Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, November 2-3, 2006

Investigation of membrane dependent permeation fluxes using AGMD and pressure-driven AGMD processes

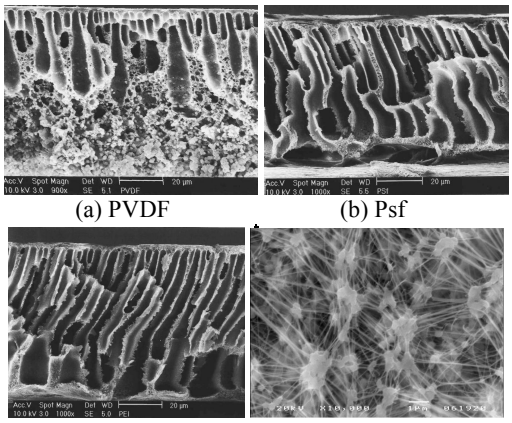
Yun-Young Choi, Sewon Bae[a], Jaewoo Kim[b], Dae-Shik Chang[b], and Hwa-Rim Choi[b]
Department of Chemistry, Kyungnam University, Masan, Kyungnam, Korea 631-701
[a]Department of Chemistry, Changwon National University, Changwon, Kyungnam, Korea 641-773
[b]Lab for Quantum Optics, Korea Atomic Energy Research Institute, Yuseong-Gu, Daejeon, Korea 305-353
yychoi@kaeri.re.kr

1. Introduction

Since early 90's, membrane distillation has been applied for separating light isotopes such as hydrogen and oxygen constituting water molecules [1-3]. Due to a merit of its high separation factor compared to a conventional fractional distillation, applicability to a real production system and economic viability of the process have been investigating since then. Because permeation flux of AGMD (Air Gap Membrane Distillation) is relatively low, it is essential to build an efficient cascade system to increase the degree of enrichment. Previous research shows the higher permeation flux of the pressure-driven AGMD which is applicable to a cascade system [4]. In addition to this, selection of the membrane material for the process is critical to enhance the system efficiency by increasing permeation flux, isotope selectivity, and system liability. This investigation focuses on the permeation flux comparison of the several types of hydrophobic membrane including PVDF (Polyvinylidene Fluoride), PEI (Polyether Imid), Psf (Polysulfone), and PTFE (Polytetrafluoroethylene) using AGMD and pressure-driven AGMD depending on the various experimental conditions.

2. Experimental

Diagram of the experimental system used in this experiment can be found in the reference [3]. Membranes used in this investigation were manufactured by the Center for Chemical Process, Korea Research Institute of Chemical Technology except commercial PTFE (Millipore) membrane. Average pore diameters of the membranes were ~ 3.2 μm for PVDF, ~ 3.0 μm for PEI, ~ 3.5 μm for Psf, and ~ 0.22 μm for PTFE. Porosities were assumed based on the SEM images of the membranes, and these were ~ 70% for PVDF, ~ 80% for PEI, ~ 80% for Psf, and ~ 85% for PTFE. Figure 1 shows the sectional SEM images of the membranes used in the experiment. Permeation fluxes were measured by weighing the membrane permeated water during a certain period time. Detailed experimental procedure and information are available in the reference [3].



(a) PVDF (b) Psf (c) PEI (d) PTFE

Figure 1. SEM images of the various types of membranes: (a, b, c are sectional images and d is plane image)

Permeation flux, in general, can be expressed [5] by a diffusion model in Eq. (1) if air is filled in the pores when the water molecules transport through air molecules in the pores, which is equivalent to the case of AGMD. On the other hand, Knudsen diffusion in Eq. (2), if the mean free path of water molecules is larger than the pore diameter, can be applied for diffusion of water molecules in the absence of air molecules in the pores, which indicates the case of pressure-driven AGMD.

$$J_D = \frac{D\varepsilon}{\chi\delta}\frac{M}{RT}\frac{(P_1 - P_0)}{Y_{\ln}} \quad (1)$$

$$J_K = 1.064\frac{r\varepsilon}{\chi\delta}\left(\frac{M}{RT}\right)^{0.5}(P_1 - P_0) \quad (2)$$

According to these relationships, permeation flux strongly dependent on the pressure differences between upper side and lower side of the membrane, i.e. temperature difference between membrane interfaces.

3. Results and Discussion

AGMD and pressure-driven AGMD under various temperature conditions were experimented to measure water vapor permeation characteristic which is strongly dependent on the equilibrium vapor pressure of the feed using the various types of the membranes. For AGMD, as the temperature of the feed water and the membrane interfacial temperature gradient increase, the equilibrium vapor pressure of the feed and the membrane interfacial driving force increase respectively,

causing increase of the permeation of flux. On the other hand, increase of the membrane interfacial pressure gradient for pressure-driven AGMD results much higher permeation flux than that of AGMD at the same temperature conditions as shown in the next sections.

3.1 Permeation Flux Dependent on Feed Temperature for AGMD and pressure-driven AGMD

Figure 2 shows the degree of the permeation flux dependent on feed water temperature for both AGMD and pressure-driven AGMD. As shown in the graphs, feed temperature must be the most important factor to increase the permeation flux for both processes. Especially PTFE membrane shows much higher permeation flux than other membranes. Pressure driven AGMD was also efficient than AGMD especially at lower feed temperature region than AGMD.

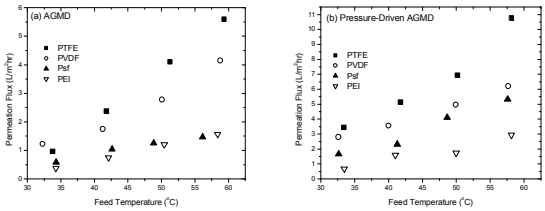


Figure 2. Feed temperature dependent permeation flux for (a) AGMD (b) pressure-driven AGMD

3.2 Permeation Flux Dependent on Temperature Gradient of Membrane Interface for AGMD and pressure-driven AGMD

Figure 3 also shows strong dependency of the temperature gradient of the membrane interface on the permeation flux for both processes. PTFE membrane in this experiment shows the highest permeation flux among other membranes. As the same with the above results, the efficiency of pressure-driven AGMD was much higher at the low temperature gradient region. Permeation flux for pressure-driven AGMD at $\Delta T \sim 10^{o}C$ was 3-fold higher than AGMD while it was only about 2-fold at $\Delta T \sim 40^{o}C$.

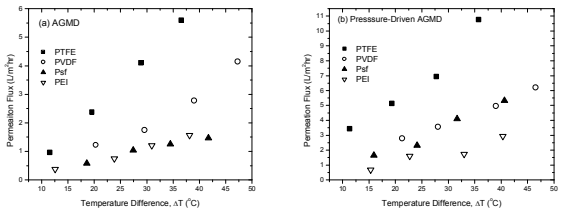


Figure 3. Temperature gradient dependent permeation flux for (a) AGMD (b) pressure-driven AGMD

4. Conclusion

Based on permeation flux measurements of the several membranes made from different materials, it was clear that pressure-driven AGMD produces higher permeation flux than AGMD. It was also confirmed that the PTFE membrane results the highest permeation flux among other membranes. Consequently, use of the PTFE membrane must be practically important for the construction of a multi-stage cascade system using pressure-driven AGMD due to its higher permeation flux than the other membranes. Also, pressure-driven AGMD using PTFE membrane will save energy input for the operational system since it is more effective at low temperature region, i.e. energy requirement for system operation should be reduced while the permeation flux can be remained at the same. Detailed experimental results including the dependency of membranes on the isotope selectivity will be presented at the meeting.

Nomenclature

D: Diffusion coefficient, M: molecular mass, P: water vapor pressure on the feed side, P: water vapor pressure on the permeate side, R: gas constant, T: temperature, δ: membrane thickness, ε: porosity, η: gas viscosity, χ: tortuosity factor

REFERENCES

[1] A. G. Chmielewski, G. Z-. Trznadel, N. Miljevic, and W. A. van Hook, "$^{16}O/^{18}O$ and H/D separation of liquid/vapor permeation of water through an hydrophobic membrane", J. Membr. Sci., Vol. 60, 319-329, 1991.

[2] A. G. Chmielewski, G. Z-. Trznadel, N. Miljevic, and W. A. van Hook, "Membrane distillation employed for separation of water isotopic compounds", Sep. Sci. Technol., Vol. 30(7-9), 1653-1667, 1995.

[3] Jaewoo Kim, Sang Eon Park, Taek-Soo Kim, Do-Young Jeong, and Kwang-Hoon Ko, "Isotopic water separation using AGMD and VEMD", Nukleonika, Vol. 49(4), 137-142, 2004.

[4] Jaewoo Kim, Hwa-Rim Choi, Dae-Shik Chang, and Yun-Young Choi, "Development of the pressure driven AGMD process applicable to a multi-stage oxygen isotope separation system", Transactions of the KNS, May 25-26, 2006

[5] R. W. Schofield, A. G. Fane, and C. J. D. Fell, "Heat and mass transfer in membrane distillation", J. Membrane Sci., Vol. 33, 299-313, 1987.