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Study on the Vacuum Membrane Distillation Performances of PVDF Hollow Fiber Membranes for Aqueous NaCl Solution

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Membrane distillation (MD) is a novel membrane seperation thechonology which can be applied in seawater or brine desalination process. In this work, hydrophobic microporous PVDF Hollow Fiber membranes vacuum membrane distillation (VMD) performancs were investigated for aqueous NaCl solution..The effect of concentration of aqueous NaCl soluton, feed flow rate and temperature were studied. The lab scale and pilot scale experiments were carried out with membrane module effective area $0.0386m^2$ and $3.7397m^2$, respectively. The VMD performance of 6wt.% aqueous NaCl solution(which is the same concentration as the brine of seawater desalination) showed that the permeation flux reached 25.171 kg/($m^2 \cdot h$) and the salt rejection was as high as 99.8%, the pressure on the vacuum side was 3kPa, the feed temperature was 343.15K and the feed linear flow rate was 0.461m/s.

1. Introduction

Membrane distillation (MD) is known as a process which refers to the thermally driven transport of vapor through microporous, MD is a membrane separation technology with low cost and energy saving process(Lawson, Lloyd,1997 ; Alklaibi, Lior, 2004). Generally, MD is carried out for producting pure water or dealing with aqueous solutions, and the MD configurations include direct contact membrane distillation (DCMD), vacuum membrane distillation(VMD), sweeping gas membrane distillation (SGMD) and air gap membrane Distillation (AGMD). The membranes for MD are typically fabricated from polytetrafluoro-ethylene (PTFE), polyvinylidene fluoride (PVDF) and polypropylene (PP)(Kevin, Douglas,1996; El-Bourawi, Ding, et.al, 2006).
VMD is a thermally driven process in which the convective mass transfer is the dominant mechanism for mass transfer. The driving force is maintained by applying vacuum at the downstream side to keep the pressure at this side below the equilibrium vapor pressure. The membrane in this process is a physical support for the vapor-liquid interface and does not affect the selectivity associated with the vapor-liquid equilibrium (Banat, Al-Rub, 2003). Compared with conventional separation techniques, VMD has many advantages: VMDcan be applied only with a limited volume of the membrane

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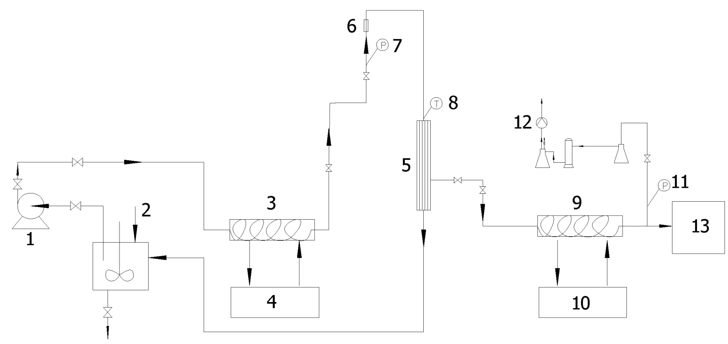
equipment(Li, Sirkar, 2005). VMD can be also operated at relatively low evaporation temperatures, typically 60~90°C. Thus, a low cost energy source is required to supply the heat for evaporation.Economically, VMD is found to be comparable when considered the separation costs of other membrane alternatives such as pervaporation, In contrast, pervaporation process depends mainly on using a dense membrane, which alters the vapor-liquid equilibrium. (Khayet , Godino, et.al, 2000; Hsu, Cheng, et.al, 2002).VMD has the potential to be one of the most common techniques used to separate dilute aqueous mixtures. Applications include the removal of trace concentrations of VOC's from water and can be used when the feed contains non-volatile salt as in desalination process (Bandini, Gostoli,et.al, 1992; Bandini, Saavedra, et.al, 1997; Banat, Simadl, 1996).

In this work, hydrophobic microporous PVDF Hollow Fiber membranes vacuum membrane distillation (VMD) performancs were investigated for aqueous NaCl solution. The lab scale and pilot scale experiments were carried out with membrane module effective area 0.0386m^2 and 3.7397m^2, respectively. PVDF Hollow Fiber membranes showed a good performance for seawater or relatived brine desalination process using VMD technology.

2. Experiment

A schematic diagram of the experimental set-up is shown in Fig. 1. The membrane module was purchased from Tianjin MOTIAN membrane ENG & TECHCO.LTD mounted with porous PVDF hollow fibers. The parameters of the hollow fiber membranes are: the internal diameter is 0.8mm, the membrane thickness is 0.15mm , the average pore size is 0.16μm and Porosity is 85%. In all experiments, the aqueous feed was circulated through the lumen of the hollow fibers. The vapor was removed from the shell side of the module by the suction of a vacuum pump. Cold traps refrigerated by liquid antifreeze were used to condense and recover the permeated vapors. In the experiments, two different scale membrane modules of which the membrane area was 0.0386m^2 and 3.7397 m^2, respectively. The effect of the VMD factors such as feed temperature, feed flow rate, concentration of the feed on the flux were studied in this work.



1. Pump 2. Storage tank 3. Heat exchanger 4. Heat thermostat 5. Membrane module

6. Flow meter 7.Pressure meter 8. Temperature meter 9. Cold exchanger

10. Cold thermostat 11. Vacuum meter 12. Vacuum pump 13. Permeate collector

Fig. 1 Schematic diagram of VMD experimental setup

2.1 Permeation and permeation selectivity

2.1.1 Permeation flux

Aqueous NaCl solution permeation flux was given by equation (1). The concentration, temperature,and flow status of the feed as well as membrane structures are main factors affecting permeation flux.

$$J = \frac{W}{S \times t} \qquad (1)$$

Where J is the permeation flux, kg/(m^2·h); W is the weight of vapour across the membrane, kg; S is the membrane effective area of membrane module, m^2; t is the operational time, h.

2.1.2 permeation selectivity

The permeation selectivity is an important index in VMD process. conductivity is used to measure the concentration of permeation solution. Salt rejection ratio was calculated for aqueous NaCl solution permeation selectivity from equation (2).

$$R = \frac{C_h - C_c}{C_h} \times 100\% \qquad (2)$$

Where R is the Salt rejection ratio of aqueous NaCl solution; C_h is the concentration of feed aqueous NaCl solution mol/L; Cc is the concentration of permeation solution, mol/L.

3. Results and discussion

3.1 Effect of feed concentration

The effect of feed concentration on the VMD performance of aqueous NaCl solution was investigated when the vacuum pressure was 0.085MPa, the feed flow rate was 0.461m/s, and the feed temperature were 323.15K, 333.15K, 343.15K respectively, the concentration of aqueous NaCl solution were 0.5 mol/L, 0.7 mol/L, 0.9 mol/L, and 1.2mol/L, respectively. The result was shown in Figure 2.

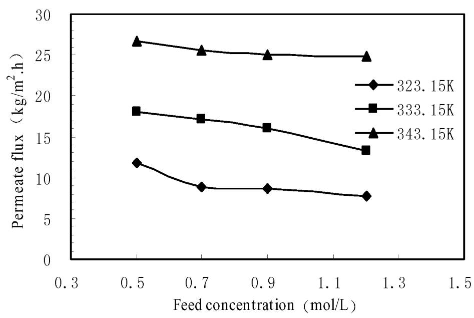


Fig.2 the effect of feed concentration on permeation flux

Fig.2 showed that the penetration flux decreased with the increasing of feed concentration, when the concentration becomes higher slightly, the tendency of decreasing is moderate. The concentration of aqueous NaCl solution influences the temperature polarization and concentration polarization on the thickness of heat transfer and mass transfer boundary layer. The lower temperature of membrane surface leads to the reducing of water vapor pressure, the increasing of resistance in transfer process and the reducing the driving force acrossing the membrane, which reduce the permeation flux. When it is in a higher concentration, the decreasing tendency is gently, and it indicates that VMD is more suitable for diluting high salinity brine, which provides a basis for the treatment of a higher concentration of salt water desalination.

3.2 Effect of feed flow rate

The permeation flux of aqueous NaCl solution in VMD was influenced by ont only the membrane morphology but also the feed flow condition. The feed liquid linear velocity in membrane module was given by equation (3).

$$u = \frac{4V_s}{\pi d_i^2 n} \qquad (3)$$

Where u is feed liquid linear velocity, m/s; V_s is the volume flow rate, m^3/h; d_i is the internal diameter of the hollow fiber membrane, m; n is the number of hollow fiber member within the membrane module.

6wt.% aqueous NaCl solution VMD performanc was investigated when the absolute pressure on vacuum side was 0.085MPa and the feed temperature were 323.15K, 333.15K, 343.15K, effect feed linear velocity on the permeation flux was shown in fig. 3 and fig.4 for lab scale experiment and pilot scale experiment, repectively.

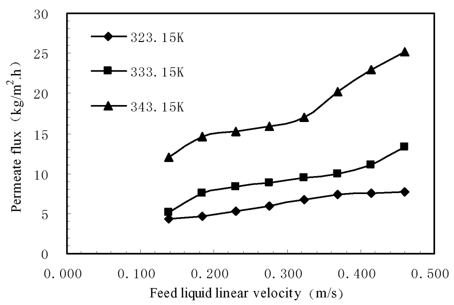


Fig.3 Effect of feed liquid linear velocities on permeation flux for lab scale experiment

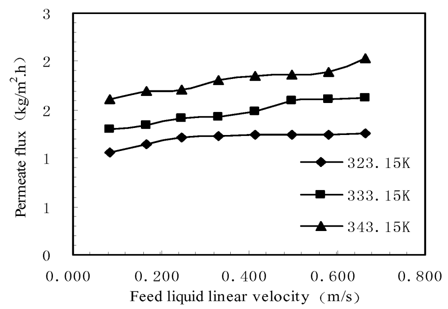


Fig.4 Effect of feed liquid linear velocities on permeation for pilot scale experiment

The result showed that the permeation flux increased with the increasing of feed linear speed , which is more obvious when feed temperature is higher. The thickness of feed heat transfer and mass transfer boundary layer decreased with the increasing of feed linear velocity, so vapour transfer resistance acrossing the membrane decreased, which induced to the incresing of permeation flux obviously.

3.3 Effect of feed temperature

PVDF hollow fiber membranes VMD performance were carried out, the concentration of aqueous NaCl solution were 3.5wt.% and 6wt.%, respectively, the absolute pressure on vacuum side was 0.085Mpa, the feed linear flow was 0.461m/s. Effect of temperature on the permeation flux was shown Fig. 5.

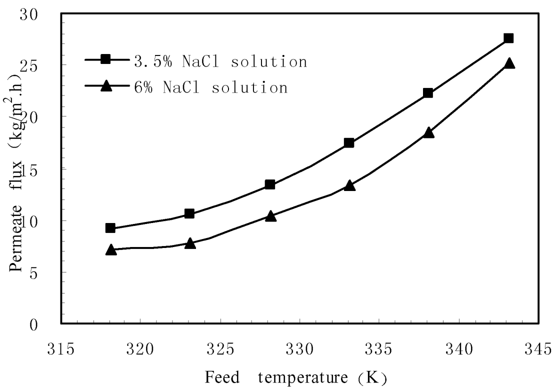


Fig.5 Effect of temperature on permeate flux

Fig.5 showed that the permeation flux of VMD process increases obviously with the increasing of feed liquid temperature at the same operaional condition. The main driving force is pressure difference acrossing the membrane in VMD process. The feed temperature increases, making the vapour pressure of gas-liquid interface on liquid feed side increases when the temperature increase, the driving force of mass transfer increases accordingly.

4 Conclusions

PVDF hollow fiber membranes VMD performance of aqueous NaCl solution was developed in this work. When the feed flux is constant, the VMD permeation flux increased with the increasing of the feed concentration. The VMD permeation flux increased obviously the increasing of feed linear flow rate at the same feed temperature. When the temperature and the flux of feed are constant , along with the increasing of liquid concentration, VMD permeation flux of aqueous NaCl solution reduced, but under slightly higher concentrations, the tendency of reduced gently.

The permeation flux reached 25.171 kg/(m^2·h) and the salt rejection was as high as 99.8%, the pressure on the vacuum side was 3kPa, the feed temperature was 343.15K and the feed linear flow rate was 0.461m/s, which showed a good prospect for the application of PVDF hollow fiber membranes in the field of high salinity brine and seawater desalination process by VMD technology.

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