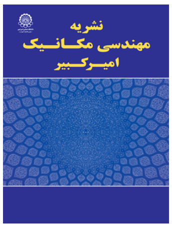

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Investigation of the Humidifier Performance of Adding Gas Diffusion Layers Around Membrane for Fuel Cell Application

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ABSTRACT: Proton exchange membrane fuel cells requires humidification the reactive gases before entering the fuel cell for good performance. Using a planar membrane humidifier with important advantages such as simple building and no moving parts, is one of the best methods to humidification the reactive gases discussed in this paper. In this study, it is proposed to insert porous layers (gas diffusion layers) on both sides of the membrane, to increase the residence time gases. Therefore, by using three-dimensional and numerical modeling of the humidifier, the effect of porous layers and the effect of their properties on the humidifier performance are investigated. For this purpose, a non-porous humidifier is first modeled, and then the porous layer is inserting on the wet side, on the dry channel side, and on two sides of the membrane, and the performance of these models is compared. The results show that the highest dew point temperature of dry side outlet is related to the use of gas diffusion layers on both sides, on the dry side, on the wet side and humidifier without gas diffusion layers respectively. In all cases of laying gas, with increasing porosity coefficient and permeability, dew point increase and improve humidifier performance.

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1. Introduction

Proton Exchange Membrane (PEM) fuel cell has many advantages such as low start-up time, high efficiency, low noise level and zero emission. Therefore, it is applied in the stationary power plants, vehicles, portable systems and the like [1,2]. The balanced performance of the proton exchange membrane fuel cell significantly depends on the heat and water management. If the water removal rate in the PEM fuel cell does not keep up with the water generation rate, it will cause water flooding and thus hinder the transport of reactant gases by blocking the pores in the porous catalyst and Gas Diffusion Layers (GDL), consequently cover up active sites in the catalyst layer and plug the gas transport channels. Instead, the ionic conductivity of the membrane is strongly dependent on its degree of humidification, with high ionic conductivities at maximum humidification. When the water removal rate exceeds the water generation rate, membrane dehydration occurs, which can result in performance degradation due to the significant ohmic losses within the PEM fuel cell [3].

There are several methods to manage water inside the PEM fuel cell. These methods includes: bubble humidification, enthalpy wheel exchanger, and membrane humidification. The bubble humidification method has a high pressure drop. In the bubble humidification method at high flow rates, it is difficult to control the temperature and humidity [4]. The enthalpy wheel method, though, reduces concerns about system overweight; But high power loss, high system complexity and high maintenance costs make it unsuitable for many applications such as cars [5].

Among these methods, the membrane humidification is the simplest and the most commonly applied one with the least energy consumption. This method reduces the complexity of fuel cell system and parasitic power. Therefore, a study on this topic is important. Numerical modeling of the membrane humidifier can help to analyze the phenomena of humidification-dominated transmission.

Various studies have been performed on the use of membrane humidifiers for PEM fuel cell systems. Most of the studies have been experimental and few studies have been performed numerically in the field of membrane humidifier. In this study, it is proposed to insert porous layers (gas diffusion layers) on both sides of membrane in order to increase the residence time of gases and by numerical and three-dimensional modeling of a humidifier, the effect of porous layers is investigated. For this purpose, a non-porous humidifier is first modeled, and then the porous layer is inserting on the wet side, on the dry channel side, and on two sides of the membrane, and the performance of these models is compared.

2. Governing Equations and Numerical Solution Method

The membrane humidifier that investigated in this study is planar type. Wet gas from the wet side and dry air through dry

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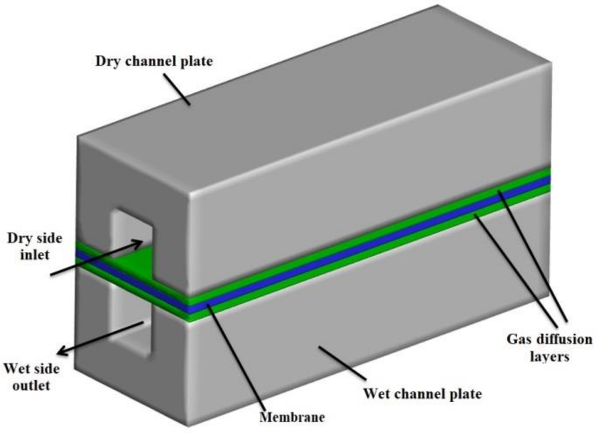

Fig. 1. Simulated three-dimensional humidifier model

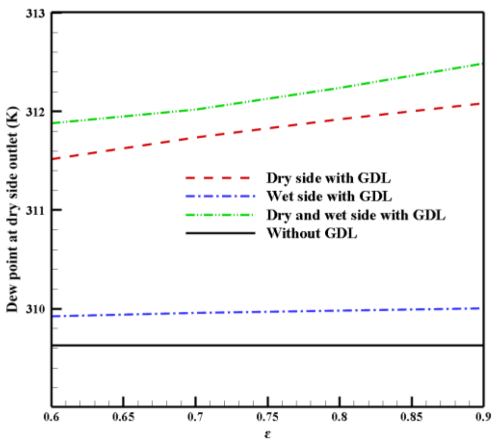

Fig. 2. Influence of porosity coefficient of porosity on dew point at dry side outlet

channels are flow. These channels are machined into sheets of graphite or metal, their duty is to transfer dry and wet gases to / from the humidifier. Between these plates is a polymer membrane made of nafion. Due to the difference in water concentration between the two sides, water is transferred from wet side to the dry side via membrane through the diffusion process and humidifies dry gas. Fig. 1 shows a modeled three-dimensional model of membrane humidifier. Various humidifier components have been shown in Fig. 1. From the lower channel, humid air enters the humidifier and from the upper channel, dry air enters. The gas diffusion layers located on either side of the membrane are shown in Fig. 1. The cross section of the channels is square and the size of each side is 2 mm. The length of the humidifier channels is 82 mm. The distance between the channels is also 2 mm.

The governing equations include the conservations of mass, momentum, species and energy equations in the porous media with the equation of water passes through the membrane. This latter relation is derived from the following equation.

$$\dot{m}_m = \frac{\rho_{m,dry}}{W_{m,dry}} A_m M_{H_2O} D_m^{H_2O} \nabla \lambda \qquad (1)$$

where the $\dot{m}_m$ is the mass flow rate of water passes through the membrane, ρm,dry is the membrane dry density, $W_{m,dry}$ is the membrane dry equivalent weight, A_m is area and M_{H_2O} is the water molar mass.

The governing equations are discretized using a finite volume method and solved using fluent software. In this model the pressure and velocity fields are treated using SIMPLE algorithm model. An iterative process is used to solve the set of equations and the solution of the equation of continuity and energy, respectively, has continued to achieve convergence with precision of 10^{-4} and 10^{-6}. The most important reason for choosing the repetition process for solving the equations is their coupling. Conservation equations in the humidifier are strongly coupled. This is due to the dependence of physical and chemical properties on the transfer parameters (such as temperature and concentration). For example, the diffusion coefficient is a function of temperature and pressure and viscosity is a function of temperature. A User-Defined Function (UDF) written in fluent software was used to solve the membrane governing equations to determine the amount of water transmitted through the membrane. A rectangular grid with a grid number of 61396 is used. With this number of grids, the results are independent of the number of grids.

3. Results

The dew point is the temperature at which the air is saturated with water vapor at the same temperature. The dew point is an appropriate criterion for evaluating humidifier performance that includes the effects of heat transfer and mass transfer. The closer the dew point of the dry side outlet to the dew point of the wet side inlet, i.e. the dew point of dry side outlet increases, the humidifier performance improves. The dew point is obtained as follows [6].

$$T_{dp} = \frac{238.3 \times \ln(\frac{p_v}{0.61078})}{17.2694 - \ln(\frac{p_v}{0.61078})} \qquad (2)$$

As shown in Fig. 2, the dew point of the dry side outlet is increased by placing the gas diffusion layer. Insert two gas diffusion layers on both dry and wet sides has the most positive effect. The reason for this is that the wet channel humidity in the gas diffusion layer has a longer residence time and over time it transfers this humidity to the membrane. This humidity enters the gas diffusion layer after passing through the membrane, and by storing this humidity in the gas diffusion layer; it causes the gas to remain in this layer and over time to transfer this humidity to the dry channel. In general, it increases dew point and water flow rate at dry side outlet. This is the same for all porosity coefficients and permeability of the gas diffusion layer. In all cases of laying gas, with increasing porosity coefficient, dew point of dry side outlet, increases and improve humidifier performance.

As shown in Fig. 3, the slope of the dew point diagram decreases with increasing permeability of the gas diffusion layer when using the gas diffusion layer on the dry side. When using the gas diffusion layer on the dry side, the dew point of the dry side outlet remains almost constant as the gas permeability increases. As permeability increases, the dew

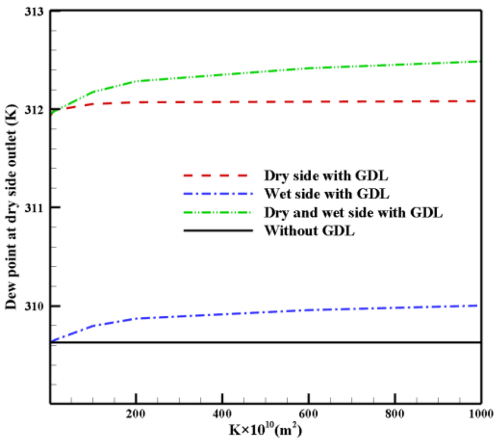

Fig. 3. Influence of porous layer permeability on dew point at dry side outlet

point of the dry side outlet increases from 2.3 to 2.9 K when the gas diffusion layer is placed on both wet and dry sides.

4. Conclusions

In this study, it is proposed to increase the residence time of gases on both sides of the membrane of humidifier, gas diffusion layers are inserted and by numerical and three-dimensional modeling of a humidifier, the effect of gas diffusion layers is investigated. For this purpose, a non-porous humidifier is first modeled, and then the porous layer is inserting on the wet side, on the dry channel side, and on two sides of the membrane, and the performance of these models is compared. The results show that in all cases of laying gas, with increasing porosity coefficient and permeability, dew point and water flow rate of dry side outlet increases.

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