that consists of two-layer, the inner layer, and the outer layer. DLHF have been applied in various kinds of field, such as forwarding osmosis, nanofiltration, separation of gas and liquid, and protein separation (Kamaludin *et al.*, 2017). Besides, it also has been applied in pervaporation and membrane distillation (Setiawan *et al.*, 2012). DLHF membrane has good flexibility as two different polymer dope solutions are used in fabrication, and each layer integrated together makes the membrane reduce certain individual materials weakness (Setiawan *et al.*, 2012). DLHF membrane also has a larger area per unit volume and has its mechanical support than other membrane types (Khan *et al.*, 2018). Once it is integrated with photocatalyst become photocatalytic DLHF membrane, outer layer acts as degradation site, and inner layer plays its role as a separation layer. Thus, DLHF membrane is among the most suitable membrane configurations to cooperate with photocatalyst and form a photocatalytic DLHF membrane.

1.2 Problem statement

Several methods have been attempted to remove BPA, which are adsorption (Boukhelkhal *et al.*, 2016), nanofiltration (Abdel-Fatah, 2018), biological agents (Alin *et al.*, 2016), and emulsion liquid membrane (Mondal *et al.*, 2018). Membrane fouling, limited to a certain particle size of pollutants, longer duration, and bad membrane stability are among the limitations of these conventional methods (Boukhelkhal *et al.*, 2016; Abdel-Fatah, 2018; Alin *et al.*, 2016; Mondal *et al.*, 2018). Meanwhile, the current development on the photocatalytic membrane is mainly on UV light. Various studies reported on the photocatalytic membrane, but it emphasizes utilizing UV light as a source of light rather than using visible light, as reported by Argurio *et al.* (2018) and Nyamutswa *et al.* (2020). Other than that, there is no study reported on using Cu_2O as a visible light photocatalyst in the membrane, not to mention in the DLHF membrane. Thus, this becomes a novelty of this study.

In this study, Cu_2O was chosen as a visible light photocatalyst because of its narrow bandgap, which lies between 2.0 – 2.4 eV, as it is a good potential in harvesting solar energy. This compound is abundant, non-toxic, can be synthesised easily, has a good visible light absorber, and is cheap (Koiki and Arotiba, 2020). Moreover, this compound can be found abundant naturally and also chemically stable (Muthukumaran *et al.*, 2019). Cu_2O was incorporated in the DLHF membrane to produce a simultaneous filtration and photocatalytic process. Other than that, the incorporation is to immobilize the Cu_2O thus, no secondary treatment is required to separate photocatalyst from BPA solution. The Cu_2O also has a longer lifetime and can be recycled compared to in suspension form (Teixeira *et al.*, 2016). Immobilization of Cu_2O also could prevent any suspension left in the BPA solution after the treatment process compared to the suspended photocatalyst. Deposition of Cu_2O into the DLHF membrane structure by co-extrusion method is preferred as it can prevent fouling, and the hydrophilicity can be controlled (Zakria *et al.*, 2021). Co-extrusion technique is more favourable compared to other spinning techniques due to it could reduce the risk of the inducing defect, adhesion between layers also improved, able to make structures of multifunction in a single process, and each layer provides a specific feature (Ullah Khan, Othman, A F Ismail, *et al.*, 2018). Photocatalytic membrane exists in a few configurations, such as hollow fiber membrane, flat sheet membrane, and tubular membrane. A hollow fiber membrane is a preferable configuration as its module processing is very easy, less expensive, and stable compared to the others (Wang, 2018). Hollow fiber membrane has two configurations: single-layer hollow fiber (SLHF) membrane and dual-layer hollow fiber (DLHF) membrane. However, the DLHF membrane has more advantages in comparison to the SLHF membrane when it comes to the amount and specific location of the nanoparticles that can be loaded into the membrane matrix (Kamaludin *et al.*, 2017). The membrane's lifetime could also be enhanced as photocatalyst has self-cleaning properties (Wan *et al.*, 2020). Moreover, this method could prevent photocatalyst leaching and low energy use (Zakria *et al.*, 2021).

As Cu_2O needs the presence of visible light irradiation, the Cu_2O was in the outer layer of the DLHF membrane as it was mixed up with PVDF during dope preparation and co-extruded together with an inner layer of the membrane. There is no study incorporating Cu_2O with PVDF in the DLHF membrane yet for BPA removal application. Outer dope flowrate 3 ml/min, 6 ml/min, and 9 ml/min were chosen based on research by Kamaludin *et al.* (2018) with some alterations to study the effect of outer dope flowrate on the outer layer thickness, membrane morphology, and membrane permeability. The ratio of Cu_2O to PVDF, 0.25, 0.5, and 0.75 also was chosen based on research by Kamaludin *et al.* (2019) with some modifications. The different ratio of Cu_2O to PVDF was varied to study the effect of photocatalyst amount on the photocatalytic performance to remove BPA. The optimum outer dope flowrate and optimum ratio of Cu_2O to PVDF resulting the best membrane in terms of morphology, permeability, hydrophilicity, water flux, and photocatalytic performance. On the other hand, the BPA concentration varied to analyse the membrane capability to remove BPA. The photocatalyst amount and amount of pollutants affect the photocatalytic membrane performance (Saravanan *et al.*, 2017). Meanwhile, the outer layer thickness affects membrane morphology and permeability (Marino *et al.*, 2018). Overall, integrating Cu_2O into the DLHF membrane will produce a visible light photocatalytic membrane with good morphology and degradation activity of BPA.

1.3 Research objectives

The aim of the present study is to develop a PVDF/Cu_2O based photocatalytic DLHF membrane for the efficient removal of BPA from contaminated water under visible light irradiation.

The specific objectives for this study are:

1. To examine the influence of outer layer dope flowrate on the physical and chemical characteristics of the DLHF membrane fabricated via co-extrusion technique.
2. To investigate the effect of Cu_2O loading in the outer layer on physicochemical properties of the DLHF membrane.
3. To evaluate the photocatalytic performance of the Cu_2O/PVDF dual layer hollow fiber membrane in removing Bisphenol A at various concentrations and analyse the treated water for leaching copper element from the membrane.

1.4 Scope of study

The present study is conducted to investigate the removal of BPA from water by photocatalytic DLHF membrane. In order to achieve the objectives of this research, the following scopes are outlined:

Scope of objective 1:

1. Preparing 0.25 ratio of Cu_2O/PVDF DLHF dope solutions. 3.75 wt.% of copper oxide (Cu_2O) as the photocatalyst, 15 wt.% of polyvinylidene fluoride (PVDF) as the polymer with 81.25 wt.% of dimethylacetamide (DMAc) as a solvent for outer layer dope solution and 15 wt.% for PVDF, 3 wt.% for polyethylene

glycol (PEG) which act as pore former and 82 wt.% for DMAc for inner layer dope solution

2. Fabricating photocatalytic dual layer hollow fiber membrane which can work under visible light by using dry/wet phase inversion co-extrusion technique with different outer layer dope extrusion flow rate 3 ml/min, 6 ml/min, and 9 ml/min and fixed other spinning condition. The fabricated membrane was subjected to post-treatment, dried at room temperature, and stored until further used.

3. Characterizing the 0.25 Cu_2O/PVDF dual layer hollow fiber membrane with different outer dope flowrate physico-chemical characteristics by scanning electron microscopy (SEM) under several magnifications, contact angle, membrane porosity, flux measurement, and Fourier-transform infrared spectroscopy (FTIR).

Scope of objective 2:

1. Preparing inner and outer dope solution with varied ratios, polyethylene glycol (PEG) as pore former and dimethylacetamide (DMAc) as solvent. Inner dope suspension solution consists of PVDF/PEG/DMAc with the concentration of 15/3/82 wt.%. While PVDF/Cu_2O/DMAc as outer dope suspension solution with different ratio concentration 15/3.75/81.25 wt.% (0.25), 15/7.5/77.5 wt.% (0.5) and 15/11.25/73.75 wt.% (0.75).

2. Fabricating photocatalytic dual-layer hollow fiber membrane which can work under visible light by using dry/wet phase inversion co-extrusion technique with the optimum outer layer dope extrusion from objective 1 and fixed other spinning conditions. The fabricated membrane was subjected to post-treatment, dried at room temperature, and stored until further used.

3. Characterizing the Cu_2O/PVDF dual layer hollow fiber membrane with different loading ratio Cu_2O/PVDF 0.25, 0.50, and 0.75 physico-chemical properties using atomic force microscopy (AFM), contact angle, membrane porosity, tensile strength and elongation at break, energy dispersive X-ray (EDX) and Fourier-transform infrared spectroscopy (FTIR).

Scope of objective 3:

1. Evaluating the removal of BPA with the concentration of 10 mg/L, 20 mg/L, and 30 mg/L by using Cu_2O/PVDF visible light photocatalytic dual layer hollow fiber membrane using the submerged photocatalytic system which consists of 23 cm length membrane in U-shape membrane module under visible light irradiation and assisted with UV-Vis spectrophotometer.

2. Analysing the treated sample to detect the leaching of Cu_2O from the Cu_2O/PVDF dual layer hollow fiber membrane into the water body using ICP-OES analysis.

1.5 Significance of study

DLHF membrane has been widely studied and well published in recent years, but for visible light photocatalytic membrane, removing EDC is quite unexplored. Using semiconductor Cu_2O, which has narrow bandgap, is chemically stable, and is widely applied in various industries, are good characteristics for it to function as an excellent photocatalyst. BPA exists in our drinking water and causes various health problems to humans and animals as it is an endocrine-disrupting compound. Few studies reported on the removal of BPA using photocatalytic membrane but need the presence of ultraviolet light. Photocatalytic Cu_2O/PVDF DLHF membrane eventually saves the electricity cost as it just needs visible light and can be operated in the night with a visible lamp or under sunlight irradiation. BPA can be removed using this photocatalytic Cu_2O/PVDF DLHF membrane without producing side effects or secondary compounds towards the environment as the photocatalytic process will totally degrade contaminants. This membrane can be used in wastewater treatment plants to remove the BPA totally. Thus, preparing the environment with BPA-free will improve the household water quality in Malaysia. Moreover, this study will contribute to society's prolonging healthiness with free from various health problems, especially related to the endocrine system. As a result, there will be significant enhancement in fulfilling the Environmental Protection Act (2012) and 6th and 7th Sustainable

Development Goal (SDG), which provide clean water and sanitation and affordable and clean energy, respectively.

1.6 Thesis organization

This thesis is organized into five chapters that describe original works on the fabrication of visible light photocatalytic DLHF membrane with different loading of Cu_2O nanoparticles and different outer dope flowrate for application towards degradation and separation process of BPA in contaminated water.

Chapter 1 briefly introduces the issues that lead to the current study. Three objectives of the study were identified, followed by the scopes of study to attain these objectives. **Chapter 2** describes the literature review on the occurrence and side effects of BPA exposure and conventional methods to remove BPA. Other than that, a comprehensive review was presented on the photocatalytic mechanism, factors affecting the photocatalysis process, and visible light photocatalyst. Besides, the review also describes membrane technology and dual-layer hollow fiber membrane configuration and development. **Chapter 3** provides the research frameworks. All the materials, experimental setups, working procedures and analytical methods for synthesized nanoparticles, fabrication of membrane, characterization techniques, and membrane performance evaluations were described.

Chapter 4 explains the fabrication of Cu_2O/PVDF DLHF membrane using the dry wet phase inversion co-extrusion technique. Different outer dope flowrate also applied on the membrane. The different ratio between Cu_2O and PVDF was varied in the outer dope solution. The effect of different outer dope flowrate in DLHF membrane was investigated on morphological analysis and permeability. The chemical properties of the membrane also well investigated. The membrane performances on BPA degradation were evaluated using a submerged membrane photoreactor. The degradation result compared with the previous study. The treated water sample was analysed to detect the leaching of copper components from the membrane into the water sample. **Chapter 5** is to conclude this thesis, the general conclusion of this study, and some recommendations for future works have been listed.

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Article paper

1. **Siti Hawa Mohamed Noor**, Mohd Hafiz Dzarfan Othman, Watsa Khongnakorn, Oulavanh Sinsamphanh, Huda Abdullah, Mohd Hafiz Puteh, Tonni Agustiono Kurniawan, Hazirah Syahirah Zakria, Tijjani El-badawy, Ahmad Fauzi Ismail, Mukhlis A. Rahman, Juhana Jaafar. Bisphenol A Removal Using Visible Light Driven Cu_2O/PVDF Photocatalytic Dual Layer Hollow Fiber Membrane. Membranes. 2022 Feb 10;12(2):208. Available from: https://www.mdpi.com/2077-0375/12/2/208

Conference proceeding

1. **Siti Hawa Mohamed Noor**, Mohd Hafiz Dzarfan Othman, Juhana Jaafar, Mukhlis A Rahman, A F Ismail (2021). Textile dye Reactive Black 5 (RB5) removal by visible light photocatalyst and its characterization. *IOP Conference Series: Materials Science and Engineering*, 1142(1), p.012017.
2. **Siti Hawa Mohamed Noor**, Mohd Hafiz Dzarfan Othman, Mukhlis A Rahman, Juhana Jaafar, Ahmad Fauzi Ismail. (2019). Cadmium sulfide as High Potential Visible Light Driven Photocatalyst: Investigation on its Characteristics and Performances for Textile Dye Reactive Black 5 (RB5) Removal. International Conference of Sustainable Environmental Technology 2019.

Book chapter

1. Nurul Jannah Ismail, Hazirah Syahirah Zakria, **Siti Hawa Mohamed Noor**, Mohd Hafiz Dzarfan Othman, Mukhlis A Rahman, Juhana Jaafar, Ahmad Fauzi Ismail. (2021). Photocatalytic Nanocomposites for Environmental Remediation. (In review of Royal Society of Chemistry)