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Kapok Fibre as Membrane Distillation for Humic Acid Wastewater Treatment

Aina Syazwana Zulkefli, Muhamad Zaini Yunos, Azlinnorazia Ahmad, Muhammad Adrian Thomas

Abstract*: Membrane distillation (MD) is a process of combining membrane with thermal desalination where it operates at two different temperatures which are hot and cold. A vapour pressure resulted between the temperature differences of two sides of the membrane is called permeate flux. In this study, kapok fibre, which provides hydrophobic properties, has been chosen as an alternative solution for synthetic membrane in the MD process. Therefore, the primary purpose of this research is to investigate the effect of feed temperature ranging from 40 to 70°C towards the separation of pure water from humic acid (HA) wastewater. An experimental investigation for the performance of vacuum membrane distillation (VMD) system was performed to treat the HA wastewater to produce pure water. The experimental set up of VMD was set with kapok fibre acting as a barrier that separates the collected pure water from HA wastewater, which is conducted for four hours. Based on this study, the increase in the amount of calculated permeate flux correlates to the increase of feed temperature. The calculated permeate flux is 0.237 kgh^{-1}m^{-2} at the temperature of 40°C. The amount of calculated flux increases steadily to 0.4 and 0.6 kgh^{-1}m^{-2} respectively for every 10°C increments. Furthermore, the physical properties of kapok fibre were analysed by using a scanning electron microscope (SEM). Surface morphology of the kapok fibre at the condition of before and after the MD process were studied without subjecting any chemical treatment on it. Accordingly, the physical properties of the kapok fibre were seen different after the MD process conducted. Additionally, the hydrophobic properties of the kapok fibre were evaluated by using an absorption test. The absorption test was conducted at varies temperature, which results in the highest percentage of absorptivity 4.823 % at 60°C. The hydrophobic kapok fibre has shown excellent properties that can be applied in the MD process and utilised in wastewater treatment.

***Keywords*: Humic Acid, Kapok Fibre, Vacuum Membrane Distillation.**

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I. INTRODUCTION

Population growth, industrial development, and enhance the standard of living has always been a threat to the environment, especially water pollution. This problem leads to an increasing demand for clean water as an estimated 844 million people on the earth did not acquire clean and freshwater [1]. Despite, each person needs 20 to 50 litres of clean and fresh water for daily uses. Meanwhile, 159 million people depend on surface water to meet their basic needs. There are at least two billion among us consume a drinking water source polluted with faeces and hazardous contaminants [2]. Wastewater discharged from many sources leads to chemical or physical pollutants also biological pollutants contain bacteria, viruses, protozoa and parasites [3]. However, wastewater can be clean up by using numerous process depending on the type of contamination that should be encouraged worldwide [4]. It can be clean in wastewater treatment plants that treat wastewater from homes and business places. Treated wastewater can be reused through several technologies also conventional methods such as chemical precipitation, coagulation or adsorption before can be used as drinking water [5].

Membrane distillation (MD) process is another useful advancement would be improving the water treatment processes, which is useful for extremely polluted water sources. Moreover, it can help to reduce worldwide water-energy stress sustainably. MD is a process of separating two different aqueous solutions at distinct temperatures via a microporous hydrophobic membrane [6]. Subsequently, the membrane creates an interface of a gas-liquid state that prevents the liquid mass transfer between two regions [7]. By comparing MD with other membrane technology, MD is a combination of thermal distillation and membrane separation [8]. Meanwhile, membrane technology is a separation process that separates the components of mixtures by using thin barriers between two miscible fluids [9]. The benefit of the MD process is using small and compact equipment also only low pressures needed lead to lower material costs compared to other conventional technology [10].

Hydrophobic materials are used for membrane distillation process to prevent the liquid from entering the membrane, whereas they only allow water vapour to pass through it [11]. In this study, a natural biopolymer distillation system utilising kapok fibre is proposed. Kapok fibre which known as Ceiba Pentandra categorised in natural fibre. The kapok fibre has homogeneous hollow fibre structures with massive lumens [12].

Kapok fibre also provides an excellence hydrophobic property is provided from the significant amount of acetyl groups (13.0%) in the kapok [13]. Additionally, owing to its high reusability, inexpensive and good environmental-friendliness, the kapok fibre can be considered as an alternative solution for synthetic membranes in the distillation process.

II. MATERIALS AND METHOD

A. Materials

In this study, kapok fibres were obtained in their natural form without any chemical treatment. The kapok fibres were harvested from Muar, Johor, Malaysia. Accordingly, obtained kapok fibres were fluffy, dry, light in weight also have a pale yellow appearance. Before it is used, all the dust and lumps were removed in ensuring the properties of kapok fibre is not cut off. Moreover, the humic acid from Sigma-Aldrich was mixed with distilled water to produce a final concentration of 0.1 g of humic acid per mL of the solution

B. Kapok Fibre Characterisation

The surface morphology of raw kapok fibre was characterised based on its physical properties by using a scanning electron microscope (SEM, Hitachi). The surface morphology of kapok fibre was observed by comparing two conditions, which are before and after the membrane distillation process. Accordingly, the water absorption test was conducted by following the ASTM 570 standard [14]. The kapok fibre dried in an oven for 24 hours at 80°C. The dried kapok fibre was immersed in distilled water with various temperature, which is room temperature, 40°C, 50°C, and 60°C. The absorptivity of kapok fibre was determined for every 15 minutes as a time interval of the immersion period, the surface water was wiped off using filter paper, and wet weight values were recorded [15].Water absorption percent, M (%) was calculated by the following formula:

$$M\,(\%) = [\,(m_t - m_o) / m_o\,] \times 100 \qquad (1)$$

Where;

m_t = Weight of the kapok fibre after the immersion process (g)

m_o = Dry weight of the kapok fibre after being dried for 24 hours in an oven (g)

From the given formula (1):

$$M\,(\%) = [\,(17.468 - 3) / 3\,] \times 100$$

In this experiment, the calculated m_t and m_o is 17.46 8g and 3 g respectively at 60°C for 105 minutes. Thus, the percentage of water absorption after immersion time, M (%) is 4.823.

C. Membrane Distillation Experiments

Fig.1 shows a simple distillation unit is prepared for two types of temperatures conditions, which are the high temperature from a hot feed stream entering a distillation module and low temperature from collected pure water in a coolant tank [16].

The critical component of the experimental setup consists of a diaphragm water pump, which is responsible for pumping the hot feed humic acid (HA) stream from the feed bath to the module at a fixed flow rate of 8L/Min as shown in Fig 1. Similarly, the pump is used for the cooling water as well. Also, the temperatures variables of the HA solution are set and controlled by a hot plate together with a thermometer. Consequently, the feed stream temperature is adjusted with every 10°C increment within the range of 40°C to 70°C. Furthermore, the cold water is controlled in the range 13 to 15°C using a coolant fluid.

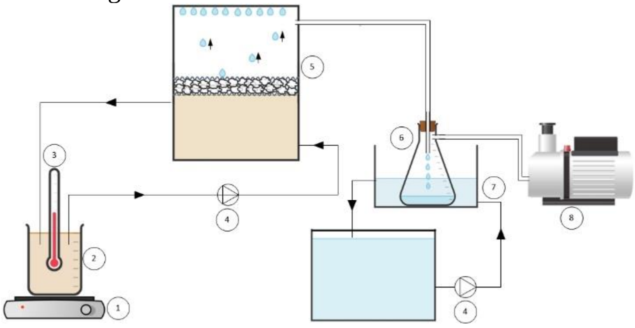

Fig. 1. Schematic diagram of vacuum membrane distillation (VMD). 1. Hot plate, 2.Hot feed tank, 3.Thermometer, 4.Diaphgram water pump, 5. Distillation module, 6. Permeate collection bottle, 7.Coolant tank, 8.Vacuum pump.

The vacuum pump was used to encourage water vapour collected to move into the permeate collection bottle. Equally important, pure water resulted from water vapour collected is weighed by using analytical balance and calculated by taking an average reading of three same tests from each set of experiment. The permeate flux, J is calculated by using the following equation:

$$J = Q / A_s \cdot t \qquad (2)$$

Where;

Q = Volume of condensing steam or water vapour collected (kg)

A_s = Surface area of kapok fibre used in this experiment (m^2)

t = Time interval (h)

From the given formula (2):

$$J = 0.077 / 0.02 * 4$$

In this experiment, the average volume of water vapour collected is 0.0077 kg at 70°C. The fixed variables are the surface area of the kapok fibre which is 0.02 m^2 and the duration taken for the MD process which is four hours.

III. RESULTS AND DISCUSSION

In this study, the characteristics of kapok fibre have been analyzing by using scanning electron microscope (SEM) and absorption test. SEM is conducted to differentiate the structure of raw kapok fibre before and after the MD process. Accordingly, the effect of high temperature towards kapok fibre is discussed clearly. Meanwhile, the absorption test is carried out to verify the water absorbency of kapok fibre with the effect of various temperature due to the exhibits a very water repellent character [17].

A. Scanning Electron Microscope (SEM)

As shown in Table 1 (a) and (c), raw kapok fibre has an even and smooth surface without any wrinkle. The resulted smooth appearance due to the inherent plant wax layer on the surface [18]. Accordingly, a hollow tubular structure or lumen can be seen on the single kapok fibre which can reach up to 90 percent of the whole structure [12].

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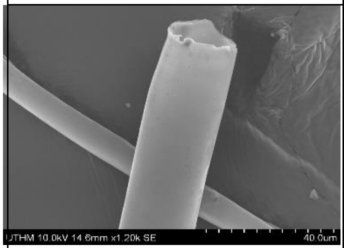
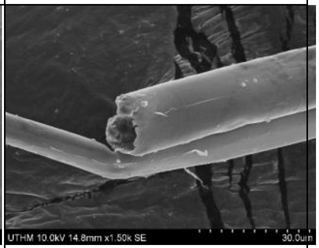
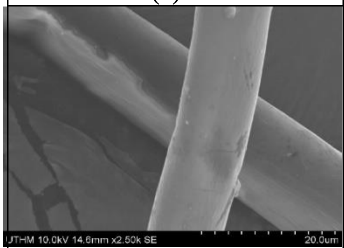
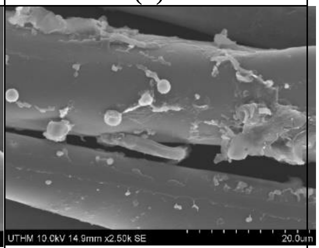
Table 1 (b) and (d) reveal a significant change on the surface of kapok fibre. By comparing Table 1 (a) and (c), revealed the hollow structure of the kapok fibre is preserved after the membrane distillation process.

TABLE-I: Scanning Electron Microscope (SEM) of raw Kapok Fibre before and after the MD Process

Before	After
	
(a)	(b)
	
(c)	(d)

B. Absorption Test

The variation of moisture content with various temperature for 105 minutes is shown in Fig. 2. The percentage of gain moisture absorption of kapok fibre for 1 hour 45 minutes at room temperature of distilled water is 1.82%, at 40°C of distilled water is 2.96%, at 50°C of distilled water is 3.04%, and at 60 °C of distilled water is 4.82%. It is shown from the graph that the initial rate of water uptake increases with increase in temperature of distilled water. This behaviour has been explained according to Kinetic molecular theory [19]. The temperature stimulates distilled water molecules to move rapidly due to each of single-molecule has more energy as it gets hot from room temperature to 60 °C. This is due to the kinetic energy of the distilled water molecule increases with increment in the vibration of molecules. Accordingly, when distilled water gets hotter, which gain rate of steam, it excites the opening of pores of kapok fibre.

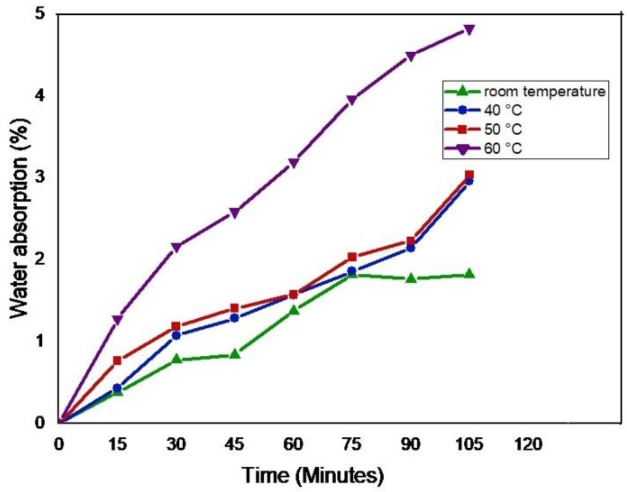


Fig. 2.Water absorption curve at various temperature

As seen in Fig. 2, the performance of MD is affected by the water absorption curve at various temperature. Therefore, evaluation of the effect of kapok fibre characteristic is discussed in the performance of the MD process.

C. Performance Evaluation of Membrane Distillation

Fig. 3. illustrated the effect of feed temperature on the permeate flux. It can be noticed that permeate flux increases with increasing feed temperature due to the exponentially increased of vapour pressure. This can be explained through the Antoine equation (2). Based on the Antoine equation, which describes the relation between vapour pressure and temperature for pure components well explained the concept of feed temperature and permeated flux [20].

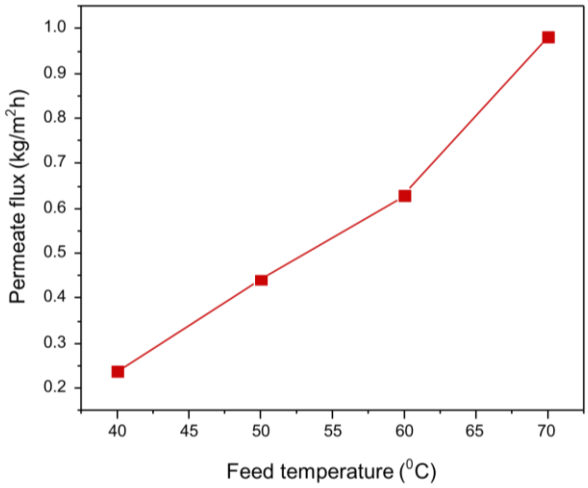


Fig. 3. Effect of feed temperature on permeate flux.

Moreover, this situation can relate with Kinetic molecular theory where the higher temperature of the water, the molecules of HA solution move rapidly that makes the chemical bonding which holds all the atoms together start to break [19]. At this point, the change of phase happens which substances of HA solution undergoes a phase change from the liquid to the gaseous state then produce water vapour. The resulted water vapour is a permeate flux collected that has been calculated by using the Antoine equation. Indeed, the water vapour collected is pure water resulted from the MD process.

IV. CONCLUSION

Kapok fibre has received increasing attention as an eco-friendly material for its intrinsic advantages. The ability of kapok fibre as an alternative solution for synthetic membrane in the MD process has been investigated in this study by analyzing the flux on different temperatures. HA has been selected by means to ensure permeate water quality, as it is one of the compound frequently found on the surface water. Study of the effect of different temperature on the performance of VMD have confirmed the type of materials acting as a barrier and control of temperature are the very important parameters which significantly affect the process. Therefore, this work has proposed a suitable natural fibre that can be highlighted in the MD process at various temperatures to enhance the removal of organic substances in wastewater.

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In this work, the highest feed temperature has resulted the highest permeate flux, which corresponded to the highest percentage of water absorption. Accordingly, the structure of the kapok fibre has shown changes after the treatment process of HA in wastewater. Interestingly, the hollow structure of the kapok fibre remains the same from the SEM. Therefore, the kapok fibre can treat thousands of organic compound in wastewater. However, MD operations applied for HA wastewater treatment must always be optimized with different barrier characteristics for an efficient and economical design of the MD plant.

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