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MEMBRANE FROM PLASTIC WASTE FOR THE TREATMENT OF CONTAMINATED RIVER WATER

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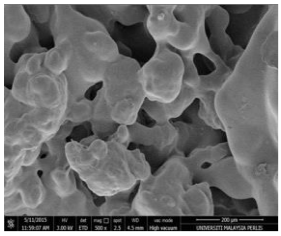
Graphical abstract



Abstract

Excessive plastic waste and river water pollution are both never ending environmental problems faced by every country around the world. In this paper, polymeric membrane was synthesized from plastic waste of high density polyethylene (HDPE) type to treat contaminated river water. The plastic waste was grinded into powder of different particle sizes before synthesizing the membrane by sintering method. The membranes were synthesized both with and without the addition of solvents. The heating temperature during membrane synthesis was also being study for membrane performance in terms of percentage of permeate rejection and permeate flux. HDPE membrane produced from average particle size of 270.7±178.6 µm achieved the highest permeate rejection and has highest heating temperature (180°C). Field Emission Scanning Electron Microscopic (FESEM) analysis showed that the sintered membranes exhibit a porous asymmetric structure. Meanwhile, Fourier Transform Infrared Spectroscopy (FTIR) analysis denote the HDPE membranes in grouped as alkanes and aromatics compounds.

Keywords: Plastic waste, particle sizes, heating temperature, permeate flux

1.0 INTRODUCTION

In present day, membrane separation is becoming a preferable technology in wastewater treatment due to its effectiveness in confiscating various contaminants, eases in operation and has high separation factor [1]. To date, commercially available membrane is costly for everyday use especially in developing country, which is one of the major factor that limit the membrane usage in the wastewater treatment. The need to find alternative materials and methods are the key for cost effective membrane to be materialized in Malaysia, Africa and other developing countries. In this research project, the synthesized membrane was produced from the recycle plastic waste and used for the treatment of contaminated river water.

River pollution is a major problems faced by most country in the world. Population growth especially alongside the river as well as urbanization and industrial activities are the major contributor to this problem [2]. Thus, there is a major concern for better water resource management which includes more effective water and wastewater treatment technologies. One of the promising technologies that should be considered is by using membrane to treat contaminated river water. Zhou and Smith (2002) clarify that membrane processes offer several advantages over conventional treatment processes such as reduce operation and maintenance cost, require no chemical addition for most circumstances, easy to control and occupy small amount of space [3].

This paper focuses on the synthesis of polymeric membrane originating from plastic waste of high density polyethylene (HDPE) type. According to Abdullah (2009), ceramic materials may have higher chemical and thermal stability compare to polymeric

materials [4]. However, the demand of polymeric membranes is far greater than ceramic membranes due to the fact that polymeric materials are easier to process and less expensive [5].

The objectives of this paper are to evaluate the membrane performance by determining the percentage of permeate rejection and permeate flux of contaminated river water using the synthesized HDPE membranes. In addition, we also study the effect of particle size and temperature on the synthesized membranes as well as the feasibility of plastic sintering method for the production of the synthesized membranes on membranes morphology.

2.0 METHODOLOGY

2.1 Preparation of Raw Materials from HDPE Plastic Waste

The HDPE plastic waste which comprised of detergent bottles, liquid soaps bottles, yogurt drinking bottles and plastic sauce bottles were collected from various area in Perlis including recreational area of Kuala Perlis beach, Uniciti Alam residential college of Universiti Malaysia Perlis (UniMAP), residential area (Taman Bukit Kubu, Kuala Perlis) and Sekolah Menengah Kebangsaan Syed Hassan, Perlis. The collected HDPE bottles were rinsed vigorously with water to remove any dirt and stains. The total weight of the clean HDPE bottles measured was approximately 10.5 kg.

2.2 Grinding of the HDPE Plastic Waste

The HDPE bottles were granulated by using plastic granulator. The HDPE granules produced from the plastic granulator was further grounded into the powder form by using an automatic continuous hammer mill herb grinder machine before the sintering process.

2.3 Sintering of the HDPE Powder

HDPE powder was subjected to a heating process below their melting points which is in the range of 120ºC-180ºC. The powder was heated on a hot plate until the adjacent powder particles adhere to one another. In this work, two different size fractions were selected; the first group was the heating of 2g HDPE powder with average particle size of 93.5±30.5 µm and the second group was the heating of 2.5 g HDPE powder with average particle size of 270.7±178.6 µm. Both groups were mixed with four different solvents (olive oil, cooking oil, water and ethylene glycol) and for control no solvents were added in the powder.

During sintering, the temperature was set to 100ºC and slowly increases to 10ºC for every 5 minutes until the HDPE powder start to melt. Once the powder melt, the temperature was maintained for another 10 minutes before the stopping the heating process. However, the temperature was maintained for 20 minutes after melting for water and ethylene glycol until a thin layer was formed. As both sides of the membrane were subjected for heating, the active side of the membrane was also being heated for 15 minutes before readily used for separation process.

2.4 Percentage of Rejection and Permeate Flux Determination

Surface water sample was collected from Sungai Seriab, Perlis at coordinates 6° 25' 7.073" N and 100° 10' 3.142" E. The turbidity (49.5 NTu) was measured in situ by turbidity meter. The filtration of river water using synthesized membrane was conducted by using vacuum pump filtration with the applied pressure of 0.85 bar (within microfiltration membranes pressure).

The synthesized membrane was cut accordingly to the ceramic filter funnel sized with diameter of 5 cm. A rubber was fitted at 0.5 cm of the membrane diameter around the very edge part of the membrane to prevent from leaking.

The feed volume of the river water sample was 100 ml and permeate was collected every 0.015 ml to measure its turbidity. To ensure the consistency of reading, turbidity readings were taken three times for each membrane. To determine the permeate flux, the volume of permeate was collected within one minute for every three times of turbidity reading taken. The percentage of permeate rejection was calculated by using the following formula:

$$[1 - (\text{Permeate turbidity, NTu}/\text{Feed turbidity, NTu})] \times 100\ \%$$

Permeate flux was determined in the formula below:

$$J = (dV/dt)/A.P$$

Where J is the permeate flux with the expressed unit of $L/m^2.bar.h$; dV/dt is permeate flow rate in L/h, A is an effective membrane area measured in m^2, and P represents the pressure of the membrane filtration in bar unit.

2.5 Morphology Analysis of the Membrane under FESEM

The highest permeate rejection percentage for membrane with average particle size of 93.5±30.5 µm and 270.7±178.6 µm were analyzed using the FESEM to study the morphological structure of the membrane. The top surface and cross-sectional view of the membranes was observed by FESEM under a high vacuum at 3 kV and at different magnifications (500 for top surface view and 5000 for cross-sectional view). The HDPE membrane was fractured under the liquid nitrogen for 15 seconds in order to preserve the cross sectional structure of the membranes. Subsequently, the HDPE membrane was sputtered coated with a thin metal layer (platinum) in order to

produce an electrical conductive surface and thus to prevent charging in the FESEM [6]

2.6. Fourier Transform Infrared Spectroscopy (FTIR) Analysis of the Membrane

The membrane selection for FTIR analysis was chose based on the HDPE membrane with the highest permeate rejection percentage. The FTIR analysis of the samples which expressed the wave numbers (cm -1) at the x-axis was used as the references to identify the functional groups and types of covalent bonding together with their vibrations (stretch, scissoring, bending or rocking) [7].

3.0 RESULTS AND DISCUSSION

3.1. Percentage of Permeate Rejection and Permeate Flux

Figure 1 and Figure 2 depicted the HDPE membranes performance in term of percentage of permeate rejection for both particle size of 93.5±30.5 µm and 270.7±178.6 µm. The highest percentage of permeate rejection for both particle size groups membranes were without any solvent addition. The HDPE membrane (without solvent) with the highest percentage of permeate rejection gained the lowest permeate flux (Figure 3 and Figure 4) due to the high quantity of trapped materials on the membrane active layer. Consequently, the pore size of the membrane became smaller and narrower and the height of filter cake (trapped materials) proportionally increase to the filtration period, resulting in a decrease in permeate flux and increase on permeate separations [8]. The fouling effect of the membrane cause the flux to decline rapidly, and thus the efficiency of the membrane would also decline with the degeneration of permeate flux [9].

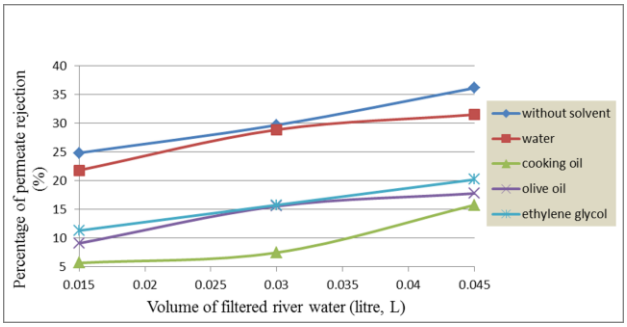


Figure 1 Percentage of permeate rejection for average particle size of 93.5±30.5 µm

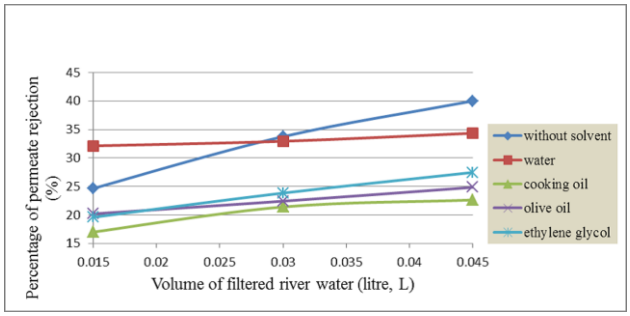


Figure 2 Percentage of permeate rejection for average particle size of 270.7±178.6 µm

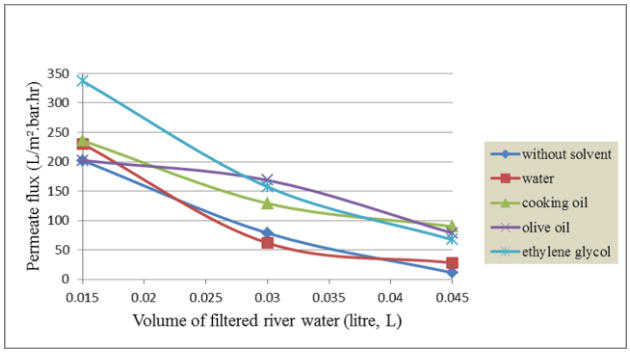


Figure 3 Permeate flux (L/m².bar.hr) for average particle size of 93.5±30.5 µm

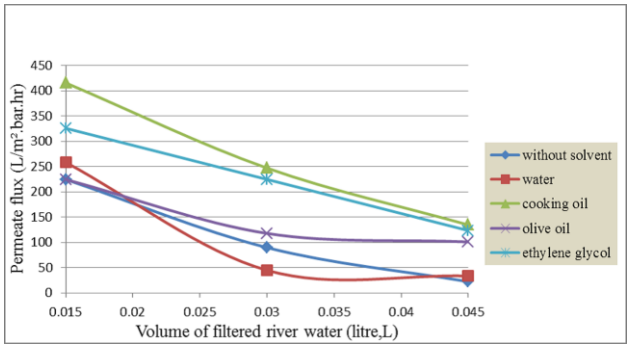


Figure 4 Permeate flux (L/m².bar.hr) for average particle size of 270.7±178.6 µm

3.2 Effect of HDPE Particle Size and Temperature on the HDPE Membranes Performance

Table 1 and Table 2 show the heating temperatures and period for HDPE membranes production at different f sizes and different conditions (with and without solvents). For HDPE powder sintering with average particle size of 93.5±30.5 µm, the lowest heating temperatures and the least time for membranes production were achieved when cooking oil was added to the powder. The mixture of HDPE powder with water and ethylene glycol gave the highest heating temperature and the longest time for membranes production.

Table 1 Heating temperatures and period of HDPE membranes production for average particle size of 93.5±30.5 µm

Type of Solvents	Temperatures (°C)	HDPE Membranes Production (min)
Without solvent	170	85
Water	180	95
Cooking oil	160	70
Olive oil	170	85
Ethylene glycol	180	95

Table 2 Heating temperatures and period of HDPE membranes production for average particle size of 270.7±178.6 µm

Type of Solvents	Temperatures (°C)	HDPE Membranes Production (min)
Without solvent	180	90
Water	180	100
Cooking oil	170	85
Olive oil	180	90
Ethylene glycol	180	100

HDPE membrane with combination average particle size of 270.7±178.6 µm, shows that cooking oil as a solvent gave the lowest heating temperature and the shortest duration for membrane production. On the other hand, HDPE membrane with solvents (ethylene glycol, water and olive oil) and without use of solvent gave the highest heating temperature (180°C).

The heating temperature for HDPE membrane of both average particle sizes (93.5±30.5 µm and 270.7±178.6 µm) for ethylene glycol and water remain unchanged, but based on the membrane production period, both recorded the longest time of 100 minutes since the HDPE powder only started to melt at temperature of 190°C for average particle size of 93.5±30.5 µm and 200°C for average particle size of 270.7±178.6 µm. High sintering temperature could led to the rise of surface resistance and also increase the shrinkage of the membrane from 16 % to 20 % of the sintering temperature [10].

The use of HDPE powder with average particle size of 270.7±178.6 µm resulted in better separation compared to average particle size of 93.5±30.5 µm alone. Particle size study by Basile (2013) mention that the narrower the particle size distribution, the narrower the pore size distribution will be which result a membrane with a good separation performance [11]. Higher particle size could actually lead to higher sintering temperature and thus increase the permeability of the membrane [12], which is shown in this work with the use of HDPE powder (270.7±178.6 µm).

Moreover, HDPE membrane (270.7±178.6 µm) without the use of solvents achieved the highest permeate rejection with the highest heating temperature and cause the period of membrane production to be longer. According to [13], increased in porosity of membrane was the result of the sintering powder that heat slower than the others. Membranes with high porosity were considerably important to provide high liquid flow per surface area for adsorption of materials [11].

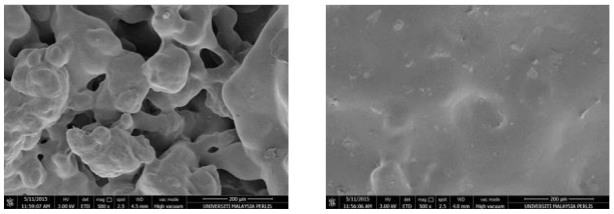
3.3 Field Emission Scanning Electron Microscopic (FESEM) Analysis

The FESEM analysis for HDPE membrane without the addition of any solvents was selected because it gave the best permeate separation in both classes of particle sizes (93.5±30.5 µm and 270.7±178.6 µm). The top surface for average particle size of 93.5±30.5 µm in Figure 5 (a) shows that the pores size was considerably big at magnification of 500. Meanwhile, Figure 5 (b) shows the top view structure for average particle size of 270.7±178.6 µm, which negatively shows clear pores formation at 500 magnifications.

Permeate rejection of contaminated river water for the non-solvents membrane (average particle size of 93.5±30.5 µm) achieved lower rejection percentage. It can be explained by the incomplete heating occurred during sintering processes which result in bigger pore size as shown in Figure 5 (a).

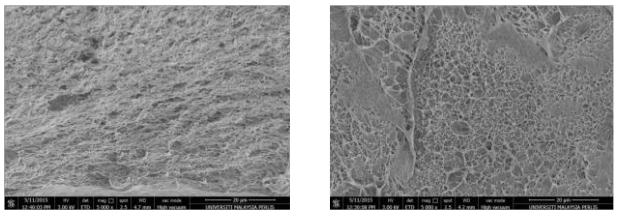
The highest permeate rejection by the non-solvent membrane (270.7±178.6 µm) do not shows any clear pores formation as shown in Figure 5 (b) which indicates sintering process was more thorough.

Figures 6 (a) and Figure 6 (b) show cross sectional FESEM images for both classes of particle size at 5000 magnification. The structures suggest that these two types of membranes exhibit symmetric porous structures. Membrane with symmetric morphology induced a uniform pore distribution [5]. According to Greco and coworker (2003), sintering of materials would result in production of most simple symmetric membranes, with low porosity of 10 % - 40 % [14]. The cross section in both of the porous membranes were sponge-like structure where the membrane sintered with polymer HDPE of average particle size of 270.7±178.6 µm was more porous compared with the other particle size (93.5±30.5 µm), which can be explained by their highest permeate separation of contaminated river water.



(a) (b)

Figure 5 Top surface FESEM image for average particle size of (a) 93.5±30.5 µm and (b) 270.7±178.6 µm at 500 magnification



(a) (b)

Figure 6 Cross sectional FESEM image for average particle size of (a) 93.5±30.5 µm and (b) 270.7±178.6 µm at 5000 magnification

3.4. Fourier Transform Infrared Spectroscopy (FTIR) Analysis

From the FTIR curve (Figure 7), the wave number was found to be 2917.26 cm-1 with transmittance of 84.39 %, where it can be categorized as alkane functional group with types of bond of C-H stretch. The presence of alkanes was detected at 2849.20 cm^{-1} where the percentage of transmission was 89.25 %, with C-H stretching vibrations. The next peak shows that the wave number value of 1472.91 cm^{-1} and 97.80 % of transmittance, where it can be classified as aromatics. The C-C stretch of bond in ring and the C-H rock vibrations at the frequency of 719.05 cm^{-1} with transmittance value of 97.36 % indicates the presence of alkanes. Kumar and Singh (2013) confirm that the HDPE polymer has characteristic of absorption peaks around 3000 cm^{-1}, 1500 cm^{-1} and 700 cm^{-1} to 750 cm^{-1} [15].

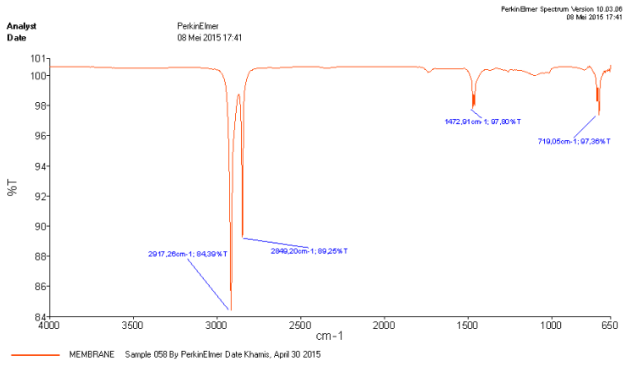


Figure 7 FTIR analysis of HDPE membrane polymer without the addition of solvents

4.0 CONCLUSION

The polymeric membranes were successfully synthesized by using the plastic waste from HDPE type. The synthesized membrane was done by subjecting the HDPE powder by sintering process and tested for the permeate rejection and permeate flux of contaminated river water. The morphology of the membranes was analyzed under FESEM and the functional groups of the membranes composition were analyzed by using FTIR analysis.

It was found that the HDPE membrane with no solvents (average particle size of 270.7±178.6 µm) has the highest percentage of permeate rejection compare to the other membranes. The increase in permeate rejection will decrease the permeate flux. Eventually the permeate rejection and permeate flux will also decrease due to fouling effect, causing low separation rate and shorten the membrane durability. Moreover, heating temperature also influence the membrane performance. Gradual increase in heating temperature will increase the rate of permeate rejection until it exceeded the maximum temperature (180°C) of HDPE membrane and destroy the membrane structure.

HDPE powder with average particle size of 270.7±178.6 µm has better separation based on higher percentage of permeate rejection compared to average particle size of 93.5±30.5 µm. FESEM analysis shows that big pores formation of the membrane from 93.5±30.5 µm HDPE powder has low separation factor, which is caused from the incomplete heating condition and less porous membrane structure. In FTIR analysis, the non-solvents HDPE membrane has two form of functional groups detected; alkanes with three absorption peak of different bonding vibrations and one absorption peak of aromatics with C-C stretch in ring.

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