FABRICATION AND CHARACTERIZATION OF NYLON 6, 6, POLYSULFONE AND POLYSTYRENE ELECTROSPUN FIBRE MEMBRANES FOR ADSORPTION OF BISPHENOL A IN WATER

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DEDICATION

Special dedications to my beloved mother, father, family, wife and daughter.

Thank you.

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ABSTRACT

The presence of new emerging pollutants (NEPs) residue in wastewater effluents, surface water and drinking water even after being subjected to the conventional treatment methods is an emerging concern. Hence, a few advanced technologies were introduced, such as pressure-driven membranes, for example, nanofiltration (NF) and reverse osmosis (RO). However, their performance has been limited due to high-pressure requirement and low permeate flux, leading to high operational costs. In this study, the utilization of the electrospun fibre membranes (EFMs) was explored as they possesses several advantages, such as the lower operating pressure requirement and ability to produce higher permeate flux that is favourable for adsorption technology. The nylon 6, 6 (Ny), polysulfone (PSf) and polystyrene (PSty) EFMs were fabricated by using the electrospinning technique and used for the adsorption of bisphenol A (BPA), acetaminophene (ACTP), sulfamethoxazole (SMX) and ibuprofen (IBP). The optimum conditions, such as applied voltage, flow rate and inner diameter of needle of the electrospinning process for: i) Ny (26 kV, 0.4 mL/h, 0.50 mm), ii) PSf (15 kV, 2.5 mL/h, 0.50 mm) and iii) PSty (16 kV, 1.6 mL/h, 0.60 mm) are considered achieved when continuous and stable streaming jet without any dripping and clogging with minimal beaded fibres is observed. The field emission scanning electron microscopy (FESEM) result showed that the average fibre diameter of Ny, PSf and PSty EFMs was measured at 98, 1291 and 1575 nm, respectively. The contact angle analysis of Ny EFM revealed a hydrophilic character, while PSf and PSty EFMs exhibited hydrophobic character. Fourier transform infrared spectroscopy (FTIR) analysis revealed the presence of hydroxyl groups in the BPA molecule, carbonyl and amine groups in Ny EFM and sulfonyl groups in PSf. These results demonstrated that the hydrogen bonding probably could be formed between Ny and PSf EFM with the BPA molecules, thus facilitating the BPA adsorption. When compared to ACTP, SMX, and IBP, the adsorption of BPA by Ny EFM was more effective. The adsorption of BPA in ultrapure water (UPW) by using five layers of Ny EFM was 96%, and the permeate volume of BPA solution was recorded at 193 mL after 30 mins of operation. The result also showed that both composites of Ny+PSf and Ny+PSty EFMs enhanced the permeate volume of BPA solution, which was recorded at 454 and 290 mL, respectively, after 30 mins of operation. The experiment for membrane regeneration and reusability for composites of Ny+PSf and Ny+PSty EFMs through three cycles of BPA adsorption in UPW was successful. This good performance was due to the BPA adsorption showing a consistent performance throughout the three cycles of operation. However, the volume of permeate BPA solution for both composites of Ny+PSf and Ny+PSty EFMs decreased from the first to the third operation cycle, from 454 to 150 mL and 290 to 119 mL, respectively. Additionally, the membrane regeneration and reusability for composite of Ny+PSf EFM through three cycles of BPA adsorption in tap water was also successful with the adsorption of 98 - 99% throughout the three cycles of operation. Meanwhile, the volume of permeate BPA solution was consistent, recorded at 348, 352 and 365 mL during the first, second and third cycles of operation, respectively. The successful BPA adsorption makes the Ny+PSf EFM composite a promising and suitable candidate for use in advanced water filtration systems.

ABSTRAK

Pada masa kini, kehadiran baki pencemar baharu (NEP) dalam efluen air buangan, air permukaan dan air minuman masih dapat dikesan walaupun setelah menjalani kaedah rawatan konvensional. Oleh itu, beberapa teknologi canggih seperti nanotapisan (NF) dan osmosis songsang (RO) diperkenalkan, namun prestasinya terhad disebabkan oleh keperluan tekanan yang tinggi, hasil fluks yang rendah dan membawa kepada kos operasi yang tinggi. Dalam kajian ini, penggunaan membran gentian elektroputaran (EFM) mempunyai beberapa kelebihan seperti dapat beroperasi pada tekanan yang lebih rendah dan menghasilkan jumlah fluks yang lebih tinggi serta sesuai digunakan untuk teknologi penjerapan. Nilon 6, 6 (Ny), polisulfon (PSf) dan polistirena (PSty) dihasilkan dengan menggunakan teknik elektroputaran dan diaplikasikan untuk penjerapan bisfenol A (BPA), asetaminofen (ACTP), sulfametoksazol (SMX) dan ibuprofen (IBP). Keadaan optimum seperti bekalan voltan, kadar aliran larutan polimer dan diameter dalaman jarum untuk elektroputaran: i) Ny (26 kV, 0.4 mL/h, 0.50 mm), ii) PSf (15 kV, 2.5 mL/h, 0.50 mm) dan iii) PSty (16 kV, 1.6 mL/h, 0.60 mm) dianggap tercapai apabila aliran jet yang berterusan dan stabil tanpa menitis dan tersumbat dengan gentian bermanik yang minimum diperhatikan. Keputusan mikroskop elektron pengimbas pelepasan medan (FESEM) menunjukkan bahawa diameter gentian untuk Ny, PSf dan PSty EFM masing-masing diukur pada 98, 1291 dan 1575 nm. Analisis sudut permukaan untuk Ny EFM menunjukkan sifat hidrofilik, sementara PSf dan PSty EFMs menunjukkan sifat hidrofobik. Keputusan spektroskopi inframerah transformasi fourier (FTIR) menunjukkan kehadiran kumpulan hidroksil dalam molekul BPA, kumpulan karbonil dan amina dalam Ny EFM, dan kumpulan sulfonil dalam PSf. Keputusan ini memungkinkan ikatan hidrogen boleh terbentuk antara Ny dan PSf EFM dengan molekul BPA dan mampu untuk menjerap BPA. Sementara itu, keputusan menunjukkan bahawa Ny EFM dapat menjerap BPA dengan berkesan berbanding ACTP, SMX dan IBP. Penjerapan BPA ke dalam air ultra tulen dengan menggunakan lima lapisan Ny EFM ialah 96% dan isipadu resapan larutan BPA direkodkan pada 193 mL selepas 30 minit operasi. Keputusan juga menunjukkan kedua-dua komposit Ny+PSf dan Ny+PSty EFMs meningkatkan isipadu resapan larutan BPA yang direkodkan masing-masing pada 454 dan 290 mL selepas 30 minit operasi. Eksperimen untuk regenerasi membran dan kebolehgunaan semula komposit Ny+PSf dan Ny+PSty EFMs melalui tiga kitaran penjerapan BPA di UPW adalah berjaya. Prestasi yang baik ini disebabkan oleh prestasi penjerapan BPA yang konsisten sepanjang tiga kitaran operasi. Bagaimana pun, isipadu resapan larutan BPA untuk kedua-dua komposit Ny+PSf dan Ny+PSty EFMs menurun daripada kitar pertama hingga kitar ketiga, masing-masing dari 454 kepada 150 mL dan 290 kepada 119 mL. Selain itu, kejayaan regenerasi membran dan kebolehgunaan semula komposit Ny+PSf EFM melalui tiga kitaran penjerapan BPA dalam air paip telah tercapai apabila penjerapan BPA menunjukkan 98 - 99% melalui kitaran operasi pertama hingga ketiga. Sementara itu, isipadu resapan larutan BPA adalah konsisten di mana 348, 352 dan 365 mL masing–masing telah dihasilkan semasa kitaran operasi pertama, kedua dan ketiga. Kejayaan penjerapan BPA oleh komposit Ny+PSf EFM menjadikan bahan ini sesuai untuk diaplikasikan dalam sistem penapisan air yang termaju.

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LIST OF ABBREVIATIONS

ACTP	-	Acetaminophene
ADWTP	-	Advanced drinking water treatment plant
AOC	-	Assimilable organic carbon
BPA	-	Bisphenol A
CWTP	-	Conventional water treatment plant
DBP	-	Disinfection by-product
DOE	-	Department of Environment
DWPP	-	Drinking water purification plant
DWTP	-	Drinking water treatment plant
EDC	-	Endocrine-disrupting chemicals
EFM	-	Electrospun fibre membrane
EO	-	Engineered osmosis
FELST	-	Fish early life stage toxicity test
FNM	-	Fanavaran Nano-Meghyas
GAC	-	Granular activated carbon
IBP	-	Ibuprofen
MF	-	Microfiltration
MW	-	Molecular weight
MWCO	-	Molecular weight cut-off
NEP	-	New emerging pollutant
NF	-	Nanofiltration
NOM	-	Natural organic matter
NP	-	Nanoparticle
NSAID	-	Non-steroidal anti-inflammatory drug
Ny	-	Nylon 6, 6
OECD	-	Organization of Economic and Cooperative Development
PAC	-	Powdered activated carbon
PPCP	-	Pharmaceuticals and personal care products
PPMU	-	University Laboratory Management Centre
PSf	-	Polysulfone

PSty	-	Polystyrene
RO	-	Reverse osmosis
SMX	-	Sulfamethoxazole
STP	-	Sewage treatment plants
UF	-	Ultrafiltration
UNICEF	-	United Nations Children's Fund
UPW	-	Ultra pure water
WHO	-	World Health Organization
WWD	-	Wastewater discharge
WWTP	-	Wastewater treatment plant

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

The availability of safe drinking water is a fundamental issue of public health that highlights to the significance of safeguarding the water supply. Good quality drinking water is required to maintain a clean environment and good health of the world population. In 2017, approximately 800 million people worldwide lacked access to even the most basic drinking water services, significantly affecting their health and wellbeing (UNICEF and WHO, 2019; Price *et al.*, 2021). A water source is considered safely managed if it is accessible on the premises, available when needed (defined as sufficient water for the last week or available for at least 12 hours per day) and free from contamination (UNICEF and WHO, 2019). In Malaysia, ensuring access to safe drinking water in a population remains a significant challenge. This is exacerbated by the inadequacy of regulations on the protection and surveillance of drinking water quality and public awareness on pharmaceutical residues in drinking water (Nasir *et al.*, 2019).

Drinking water is the final product of the production chain from source to tap. The primary drinking water sources are obtained from surface water and groundwater (Berg *et al.,* 2019). High-quality surface water is critical in maintaining healthy ecosystems and ensuring safe drinking water. One issue threatening the quality of our drinking water is the presence of new emerging pollutants (NEPs) which generally belong to three broad groups such as industrials, pesticides and pharmaceuticals and personal care poducts (PPCPs) (Murray *et al*., 2010). To date, there is no specific policy or regulations dedicated to NEPs as per National Water Quality Standards for Malaysia (Jabatan Alam Sekitar Kementerian Alam Sekitar, 2021).

Moreover, the presence of NEPs that may act as endocrine-disrupting chemicals (EDC) has been reported in wastewater treatment plant (WWTP) effluent, surface water, as well as tap water (Esplugas *et al.*, 2007; Luo *et al.*, 2014). EDC is defined by the Organization of Economic and Cooperative Development (OECD) as an exogenous substance or mixture that alters the function(s) of the endocrine systems and consequently causes adverse health effects in an intact organism or its progeny or (sub) populations (Esplugas *et al.*, 2007). However, compounds that should be classified as EDC remain to be adequately addressed (Kim *et al.*, 2007). Among some notable NEPs are bisphenol A (BPA), acetaminophene (ACTP), sulfamethoxazole (SMX) and ibuprofen (IBP). The molecular structures of the BPA, ACTP, SMX and IBP are shown in Figure 1.1.

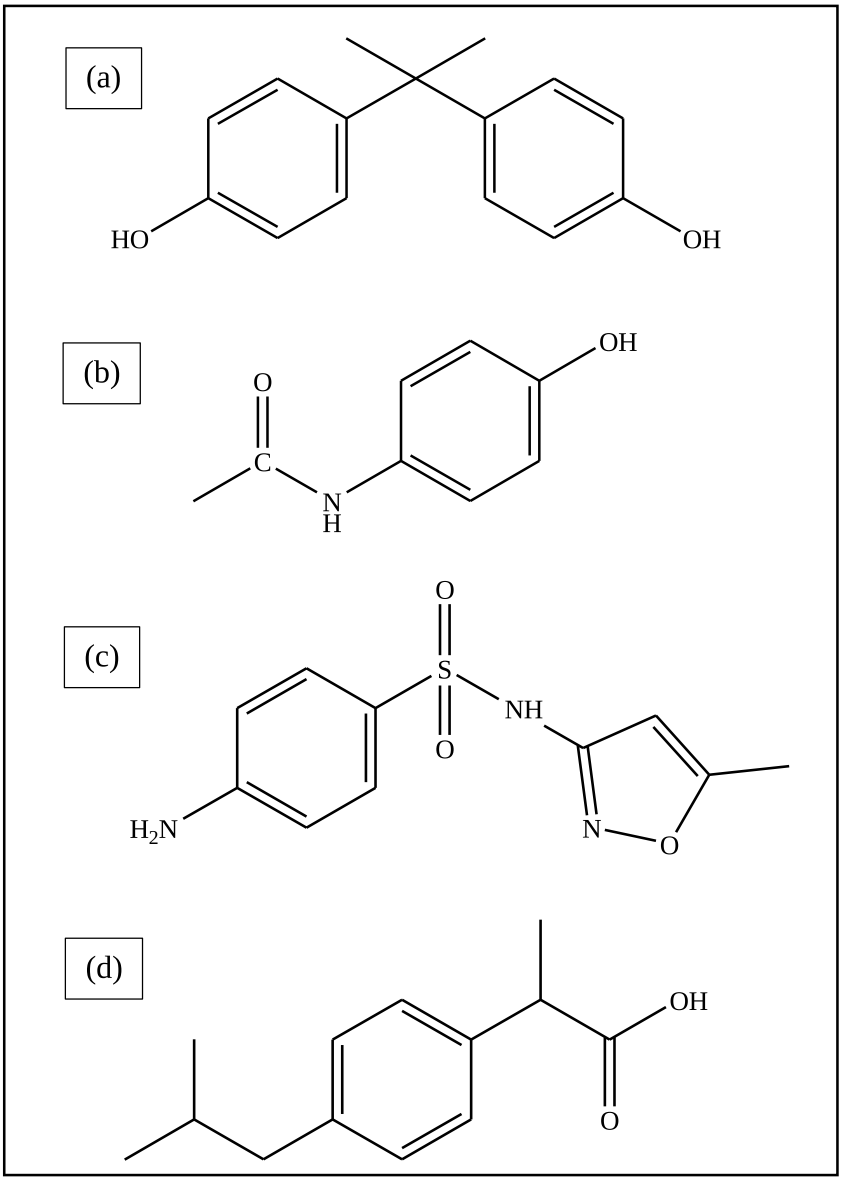

Figure 1.1 The molecular structures of NEP compounds, a) BPA, b) ACTP, c) SMX and d) IBP

It was reported that BPA had been detected in all tap water samples from houses in Kuala Lumpur (the source of water is located at the Langat River) at levels ranging from 3.5 to 59.8 ng/L (Santhi *et al.*, 2012). BPA is an estrogenic EDC widely used in producing polycarbonate, epoxy resins and as a non-polymer additive in plastics (Saal and Welshons, 2006). Another form of NEP is IBP, a non-steroidal anti-inflammatory drug (NSAID). It works by reducing hormones that cause inflammation and pain in the body and is used widely by arthritis patients (Choong *et al.*, 2019). IBP has been detected at concentrations of 72 ng/L in surface water (Palma *et al.*, 2020). SMX is a sulfonamide antibiotic commonly used in human, aquaculture and livestock breeding. SMX is categorised as a pharmaceutically-active compound with its half-life found to be between 85 to 100 days (Chang *et al.*, 2019). A literature search showed that SMX compounds were found in tap drinking water of residential areas in Putrajaya and Kajang, Malaysia, with concentrations of 0.16 and 0.23 ng/L, respectively (Praveena *et al.*, 2019; Nasir *et al*., 2019). Another commonly used NSAID is ACTP, a widely used NSAID to treat headaches, fever and chronic pain from cancer (Periyasamy and Muthuchamy, 2018). About 58 to 68% of ACTP is excreted from the human body through urine after therapeutic use (Slamani *et al.*, 2018). ACTP has been reported to be found in the surface water of Brisbane River, Australia, with a concentration of 6 ng/L (Anim *et al.*, 2020). ACTP with a concentration of 6.2 ng/L has also been detected in tap drinking water even after undergoing conventional treatment (Wang *et al.*, 2011).

The presence of EDCs in the environment can lead to the breakage of eggs of birds, fishes and turtles; feminisation of male fish; deteriorate reproductive system in fishes, reptiles, birds and mammals; and affect the immunologic system of marine mammals (Esplugas *et al.*, 2007). Furthermore, the presence of EDC in human beings is reported to cause a reduction of the amount of sperm, increase the incidence of breast, testicle and prostate cancers (Esplugas *et al.*, 2007). Xu *et al.* (2019) state that some PPCPs and pesticides at the ng/L to µg/L levels are potentially harmful to the ecological environment and human health, such as carcinogenicity, teratogenicity, mutagenicity, endocrine-disrupting effects and reproductive developmental toxicity. More alarmingly, PPCPs may induce various physiological changes, reversible or not, in non-target aquatic organisms such as macroalgae, molluscs, crustaceans and fish in the marine environment (Palma *et al.*, 2020).

A number of researchers had proposed a variety of conventional and advanced treatment processes in order to reduce the concentration of NEPs in water. The suggested conventional treatment processes include flocculation (Kooijiman *et al.*, 2020), sand filtration (Sabogal *et al.*, 2020), coagulation and sedimentation (Lin *et al.*, 2016) and filtration and chlorination (Azzouz and Ballesteros, 2013). In addition, many researchers suggest advanced treatments such as activated carbon (powdered activated carbon, PAC or granular activated carbon, GAC) (Rossner *et al.*, 2009; Acero *et al.*, 2012), oxidation (Azuma *et al.*, 2019; Lin *et al.*, 2016), NF (Escalona *et al.*, 2014) and RO (Yuksel *et al.*, 2013).

However, the presence of NEPs residue in wastewater effluents, surface water and drinking water can still be detected even after being subjected to the aforementioned conventional treatment methods. This is because the current technology in sewage treatment plants (STPs) are not designed to eliminate all the NEPs completely (Nasir *et al.*, 2019). In Malaysia, this has been proven by a few researchers, who reported the presence of NEPs in wastewater, surface water and drinking water such as ACTP (Al-Odaini *et al.*, 2010), SMX (Praveena *et al.*, 2018; Nasir *et al.*, 2019; Praveena *et al.*, 2019) and BPA (Santhi *et al.*, 2012).

On the other hand, a few researchers have explored the use of advanced technologies such as ozonation, adsorption by activated carbon and pressure-driven membrane such as NF and RO (Azuma *et al*., 2019; Rossner *et al*., 2009; Escalona *et al*., 2014). Although ozonation is an effective technique to remove NEPs, it has the inherent hazardous tendency to produce toxic oxidation by-products such as assimilable organic carbon (AOC) and total aldehydes, which impair the sustainability of wild fish populations (Wert *et al.*, 2007; Stalter *et al.*, 2010). According to Stalter *et al.* (2010), ozonation should be followed by post-filtration with sand to adsorb the oxidation by-product, subsequently leading to higher operational costs. Furthermore, the main disadvantage of the activated carbon treatment stands in the difficulty of post-treatment disposal of used and contaminated carbon (Stalter *et al*., 2010).

The application of membrane possesses several vital attributes such as low energy consumption, no requirement of chemical substances to be added, the possibility to easily join membrane processes with other unit processes (hybrid processes) and the separation can be carried out in mild environmental conditions that make them very substantial in separation technology (Figoli *et al.*, 2010). In previous works of research, it has been demonstrated that the NEPs can be effectively adsorbed by using membrane technologies; examples of which include NF (Escalona *et al.*, 2014; Yuksel *et al.*, 2013), RO (Yuksel *et al.*, 2013) and microfiltration (MF) (Bing *et al.*, 2010). The membranes in those studies were provided by Dow Filmtec, GE Osmonics and Toray Corporation, respectively. Meanwhile, a few researchers had successfully fabricated membranes via the phase inversion method for NEPs adsorption (Wu *et al.*, 2016; Nasseri *et al.*, 2018). However, there are a few limitations that restrict the performance of these membranes.

For example, the operation of NF and RO requires high pressure and low permeate flux. Due to that, the procedure will limit the efficiency of the membrane, thus leading to higher costs of operation (Nghiem *et al.*, 2006; Kimura *et al.*, 2003; Yuksel *et al.*, 2013; Escalona *et al.*, 2014). According to their studies, the permeate flux produced was low since the NF and RO membranes have a tighter structure that will increase the flow resistance of the solution across the membranes. Meanwhile, a few researchers reported that the small particulates presented in the MF membrane could adsorb, accumulate, or precipitate within or on the membrane polymer, which will lead to membrane fouling (He and Vidiv, 2016; Park *et al.*, 2020). Fouling in the MF membrane will cause a more severe permeate flux decline due to the formation of a thick and compressed cake layer on the surface of the membrane. To reduce the MF membrane fouling, the integration of nanoparticles (NPs) into polymeric membranes via phase inversion is one of the proposed methods (Akbari *et al*., 2018). However, the performance of this method is limited due to the low dispersion and agglomeration of the NPs in polymeric membranes.

One of the techniques to fabricate membranes for the adsorption of NEPs is the electrospinning method. The electrospun fibre membranes (EFMs) possess several attributes that make them very attractive in separation technology, such as high porosity, interconnected open pore structure ranging from sub-micron to several micrometres and high permeability for pure water and micro-particles (Gopal *et al.*, 2017; Zahari *et al.*, 2018). The electrospinning technique is a well-known process to produce novel fibres with diameters in the range of from less than 3 nm to over 1000 nm (Renekar *et al*., 2000). The nano-prefix is applied to a material having dimensions ranging from less than 100 to 800 nm (Wong *et al*., 2017). However, a previous researcher mentioned that around 100 fabricated nanofibres from different polymers using the electrospinning process having a diameter ranging from 40 to 2000 nm (Awal *et al*., 2011).

Among the materials that are suitable to be for the preparation of EFMs are nylon 6, 6 (Ny), polysulfone (PSf) and polystyrene (PSty). Ny has played an essential role in several applications due to its intrinsic hydrophilicity, good mechanical properties, outstanding durability, chemical and abrasion resistance, high thermal stability and enhanced electrochemical properties (Choi *et al.*, 2010; Palazzetti *et al.*, 2013; Huang and McCutcheon, 2014; Yanilmaz *et al.*, 2014). As for PSf, it is commonly fabricated as a nanofibre membrane due to its excellent mechanical strength, chemical resistance, thermal and hydraulic stability (Obaid *et al.*, 2015). Meanwhile, PSty is most commonly used as a commodity polymer in packaging, insulation and filtration (Uyar and Besenbacher, 2008). For filtration application, PSty is a promising membrane material due to its excellent characteristics such as being cost-friendly, good chemical inertia, high hydraulic stability, easy to handle and superhydrophobic behaviour (Moatmed *et al.*, 2019).

In this work, Ny, PSf and PSty EFMs were fabricated by using the electrospinning method. During the fabrication process of EFMs, the electrospinning parameters such as applied voltage, needle size and flow rate of polymer solution were optimised. The fabricated EFMs were then characterised by field emission scanning electron microscopy-energy dispersive X-ray (FESEM-EDX), contact angle analyser, tensile strength tester, zeta potential analyser and fourier transform infrared spectroscopy (FTIR) to measure the chemical and physical properties. The efficiency of the fabricated EFMs was evaluated through NEPs adsorption, wherein the targeted

NEPs were BPA, ACTP, SMX and IBP. The sample solution was then analysed by using high-performance liquid chromatography (HPLC).

1.2 Problem Statement

Numerous researchers reported that NEPs such as BPA, SMX and IBP could be found in wastewater, surface water, as well as our drinking water (Al-Odaini *et al.*, 2010; Praveena *et al.*, 2018; Nasir *et al.*, 2019; Praveena *et al.*, 2019; Santhi *et al.*, 2012). This is a clear indication that the current WWTP and drinking water treatment plant (DWTP) in Malaysia are not designed for the adsorption of NEPs. The situation is worsened by the lack of specific policy or regulations, including the permissible level dedicated to NEPs in the National Water Quality Standards for Malaysia.

To address this issue, a few researchers proposed pressure-based membrane processes; NF, RO and MF. One of the advantages of the NF and RO is the possession of a very tight structure of membranes that can potentially adsorb NEPs. However, the performance of these technologies is limited due to several factors, such as the high-pressure requirement and low permeate flux production, leading to high operational costs. These issues were highlighted in a few studies, where commercial NF and RO membranes were utilised for the adsorption of NEPs. The applied pressure during the filtration process was recorded at 6 to 12 bar, while the permeate flux produced was low, at 0.9 to 77 L/m^{2}h (Escalona *et al.*, 2014; Yuksel *et al.*, 2013; Kimura *et al.*, 2003; Nghiem *et al.*, 2006). Additionally, the application of MF water treatment is also limited by membrane fouling (He and Vidiv, 2016; Park *et al.*, 2020). Meanwhile, the fabrication of NP-polymeric MF membrane via the phase inversion method is restricted due to low dispersion and NPs exhibiting lower stability in the polymer matrix that will impact the membrane performance (Akbari *et al.*, 2018).

In this study, EFMs from materials such as Ny, PSf and PSty were fabricated by using the electrospinning method. Based on the literature, the fabricated EFMs possess a loose structure of membrane that could be confirmed through FESEM images. The reported literature mentioned that the fabricated EFMs that have loose structures could produce high permeate flux, even at the low pressure of 1 bar (Aussawasathien *et al*., 2008). Furthermore, the Ny EFM that contain carbonyl and amine group probably could form hydrogen bonding with the NEPs, thus facilitating the NEPs adsorption. Meanwhile, PSf and PSty are also hydrophobic membranes, which will further enhance permeate flux.

1.3 Objective of Research

The objectives of this research were:

a) To fabricate Ny, PSf and PSty based EFMs by using the electrospinning method and investigate the physical and chemical properties of the EFMs produced using optimised parameters.
b) To evaluate the efficiency of the fabricated Ny EFMs in the BPA, ACTP, SMX and IBP adsorption.
c) To evaluate the efficiency of the fabricated composites of Ny+PSf and Ny+PSty EFMs in the BPA adsorption.

1.4 Scope of Research

In this research, three different EFMs, namely Ny, PSf and PSty, were fabricated using the electrospinning method. During the preparation of EFMs, the operational conditions of the electrospinning process, such as applied voltage, flow rate of polymer solution and inner diameter of the needle, were optimised. The optimisation of the applied voltage was varied in the ranges of 1 to 26, 1 to 15 and 1 to 16 kV for Ny, PSf and PSty EFMs, respectively. Meanwhile, the optimisation of flow rate was carried out by varying from 0.1 to 0.4, 0.1 to 2.5 and 0.1 to 1.6 mL/h for Ny, PSf and PSty EFMs, respectively. Furthermore, the optimisation for the inner diameter of the needle was carried out by varying at 0.45, 0.5 and 0.6 mm for Ny, PSf and PSty EFMs.

The morphology, fibre diameter and elements of the EFMs were studied by utilising FESEM-EDX, while the water contact angle was measured to evaluate the hydrophobicity of the EFMs. The mechanical strength of the EFMs was assessed by using a tensile strength tester. The zeta potential analyser was used to study the steaming potential of the EFMs and the functional groups of the EFMs were determined by using FTIR. Since the physical and chemical properties for each Ny, PSf and PSty EFMs have been characterized, and very likely bear the same properties as the composites of Ny+PSf and Ny+PSty EFMs, the characterization for both composites of EFMs was not performed as part of the study. Meanwhile, all the fabricated EFMs are classified as microfiltration membranes since they have pore sizes ranging from sub-micron to several micrometres (Gopal *et al*., 2007). Since the EFM are well known for having larger and high porosity, the porosity analysis was not carried out as part of a study. Furthermore, the performance of composite between PSf and PSty EFMs was not evaluated as part of the study. This is due to the fact that both EFMs possess a hydrophobic character and probably give higher pure water flux. Higher pure water flux is a desirable characteristic; however, this behavior probably limits the occurrence of NEPs adsorption.

The efficiency of the fabricated EFMs was evaluated through pure water flux and NEPs adsorption measurement. The pure water flux was measured by using one, three, five and eight layers of EFMs through the filtration process. Then, the fabricated one, three, five and eight layers of Ny EFM was evaluated through the adsorption of BPA, ACTP, SMX and IBP in UPW with a concentration of 5 ppm by using a permeation cell. In order to improve the pure water flux, one layer of PSf or PSty EFM was composited with 5 layers of Ny EFM. Furthermore, the composite of 5 layers of Ny + 1 layer of PSf (Ny+PSf) and 5 layers of Ny + 1 layer of PSty (Ny+PSty) EFMs were proceeded for BPA adsorption and undergone membrane regeneration and reusability with three cycles of adsorption. Following that, the composite of Ny+PSf EFM was applied for BPA adsorption in tap water. The sample solution was analysed by using HPLC.

1.5 Significance of Study

The development of Ny, PSf and PSty EFMs, which have the capability to remove NEPs, are proposed as a new technology of advanced water treatment process in removing the contaminants from drinking water samples. The introducing of this new technology will yield high removal of NEPs as well as high water flux at low pressure. This is crucial as the presence of NEPs in surface water, WWTP effluent, and drinking water have been extensively reported in Malaysia. Therefore, the implementation of effective technology is projected to provide safe drinking water, particularly for Malaysia. The success of this research will indirectly create a higher recognition of Malaysia's water research activities and institutes.

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