CHARACTERIZATION OF WATER VAPOR TRANSMISSION RATE THROUGH FUEL CELL COMPONENTS

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ABSTRACT

An instrument capable of measuring vapor transmission rates under any desired gradient of concentration and pressure is described. The test temperature, pressure, humidity and flow rates are precisely controlled and accurately measured. The instrument is completely automated to obtain objective and accurate results and minimal involvement of the operator. Using this instrument a variety of materials, including a fuel cell component, have been successfully investigated.

INTRODUCTION

The rate of water vapor transmission through fuel cell components is a critical parameter that determines the performance of the fuel cell. Water vapor transmission can be a very complex process (Jena and Gupta, 2002). The component might react with the water vapor, swell and cause many physical property changes. The vapor might migrate through small pores in the component or diffuse through the material. One of the examples is water vapor transmission through nafion membrane under a pressure gradient (Jena and Gupta, 2002). Presence of concentration gradient, presence of pressure gradient, presence of temperature gradient or simultaneous presence of some of the gradients could drive the vapor transmission process. A technique has been developed, and an instrument has been fabricated, to measure vapor transmission rates under controlled conditions in which all the variables can be independently controlled. Water vapor transmission rates through a variety of materials have been investigated. A fuel cell component has been investigated, and water vapor transmission rate through the component has been successfully determined as a function of average humidity at a constant humidity gradient.

TECHNIQUE

Basic Principle

When a gas containing water vapor flows below as well as above a sample, vapor transport through the sample can occur due to an imposed concentration or pressure gradient. Consider mass balance in the chamber in to which vapor is transported through the sample. The rates of addition of water vapor by the incoming gas and by the transport through the sample must be equal to the rate of removal of water vapor by the outgoing gas under steady state conditions (Figure 1).
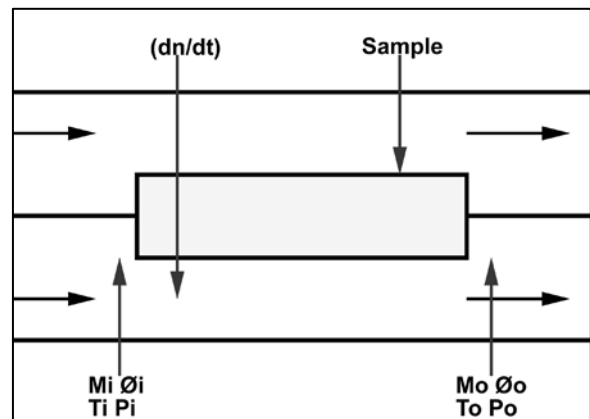

Fig. 1 Basic principle of the technique

$$(dn/dt) + [(p_{e,i}\phi_i/ P_i) M_i] = [(p_{e,o}\phi_o / P_o) M_o] \qquad (1)$$

Where
dn/dt = Rate of vapor transport in moles

p_e = equilibrium vapor pressure at temperature, T and total pressure, P.

ϕ = humidity = (p_v/p_e)

p_v = partial pressure of vapor in unsaturated gas

M = Rate of gas flow in moles

$_i$ = incoming flow

$_o$ = outgoing flow

Vapor transport rate is computed from known T, P, ϕ and M.

Technology

The outline of the instrument designed for this study is shown in Figure 2. The sample is contained in a holder. Two gas streams are allowed to flow independently on both sides of the sample. A part of the gas flowing through each stream is allowed to go through bubblers while the other part bypasses the bubblers and mixes with the gas passing through the bubblers. The flow rate of each part of the gas is controlled and measured by flow controllers. The humidity and temperatures of gas streams are measured. The differential pressure between both sides of the sample is measured. Two valves are provided at the outlet ends of the gas streams. The sample holder and all the attachments are maintained at a constant temperature.
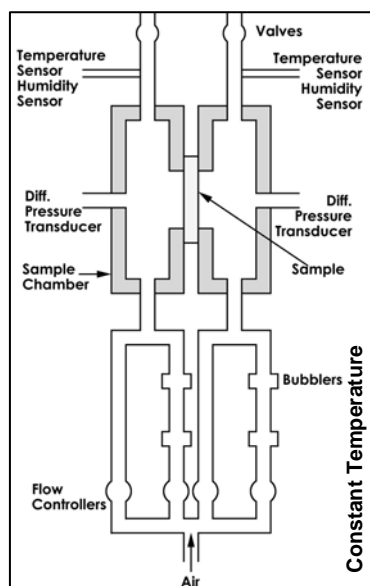

Fig. 2 Outline of the setup

The apparatus is enclosed in a constant temperature chamber whose temperature is monitored. The temperatures of the gas streams on the two sides of the sample are also constantly monitored to see if there is appreciable temperature fluctuation because of reaction of the vapor with the sample.

The humidity of the gas entering any one side of the sample is controlled by mixing the gas bypassing the bubblers with the gas going through the bubblers. Gas going through the bubblers is saturated with water vapor. Saturation vapor pressure is a function of temperature and total pressure. Assuming water vapor at the constant temperature to behave like an ideal gas:

$$p_{e(P)} = p_{e(P=1)} \exp [(V_L(P-1)/RT] \qquad (2)$$

where V_L is molar volume of liquid, P is pressure in atmospheres, T is absolute temperature and R is the gas constant. This equation suggests that the error in p_e is about 0.075 % at two atmosphere pressure. At high pressures, water vapor does not behave like an ideal gas. The errors in p_e due to non-ideal behavior is about 0.7 % at two atmosphere pressure (Hayland, 1975). Therefore, to minimize errors, the total pressure is measured and kept close to one atmosphere. p_e is either measured or taken from literature.

Desired humidity in the incoming gas is obtained by automatically manipulating the flow through flow controllers. Under the test condition of constant temperature and close to one atmospheric pressure, water vapor is expected to show ideal behavior. Consequently, the humidity, ϕ in the incoming gas is given by:

$$\phi = (p_v/p_e) = 1/\{1+[n_2/n_1][1-(p_e/P)]\} \qquad (3)$$

Where n_1 and n_2 are molar flow rates of gas through bubblers and bypassing the bubblers respectively. Thus, the desired value of ϕ is maintained by maintaining a constant ratio (n_2/n_1) for known values of p_e and P. It was possible to maintain as high as 95 % humidity.

Vapor from gas on one side of the sample diffuses through the sample and is transported to the gas on the other side. Therefore, humidity of the outgoing gas on one side of the sample will be reduced while that on the other side will increase. The humidity of the outgoing gas on both sides of the sample is directly measured.

The average humidity in the incoming and outgoing gases on one side of the sample yields the average humidity on that side. The difference between the average humidity is the driving force for vapor transport.

The pressure is controlled by the valve at the end of each gas flow line. A differential pressure transducer continuously records the pressure difference across the sample. The valves are automatically controlled to maintain either zero differential pressure or a definite pressure difference.

Flow rates of outgoing gas on both sides of sample are directly measured. Consideration of mass balance suggests that,

$$M_o = M_i + (dn/dt) \qquad (4)$$

Water vapor transmission rate through the sample is obtained from Eqs. (1) and (4). During the test, T is a constant. p_e, $p_{e,o}$ and $p_{e,i}$ are equal and are in atmospheres. P, P_o and P_i are one atmosphere each. Hence,

$$(dn/dt) = [p_e\phi_o - p_e\phi_i] M_o / [1 - p_e\phi_i] \qquad (5)$$

All the parameters required for computing vapor transmission rate using Eq. (5) are measured.

RESULTS AND DISCUSSION

Plastic sheet

In order to test the equipment a plastic sheet with very low porosity was used as the sample. Water vapor transmission rates were measured as functions of applied humidity. The water vapor transmission rate at a humidity difference of 0.5 across the sample was measured as a function of average humidity. The data are listed in Table 1. Although the variation of transmission rate with humidity is very small, it is detectable as shown in Figure 3. The very small vapor transmission rate is in excellent agreement with the very low porosity of the plastic sheet.

Table 1. Water vapor transmission rate through a plastic sheet of very low porosity

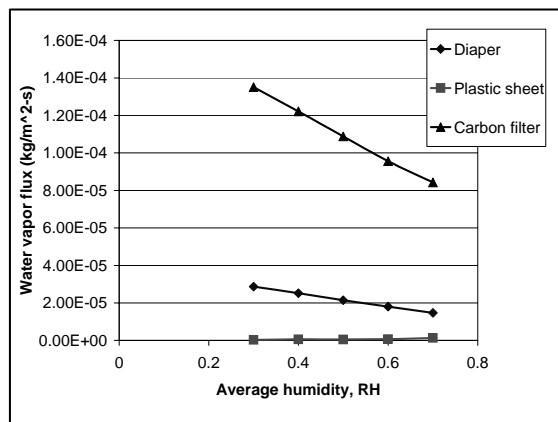| Relative humidity, %			Flux of water vapor, kg/m^{2}s
Top	Bottom	Average	
55	5	30	2.81 E-07
65	15	40	5.99 E-07
75	25	50	4.87 E-07
85	35	60	7.60 E-07
95	45	70	1.27 E-06

Fig. 3 Variation of water vapor transmission rate through a number of materials as a function of average humidity

Diaper and carbon filter

Two other materials were tested in order to further examine the capability of the equipment. A diaper having higher permeability than the plastic sheet was examined. The results are shown in Figure 3. The transmission rate of about 2×10^{-5} kg/m^{2}s is reasonable for the diaper. A carbon filter with an order of magnitude higher transmission rate was also examined. The vapor transmission rate through the carbon filter is shown in Figure 3 as a function of average humidity at a constant humidity difference of 0.5. The result is in the expected range.

Fuel cell component

The cathode component of a leading fuel cell developer was tested in the equipment for water vapor transmission rate. The temperature was kept constant at 25°C. The pressure gradient was kept at zero. Humidity was varied between 0.95 and 0.55 in the top chamber and between 0.45 and 0.05 in the bottom chamber. The water vapor transmission rate was computed in kg/m^{2}s. The results are listed in Table 2.

Table 2. Water vapor transmission rate through the cathode component of a fuel cell

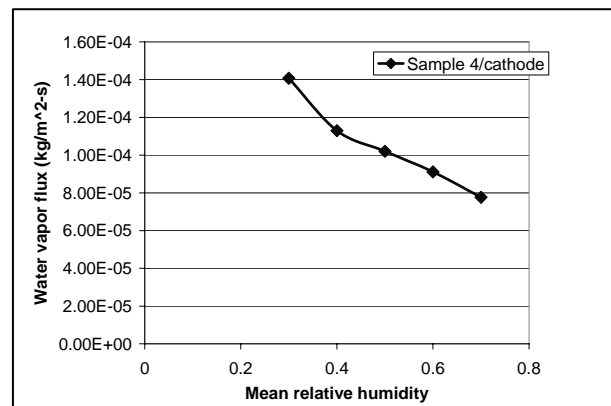| Relative humidity, %			Flux of water vapor, kg/m^{2}s
Top	Bottom	Average	
55	5	30	1.41E-04
65	15	40	1.13E-04
75	25	50	1.02E-04
85	35	60	9.11E-05
95	45	70	7.77E-05

Fig. 4 Water vapor transmission rate through the cathode component of a fuel cell

The variation of water vapor transmission rate through the cathode component is shown in Figure 4. The variation

is nonlinear. This is unlike the behavior of other materials (Figure 3). The water vapor transmission rate through the cathode material increases with increasing rate with decrease in average humidity. The interaction of the cathode material tends to change with changing humidity. The material could physically interact with water vapor in many possible ways. The vapor may be absorbed, the material may swell, pore shape and size may change and vapor may condense in some of the pores.

SUMMARY AND CONCLUSION

1. An instrument has been designed with potential to determine water vapor transmission rates through fuel cell components at the desired temperature under a range of humidity gradients at any desired average humidity, and a range of pressure gradients. The instrument is fully automated.
2. A plastic sheet with very low permeability was examined to test the system. As expected the instrument gave very low vapor permeability.
3. A diaper and a carbon filter were also investigated in order to test the capability of the instrument. The results were satisfactory.
4. A fuel cell cathode component was tested at 25° C keeping the pressure gradient zero and varying the average humidity over a wide range at a constant

5. It is proposed to continue testing a variety of fuel cell components under humidity as well as pressure gradients in order to further evaluate the instrument.

REFERENCES

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humidity gradient. The instrument yielded satisfactory results over the wide range of humidity.