ENHANCEMENT THE FLUX OF PVDF-CO-HFP HOLLOW FIBER MEMBRANES FOR DIRECT CONTACT MEMBRANE DISTILLATION APPLICATIONS

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ABSTRACT

Phase inversion technique has been utilized to prepare Poly (vinylidene fluoride-co-hexafluoropropylene) PVDF-co-HFP, hollow fiber membranes. Polyvinylpyrrolidone (PVP) with 9 wt. %. added as a pore former additives to the polymer dope solution. Characteristics of the PVDF-co-HFP hollow fiber membrane with / without PVP particles have been studied. It was found that the membrane prepared without PVP additives has a low porosity and a high contact angle. Existence the PVP additives of 9 wt. % causing the increase of the membrane porosity by 28 %.Whilst increase PVP content resulting in decrease of membrane hydrophobicity. MD experiment was done using a direct contact membrane distillation (DCMD) configuration as crucial test to investigate performance of product PVDF-co-HFP hollow fiber membrane. Increase the amount of PVP to 9 wt. % in dope solution, this in turn leads to an increased the permeate flux from of 4.5 to 15.8 Kg/m2.h at 70 oC The effect of operating conditions such as feed temperature, concentration of feed solution and permeate flow pattern on the performance flux of the hollow fiber membranes were studied.

Keywords: Poly (vinylidene fluoride-co-hexafluoropropylene), Polyvinylpyrrolidone, contact angle, permeate flux.

INTRODUCTION

Membrane distillation (MD) is a novel separation process which depends on the phenomenon that fresh water can be permeate from aqueous solutions by evaporation using membrane (Camacho *et al.* 2013),(Gryta, 2011),.When a temperature difference is occurs across a hydrophobic microporous membrane while the vapor crossing it. A vapor pressure variation will be established across the membrane because of the temperature difference. Just the vapor passes through the membrane as a result of the hydrophobic nature of the membrane. It is recognized that the driving force of membrane distillation operation is the temperature difference across the membrane (Al-Anezi *et al.* 2012), (Alsaadi *et al.* 2013), (Yu *et al.* 2011), (Qtaishat *et al.* 2008).

There are four kinds of MD according to the design of the cold side of the membrane; Direct Contact Membrane Distillation (DCMD), the hydrophobic microporous membrane will be in the direct contact with the liquid in both sides. Air gap membrane distillation (AGMD), by an air gap a cold surface will receives the condensed water vapour which has been separated. Sweeping gas membrane distillation (SGMD), for sweeping and holding the vapour particles to the outside of the membranes via a cold inert gas in permeate part. Vacuum membrane distillation (VMD), Using vacuum at the permeate parts achieves the driving force across the membrane (Hwang *et al.* 2011), (Cath *et al.* 2004). The effect of two typical additives, lithium chloride (LiCl) and glycerol, and the effect on the manufacturing of poly (vinylidene fluoride-co-hexafluoropropylene) (PVDF-HFP), was studied by (Shi *et al.* 2008). He pointed out that these additives led to the obtainment of the asymmetric microporous hollow fiber membranes that have been investigated in terms of membrane conformation, installation, permeation performance, hydrophobicity and effectiveness.

Many of the previous research in the field have pointed out that the polymeric additives are appropriate with good miscibility with the base material, which indicates that these materials may be advantageous in multiple applications. It can form some highly hydrophilic membranes with highly effective resistance to protein adsorption using several functional groups, such as the s, pegylated, and carboxylated groups, and this is due to the creation of highly hydrophilic membranes (Ahmad *et al.* 2013). (Gryta and Barancewicz, 2011) pointed out that by blending PTFE with PVDF allows to reduce the rate of membrane wettability, so PTFE blending can be utilized to improve hydrophobic properties of the PVDF membrane.

EXPERIMENTAL WORK MATERIALS

For the removal of trapped moisture PVDF-co-HFP and PVP were dried in a vacuum oven (Model 282A, Thermo Fisher Scientific Inc.) at 50 °C. DMAC, used as a solvent. PVP with 9 wt. % was first dissolved with DMAC in a glass flask. Then, PVDF-co-HFP was added to the mixture at 50 °C. The casting solution was kept under magnetic stirring until a homogeneous dope was gained and removing air bubbles from it before spinning was also done. The casting solution was transferred to a vertical stainless steel tube. Via a phase inversion spinning method the PVDF-co-HFP hollow fiber membranes were fabricated.

Direct Contact Membrane Distillation

Stainless steel hollow fiber membrane modules were first prepared. Five PVDF-co-HFP hollow fiber

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membranes have been manufactured in previous work (Khalid et al) were cut off and insert in the module using epoxy resin for both ends was used in DCMD system that illustrate in Figure-1. There are two hot feed stream and cold permeate cycles in this setup, The feed which heated by water bath has been circulated in lumen side of the hollow fiber membrane using peristaltic pump. While the cold stream was fed and circulated through the shell side of the module via peristaltic pump (WT600-1F- China). The flow rate of feed and permeate streams were measured using a flow meters were connected between module and the pump. For the inlet and outlet of the feed streams membrane module there are a temperature gauge. The feed and permeate streams flowed through the membrane in a countercurrent and co-current configurations for the DCMD system. The permeate flux can be estimated using the volume of accumulated water by the equation (Shi *et al.* 2009):

$$J= \frac{V * \rho}{\pi * D * L * t} \qquad (1)$$

Where J is the permeate flux in Kg/m2.h, V is the volume of liquid accumulated in m3, ρ is the density of water in Kg/m3, D is the membrane diameter in m, L is the length of the fibers , t is the time in hours.

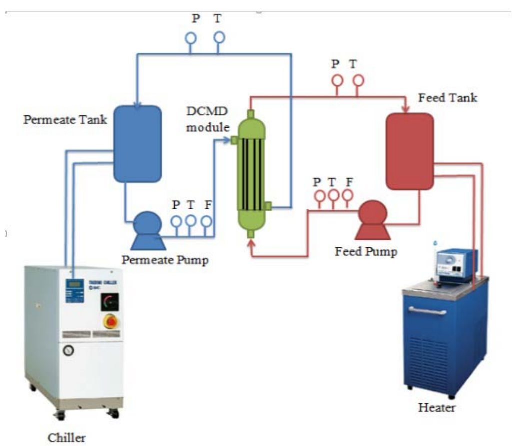

Figure-1. Schematic DCMD experimental setup.

RESULTS AND DISCUSSION

Experiments were accomplished using pure water and various concentration of sodium chloride NaCl aqueous solution. The impact of operating parameters, viz, feed temperature, flow pattern, and feed concentration on the permeate flux of PVDF-co-HFP hollow fiber membrane were tested in this study.

Pure Water and Aqueous Solution Feed

For various feed temperature, pure water firstly was fed to the DCMD system. Feed temperature were 40, 50, 60 and 70 ºC whilst the feed flow rate and permeate temperature were kept constant at 0.6 L/min ,20 ºC respectively .The accumulated permeate water with the time was used to calculate the permeate flux using equation (1). Subsequently aqueous NaCl solution with concentration of (0.6, 0.7, 0.75and 0.8 M) was used as a feed stream to the DCMD system.

Effect of Feed Temperature

Feed temperature is one of the most significant MD process parameter. The influence of feed temperature difference (40-70) ^{0}C on PVDF-co-HFP membrane permeate flux was investigated, whilst the permeate temperature was kept constant at 20 ^{0}C. Figure-2 displayed the PVDF-co-HFP hollow fiber permeate flux gained with different temperature.

It can be observed that there is a noticeable increase in permeate flux through PVDF-co-HFP hollow fiber membrane with the increasing the feed temperature. Raise the temperature from (40 to 70) ^{0}C resulting in an increase in the membrane permeate flux from 4.5 to 16 Kg/m^2.h.This is in agreement with finding of (Boubakri *et al.* 2014). The increase in permeate flux is due to the fact that the vapour pressure variation across the membrane is a function of transmembrane temperature variation through the membrane. Increase the temperature difference across the membrane leads to increase the vapor pressure as a result of this increasing driving force through the membrane will increase which causes increased the membrane permeate flux.

Effect of Permeate Temperature

Figure-3 describe the effect of cool permeate temperature on the membrane permeate flux. A decrease in temperature difference between the feed and the permeate streams across the membrane will occur because of the temperature decreasing of permeate stream which in turn will adversely affect the value of permeate flux of the membrane. The likely explanation is the decrease in temperature difference across the membrane causes a decrease in water vapor pressure on both sides of the membrane, thereby reducing the driving force.

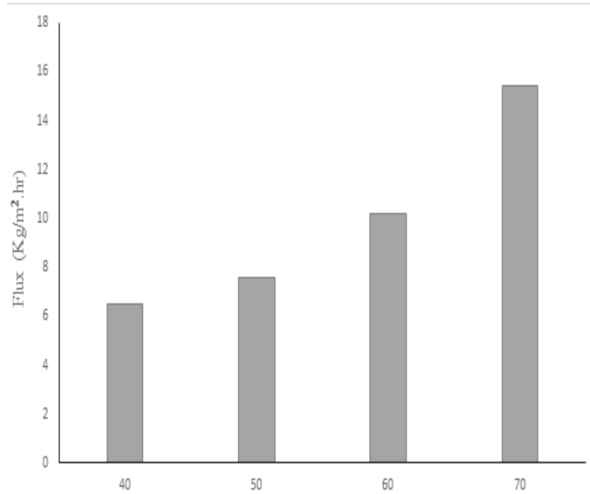

Figure-2. Permeate flux as a function of feed temperature.

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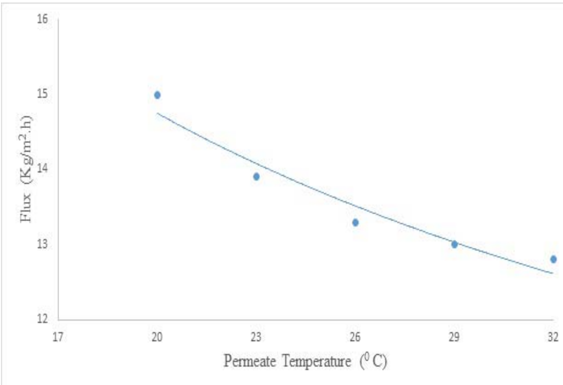

Figure-3. Permeate flux as a function of permeate temperature.

Effect of Feed Concentration

Generally, the effect of feed NaCl concentration on the membrane permeate flux is less considerable compared to other operating parameters. Vision of the effect feed concentration on the permeate flux for different NaCl feed concentration solutions is shown in Figure-4 which refers that the flux for the all NaCl concentration solution is always been lower than that of distilled water. It is possible predict that the NaCl contents in the feed solution would lead to the reduction of vapor pressure, accordingly result in the reduce of membrane permeate flux. This is similar to results obtained by (Li *et al.* 2015), who has studied the effect of the feed NaCl salt concentration on the membrane permeate flux.

Effect of Flow Pattern

Figure-5 shows flow pattern inside the tubes and shell of the membrane module; (A) co-current and (B) countercurrent arrangement. For the co-current mode the hot feed and cold permeate streams flow to inside of membrane module at the same trend. It is expected to be the difference in temperature between the hot feed and cold permeate was high at the entering part of the module but as they flow through the module, their temperature becomes closer to each other; hence, the temperature slope becomes low and low which leads to lower permeate fluxes throughout the last part of the module. Meanwhile, for the counter current mode, the feed hot and permeate cold streams enter at opposite direction of the membrane module. This will leads to an average temperature slope which will keep constant throughout the flow, which can be seen in the value of the individual permeate fluxes. This constant temperature slope will leads to a high permeate flux at the last part of module when compare to the co-current pattern and a higher permeate total flux from the whole system.

Figure-6 demonstrates the permeate flux for co-current and counter current as a function of feed temperature. This is consistent with the results mentioned by (Manawi *et al.* 2014). Therefore the significant indication for countercurrent flow is outperformed the countercurrent flow, for this counter current is the favorite in use in the most DCMD application.

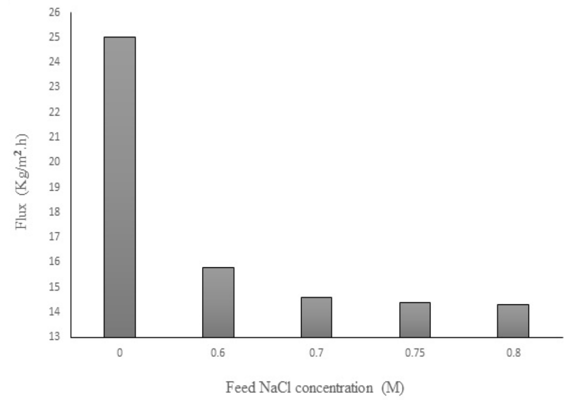

Figure-4. Permeate flux as a function of different feed NaCl solutions concentrations.

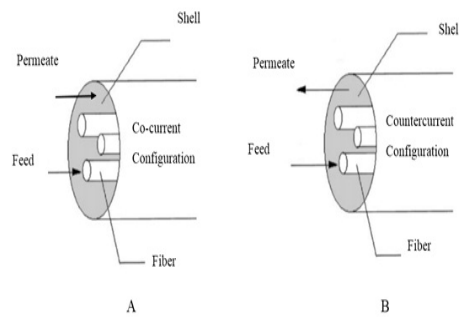

Figure-5. Flow pattern in the hollow fibre membrane module A: co-current, B: Counter current configuration.

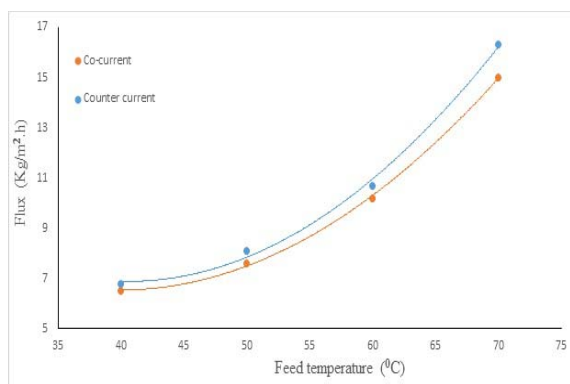

Figure-6. The permeate flux for co-current and counter current configuration with different feed temperature.

CONCLUSIONS

In this study, PVDF-co-HFP asymmetric microporous hollow fiber membranes were fabricated via phase inversion technique. An experimental study of DCMD process was implement using PVDF-co-HFP hollow fiber membrane. Pure and seawater solutions desalination be performed by using DCMD system.

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The influence of feed temperature, feed concentration and flow pattern on the permeate flux were investigate for pure and sea water. The increased of feed temperature leads to increased permeation flux for the DCMD process.

The permeation flux of PVP-co-HFP hollow fiber reduction with increasing of NaCl concentration in feed solution. The fluxes show higher values with operated at higher temperature, lower NaCl feed concentration, low permeate temperature and they seem to reach maximum values when countercurrent configuration used. Results have proved that the addition of PVP with 9 wt. % as pore former led to increase the permeate flux of the PVDF-co-HFP hollow fiber membrane by 70 %. The results of this study indicate that the PVDF-co-HFP hollow fiber membrane is appropriate for DCMD application because of its good characteristics.

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