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EVALUATION AND PERFORMANCE OF MEMBRANE DISTILLATION MD PROCESS FOR BRACKISH WATER DESALINATION

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Abstract:

Desalination has been progressively more adopted over the last decades as an opportunity, and sometimes as a necessity to beat water shortages in many areas around the world. Today, quite a lot of thermal and physical separation technologies are well established in large scale production for domestic and industrial purposes. Membrane distillation is a novel thermally-driven process that can be adapted efficiently for water desalination, due to its prospective lower energy consumption and simplicity.Membrane distillation is a membrane separation process which may overcome some limitations of the other membrane technologies . The membrane distillation process constitutes one of the potential for a new method for water desalination in particular, high solute concentrations can be reached, overcoming concentration polarization phenomenon and ultrapure water can be formed as a permeate. In this process a micro-porous hydrophobic membranes is used , liquid water impermeable to the transport ,only water vapour can be transported through them, having a vapour pressure difference as driving force at the two solutions membrane interface. A variety of polymeric hydrophobic membranes have been prepared with an suitable micro-porosity . The effect of the feed temperature, feed flow rate , cooling water temperature ,cooling water flow rate etc .have been studied theoretically and tested experimentally and also energy consumption. Membrane distillation has shown motivating potential in water desalination,. In addition, the overall performance of the processes can improved .if membrane distillation is integrated with other process to achieve higher concentration standards .

Key words : - Membrane distillation, desalination, hydrophobic membrane, brackish water

INTRODUCTION

Relatively Membrane distillation is a new membrane separation process which may be overcome some restrictions of the traditional membrane technologies. A high solute concentrations can be achieved and pure water can be produced in a one step. The opportunity of an industrial improvement of this technology is related to the growing commercial accessibility of membranes of potential interest .[1,2]

When at different temperatures a micro-porous hydrophobic membrane separates two aqueous solutions, mass transfer across the membrane occurs: this process is carried out at atmospheric pressure and at much lower temperatures which may be below the boiling point of the solutions. The transport of the liquid is prevented due to hydrophobicity of the membrane, while the water vapor can be transported across them from the warm side, condensing at the cold surface. The driving force is the vapor pressure difference at the two solution membranes interfaces. [3-6]

Hydrophobic micro-porous membranes allow easy passage of water vapor, but completely lock the flow of liquid water. The water is prevented to passage through the pores of the hydrophobic material due to Surface tension .If the feed water is in contact with one of the surface of the membrane ,the contamination of the feed water can be prevented by the gap distance between the evaporation and condensation surfaces .. [7-9]

One of the four common MD configurations is Air gap membrane distillation (AGMD) . In AGMD, air-gap is introduced between the membrane and condensation surface to reduce the heat loss by conduction [10]. The latent heat can be recovered during the condensation of the vapor on cooling plate in AGMD configuration. The AGMD has a disadvantage that it has a low permeate flux due to the additional resistance to mass transfer [11]. Among the four MD configuration the major advantages of AGMD configuration are as low temperature polarization effect, low conductive heat losses, and possible internal heat recovery [15–20], and lower chance to surface membrane wetting due to absence of direct contact between the membrane and permeate side as due to an air gap [21]. The researchers studied the integrated MD process with AGMD configuration [22,23].

Materials and Methods

The flat sheet membrane made of polytetrafluroethylene (PTFE) polymer which is commercially available microporous hydrophobic membrane was used in the experiment. The membrane sheet was purchased from Trinity Technologies Ltd. Mumbai. The detailed characteristic of the membrane is shown in Table 1.

Brackish water used was taken as a rejectant (concentrate) from reverse osmosis (R O) process collected from Airoli Navi Mumbai borewell water .The concentrate having TDS of 9837.21(mg/l). Membrane is purchased from Trinity Technologies Ltd. Mumbai, for Membrane distillation. PTFE membrane filters used in this experiment for AGMD configuration has the effective membrane area, 80 cm^2 given by the manufacturers. The method of operation of desalination for this work is Air Gap Membrane Distillation configuration. Here the feed is in direct contact with the hot membrane side surface, evaporation takes place at the feed-membrane surface and the vapour is moved by the pressure difference across the membrane to the permeate side and condenses inside the membrane module. It is the simplest configuration capable of producing reasonably high flux. It is best suited for applications such as desalination. The detailed MD plant specification is shown in. Fig.1 Shows picture of experimental Setup of AGMD . Table 2 shows operating parameter used in MD process.

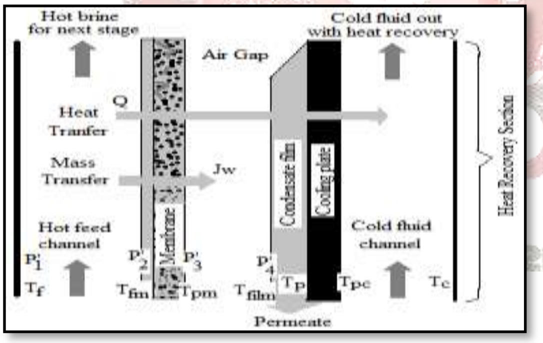

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Fig 1 Transport mechanism of AGMD Module [1]

Table 1. Characteristics of PTFE membrane

Parameter	**Characteristic**
Manufacturer	GmbH, Germany
Pore size	0.45 µm
Porosity	70%
Thickness	175 µm
Tortuosity	2
Effective membrane area of single stage	80 cm^2

Table 2. Experimental operating parameter used in MD

Sr. No.	Operating Parameter	Range
1.	Feed temperature	40 – 80 ^{0}C
2.	Feed flow rate	0.5 to 2 L/min
3.	Cold water temperature	20 – 40 ^{0}C
4.	Cold water flow rate	0.2 – 1 L/min
5.	Air gap thickness	4-10 mm
6.	Depth of feed flow channel	4-10 mm

Result and discussion

Validation of MD model results at different operating conditions

Effect of feed temperature on permeate flux

The model results of the MD process were presented and was compared with the different experimental data. Fig. 1 represents the mathematical model predict and exponential behaviour of the MD permeate flux as a function of feed temperature. The MD permeate flux were measured. Such model also supported by an experimental data. The feed temperature was varied from 40 to 80 ^{0}C at the constant other operating parameters like feed flow rate of 2 L/min, coolant temperature of 25 ^{0}C and coolant flow rate about 0.83 L/min, and air gap thickness of 4 mm. It can be observed that increasing the feed temperature from 40 to 80 ^{0}C leads to about 484% rise in MD flux .This may be due to the higher vapor pressure as a driving force significantly improved the performance of the system at a higher temperature.. Fig. 1 shown that the mathematical model is better in predicting feed temperature. The maximum and minimum record percentage error in the MD between the model and experimental data are 13.7% and 8.7% respectively.

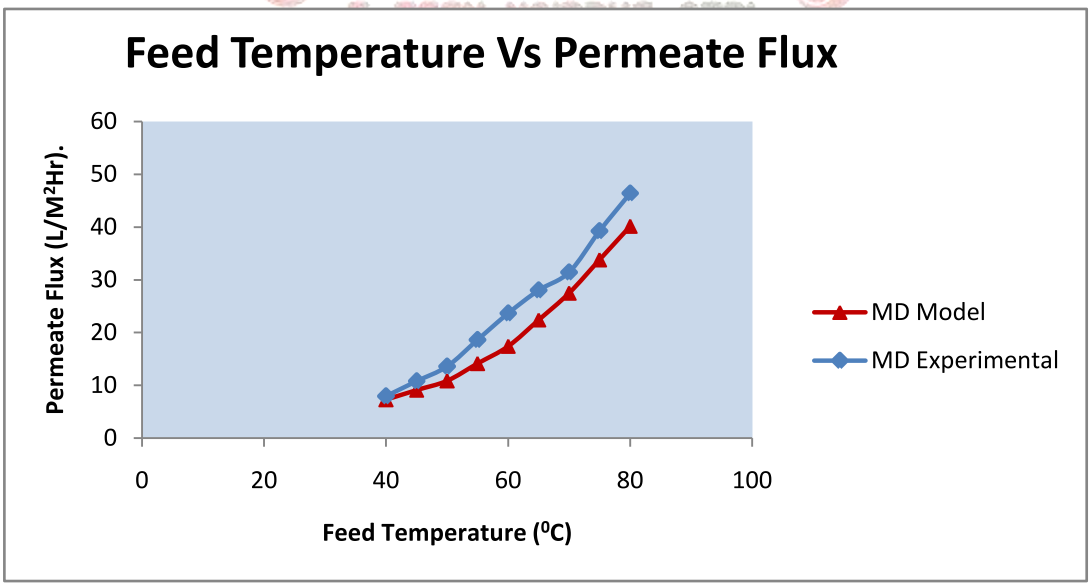

Fig. 1 Effect of feed temperature on permeate flux (feed flow rate 2 L/min, coolant water temperature 25 ^{0}C, coolant water flow rate 0 .83 L/min, air gap 4 mm, feed TDS 9837.21 mg/l)

Effect of feed flow rate on permeate flux

To further validate the model, the mathematical model fitted with the experimental data by variation of the feed flow rate is as shown in fig.2. The feed flow rate varied from 0.5 to 2 L/min at constant feed temperature of 80 ^{0}C, coolant temperature of 25 ^{0}C, coolant flow rate in each coolant channel of 0.83 L/min, and air gap thickness of 4 mm. Increasing the feed flow rate in MD from 0.5 to 2 L/min leads to about 92 % rise in permeate flux. This is an increasing turbulence in the feed flow channels and improved the heat transfer coefficient of the feed boundary layer.[22]. The analysis of the maximum and minimum percentage error between the model and experimental data are 12.63% and 6.8% respectively which was in the range of the experimental error.

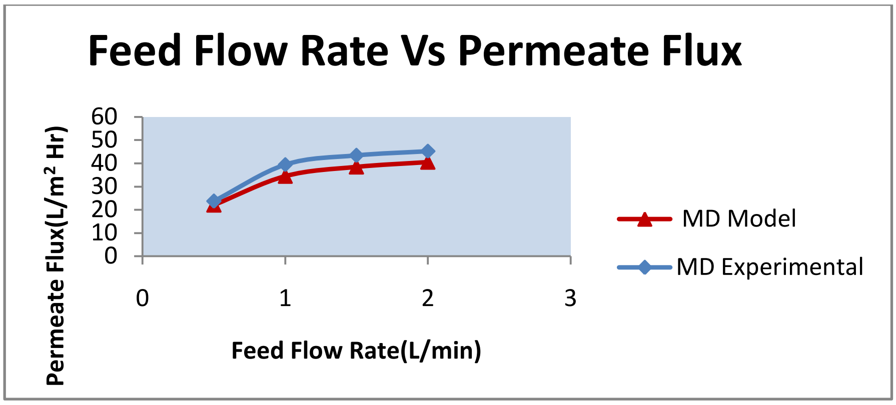

Fig. 2 Effect of feed flow rate on permeate flux (feed temperature 80^{0}C, coolant water temperature 25 ^{0}C, coolant water flow rate 0.83 L/min ,air gap 4 mm feed TDS 9837.21 mg/l)

Effect of cooling water temperature of permeate flux

The effects of coolant temperature on the permeate flux in MD mathematical model and experimental data were compared and represented in fig. 3. It was observed that the flux decompose i as the coolant temperature increased. The coolant temperature increased from 20 to 40^{0}C at constant feed temperature and flow rate of 80 ^{0}C and 2 L/min. respectively, coolant flow rate is of 0.83 L/min, and air gap thickness of 4 mm. The permeate flux was decreased about 50 % as increased the coolant temperature from 20 to 40 ^{0}C. The decrease in the permeate flux is due to the reduction in the transmembrane driving force responsible for the permeate flux. The reduction in temperature difference in the feed and coolant channels were caused by increasing the coolant temperature, which leads to demur the driving force. The result shows that the maximum and minimum error in the model and experimental data are about 15.9% and 6.1% respectively. The model and experimental data were established for the minimum cooling water temperature.

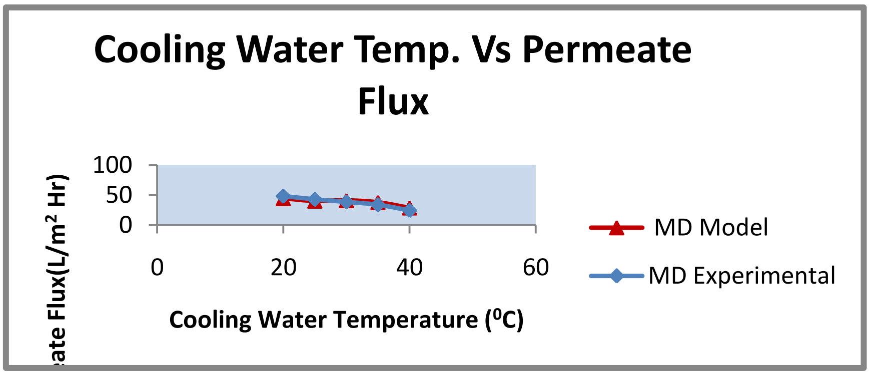

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Fig. 3 Effect of cooling water temperature on permeate flux ((feed temperature 80^{0}C, feed flow rate 2 L/min, coolant water flow rate 0 .83 L/min, air gap 4 mm, feed TDS 9837.21 mg/l)

Effect of coolant flow rate on permeate flux

Additional the model was validate against the experimental data using different coolant flow rates. The results find of the model and experimental are shown in fig. 4. The cooling water flow rate in each cooling channel was increased from 0.2 L/min to 1 L/min at the constant feed temperature and flow rate of 80^{0}C and 2 L/min respectively, coolant temperature of 25 ^{0}C and air gap thickness of 4 mm. Increase in the cooling water flow rate leads to minor impact on the permeate water flux in all cases. The total increase of the flux was very insignificant as 7.27%. The model prediction was a good enough and within the experimental error for maximum and minimum about 13.7% and 9.0% respectively.

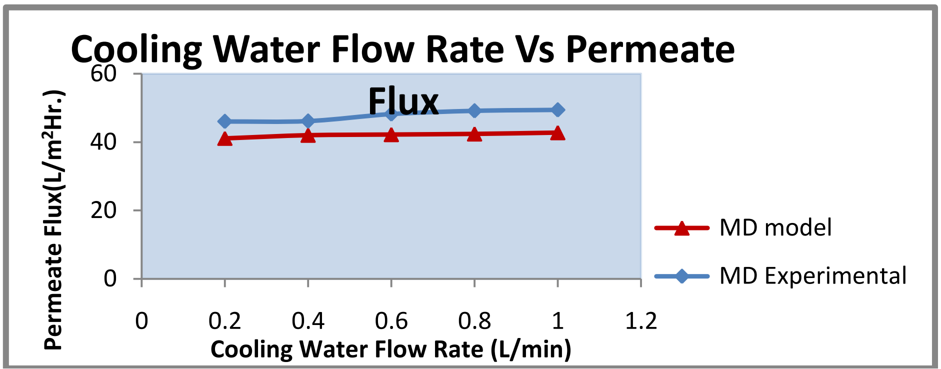

Fig. 4 Effect of coolant water flow rate on permeate flux ((feed temperature 80^{0}C, feed flow rate 2 L/min, coolant water temperature 25 ^{0}C, air gap 4 mm feed TDS 9837.21 mg/l,)

Effect of air gap thickness on permeate flux

The effect of an air gap thickness on the permeate flux was also investigated here and shown the results in fig.5. The model and experimental data demonstrate a decrease in the permeate flux as the air gap increased. This is due to increase in the mass transfer resistance. the air gap was increased from 4 mm to 10 mm at constant feed temperature and feed flow rate of 80 ^{0}C and 2 L/min respectively, and coolant temperature and flow rate in cooling channel of 25 ^{0}C and 0.83 L/min respectively. The resulting analysis shows that the permeate flux was very susceptible to the change in air gap thickness. Hence, the air gap thickness is an important parameter in the design of the module. The maximum and minimum error in the model and experimental data are about1 4.5% and 4.3% respectively. when the air gap thickness was reduced from 10 mm to 4 mm. Hence it is recommended to use the minimum possible air gap thickness in the design in order to considerably enhance the performance of the system.

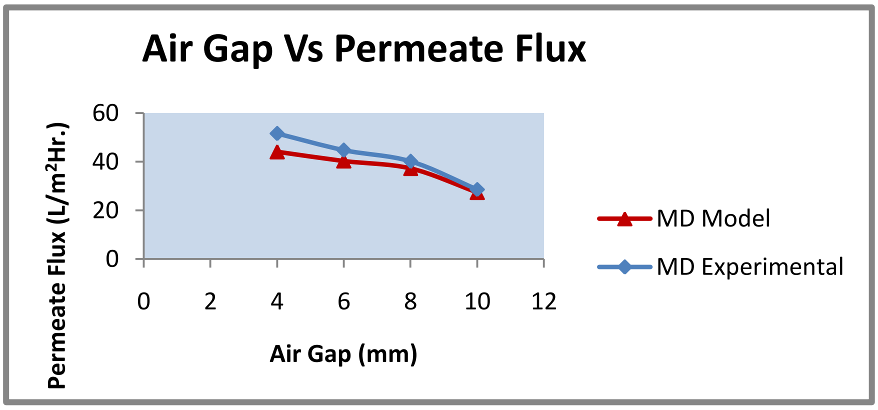

Fig.5 Effect of AIR GAP on permeate flux ((feed temperature 80^{0}C, feed flow rate 2 L/min, coolant water flow rate 0 .83 L/min, coolant water temperature 25 ^{0}C , *feed TDS 9837.21 mg/l*)

Conclusions

The performance of AGMD for desalination of brackish water by using a flat sheet PTFE membrane is presented experimentally and validate with MD model . The AGMD permeate flux were increased with increasing the feed temperature, 40 ^{0}C to 80 ^{0}C, and feed flow rate, 0.5 L/min to 2.00 L/min. Permeate flux was decreases with increasing cooling water temperature from 20 ^{0}C to 40 ^{0}C, and with an air gap thickness, 4.00 mm to 10 mm. Brackish water was taken as a rejectant (concentrate) from reverse osmosis (R O) process collected from Airoli Navi Mumbai borehole water .The RO concentrate having TDS of 9837.21(mg/l) was used for determining the optimum operating parameters of AGMD process. The permeate flux of brackish was reached from 7.95 L/m^2 h to 46.42 L/m^{2}h at feed temperaturefrom 40^{0}C to 80^{0}C respectively at the optimum operating conditions as, feed flow rate, 2.00 l/min; coolant temperature, 25 ^{0}C; and air gap thickness, 4 mm.

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