International Journal of Chemistry and Chemical Engineering.
ISSN 2248-9924 Volume 3, Number 3 (2013), pp. 209-214

http://www.ripublication.com

Application of Vacuum Membrane Distillation for Fluoride Removal

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Abstract

This study aims to investigate the applicability of vacuum membrane distillation for fluoride removal from its aqueous solutions. Fluoride, although beneficial when present in concentration of 0.8-1.0 mg/l, has been associated with mottled enamel of teeth when present in potable waters in excess of 1.5 mg/l and skeletal fluorosis beyond 3 mg/l. Among the different recognized membrane distillation configurations, vacuum membrane distillation is applied in the present work for fluoride removal. The effects of different operating parameters on fluoride removal from aqueous solutions of different concentrations have been investigated. Experimental results showed that high feed temperatures, low downstream pressures and low initial feed concentrations and feed flow rate enhance fluoride removal efficiency. Temperature and concentration polarizations within feed boundary layer proved to have a significant influence on mass transport. High feed flow velocity is an important tool diminishing temperature and concentration polarizations effects. The maximum flux reached to 16.98 kg/m^{2}h at feed temperature 333 K, vacuum pressure of 200mmHg, feed flow rate 90 l/h and feed concentration 20 mg/l. Fluoride removal in the range of 97.8 to 99.7 % was achieved in this study.

Keywords: Vacuum membrane distillation; fluoride; PTFE hydrophobic microporou membrane.

1. Introduction

With increasing global population, the gap between the supply and demand for water is widening and is reaching such alarming levels that in some part of the world, it is passing a threat to human existence [Li 2009]. The U.S. geological survey found that 96.5% of earth's water is located in seas and oceans, and 1.7% of earth's water is located in the ice caps. Approximately 0.8% is considered to be fresh water. The remaining percentage is made up of brackish water, slightly salty water found as surface water in estuaries and as groundwater in salty aquifers [Greenlee 2009].

Fluorine, a fairly common element of the earth's crust, is present in the form of fluorides in a number of minerals and in many rocks. Industrial activities involving the use of fluorine-containing substance results in fluoride contamination of the environment. Thus plants, food stuff and water all contain traces of fluoride [Nawlakhe1993]. The routes of human exposure to fluorides are essentially through drinking water and food and exposure through air is insignificant in comparison with ingested fluorine. Fluorine ingested with water is almost completely absorbed while that in the diet is not as fully absorbed. Absorbed fluoride is distributed rapidly throughout the body and is retained mainly in the skeleton with a small portion in the teeth. Once incorporated in the acidic conditions and thereby provides protection against dental caries. Fluoride although beneficial when present in concentration of 0.8-1.0 mg/l, has been associated with mottled enamel of the teeth when present in potable waters in concentrations excess of 1.5 mg/l. Skeletal fluorosis has been observed at concentration beyond 3 mg/l. According to WHO revised Guideline for drinking water quality (2004), the excessive limit for fluoride is fixed as 1.5 mg/l, after which the water needs treatment for its removal. Excessive fluorides in drinking water in India, it occurs in the state of Andhra Pradesh, Bihar, Gujarat, Haryana, Karnataka, Madhya Pradesh. Maharashtra, Orissa, Punjab, Rajasthan, Tamil Nadu and Uttar Pradesh. There are 8700 villages in India which have the problem of excessive fluoride in water affected 25 million people [Nawlakhe 1993].

This study proposes VMD process, in which a feed solution is brought into contact with one side of a micro porous membrane, and vacuum is pulled on the opposite side to create a driving force for mass transfer. When feed is a water containing salts, the water is a vaporized close to the pores and then passes as a vapor through the membrane pores. Permeate condensation take place outside the module. VMD can be characterized by the following steps: vaporization of the more volatile compounds at the liquid-vapor interface and diffusion of the vapor through the membrane pores according to a Knudsen mechanism [Mohammadi et. Al 2005-Banat et. al.2003]. Compared with conventional separation techniques, VMD is found economically to be comparable with respect to the separation costs of the membrane alternatives such as pervaporation. Hence, recently VMD has become an active area of research by many. Most of the researchers studied the use of VMD in the removal of trace gases and volatile organic compounds from water and it has also been proposed as a means for the sea water desalination. Also, the major advantage is to reduce the environmental impact of rejected brines of reverse osmosis technology, means to reduce the brine volume and disposal [Banat 2003, Mericq 2009].

2. Experimental

The experimental process simply consists of a flat sheet hydrophobic micro porous PTFE membrane (Millipore) and diaphragm vacuum pump with a condenser for water recovery or trap as shown in fig. 1. The typical characteristics of the membrane are summarized in Table 1. The membrane was located in 90 mm diameter plate type of module prepared from stainless steel material. The diameter of inlet and outlet is 10 mm. The aqueous feed solution of 20 and 30 mg/l NaF in pure water were prepared and continuously fed to the membrane module from a reservoir by using a pump. A flow rate of feed water was measured by the flow meter connected in between the pump and module. A vacuum pump was connected to the permeate side of the membrane module to remove the water vapor flux. Cold trap was used to condense and recover the water permeating vapor. The condensed pure water was collected to calculate the distillate flux. Calibrated vacuum gauge was used to measure the pressure at the permeate side of the module. The feed temperature was 333 K and downstream pressure was 200 mmHg respectively. After every 2 hours, the permeate flux was collected and examined.

Table 1: Membrane characteristics.

S. No.	Properties	Specifications
1	Membrane material	PTFE
2	Surface property	Hydrophobic
3	Diameter, mm	90
4	Pore size, µm	0.22
5	Thickness, µm	175
6	Porosity %	70
7	Effective membrane area, m^2	0.00212
8	Maximum operating temperature, ^0C	130
9	Supplier	Millipore

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

$$N = \frac{V.\rho}{A.t} \quad (1)$$

Where V is volume of permeate water (l); ρ is density of permeate water (kg/l); A is effective membrane area (m^2) and t is the running time of VMD. The concentration of ionic species in the feed water (C_1, mg/l) and in permeate water (C_2, mg/l) were calculated by the fluoride ion meter [Upadhyaya2010, 2011]. The percentage removal (% R) of the species was calculated from eq. (2):

$$R = \frac{C_1 - C_2}{C_1} \times 100 \tag{2}$$

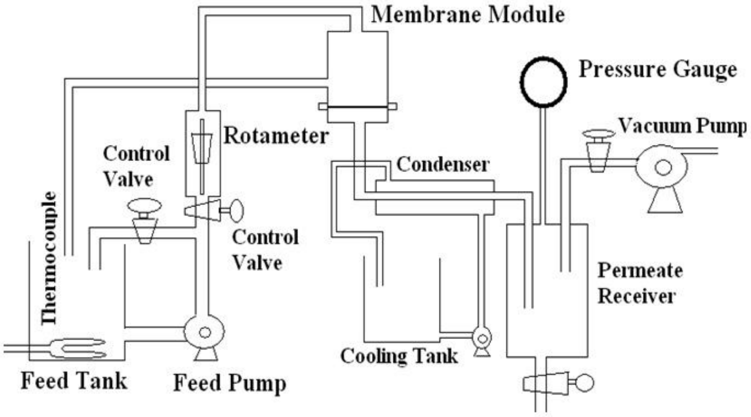
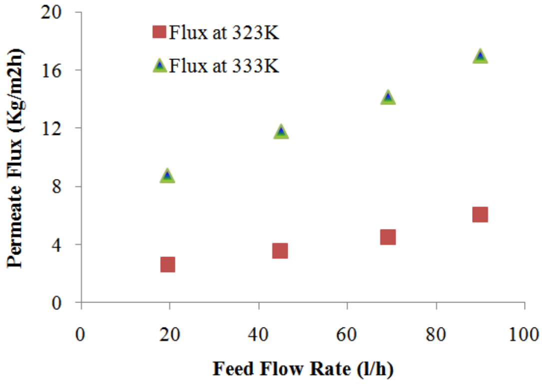


Fig. 1: Schematic representation VMD setup.

3. Results and Discussion

3.1 Effect of feed flow rate

The effect of feed flow rate on permeate flux at 20 mg/l sodium fluoride feed solution, 200 mmHg permeate pressure and feed temperature of 323 and 333K is shown in fig 2. Positive effect on permeate flux is observed on increasing feed flow rate range from 20 to 90 l/h. Fluoride rejection greater than 99 % is seen throughout all the experiments . The maximum permeate flux of 16. 98 kg/m^2 h obtained at feed flow rate of 90 l/h, feed temperature of 333K under 200 mmHg pressure.



Pressure = 200 mmHg and feed flow rate 90 l/h

Fig. 2: Effect of feed flow on permeate flux.

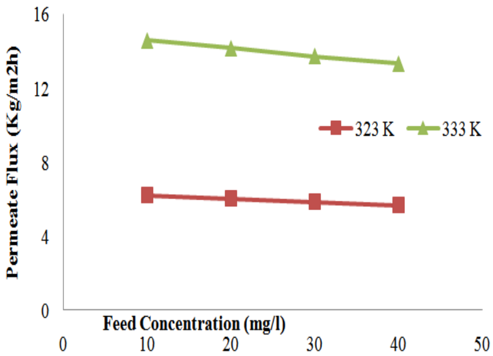


Fig. 3: Effect of feed concentration at Permeate.

3.2 Effect of feed concentration

The effects of feed concentration on permeate flux under vacuum pressure of 200 mmHg is shown in fig 3. The feed temperature is kept at 323 and 333K respectively at feed flow rate of 90 l/h. Only 3% reduction in permeate flux is observed on increasing the feed salt concentration from 10 to 40 ppm of fluoride. Hence, one of the most significant advantages of the VMD process for desalination is the relative nominal effect at lower feed salt concentration on the performance of the system.

4. Conclusion

The effect of feed flow rate and feed salt (sodium fluoride) concentration on permeate flux were studied. It is found that the permeate flux increase linearly on increasing the feed flow rate from 20 to 90 l/h under 200 mmHg vacuum pressure. The maximum permeate flux of 16.98 kg/m^2 h is obtained at feed flow rate of 90 l/h, feed temperature of 333K and feed salt concentration of 20 mg/l. The negligible effect of feed salt concentration is seen on permeate flux. The declination in permeate flux of 3 % is depicted on increasing the feed salt concentration. Fluoride removal in the range of 97.8 to 99.7 % was achieved in this study.

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