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막 두께 및 유동 조건에 따른 PEMFC 용 Gas to Gas 막가습기의 열/물 교환 특성

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Characteristics of Heat and Water Transfer in Gas to Gas Membrane Humidifiers with Various Membrane Thickness and Flow Condition

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Key words : PEMFC, Humidifier(가습기), Nafion Membrane(나피온 막), Heat Transfer(열전달), Water Transfer(물전달)

Abstract : Characteristics of heat and water transfer in gas-to-gas membrane humidifiers have been experimentally investigated for various humidity and flow rates of gas and for different thickness of Nafion membrane. The results emphasizes the importance of flow velocity for both water and heat transfer. Aso, the effect of membrane thickness has been revealed to be significant to water transfer especially for unsaturated flows, while the significance of membrane thickness is minimal to heat transfer.

Nomenclature

A_{ex}	effective exchange area
DP	dew point
RH	relative humidity
T	temperature
V	velocity
c_p	specific heat
h	enthalpy
$\dot{m}$	mass flow rate,
$\overline{m}_w''$	average mass flux
$\overline{q}''$	average heat flux
ω	humidity ratio

subscrip

DI	dry side inlet
HO	humid outlet
WI	wet side inlet
WO	wet side outlet
a	air
avg	average of dry and wet side inlets
w	water
tr	transfer

1. Introduction

Gas-to-gas membrane humidifiers draw attraction in PEMFC system due to their high performance in transferring heat and water without any extra component or any parasitic loss or any moving part[1, 2]. The heat and water transfer in a membrane humidifier is mainly determined by diffusion inside the membrane and convection at the surface of the membrane and, therefore, highly linked with temperature and water content of membrane as well as the velocity and thermo-physical property of the fluid[3, 4]. In the present study, characteristics of heat and water transfer in a gas-to-gas membrane humidifier have been experimentally investigated for various flow conditions and various thickness of membrane.

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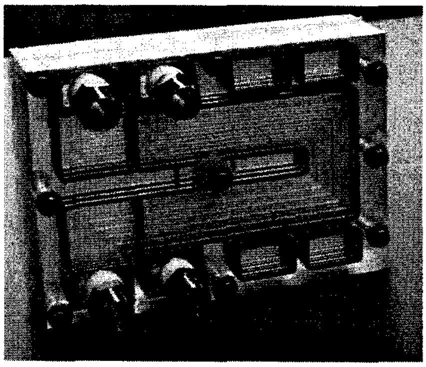

Fig. 1 A photoraph of the humidifier

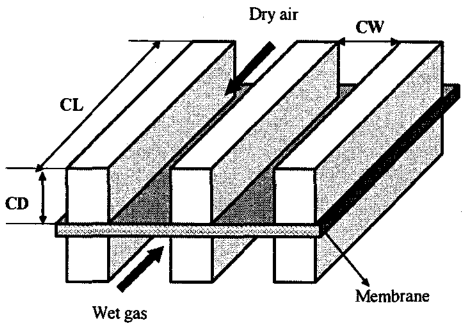

Fig. 2 A schematic of the internal structure of the humidifier

2. Experimental

The humidifier consists of multiple layers of plates, each of which has flow channels on the both sides. Nafion membranes are located between the plates to separate the flow channels so that the structure is similar to that of a FC stack. A photo and a schematic of the internal structure of the humidifier are shown in Fig. 1 and Fig. 2, respectively.

In Fig. 2, Dry and wet air flows in counter direction at each side of the membranes. The Depth and width of the flow channels, represented respectively as CD and CW in Fig. 2, are commonly 3 mm for both dry and wet sides. The effective length of the channel, CL, is 286 mm.

A schematic apparatus of the test equipment is also shown in Fig. 3. In this figure, DI, HO, WI, and WO represents dry air inlet, humidified air outlet, wet gas inlet, and wet gas outlet, respectively and T, P, H, M, and LH are temperature sensor, pressure sensor, humidity sensor, mass flow controller, and line heater, respectively. The equipment independently controls mass flow rate, temperature, and humidity of the inlet gases and monitors

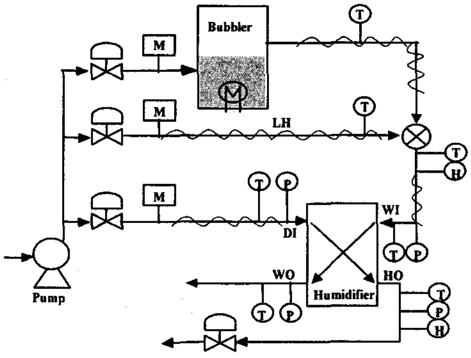

Fig. 3 A schematic apparatus of the test equipment

pressure, temperature, and humidity at the inlet and outlet ports of the humidifier. The monitored data are automatically acquired to PC and the overall heat and water transfers are calculated from the measured data. In the present study, the same amount of dry air is supplied to both dry and wet lines while corresponding amount of water vapor is added to the air in the wet side. The inlet temperatures of dry and wet airs are maintained to 25 °C and 65 °C, respectively.

From the measured temperatures and humidities at inlets and outlets, average mass flux, $\overline{m}_w''$ and average heat flux, $\overline{q}''$ could be obtained from following equations,

$$\overline{m}_w'' = \frac{\dot{m}_{w,HO}}{A_{ex}} = \frac{\omega_{HO}\dot{m}_a}{A_{ex}} \qquad (1)$$

$$\begin{aligned} \overline{q}'' &= \frac{\dot{m}_a}{A_{ex}}\left(h_{a,HO} - h_{a,DI} + \omega_{HO}\left(h_{w,HO} - \overline{h}_w\right)\right) \\ &\cong \frac{\dot{m}_a}{A_{ex}}\left(c_{p,a}\left(T_{HO} - T_{DI}\right) + \omega_{HO}c_{p,w}\left(T_{HO} - \overline{T}_{tr}\right)\right) \qquad (2) \\ &\approx \frac{\dot{m}_a c_{p,a}}{A_{ex}}\left(T_{HO} - T_{DI}\right) \end{aligned}$$

where, $\dot{m}$ is mass flow rate, A_{ex} is effective exchange area, ω is humidity ratio, h is enthalpy, c_p is specific heat, and T is temperature, respectively, and subscripts w, a, and tr menas water, air, and transfer, respectively.

3. Results

3.1 Heat Transfer

Figure 4 shows the average heat flux across the membrane as a function of channel flow velocity for

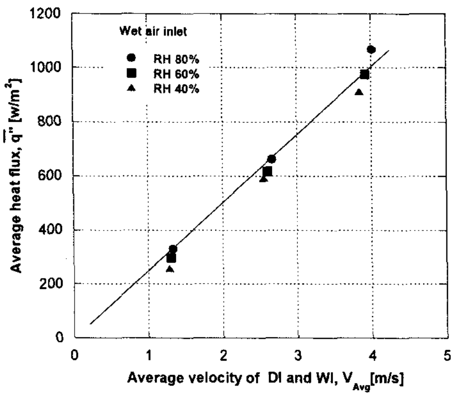

Fig. 4 Average heat flux across Nafion 115 as a function of channel flow velocity

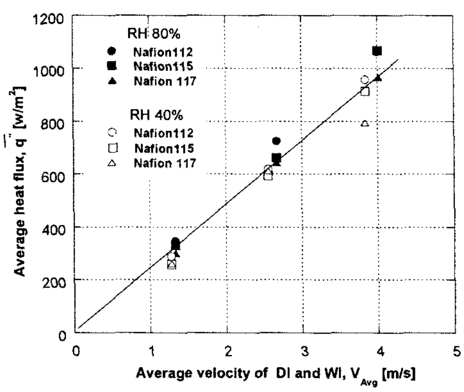

Fig. 5 Average heat flux across Nafion 112, 115, and 117 membranes as a function of channel flow velocity

various wet air humidity at the inlet. Here, RH means relative humidity at wet air inlet. As shown in Fig. 4, heat flux increases linearly with flow velocity emphasizing the importance of convective heat transfer especially in thermal entry region. Humidity is also shown to increase heat flux slightly. Considering that the increase of humidity decreases conductivity of the air, it is likely that the increase of heat flux is due to the increase of thermal conductivity in membrane having higher water contents.

Figure 5 shows the average heat flux vs channel flow velocity for 3 different Nafions with 80% and 40% relative humidity in wet air at the inlet. Here, Nafion 112, 115, and 117 have thickness of 51, 127, and 183 μm, respectively. Obviously, membrane thickness decreases overall heat flux, which is also can be seen in this figure. However, the amount of variation is not much serious considering that thickness of Nafion 117 is more than 3 times larger than that of Nafion 112. This represents, in this study, that thermal resistance via conduction through membrane is much smaller than those via convections at the surfaces. What is more interesting is that the heat flux for Nafion 117 with 80% and Nafion 112 with 40% is almost same implying that the variation of thermal conductivity with water content in membrane is comparable to the variation of thickness which is more than 300%.

3.2 Water Transfer

Figure 6 shows the average mass flux of water across the membrane as a function of flow velocity for various wet air humidity at the inlet. Similarly to heat flux, water flux also increases linearly with flow velocity, which suggests a strong similarity between heat and mass transferring phenomena.

Figure 7 shows the average water flux as a function of the thickness of Nafion membrane. For relatively humid membranes when humidity of wet air inlet is 80%, as shown in Fig. 7a, the influence of the membrane thickness is not quite significant even though the water flux decreases consistently with the thickness. However, for relatively dry membranes when humidity of wet air inlet is 40%, as shown in Fig. 7b, the membrane thickness plays a major role in determining overall water transfer. Considering that the thickness of the membrane is not likely to affect the convective transfer, the different behavior between dry and humid conditions implies the importance of humidity to diffusive water transfer coefficients of the membranes.

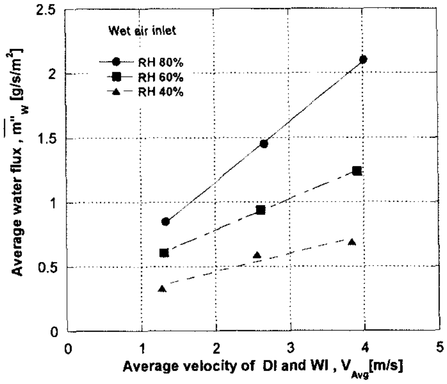

Fig. 6 Average water flux across Nafion 115 membrane as a function of channel flow velocity

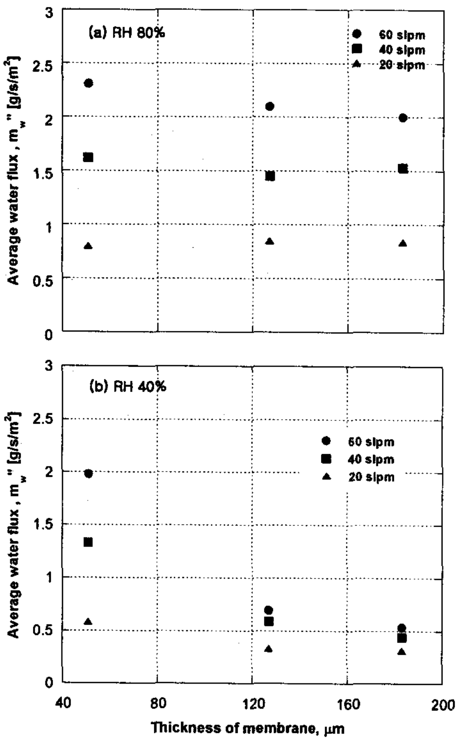

Fig. 7 Average water flux as a function of the thickness of Nafion membrane for (a) RH = 80% and (b) RH = 40% at the inlet of wet air

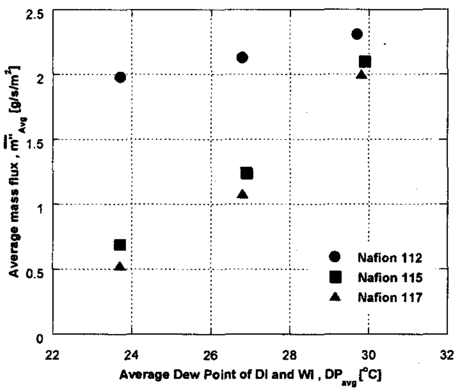

Fig. 8 Average water flux as a function of the average dew point of gas inlets

In order to investigate the relation between humidity and the water diffusion in Nafion membranes, water flux is shown as a function of the average dew point of gas inlets for various membrane thickness. In this figure, it can be clearly seen that the effect of membrane thickness on overall water flux varies significantly with flow humidity. This result demonstrates that the diffusion coefficient increase dramatically with water contents in Nafion membrane which is consistent with the previous studies[3, 4].

4. Concluding Remarks

Characteristics of heat and water transfer in gas-to-gas membrane humidifiers for PEMFC were investigated experimentally. The study conducted on the heat flux and water flux for various humidity and flow rates of gas and for different thickness of Nafion membrane.

In the present study, both heat and water fluxes increase linearly with flow velocity, implying similarity of convective transfer between heat and mass. Since thermal resistance to convection is sufficiently large compared to conduction, the effect of membrane thickness or humidity on overall heat flux is minimal. On the other hand, hydro-permeability of Nafion has been revealed to be a strong function of water content so that membrane thickness becomes important for relatively dry flows while the importance becomes nominal for relatively humid flows.

후 기

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References

[1] K. H. Choi, D. J. Park, Y. W. Rho, Y. T. Kho, and T. H. Lee, "A Study of the Internal Humidification of An Integrated PEMFC Stack," J. Power Sources, Vol. 74, pp. 146-150, 1998.

[2] S. Miachon and P. Aldebert, "Internal Hydration H2/O2 100 cm2 Polymer Electrolyte Membrane Fuel Cell," J. Power Sources, Vol. 56, pp. 31-36, 1995.

[3] D. Chen and H. Peng, "A thermodynamic Model of Membrane Humidifiers for PEM Fuel Cell Humidification Control," J. Dyn. Sys., Meas. Ctrl., Vol. 127, pp. 424-432, 2005.

[4] T. F. Springer, T. A. Zatwodzinski, and S. Gonesfeld, "Polymer Electrolyte Fuel Cell Model," J. Electrochem. Soc., Vol. 138, No. 8, pp. 2234-2342, 1991