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The effect of Sodium Dodecyl Sulfate on Polysulfone membrane for Pb (II) ions removal in an aqueous solution

[1]Nurul Qistina Ismail, [1*]Abdul Hafidz Yusoff, [1]Noor Fazliani Shoparwe, [2]Nur Nabihah Yusof, [3]Muhammad Noorazlan, [1]Nadiah Ameram, [4]Mohammad M. Fares

[1] Universiti Malaysia Kelantan, Jeli 17600, Kelantan, Malaysia
[2] School of Physics, Universiti Sains Malaysia, 11800 USM, Penang, Malaysia
[3] University Pendidikan Sultan Idris, 35900 Tanjong Malim, Perak, Malaysia
[4] Jordan University of Science & Technology, P.O. Box 3030, 22110, Irbid, Jordan

** Corresponding author email: hafidz.y@umk.edu.my*

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ABSTRACT

An unsustainable level of contamination increase is driven by industrialization, population growth and growth in developing countries. Contamination of heavy metal ions in wastewater such as Pb (II) are non-biodegradable and poses a serious threat to human health and other living things. One of the major methods for treating heavy metals contamination is by chemical precipitation. However, it produced hazardous sludge that requires further treatment and used a significant quantity of chemicals during the heavy metals treatment process due to its low impact on the environment. As a result, a membrane filtration method as an alternative treatment for treating heavy metals in wastewater has been investigated. In this study, the membranes were fabricated using the wet phase inversion method approach by incorporating polysulfone (PSF) polymer with dimethylacetamide (solvent) and inclusion of different concentrations of sodium dodecyl sulfate (SDS) (M1= 0 wt%, M2= 0.5 wt%, M3= 1.0 wt%, M4= 1.5 wt%, M5= 2.0 wt%). The fabricated membranes were tested to remove 50 mg/L Pb (II) ions in aqueous solution. Scanning electron microscopy (SEM) was used to investigate the morphological structures of membranes. Moreover, the structural characteristics of fabricated membranes were evaluated according to these parameters; contact angle, porosity and mean pores radius. Furthermore, the performance of the membrane was also evaluated for permeation and rejection flux by using dead-end cell filtration. The results indicate that the M4 membrane with 1.5 wt% SDS had the highest rejection rate (90.52%) for Pb (II) ions. This is likely due to the presence of macrovoids and a porous structure, as shown by SEM analyses. Other supporting evidence includes a lower contact angle (63.91°), higher water uptake (43.58%), higher porosity (85.21%), and a lower mean pore radius (6 nm) for the M4 membrane. The fouling mechanism model suggests that the complete blocking observed in the experimental data indicates that porous blockage occurred on the membrane's surface during the absorption of Pb (II) ions. In conclusion, compared to the pure membrane, it becomes evident that the addition of SDS into the membrane solution enhanced the properties of the membranes. The M4 membrane with a composition of 1.5 wt% concentration SDS demonstrated optimal filtration for removing Pb (II) ions in a water treatment process due to excellent properties mentioned above.

Keywords: polysulfone; sodium dodecyl sulfate; lead; membrane filtration; phase inversion.

Information about authors:

Nurul Qistina Ismail — *Postgraduate Students at Gold, Rare Earth and Material Technopreneurship Centre (GREAT), Faculty of Bioengineering and Technology, Universiti Malaysia Kelantan, 17600 UMK kampus Jeli, Kelantan. Email: nurulqistinaa98@gmail.com*

Abdul Hafidz Yusoff — *Associate Professor at Gold, Rare Earth and Material Technopreneurship Centre (GREAT), Faculty of Bioengineering and Technology, Universiti Malaysia Kelantan, 17600 UMK kampus Jeli, Kelantan. Email: hafidz.y@umk.edu.mu*

Noor Fazliani Shoparwe — *Dr. Gold, Rare Earth and Material Technopreneurship Centre (GREAT), Faculty of Bioengineering and Technology, Universiti Malaysia Kelantan, 17600 UMK kampus Jeli, Kelantan. Email: fazliani.s@umk.edu.my*

Nur Nabihah Yusof — *Dr., School of Physics, Universiti Sains Malaysia, 11800 USM, Penang, Malaysia. Email: nurnabihah7@usm.my*

Muhammad Noorazlan — *Dr., Physics Department, Faculty of Science and Mathematics, Universiti Pendidikan Sultan Idris, Tanjung Malim, Perak, 35900, Malaysia. Email: azlanmn@fsmt.upsi.edu.my*

Nadiah Ameram — *Dr, Gold, Rare Earth and Material Technopreneurship Centre (GREAT), Faculty of Bioengineering and Technology, Universiti Malaysia Kelantan, 17600 UMK kampus Jeli, Kelantan. Email: nadiah@umk.edu.my*

Mohammad, M. Fares — *Professor, Department of Applied Chemistry, Jordan University of Science & Technology, P.O. Box 3030, 22110, Irbid, Jordan. Email: fares@just.edu.jo*

Introduction

The aquatic species that are harmed by the hazardous contaminant discharged in wastewater can make ordinary waterways unsuitable for drinkable water sources. The heavy metals that contaminate water supplies are harmful to humans and other living things [[1], [2]]. In this paper, we are focusing on removal of heavy metals contamination in synthetic wastewater.

The majority of heavy metals contamination comes from industrial effluent, including from mining, metal finishing, fertilizer production, electroplating and petroleum refineries [[1], [2], [3]]. The example for heavy metals are arsenic, cobalt, chromium, copper, nickel, lead, titanium, strontium and mercury. Even at low metal ion concentrations, almost all heavy metals are harmful to humans a living thing. Excessive exposure to heavy metals may cause a variety of diseases such as osteoporosis, cardiovascular problems, and gastrointestinal and renal toxicity [4]. Additionally, these heavy metals are nonbiodegradable, which makes them more challenging to remove from water surfaces. Therefore, the measurement and understanding to control the heavy metals contamination in wastewater are essential.

Chemical precipitation is a common method for treating water. However, this method created a significant volume of hazardous sludge that needed to be treated later and required the application of several chemicals for their treatment before they could be properly disposed [[5], [6], [7]]. Therefore, a focus is being placed on an innovative membrane filtering technology treatment since it offers a sustainable and low-energy process for removing Pb (II) ions.

The primary structural chain of polysulfone (PSF) is mostly made up of benzene rings connected by sulfonyl (-SO2-), ether (-O-) and isopropylidene (-C(CH3)2-) groups [8]. The researchers are interested in PSF polymeric membranes because of their exceptional stability, high mechanical strength and excellent thermal properties [[8], [9]]. However, the PSF membrane's hydrophobic characteristics affect a number of its potential and make it less effective in the water purification process [[8], [10], [11]]. Furthermore, PSF membranes have minimal water flow and can significantly increase membrane fouling because of their hydrophobicity [[12], [13], [14]]. Hence, to improve the hydrophilicity feature in PSF membrane, it is crucial to amend hydrophilicity modification [[15], [16], [17]]. Therefore, the inclusion of PEG as a hydrophilic inorganic nanomaterial was used as an additives.

In this study, we aimed to enhance the ability of the PSF membrane by altering the surface of PSF with SDS anionic surfactant to have better removal of Pb (II) ions. Due to the existence of hydrophobic interactions, it should be highlighted that the alkyl chain of the surfactant is a significant feature that substantially determines the adsorption behaviour and the structure of the adsorbed layer [[18], [19]]. The amphiphilic nature of SDS surfactant allows it to aggregate and form micelles at a certain concentration (referred to as the critical micelle concentration (CMC)) as well as to adsorb at interfaces of polymer chains and modify their characteristics [20]. SDS surfactant is used in remediation technologies based on the aforementioned strengths. Specifically, the capacity to assemble at interfaces promotes the desorption and mobility of contaminants, whereas their ability to micellize and incorporate the contaminants into aggregations makes it much easier to remove and further separate contaminants that have been trapped inside micelles [[21], [22]].

To preserve river ecosystems and ensure the long-term survival of both human and aquatic life, a sustainable wastewater treatment process using membrane filtration is suggested in this study. This research used PSF as polymeric membrane mixes with different concentrations of SDS (0.5, 1.0, 1.5, 2.0 wt%) in preparation of membrane dope solution via phase inversion method. This study aims to investigate the influence of SDS as an ionic surfactant in developing the morphology properties and performance of the membranes.

Experimental part

2.1. Material

The polysulfone (PSF) ($C_{27}H_{24}Cl_2O_4S$), polyethylene glycol (PEG) ($C_{2n}H_{4n+2}O_{n+1}$) and sodium dodecyl sulfate (SDS) ($CH_3(CH_2)_{11}OSO_3Na$) were purchased from Sigma-Aldrich (United States, American). Dimethylacetamide (DMAc) (C_4H_9NO) and lead nitrate ($(PbNO_2)_3$) were from Merck (Selangor, Malaysia) and distilled water.

2.2. Fabrication of PSF/GO membrane

The wet phase inversion method was used to prepare the fabricated membrane solution. Table 1 is a summary of the dope solutions composition. The requisite amount of PEG was put into the media bottle containing DMAc solution and the mixture was agitated until homogenous at 60^oC before PSF

were added. The solution continues agitated for 8 hours. To verify there were no air bubbles in the mixed solution, the solution was left undisturbed at room temperature for at least 1 hour. The casting membrane was cast by feeding dope solution onto a casting blade with 250 m thickness. The solution then was drawn with a consistent pace on a glass plate. The glass plate containing the casting membrane was immersed in a coagulation batch containing distilled water overnight before cutting to a small circle size of 5x5 cm for storage.

Table 1 - Fabricated PSF membrane dope solution

Membrane		Composition (wt %)			
		PSF	***PEG***	***DMAc***	***SDS***
M1	PURE PSF	16	10	74	0
M2	SDS 0.5	16	10	73.5	0.5
M3	SDS 1.0	16	10	73	1.0
M4	SDS 1.5	16	10	72.5	1.5
M5	SDS 2.0	16	10	72	2.0

Notes: PSF=Polysulfone, PEG=Polyethylene glycol, DMAc= Dimethylacetamide, SDS= sodium dodecyl sulfate

2.3. Characterization of fabricated membrane

2.3.1. SEM analysis

SEM was employed by HITACHI TM3000 to examine the cross section of morphology membranes. The membranes were submerged into a nitrogen liquid to be frozen for 5 to 10 minutes. After being shattered, the membrane structure was preserved. At 10 and 25 kV, the images were captured under extremely high vacuum conditions.

2.3.2. Contact Angle

The hydrophilicity of the membrane was evaluated using contact angle goniometer. The membrane samples were placed on glass slide with double tape. The micro syringe was used to drop 10 µl of methylene blue solution onto the membrane surfaces at room temperature. Thereafter, the images of water droplet with membrane surface were analyses by ImageJ.JS images software [20].

2.3.3. Water uptake

The water uptake test was performed to evaluate the amount of water absorbed by fabricated membranes. The wet membranes were weighed using analytical balance before dried up in an oven at 60°C for 24 hours to measure dry membrane weight. The water uptake measurements of three membrane samples were averaged. Equation 1 below was used to calculate the water uptake of the samples [20];

$$\%\ uptake = \left(\frac{w_1 - w_2}{w_2}\right) \times 100 \qquad (1)$$

Where W_1 indicated the weight of wet state membrane (g) and W_2 indicated the weight of dry state membrane (g).

2.3.4. Porosity

An analytical balance was used to measure the wet weight while the membrane is wet. The dry membrane weight value was taken by drying a membrane in an oven for 24 hours at 60°C. An averaged value of three membrane samples were recorded. The following equation used to evaluate the porosity using the data taken [20];

$$Porosity, \varepsilon = \frac{\frac{w_1 - w_2}{\rho_w}}{\frac{w_1 - w_2}{\rho_w} + \frac{w_2}{\rho_m}} \times 100\% \qquad (2)$$

Where, W_1 indicated the weight of wet state membrane (g), W_2 indicated the weight of dry state membrane (g), ρ_w is the density of distilled water (0.998 g/mL) and ρ_m is the density of polymer (PSF = 1.24 g/mL)

2.3.5. Mean Pore Radius

The mean pore radius of the membranes is determined based on the membrane porosity and pure water flux values. The Guereout–Elford–Ferry equation was used to calculate the mean pore radius [20];

$$rm = \sqrt{\frac{(2.9 - 1.75\varepsilon) \times 8\eta l Q}{\varepsilon \times A \times \Delta P}} \qquad (3)$$

Where η is the water viscosity (8.9 x 10^{-4} Pa.s), l is the membrane thickness (m), Q is the volume of permeate water per unit time (m^3/s), A is the membrane area (m^2), and ΔP is the operational pressure (Pa).

2.4. Performance Studies for Humid Acid Removal

2.4.1. Permeation flux

This process was performed using a dead-end cell membrane module as shown in Figure 1. The membrane was cut 5x5 cm into a circle shape to fit in the flat sheet membrane separation unit. The procedure was done by passing feed through the membrane. The 2 bar pressure reservoir is used in the membrane. The permeation flux was calculated using the equation below [20];

$$J_w = \frac{V}{A \cdot \Delta t} \quad (4)$$

Where J_w is the pure water flux (PWF), V is the permeate volume, Δt is the permeate time (h) and A is the area of membrane (m^2).

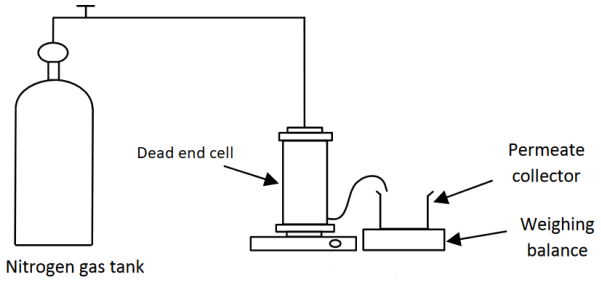

Figure 1 - Dead-end cell membrane module for permeation testing diagram.

2.4.2. Rejection test

For the rejection test, Pb (II) ions aqueous solution was used as a solute to analyse the solute rejection membranes. The permeate for Pb (II) ions was measured with Induced Coupled Plasma Optical Emission Spectroscopy (ICP-OES Agilent 1100) at 187 nm wavelength. The solute rejection is defined as [21];

$$\%R = \left(1 - \frac{C_\rho}{C_f}\right) \times 100 \quad (5)$$

Where, C_p is the Pb (II) ions concentration in the permeate and C_f is the Pb (II) ions concentration in the feed.

2.5. Fouling and kinetic studies

2.5.1 Fouling study

The fouling analysis of each membrane involves three stages. The first stage, lasting for 30 minutes, focuses on measuring the pure water flux ($JWF2$). The second stage involves aqueous filtration of Pb (II) ions, and the third stage, also lasting for 30 minutes, involves washing the membrane with distilled water ($JWF2$). The average values obtained after these three stages are measured and used to determine the membrane's fouling resistance. In this analysis, equations (6) and (7), as described by [20], are utilized to calculate the relative flux reduction (RFR) and fouling resistance ratio (FRR).

$$RFR\ (\%) = \left(1 - \frac{J_{TS}}{J_{WF}}\right) X\ 100\% \quad (6)$$

Where, RFR was relative flux reduction, J_{TS} was Pb (II) ions permeate flux and J_{WF} was the initial pure water flux.

$$FRR\ (\%) = \frac{J_{WF2}}{J_{WF}} X\ 100\% \quad (7)$$

Where FRR was the fouling resistance ratio and J_{WF2} was the pure water flux after the washing step.

2.5.2. Kinetic studies

Hermia's blocking models were utilized to analyze the experimental data and identify the predominant fouling mechanism in this filtration process. The fouling equations for complete blocking (8), standard blocking (9), intermediate blocking (10), and cake filtration (11) mechanisms are provided in Table 2.

Table 2 - Four types of fouling mechanisms and their equations

Fouling mechanism	Equations	
Complete blocking, b	$J = J_0 e^{-k_b t}$	(8)
Standard blocking, s	$J = \frac{J_0}{\left(1 + \frac{k_s J_0}{2} t\right)^2}$	(9)
Intermediate blocking, i	$J = \frac{J_0}{1 + k_i J_0 t}$	(10)
Cake filtration, c	$J = \frac{J_0}{\left(1 + 2k_C J_0^2 t\right)^{\frac{1}{2}}}$	(11)

Notes;
J_0 – initial flux,
t – time taken (min),
k – fouling parameter for each fouling mechanism

Results and Discussion

3.1. Characterization of PSF/SDS membrane

3.1.1. SEM analysis

Scanning electron microscopy was used to photograph membrane morphology. The membrane revealed as the concentration of SDS increases, the membrane morphology transformed to a thin skin layer, finger-like porous and macrovoids upon analysis of the cross-sectional structure membrane. As seen in Figure 2, the pure membrane, M1 has a thick dense layer and a sponge structure with few isolated close-end drop-like pores. In fabricated membranes, the M2 membrane with total 0.5 wt% of SDS concentration displayed the drop-like holes were displaced by irregular porous and larger macrovoids at the bottom of the cross-section

surfaces, yet, the sponge sections are still present. Moreover, finger-like structures that potentially increase water permeability emerged in the M3 membrane at the top layers and the larger macrovoid in the bottom layer. Furthermore, at membrane with concentrations 1.5 wt% and 2.0 wt% SDS (M4 and M5), the formation of a narrow finger-like structure became more elongated and had an enormous channel of macrovoids.

The interaction of PSF-SDS complex attributed to the suppresses in the development of finger like structure in the interlayer. In addition, the free micelles that may separate from polymer chains during the immersion process might result in enormous macrovoids inside the membrane structure. Moreover, the rapid demixing of the membrane solution leads to the creation of the porous structure with finger-like macrovoids while the delayed demixing of the membrane solution leads to the bicontinuous sponge-like structure. The slower rate exchange of solvent and nonsolvent during the phase inversion process leads to smaller pores and a spongy structure and more drop-like pores which can change the membrane permeability, in contrast to rapid exchange rate solvent and nonsolvent resulted in larger pores, more finger-like pores structures as well as more channel available.

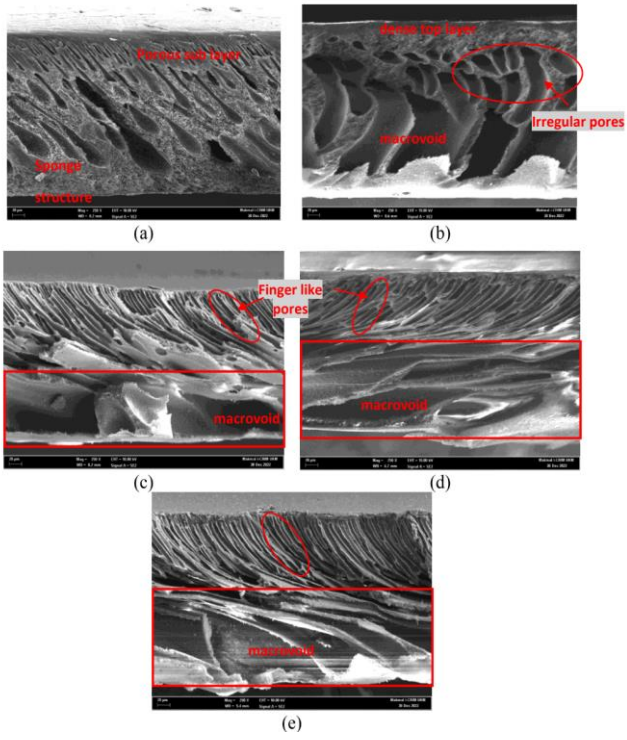

Figure 2 - The SEM analyses for cross-section (x250) morphology on fabricated membrane (**a**= pure PSF; **b**= 0.5 wt%; **c**= 1.0 wt%; **d**= 1.5 wt%; **e**= 2.0 wt%)

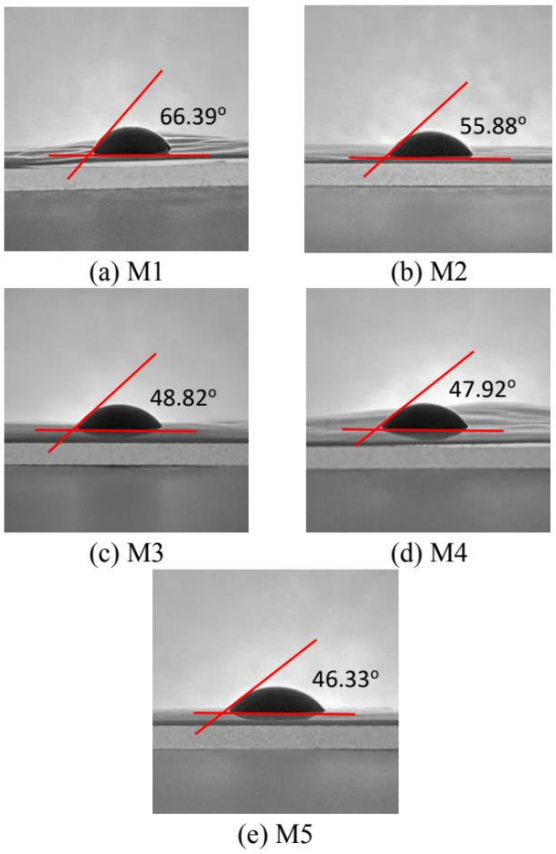

Figure 3 - The images of contact angle for all fabricated membranes (M1= pure PSF; M2= 0.5 wt%; M3= 1.0 wt%; M4= 1.5 wt%; M5= 2.0 wt%)

3.1.2. Physical evaluations on fabricated membranes

Table 3 summarizes the contact angle, porosity and mean pore radius of the fabricated membrane. The angle that forms between water droplets and membrane surfaces is known as contact angle. The membrane's hydrophilicity may be assessed by measuring contact angle. The membranes were referred to as hydrophilic if the contact angle measurement was >90° and vice versa [21]. Figure 3 shows the images of the contact angle for each fabricated membrane. Results show the pure membrane M1 had the highest value 66.39° of contact angle than other membranes which revealed the characteristic of PSF membrane as a hydrophobic polymer. Among the fabricated membranes, the M5 membrane with 2.0 wt% of SDS concentration has the lowest contact angle value of 46.33° which indicates that the membrane surface has the highest hydrophilicity. This result showed the addition of hydrophilic inorganic compound, PEG and hydrophilic surfactant, SDS giving an effect on the membrane surface properties. The O-H hydroxyl group facilitates the linkage of hydrogen

bonds between water molecules on the membrane surface, which increases the membrane hydrophilicity [[22], [23]]. The increment of SDS concentration causes the membrane surface to become more hydrophilic. Therefore, the overall contact angle for all the membranes was arranged in descending order M1> M2> M3> M4> M5 with value 66.39^{o}> 55.88^{o}> 48.82^{o}> 47.92^{o}> 46.33^{o}, respectively.

Studying water uptake is a dependable method to gain insights into the hydrophilic properties of a membrane. The level of hydrophilicity on the membrane surface greatly influences the amount of water absorbed and if the polymer contains macrovoids. The research findings indicate that an increase in SDS inclusion leads to higher water uptake by the membrane. Generally, measuring water uptake aligns with porosity. An increase in membrane porosity strongly suggests a corresponding increase in water uptake, indicating a greater hydrophilicity of the membrane surface.

The modification of membrane morphology was quantified by calculation of membrane porosity. The overall porosity value increased with an increase in SDS concentration. The porosity value for M1, M2, M3, M4 and M5 were 73.35%, 83.33%, 84.48%, 85.21% and 85.30%, respectively. According to the findings, the pure membrane M1 had a lower porosity value than other membranes treated with SDS. this demonstrated the inclusion of SDS modified the structure and morphology of the membrane. This conclusion has been proved by FESEM analysis that have been discussed in Figure 2 above.

Furthermore, the mean pore radius value for pure membrane (M1) was much smaller (3 nm) than the membrane containing SDS. This is due to the hydrophobic characteristic of polymeric PSF that enable the prevention of water to passing through the pure membrane and give effect on membrane permeability. Among the membranes treated with SDS, the pore size was improved with increasing SDS concentration to 1.0 wt%. However, the pore size started to decrease at 1.5 wt% concentration of SDS. This is because of the delay in demixing of solvent and non-solvent during the immersion phase due to the presence of the PSF/SDS complex which enhanced the finger-like structure in the sub-layer membrane. As a consequence, the pore size on the membrane surface decreases. Based on other study, the decreasing in membrane pore size enables in high rejection of solutes [20].

Table 3 - Summary of contact angle, water uptake, porosity and mean pore radius of fabricated membrane.

Membranes	Contact angle (^{o})	Water uptake (%)	Porosity (%)	Mean pore radius (nm)
M1	66.39	33.29	73.35 ± 0.09	3
M2	55.88	39.01	83.33 ± 0.09	8
M3	48.82	41.28	84.48 ± 0.04	10
M4	47.92	43.58	85.21 ± 0.15	6
M5	46.33	44.22	85.30 ± 0.07	7

Notes; M1= pure PSF, M2= 0.5 wt% of SDS, M3= 1.0 wt% of SDS, M4= 1.5 wt% of SDS, M5= 2.0 wt% of SDS.

3.2. Membrane performance studies

3.2.1. Permeation flux

Table 4 displays the summary of membrane performance on permeability testing. The comparison of permeation flux for pure water flux (PWF) and Pb (II) ions flux was also present in Table 4. The PWF was testing by dead-end cell filtration with 2 bar pressure in a nitrogen atmosphere. Results showed the PWF for pure membrane exhibited the lowest flux due to the hydrophobic characteristic of the polymer membrane. Among fabricated membranes, the PWF increased when the amount of SDS concentration increased at a total of 1.0 wt% SDS. However, the water flux rate appeared to deceases in the concentration of 1.5 wt% and 2.0 wt% SDS. Water flux rates can be arranged in descending order for all the membranes M3>M2>M5>M4>M1 with water flux rates 20.46>13.60>9.83>6.19>1.66 g/m^{2}h, respectively.

The increase of water flux after the addition of SDS in membrane dope solution is due to the hydrophilicity improvement on the fabricated membrane surface. Meanwhile, the decrease of water flux at SDS with high concentration can be related to the size of the mean pore radius on the membrane surface as shown in Table 4. The smaller pore size gives an effect on the lack of water flow permeating through the membrane at one time. According to FESEM analyses on the cross-section morphology that were shown in Figure 2, the images displayed the narrow finger like structure on M4 and M5 which indicated the reason for the permeability rates of water flux through the membrane.

The Pb (II) ions feed aqueous solution were tested at 2 bar pressure in a nitrogen atmosphere

and displayed a similar sequence with PWF flux. The pure PSF membrane has the lowest Pb (II) ions flux 1.61 g/m^{2}h, followed by M4< M5< M2< M3 with Pb (II) ions flux of 3.06< 9.13< 10.95< 19.88 g/m^{2}h, respectively. The addition of SDS to PSF membrane dope solution gives the formation of finger-like pores and macro-void structure on the morphology of the membrane. Hence, we can conclude the addition of SDS to the fabricated membrane increases membrane water flux better than the pure membrane, M1.

Table 4 - Summary of PWF, Pb (II) ions flux, Pb (II) ions concentration (ppm) and Pb (II) ions rejection after filtration process using dead end cell for fabricated membranes

Membrane	PWF flux (g/m²h)	Pb (II) ions flux (g/m²h)	Pb (II) ions concentration (ppm)	Pb (II) ions Rejection (%)
M1	1.66	1.61	44.72	10.56
M2	13.20	10.95	23.49	53.02
M3	20.46	19.88	26.63	46.74
M4	6.19	3.06	4.74	90.52
M5	9.83	9.13	11.24	77.52

Notes; PWF= Pure Water Flux, PB= Lead, M1= pure PSF, M2= 0.5 wt% of SDS, M3= 1.0 wt% of SDS, M4= 1.5 wt% of SDS, M5= 2.0 wt% of SDS.

3.2.2. Rejection

The Pb (II) ions rejection of fabricated membranes was shown in Figure 4. The membrane treated with SDS removed more Pb (II) ions compare to a pure membrane. Among the fabricated membrane, the rejection of Pb (II) ions increased when the amount of SDS concentration increased at a total of 1.5 wt% SDS (M4). However, after the SDS concentration is increases to 2.0 wt% (M5), the rejection of Pb (II) ions became slightly decreases. The M4 membrane had the maximum removal of 90.52% for Pb (II) rejection compared to other membranes even though it had a lower penetration flux. This is due to the production of the PSF-SDS complex and the deposition of the SDS polarisation layer that stops it from passing through the membrane [22]. Despite having a higher SDS concentration, the M5 membrane had lower Pb (II) removal than the M4 membrane. This is because, at 2.0 wt% of SDS concentration, the micelles deform close to the membrane surface, allowing metal ion-containing micelles to pass through the membrane and resulting in having a lower removal performance than the M4 membrane. The rejection of Pb (II) ions was followed by M1<M3<M2<M5<M4 with rejection values of 10.56<46.74<53.02<77.52<90.52 per cent rejection.

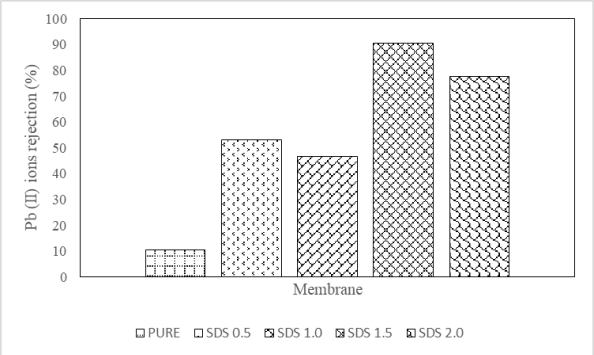

Figure 4 - The Pb (II) ions rejection for fabricated membranes (M1= pure PSF; M2= 0.5 wt%; M3= 1.0 wt%; M4= 1.5 wt%; M5= 2.0 wt%)

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3.3 Fouling and kinetic studies

3.3.1 Fouling studies

A study was conducted to examine membrane fouling, which is a drawback in membrane filtration. In this analysis, the reversible fouling ratio (RFR) and flux recovery ratio (FRR) were investigated. A higher RFR value indicated a larger accumulation of Pb (II) ions on the membrane surface, which then adsorbed onto the membrane pore [20]. Additionally, a lower FRR value indicated a higher susceptibility to membrane fouling. The fouling analysis of all the produced membranes is illustrated in Figure 5.

According to Figure 5, the membrane containing SDS has better resistance to fouling compared to the pure membrane. Among the membranes tested, the M4 membrane has the highest RFR value (33.57%), indicating a higher deposition of Pb (II) ions on its surface. Previous research has shown that membrane fouling can be influenced by factors such as surface morphology, roughness, and hydrophobicity [20]. Membranes with higher porosity are more prone to pore clogging, resulting in lower permeation flux and increased fouling. The RFR values for the M1, M2, M3, M4, and M5 membranes are approximately 55.20%, 13.00%, 14.46%, 33.57%, and 26.34%, respectively.

After thoroughly rinsing the membrane with distilled water, the secondary water flux was measured. The membrane's morphology can impact the FRR values, as the Pb (II) ions can easily get trapped on the membrane's surface and pores, making it difficult to clean the membrane. The FRR values for M1, M2, M3, M4, and M5 were 44.47%, 87.43%, 81.24%, 73.54%, and 72.96%, respectively. Except for the pure membrane, M1, the FRR values

were higher than the RFR values. This could be attributed to the formation of a micellar gel layer due to the increased SDS concentration. The adsorption of Pb (II) ions onto the SDS gel layer effectively removed the ions, while particle aggregation led to larger micelles and higher FRR levels [21].

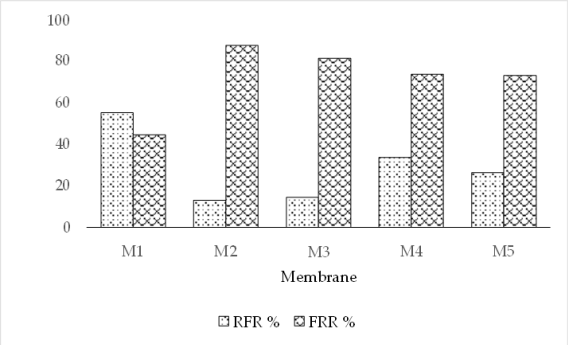

Figure 5 - Membrane fouling for reversible fouling ratio (RFR) and flux recovery ratio (FRR)

Conclusions

In this study, the PSF polymer membrane was fabricated with different concentrations of SDS (0.5 wt%, 1.0 wt%, 1.5 wt% and 2.0 wt%) and DMAc solvent. Our results suggest the addition of SDS into the membrane solution enhanced the properties of the membranes. The results show that fabricated M4 membrane with the addition of 1.5% of SDS had greater results for Pb (II) removal from aqueous solution with 90.52% rejection due to the presence of macrovoids and a porous structure, as shown by SEM analyses. In addition, the fouling mechanism model suggests that the complete blocking observed in the experimental data indicates that porous blockage occurred on the membrane's surface during the absorption of Pb (II) ions.

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Су ерітіндісінде Pb (II) иондарын жою үшін натрий додецил сульфатының полисульфонды мембранаға әсері

[1]Nurul Qistina Ismail, [1*]Abdul Hafidz Yusoff, [1]Noor Fazliani Shoparwe, [2]Nur Nabihah Yusof, [3]Muhammad Noorazlan, [1]Nadiah Ameram, [4]Mohammad, M. Fares

[1] Малайзия Келантан университеті, Джели 17600, Келантан, Малайзия
[2] Физика мектебі, Сайнс Малайзия Университеті, 11800 USM, Пенанг, Малайзия
[3] Пендикан Сұлтан Идрис университеті, 35900 Tanjong Malim, Перак, Малайзия
[4] Иордания ғылым және технология университеті, Ирбид, Иордания

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ТҮЙІНДЕМЕ

Ластану деңгейінің өсуіне индустрияландыру, халық санының өсуі және дамушы елдердегі даму себеп болады. Pb (II) сияқты ауыр металдар иондарымен ластанған ағынды сулар биологиялық ыдырамайды және адам денсаулығына және басқа да тіршілік иелеріне үлкен қауіп төндіреді. Ауыр металдармен ластанумен күресудің негізгі әдістерінің бірі химиялық тұндыру болып табылады. Дегенмен, бұл әдісті қолданғанда ары қарай өңдеуді қажет ететін қауіпті лай пайда болады. Қоршаған ортаға әсерінің төмен болуына байланысты ауыр металдарды өңдеу процесінде химиялық заттар көп пайдаланылады. Осыған байланысты ағынды сулардағы ауыр металдарды тазартудың балама әдісі ретінде мембраналық фильтрация әдісі зерттелді. Бұл зерттеуде мембраналар диметилацетамидпен (еріткіш) полисульфонды (ПСФ) полимерді және натрий додецил сульфатының (SDS) әртүрлі концентрациясын қосу арқылы ылғал фазалық инверсия әдісін қолдана отырып жасалды (M1 = 0 масса %, M2 = 0,5 масса %, M3= 1,0 масса %, M4= 1,5 масса %, M5= 2,0 масса %). Дайындалған мембраналар сулы ерітіндідегі 50 мг/л Pb (II) иондарын жою үшін сынақтан өтті. Сканерлеуші электронды микроскоп (SEM) мембраналардың морфологиялық құрылымдарын зерттеу үшін пайдаланылды. Сонымен қатар, дайындалған мембраналардың құрылымдық сипаттамалары – жанасу бұрышы, кеуектілік және орташа кеуектер радиусы сияқты параметрлерге сәйкес бағаланды. Сонымен қатар, мембрананың өнімділігі тұйық жасушаларды фильтрациялау арқылы өткізгіштік және қабылдамау ағыны бойыншада бағаланды. Нәтижелер салмағы 1,5% SDS бар M4 мембранасында Pb (II) иондары үшін ең жоғары қабылдамау жылдамдығы (90,52%) болатынын көрсетті. Бұл FESEM талдаулары көрсеткендей, макрооидтардың және кеуекті құрылымның болуына байланысты болуы мүмкін. Басқа растайтын дәлелдер төменгі жанасу бұрышын (63,91^0), жоғары суды сіңіруді (43,58%), жоғары кеуектілікті (85,21%) және M4 мембранасының төменгі орташа кеуек радиусын (6 нм) қамтиды. Ластану механизмінің моделі эксперименттік деректерде байқалған толық блоктаудың Pb (II) иондарын сіңіру кезінде мембрана бетінде кеуекті бітелу пайда болғанын көрсетеді. Қорытындылай келе, таза мембранамен салыстырғанда, мембраналық ерітіндіге SDS қосу мембраналардың қасиеттерін жақсартатыны анықталды. Құрамы салмағы 1,5% SDS концентрациясы бар M4 мембранасы жоғарыда айтылған қасиеттерге байланысты суды тазарту процесінде Pb (II) иондарын жою үшін оңтайлы фильтрлейтінін көрсетті.

Түйін сөздер: полисульфон, натрий додецил сульфаты, қорғасын, мембраналық фильтрация, фазалық инверсия.

Авторлар туралы ақпарат:

Nurul Qistina Ismail *Алтын, сирек жер және материалдық технологиялар орталығының магистрі (GREAT), биоинженерия және технология факультеті, Малайзия университеті Келантан, 17600 UMK kampus Jeli, Келантан. Email: nurulqistinaa98@gmail.com*

Abdul Hafidz Yusoff *Алтын, сирек жер және материалдық технология орталығының (GREAT) доценті, биоинженерия және технология факультеті, Малайзия университеті Келантан, 17600 UMK kampus Jeli, Келантан. Email: hafidz.y@umk.edu.mu*

Noor Fazliani Shoparwe *Доктор, Алтын, сирек жер және материалдық технология орталығы (GREAT), биоинженерия және технология факультеті, Малайзия университеті Келантан, 17600 UMK kampus Jeli, Келантан. Email: fazliani.s@umk.edu.my*

Nur Nabihah Yusof *Доктор, физика мектебі, Сайнс Малайзия Университеті, 11800 USM, Пенанг, Малайзия. Email: nurnabihah7@usm.my*

Muhammad Noorazlan *Доктор, Физика бөлімі, ғылым және математика факультеті, Университет Пендидикан Султан Идрис, Танжунг Малим, Перак, 35900, Малайзия. Email: azlanmn@fsmt.upsi.edu.my*

Nadiah Ameram *Доктор, Алтын, сирек жер және материалдық технология орталығы (GREAT), биоинженерия және технология факультеті, Малайзия университеті Келантан, 17600 UMK kampus Jeli, Келантан. Email: nadiah@umk.edu.my*

Mohammad, M. Fares *Иордания ғылым және технология университетінің қолданбалы химия кафедрасының профессоры, П.О. Қорап 3030, 22110, Ирбид, Иордания. Email: fares@just.edu.jo*

Влияние додецилсульфата натрия на полисульфоновую мембрану для удаления ионов Pb(II) в водном растворе

[1]Nurul Qistina Ismail, [1*]Abdul Hafidz Yusoff, [1]Noor Fazliani Shoparwe, [2]Nur Nabihah Yusof, [3]Muhammad Noorazlan, [1]Nadiah Ameram, [4]Mohammad M. Fares

[1] Университет Малайзии Келантан, Джели 17600, Келантан, Малайзия
[2] Школа физики, Университет Сайнс Малайзия, 11800 USM, Пенанг, Малайзия
[3] Университет Пендидикан Султан Идрис, 35900 Танджонг Малим, Перак, Малайзия
[4] Иорданский университет науки и технологий, Ирбид, Иордания

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АННОТАЦИЯ

Неустойчивый рост уровня загрязнения обусловлен индустриализацией, ростом населения и ростом развивающихся стран. Загрязнения сточных вод ионами тяжелых металлов, таких как Pb (II), не поддаются биоразложению и представляют серьезную угрозу для здоровья человека и других живых существ. Одним из основных методов борьбы с загрязнением тяжелыми металлами является химическое осаждение. Однако на нем образовывался опасный ил, требующий дальнейшей обработки, и использовалось значительное количество химикатов в процессе очистки от тяжелых металлов из-за его низкого воздействия на окружающую среду. В результате был исследован метод мембранной фильтрации как альтернативный метод очистки сточных вод от тяжелых металлов. В этом исследовании мембраны были изготовлены с использованием метода инверсии влажной фазы путем включения полимера полисульфона (PSF) с диметилацетамидом (растворителем) и включения различных концентраций додецилсульфата натрия (SDS) (M1 = 0 мас.%, M2 = 0,5 масс. %, M3= 1,0 масс. %, M4= 1,5 масс. %, M5= 2,0 масс. %. Изготовленные мембраны были протестированы на удаление 50 мг/л ионов Pb(II) в водном растворе. Сканирующую электронную микроскопию (СЭМ) использовали для исследования морфологической структуры мембран. Кроме того, по этим параметрам оценивались структурные характеристики изготовленных мембран; контактный угол, пористость и средний радиус пор. Кроме того, характеристики мембраны также оценивали по потоку проникновения и отторжения с использованием тупиковой клеточной фильтрации. Результаты показывают, что мембрана M4 с 1,5 мас.% ДСН имела самый высокий уровень отторжения (90,52%) ионов Pb (II). Вероятно, это связано с наличием макропустот и пористой структуры, как показали анализы FESEM. Другие подтверждающие данные включают меньший угол контакта (63,91°), более высокое поглощение воды (43,58%), более высокую пористость (85,21%) и более низкий средний радиус пор (6 нм) для мембраны M4. Модель механизма загрязнения предполагает, что полная блокировка, наблюдаемая в экспериментальных данных, свидетельствует о том, что закупорка пор произошла на поверхности мембраны при поглощении ионов Pb(II). В заключение, по сравнению с чистой мембраной становится очевидным, что добавление ДСН в раствор мембраны улучшило свойства мембран. Мембрана M4 с содержанием ДСН 1,5 мас.% продемонстрировала оптимальную фильтрацию для удаления ионов Pb(II) в процессе водоочистки благодаря отличным свойствам, упомянутым выше.

Ключевые слова: полисульфон, додецилсульфат натрия, вести, мембранная фильтрация, инверсия фазы.

Информация об авторах:

Nurul Qistina Ismail — *Магистр Центра технологического предпринимательства в области золота, редких земель и материалов (GREAT), факультета биоинженерии и технологий, Университет Малайзии Келантан, 17600 кампус UMK Джели, Келантан. Email: nurulqistinaa98@gmail.com*

Abdul Hafidz Yusoff — *Доцент Центра технологического предпринимательства в области золота, редких земель и материалов (GREAT), факультет биоинженерии и технологий, Университет Малайзии Келантан, 17600 UMK кампус Джели, Келантан. Email: hafidz.y@umk.edu.mu*

Noor Fazliani Shoparwe — *Доктор, Центр технологического предпринимательства редкоземельных металлов и материалов (GREAT), факультет биоинженерии и технологий, Университет Малайзии Келантан, 17600 UMK кампус Джели, Келантан. Email: fazliani.s@umk.edu.my*

Nur Nabihah Yusof — *Доктор философии, Школа физики, Университет Сайнс Малайзия, 11800 USM, Пенанг, Малайзия. Email: nurnabihah7@usm.my*

Muhammad Noorazlan — *Доктор физических наук, факультет естественных наук и математики, Пендидиканский университет Султана Идриса, Танджунг Малим, Перак, 35900, Малайзия. Email: azlanmn@fsmt.upsi.edu.my*

Nadiah Ameram — *Доктор, Центр технологического предпринимательства редкоземельных металлов и материалов (GREAT), факультет биоинженерии и технологий, Университет Малайзии Келантан, 17600 UMK кампус Джели, Келантан. Email: nadiah@umk.edu.my*

Mohammad, M. Fares — *Профессор кафедры прикладной химии Иорданского университета науки и технологий, П.О. Box 3030, 22110, Ирбид, Иордания. Email: fares@just.edu.jo*

References

[1] Singh J, Sharma M, and Basu S. Heavy metal ions adsorption and photodegradation of remazol black XP by iron oxide/silica monoliths: Kinetic and equilibrium modelling, Advance Powder Technology. 2018; 29(9):2268-2279. https://doi.org/10.1016/j.apt.2018.06.011

[2] Kolbasov A, Sinha-Ray S, Yarin A L, and Pourdeyhimi B. Heavy metal adsorption on solution-blown biopolymer nanofiber membranes, Journal Membrane Science. 2017; 530:250–263. https://doi.org/10.1016/j.memsci.2017.02.019

[3] Xu M, Hadi P, Chen G, and McKay G. Removal of cadmium ions from wastewater using innovative electronic waste-derived material, Journal Hazardous Material. 2014; 273:118-123. https://doi.org/10.1016/j.jhazmat.2014.03.037

[4] Vardhan K H, Kumar P S, and Panda R C. A review on heavy metal pollution, toxicity and remedial measures: Current trends and future perspectives, J. Mol. Liq. 2019; 290:111197. https://doi.org/10.1016/j.molliq.2019.111197

[5] Azimi A, Azari A, Rezakazemi M, and Ansarpour M. Removal of Heavy Metals from Industrial Wastewaters: A Review, ChemBioEng Rev. 2017; 4(1):37-59. https://doi.org/10.1002/cben.201600010

[6] Chaemiso T D. Removal Methods of Heavy Metals from Laboratory Wastewater, J. Nat. Sci. Res. 2019; 9(2):36-42. https://doi.org/10.7176/jnsr/9-2-04

[7] Chandra Joshi N, Sharma R, and Singh A. Biosorption: A Review on Heavy Metal Toxicity and Advances of Biosorption on Conventional Methods, J. Chem. Chem. Sci. 2017; 7(9):714-724. www.chemistry-journal.org

[8] Chukov D, Nematulloev S, Zadorozhnyy M, Tcherdyntsev V, Stepashkin A, and Zherebtsov D. Structure, mechanical and thermal properties of polyphenylene sulfide and polysulfone impregnated carbon fiber composites, Polymers (Basel). 2019; 11(4). https://doi.org/10.3390/polym11040684

[9] Abd Hamid S, Shahadat M, and Ismail S. Zeolite–polysulfone-based adsorptive membrane for removal of metal pollutants, Chem. Pap. 2021; 75(9):4479-4492. https://doi.org/10.1007/s11696-021-01668-x

[10] Shokri E, Yegani R, and Akbarzadeh A. Novel adsorptive mixed matrix membranes by embedding modified montmorillonite with arginine amino acid into polysulfones for As(V) removal, Appl. Clay Sci. 2017; 144:141-149. https://doi.org/10.1016/j.clay.2017.05.011

[11] Benkhaya S, et al. Polysulfone/Polyetherimide Ultrafiltration composite membranes constructed on a three-component Nylon-fiberglass-Nylon support for azo dyes removal: Experimental and molecular dynamics simulations, Colloids Surfaces A Physicochem. Eng. Asp. 2021; 625:126941. https://doi.org/10.1016/j.colsurfa.2021.126941

[12] Gao Y, Li B, Zhong L, Zhang L, and Ding Z. Effect of nano-amphiphilic cellulose as a modifier to PSf composite membranes, Vacuum. 2014; 107:199-203. https://doi.org/10.1016/j.vacuum.2014.01.029

[13] Ibrahim G P S. et al. Novel, one-step synthesis of zwitterionic polymer nanoparticles via distillation-precipitation polymerization and its application for dye removal membrane, Sci. Rep. 2017; 7(1):1-16. https://doi.org/10.1038/s41598-017-16131-9

[14] Ibrahim G P S. et al. Performance intensification of the polysulfone ultrafiltration membrane by blending with copolymer encompassing novel derivative of poly(styrene-co-maleic anhydride) for heavy metal removal from wastewater. Chem. Eng. J. 2018; 353:425-435. https://doi.org/10.1016/j.cej.2018.07.098

[15] Khajouei M, Najafi M, and Jafari S A. Development of ultrafiltration membrane via in-situ grafting of nano-GO/PSF with anti-biofouling properties, Chem. Eng. Res. Des. 2019; 142:34-43. https://doi.org/10.1016/j.cherd.2018.11.033

[16] Fainerman V B, Mobius D, and Miller R. Surfactants: Chemistry, Interfacial Properties, Applications. 2001.

[17] Mao X, Jiang R, Xiao W, and Yu J. Use of surfactants for the remediation of contaminated soils: A review, J. Hazard. Mater. 2015; 285:419-435. https://doi.org/10.1016/j.jhazmat.2014.12.009

[18] Fernández E, Benito J M, Pazos C, and Coca J. Ceramic membrane ultrafiltration of anionic and nonionic surfactant solutions, Journal Membrane Science. 2005; 246(1):1-6. https://doi.org/10.1016/j.memsci.2004.04.007

[19] Peyravi M, Rahimpour A, Jahanshahi M, Javadi A, and Shockravi A. Tailoring the surface properties of PES ultrafiltration membranes to reduce the fouling resistance using synthesized hydrophilic copolymer, Microporous Mesoporous Material. 2012; 160:114-125. https://doi.org/10.1016/j.micromeso.2012.04.036

[20] Shoparwe N F, Kee L C, Otitoju T A, Shukor H, Zainuddin N, and Makhtar M M Z. Removal of humic acid using 3-methacryloxypropyl trimethoxysilane functionalized MWCNT Loaded TiO_2/PES hybrid membrane, Membranes (Basel). 2021; 11(9):721. https://doi.org/10.3390/membranes11090721

[21] Ariono D, Khoiruddin, Prabandari D, Wulandari R, and Wenten I G. Preparation and characterization of polysulfone/PEG heterogeneous ion exchange membrane for reverse electrodialysis (RED), J. Phys. Conf. Ser. 2017; 877(1). https://doi.org/10.1088/1742-6596/877/1/012075

[22] Folgado E, Ladmiral V, and Semsarilar M. Towards permanent hydrophilic PVDF membranes. Amphiphilic PVDF-b-PEG-b-PVDF triblock copolymer as membrane additive, Eur. Polym. J. 2020; 131:109708. https://doi.org/10.1016/j.eurpolymj.2020.109708

[23] Toosi M R, Emami M R S, and Hajian S. Dynamic filtration and static adsorption of lead ions in aqueous solution by use of blended polysulfone membranes with nano size MCM-41 particles coated by polyaniline, Environ. Sci. Pollut. Res. 2018; 25(20):20217-20230. https://doi.org/10.1007/s11356-018-2236-3