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Flux enhancement of air gap membrane distillation for desalination of groundwater by surface modification of membrane

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Abstarct: Membrane distillation (MD) is an emerging technology for seawater or ground water desalination process. In this work, an air gap membrane distillation (AGMD) process was applied for the purification of natural ground water with modification of the membrane. The commercial hydrophobic polytetrafluoroethylene (PTFE) membrane of pore size 0.22 µm and porosity 70% were used. The surface modification of the membrane has been carried out by treating membrane with alcohol. The effect of the feed flow rate, feed temperature, coolant temperature, air gap thickness and operating time on the permeate flux were studied for treated and non treated membrane. Within the tested range, the MD flux was significantly increased by 69% reached to 40.48 kg/m^2h, because it increased to 42% of the membrane mass transfer coefficient due to the surface modification of the membrane.
Keywords: MD, ground water, AGMD, surface modification, desalination, groundwater.

1. INTRODUCTION

MD is a thermal, vapor-driven transportation process through micro porous and hydrophobic membranes. MD is applied a non-isothermal membrane process in which the driving force is the partial pressure gradient across a membrane that is porous, not wetted by the process liquid. In this process saline water is heated to increase its vapor pressure, which generates the difference between the partial pressure at both sides of the membrane. Hot water evaporates through non-wetted pores of hydrophobic membranes, which cannot be wetted by the aqueous solutions in contact with and only vapor and non-condensable gases should be present within the membrane pores [1-4].

The MD process offers some advantages: (1) can be performed at lower operating pressure and lower temperatures than the boiling point of feed solution, (2) requires lower vapor space, (3) is unlimited by high osmotic pressure and fouling, (4) permits very high separation factor of non-volatile solute, (5) has potential applications for concentrating aqueous solutions or producing high-purity water, and (6) can use any form of low –grade waste heat or be coupled with solar energy systems which makes it attractive for production of potable water from brackish water in arid regions. These advantages make MD more attractive than other popular separation processes. [5-9].

The four types of MD configurations are used to impose a vapor pressure difference across the membrane to drive a flux. The permeate side may be a cold liquid in direct contact with the membrane, called direct contact membrane distillation (DCMD) or a condensing surface separated from the membrane by an air gap called air gap membrane distillation (AGMD) or a sweep gas blown across the membrane called sweep gas membrane distillation (SGMD) or vacuumed called vacuum membrane distillation (VMD). Because AGMD and DCMD do not need an external condenser, they are best suited for applications where water is the permeating flux. SGMD and VMD are typically used to remove volatile organic or dissolved gas from an aqueous solution [5, 10-12].

In AGMD process, only the feed solution is in direct contact with the membrane. The permeate is condensed on a cold surface. There is an air gap situated between the membrane and the cold surface to reduce energy losses by heat conduction through the membrane. The main drawback of the air gap is that it is also an additional resistance to mass transfer. Air gap MD is suitable for all direct contact MD applications. However, it is also suitable to separate other volatile substances such as alcohols from an aqueous solution [13, 14].

Most of MD studies deal with theoretical MD transport model and experimental studies on the effects of operating conditions. In most of experiments, commercially available membranes in flat sheet or capillary form, typically fabricated from polytetrafluoroethylene (PTFE), polypropylene (PP) or polyvinylidenedifluoride (PVDF) has been used. Many researchers have been performed on new application of MD but only few have over tried to design and synthesis membranes for MD processes. [3, 15, 16]. The objective of this study is the enhancement of MD flux by treating the commercial available membrane with alcohol and determining the effects of operating conditions on MD flux in AGMD process.

Table 1: Membrane Characteristics

Material	Hydrophobic PTFE
Pore Size, µm	0.22
Porosity, %	70
Thickness, µm	175
Membrane area, cm^2	3.6

2. EXPERIMENTAL

2.1 Membrane treatment

The PTFE membrane was treated by circulating 25% ethyl alcohol water mixture for one hour. This treatment was made the membrane hydrophilic. Again this membrane was dried and made the hydrophobic. This treatment modified the surface of the membrane.

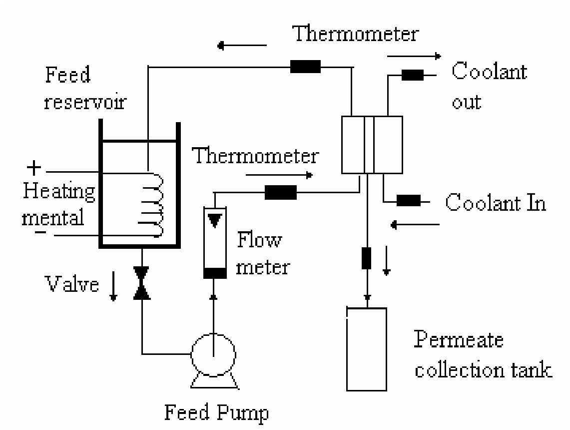

Figure 1. Experiemntal set up of AGMD

2.2. Experimental material and methodology

The experimental setup simply consists of a flat sheet hydrophobic micro porous PTFE membrane (Millipore) fixed in the PVC pipe, the feed compartment (150 x 25 mm) and cooling compartment (150 x 25 mm) **as** shown in Fig. 1. The typical characteristics of the membrane are summarized in Table 1. The permeate vapor diffused through the membrane and condensed due to contact with the cooling plate. The permeated liquid was collected in a graduated cylinder and the volume of permeates collected was noted with regular intervals of time and the collected samples were analyzed simultaneously. The natural ground water, 2938 mg/l TDS concentration, was used for the experimentation.

The effects of various operating parameters, such as the feed and coolant temperatures, feed flow rate, air gap thickness and operating time were analyzed and determined the optimum parameters for treated and non treated membrane. All the AGMD experiments were carried out for 2-3 h and after almost 2 h; the flux reaches equilibrium.

The MD flux (j, kg/m^2 h) is calculated by eq (1):

$$j = \frac{V \cdot \rho}{A \cdot t} \quad (1)$$

Where V is volume of freshwater (l); ρ is density of freshwater (kg/l); A is effective membrane area (m^2) and t is the running time. The concentration of ionic species in the feed water (C_1, mg/l) and in freshwater (C_2, mg/l) were calculated by the water analysis kit. The percentage removal (% R) of the species was calculated from eq. (2):

$$R = \frac{C_1 - C_2}{C_1} x100 \quad (2)$$

The membrane permeates flux, j, which is dependent on the membrane characteristics and the established driving force. The membrane distillation coefficient, B, was calculated by using the following expression as [4, 13].

$$j_i = B_i \Delta p_i \quad (3)$$

Where, Δp_i is the water vapor pressure difference between evaporating and condensing surface. The vapor pressure of the pure water component determined with the Antoine equation.

$$p_i = \exp\left[23.1964 - \frac{3816.44}{T - 46.13}\right] \quad (4)$$

3. RESULTS AND DISCUSSIONS

3.1. Effect of feed flow rate

The effect of feed flow rate was studied under the conditions of constant initial conditions of ground water are: feed temperature (333 k), coolant temperature (288 K) and air gap thickness of the module (1.2 mm). The changes in the permeate flux of ground water with respect to the various feed flow rates are shown in **Fig. 2.** The permeate flux increases rapidly with increasing feed flow rate for both treated and non treated membrane. The increase of the MD flux of treated membrane was 27 to 69 % as compared to the non treated membrane. Hence high turbulence as well as treating the membrane with alcohol is an effective tool for enhancement of the MD flux. After 55 l/h feed flow rate, no effect was found on the permeation flux for both membrane. The TDS rejection was greater than 99.9 % throughout all the experiments.

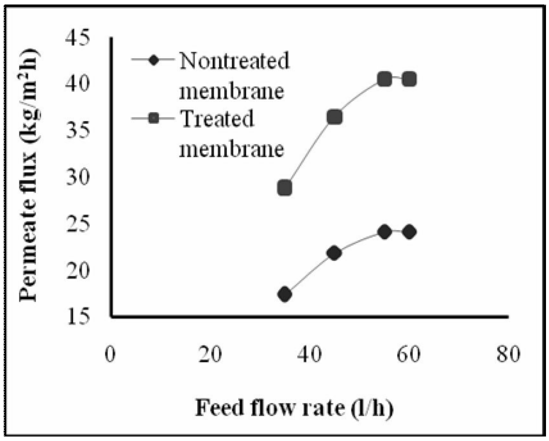

Figure 2. Effect of feed flow rate at feed temperature, 333 K, coolant temperature, 288 K and air gap thickness, 1.2 mm

3.2. Effect of feed temperature

The feed temperature plays an important role on permeation flux in MD performance along with the feed flow rate. **Fig. 3** shows the results obtained by varying the feed temperature, 313 to 333 K, by using treated and non treated membrane at constant feed flow rate, 55 l/h and coolant temperature, 288 K. The favorable results were found during the experiment for a treated membrane. The actual driving force for AGMD is the vapor pressure difference across the membrane, which is induced by this temperature difference. Although increase of feed temperature increases the water vapor pressure and the Reynolds number somewhat, it drastically increases the driving force. So the optimization of feed temperature is an effective way to get high water vapor flux.

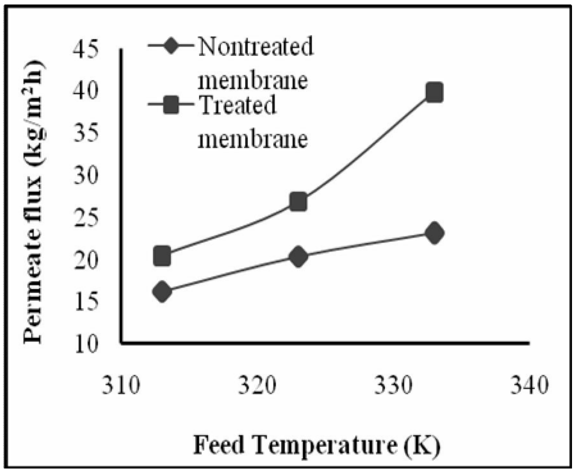

Figure 3. Effect of feed temperature at feed flow rate, 55 l/h, coolant temperature, 288 K and air gap thickness, 1.2 mm

3.3. Effect of coolant temperature

In AGMD process the permeate side temperature is very important at constant feed temperature. The effect of coolant temperature were studied by varying the cold-side temperature between 283 K and 298 K at a constant feed temperature, feed flow rate of natural ground water. The results of permeate flux is shown in **Fig. 4** for both the membrane. The flux did not change significantly with the coolant temperature but it was changed by using the treated membrane.

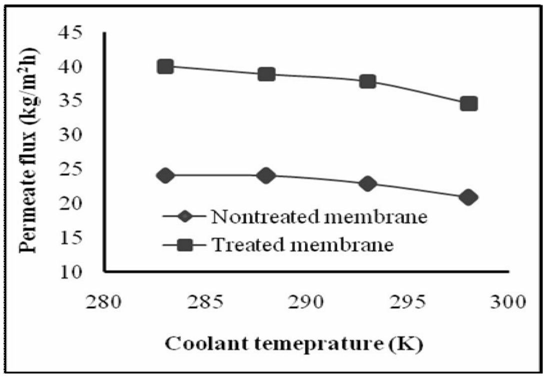

Figure 4. Effect of coolant temperature at feed flow rate, 55 l/h, feed temperature, 333 K and air gap thickness, 1.2 mm

3.4. Effect of air gap thickness

The air gap thickness was varied from 1.2 mm to 3.2 mm using gaskets. The effect of the air gap thickness were studied at constant feed concentration for ground water at feed flow rate (55 l/h), feed temperature (333 K), and coolant temperature (288 K). The results are shown in the **Fig. 5.** The permeate flux was significantly reduced due to increasing air gap thickness in the module at permeate side for both membrane because of the higher mass transfer resistance due to the air gap. So, the performance of AGMD process was improved by kept the minimum air gap thickness along with using the treated membrane.

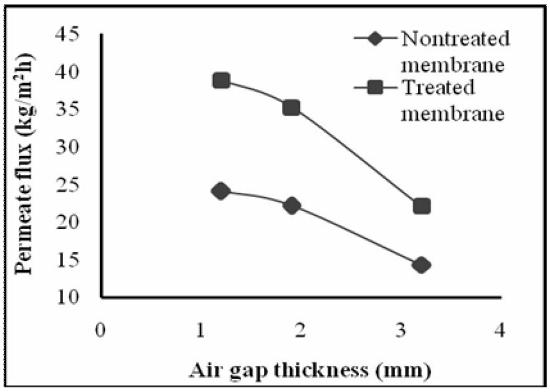

Figure 5. Effect of air gap thickness at feed flow rate, 55 l/h, feed temperature, 333 K and coolant temperature, 288 K

3.5. Effect of operating time

The experimental results of long term experimentation for both treated and non treated membrane are shown in **fig. 6.** The significant decline of the permeate flux were observed due to the formation of deposits on the non treated membrane surface. The flux decreases represents 14% for ground water by using non treated membrane and 2% by using treated membrane, in 90 h continuous operation. During the experiment, TDS of ground water was decreased >99.9% by using both the membrane over 90 h operation. Hence, the surface modification means changing the membrane morphology by treating the membrane with alcohol is the good sense for the treatment of ground water by reasonably for the large communities.

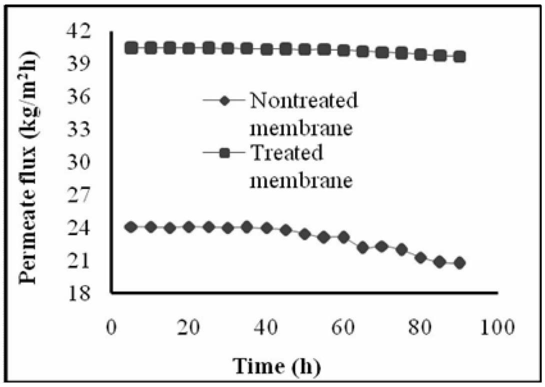

Figure 6. Time variation of permeate flux of natural ground water at feed flow rate, 55 l/h, feed temperature, 333 K and coolant temperature, 288 K

3.6. Mass transfer analysis

The membrane mass transfer coefficient was calculated for the ground water feed by experimentally using equation (3) and was found to be 3.15 x 10^{-3} kg/m^2h.Pa for non treated membrane. The vapor pressure of the water was calculated by using Antoine equation(4). The membrane mass transfer coefficient is dependent on the membrane characteristics. Because the membrane mass transfer coefficient of the treated membrane was increased to 4.47 x 10^{-3} kg/m^2h.Pa means increased by 42%.

4. CONCLUSIONS

The enhancement of the MD flux of AGMD process due to the surface modification of the PTFE membrane for desalination of natural ground water is presented experimentally. The influence of various parameters such as feed flow rate, feed temperature, coolant temperature, air gap thickness on AGMD permeate flux were studied by using treated and non treated membrane. It was observed that the transmembrane flux for treated membrane was 69% more than non treated membrane. Also, analyzed the membrane mass transfer coefficient of both the membrane and found for treated membrane was 42% more than non treated membrane. This was due to the change in morphology of the membrane and hence improved the MD flux.

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