

Wick based in-situ humidification in PEMFCs: A comparative study

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Abstract: In the present study, water management in PEMFC is carried out internally by a novel wick based humidification. This technique is feasible in comparison to other conventional methods, wherein water management requires external humidifiers resulting in increased cost and complexity of PEMFC system. Prior to the cell polarization and impedance measurements, wick under subject is characterized for its physico-chemical properties like contact angle, wetting energy, pore size and gas permeability. Cell performance of Wick based in-situ humidification was found comparable with the conventional PEMFC system operating with commercial humidifiers.

Keywords: PEMFC, Water management, In-situ humidification, Wick

1. Introduction

Proton exchange membrane fuel cells (PEMFCs) have gained tremendous attention for its potential to replace environment polluting internal combustion engines that run on petroleum products. However, along with its virtues it also poses certain challenges that have been restricting the mass commercialization of this technology [1]. Among all the potential technologies available for sustainable transport, fuel cells can be an alternative source for long-term CO₂ emission reduction [2]. Proton exchange membrane fuel cells (PEMFCs) are advantageous for transportation due to their high efficiency, low operating temperature, and high power density [3]. A persistent challenge in PEM fuel cell systems, however, is the water management [4]. Membrane humidity is a critical factor in water management and must be optimized for good ionic conductivity [5], while excess product water must be removed to prevent flooding of electrodes, gas diffusion layer (GDL), and flow field channel [4]. Under continuous operation of PEMFC in absence of proper water management, electro-osmotic drag leads to dehydration of membrane at the anode resulting in reduced performance due to the decreased ionic conductivity of the membrane [6].

In-situ water management techniques have gained attraction recently among the fuel cell system developers as it renders reduced parasitic power loss, low operational costs and less system complexity [7]. The favorable temperature range for PEMFC operation is usually 50-80°C. A higher temperature can significantly exacerbate the degradation of the membrane and the catalyst resulting in reduced PEMFC performance, whereas a lower temperature is not favorable for the reaction kinetics and may lead to flooding, which is a major concern from the water management perspective [8]. Hence, effective water management is critical for stable and long-term reliable performance. This is often addressed by using fully humidified inlet gas streams and incorporating serpentine channel cathode flow fields for fuel input [7]. The long channel length and reduced air channel cross-sectional area of serpentine flow fields lead to increased pressure drop and air velocities, which advectively remove excess product water from the electrode's surface. Although stable performance is achieved, this approach results in high parasitic power losses (as high as 35% of stack power) and increased system complexity [9]. Auxiliary compressor and gas humidification systems also reduce power density by adding towards the weight of the system, sometimes accounting for up to 20% of the total fuel cell system volume [10].

In view of above issues, the present study deals with the use of an electrically conducting porous material for its ability to provide internal humidification of gases in PEMFC for a 100 cm² cell. The performance of the cell using passive in-situ humidification technique is compared with water management using external humidifiers in PEMFCs.

2. Experimental

2.1. Materials

Hydrogen Screener Membrane Electrode Assembly (MEA-5 layer), Active Area 100 cm² was procured from Alfa Aesar, Johnson Matthey Pvt. Ltd. Monopolar plates were procured from Schunk Graphite Technology, LLC, USA.

2.2. Wicking Characteristics

Capillary flow porometer (Porous Materials Inc., USA) was used to calculate the pore size and gas permeability of the Wick. Average pore size, air flow rate and permeability through the wick were measured in relation to varying differential pressure. Contact angle and surface wetting energy for the Wick was measured by Sessile Drop method using Surface Electro Optics (Model Phoenix-300, 204 Korea).

2.3. Performance evaluation

Wicking material in single cell PEMFC setup is sandwiched between flow field (serpentine) plate and MEA. Different configurations of single cell were tested with wick and also in absence of wick as represented in Table 1.

Configurations	Anode	Cathode	Humidification	
			Anode	Cathode
A	Without Wick	Without Wick	External	External
B	Wick with Water Trough	Without Wick	In-Situ	External
C	Without Wick	Wick with Water Trough	External	In-Situ
D	Wick With Water Trough	Wick With Water trough	In-Situ	In-Situ

Table 1. Configurations for single cell performance evaluation

Water for the wick is supplied by means of a trough at the bottom of the cell. Thus, for configurations B, C and D, a water trough was provided at the bottom of the cell with wick dipping in it. Distilled water was used for supply. For all the configurations, torque of 140 lbf-inch was provided over the end plates for cell assembly. The testing was performed using Bio-Logic Fuel Cell Test Station. The humidity of the gas streams were maintained near 80% at the anode and 50% at cathode. The parameters for the testing are represented in Table 2.

Parameter	Value
Cell Temperature	55 ⁰ C
Cathode Gas Humidifier Temperature	45 ⁰ C
Anode Gas Humidifier Temperature	50 ⁰ C
Gas line Temperature	65 ⁰ C
Hydrogen Stoichiometry (λ_{H_2})	1.2
Air Stoichiometry (λ_{Air})	3
Number of Channels	49
Channel Length (L)	78.5 cm
Active Area	100 cm ²
Anode/Cathode Outlet Pressure	1atm (abs)
Wick Thickness	0.2mm
MEA Thickness	0.41mm

Table 2. Parameters for single cell performance evaluation

3. Results and Discussion

3.1. Effect of Wick Characteristics

Pore size distribution, permeability and contact angle play an important role for wicking action in a porous hydrophilic material. It also gives an idea about the possibility of flooding of electrodes in a cell due to excess wicking. From the Fig. 1, it is clearly seen that with increased differential air pressure, the average pore diameter of wick is found to reach a minimum value which is in agreement with the desired range for wicking action.

Table 3. shows the various parameters that were used for determination of differential capillary pressure and wicking velocity. On the other hand gas permeability should be as high as possible in order to achieve maximum wicking action. It can be observed from Fig. 2 that gas permeability for wet and dry wick surfaces varies significantly with as high as 35% reduction in gas permeability for wet wick surface as compared to dry wick. From the contact angle experiments represented in Fig. 3, it is noteworthy that with increase in drop volume, contact angle decreases thereby increasing the surface wetting energy of the wick. In order for wick to supply water to the fuel streams internally, it is essential that a positive wicking velocity should always be maintained. Therefore, optimum pore size distribution and permeability are critical for flood free cell performance. Wicking action is in turn determined by two important factors namely Differential capillary pressure and wicking velocity which are determined using the formula given in Table 4 [11]. It is noteworthy that higher the pore diameter and contact angle, lower will be the differential capillary pressure in the wick and hence a reduced wicking effect.

Parameter	Value
Surface Tension (σ) of Water at 30°C (N/m)	7.12×10^{-2}
Contact Angle (θ) (degrees)	6.7977 - 83.0689
Pore Diameter (d_{pore}) (microns)	25.7662 - 94.5139
Void Fraction (%)	85-96
Average Permeability (K) for Dry-Wick (Darcys) ($1\text{Darcy} \sim 10^{-12} \text{ m}^2$)	0.31955
Average Permeability (K) for Wet-Wick (Darcys) ($1\text{Darcy} \sim 10^{-12} \text{ m}^2$)	0.20829
Viscosity (μ) of Water at 30°C (Pa-s)	0.798×10^{-3}
Differential Flow-Field Pressure ($dP_{\text{flowfield}}$) for anode side (N/m ²)	978.31
Differential Flow-Field Pressure ($dP_{\text{flowfield}}$) for cathode side (N/m ²)	10481
Differential Capillary Pressure (N/m ²) $\left(dP_{\text{cap}} = \frac{4\sigma \cos\theta}{d_{\text{pore}}} \right)$	363.6336 – 10975.5388
Wicking Velocity (mm/s) $\left(V_{\text{wick}} = \frac{K(dP_{\text{cap}} - dP_{\text{flowfield}})}{\mu L} \right)$	$1.64\text{e-}4 - 3.34\text{e-}3$

Table 4. List of important parameters for wick

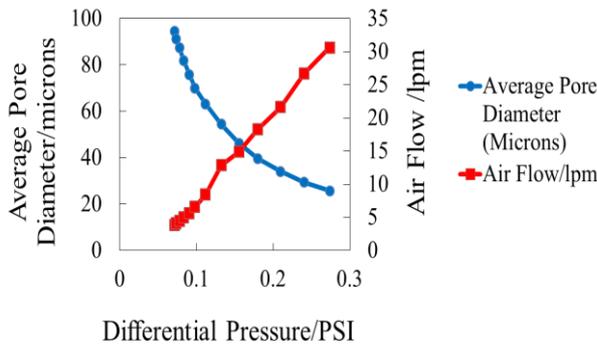


Fig. 1: Average pore diameter and air flow versus differential air pressure across the wick

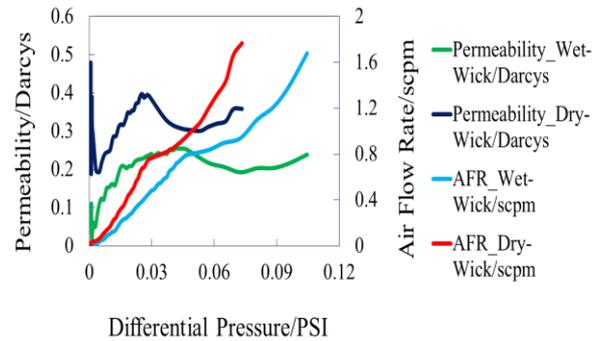


Fig. 2: Gas permeability and Air flow versus differential air pressure across the wick, in wet and dry conditions

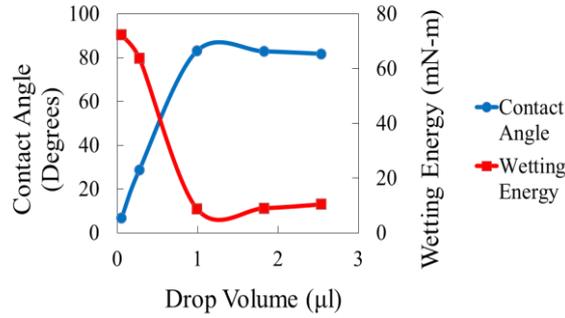


Fig. 3: Contact angle and surface wetting energy versus drop volume on the wick

3.2. PEMFC performance evaluation

Fig. 4 shows the cell polarization for all the configurations represented in Table 1. The control (configuration A) setup was used as the baseline performance for comparison with other configurations. For all the configurations the performance of the single cell was compared at 0.6V. It was found that flooding was most significant for configurations A, B and D thereby limiting the maximum current density. However, no flooding was observed in case of Configuration C. This is due to the higher stoichiometry used for the cathode that helps in removing excess water. Daniel et al [7] also reported higher stoichiometry (~ 2) at cathode on a 25 cm^2 area for flood free performance of cell. Configurations B and D have wick over the anode and a stoichiometry of 1.2, which is very less for the present wick setup leading to flooding of the cell. Further, it can be seen from configurations B, C and D where the wick is wet, would offer resistance towards gas permeability which is in accordance with the permeability results shown in Fig. 3. Therefore, the slight reduction in cell performance is justified since the gas molecules accessibility to the electrodes is reduced in these configurations. Table 5. represents the quantitative comparison at 0.6 V for different configurations.

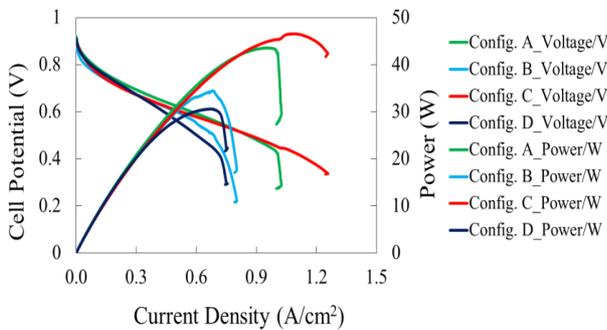


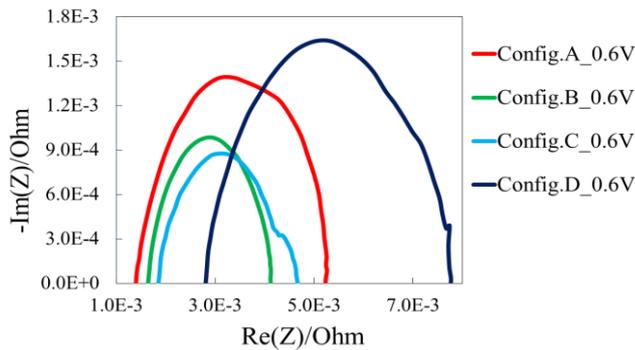
Fig. 4: Single Cell Performance for Configuration A, B, C and D at $\lambda_{H_2} = 1.2$ and $\lambda_{Air} = 3$

Configurations	Cell Potential (V)	Current Density (A/cm^2)	Power Density (W/cm^2)	Percentage Drop in Performance (%)
A	0.6	0.573	0.344	0
B	0.6	0.500	0.300	12.79
C	0.6	0.522	0.313	9.01
D	0.6	0.437	0.262	23.83

Table 5: Performance comparison for different configurations

3.4 Electrochemical Impedance Measurements

Since additional layer of wick is/are present in the normal fuel cell assembly, it is pertinent to follow its influence on the resistance that the wick may cause towards Ohmic and charge transfer processes. Therefore, impedance measurement for all the configurations was performed by plotting the Nyquist Plot at 0.6 V for frequency range of 0.1 Hz to 10,000 Hz and the Ohmic and charge transfer resistances were determined. It can be observed from Fig. 6, that the increase in the high frequency resistance of the cell on addition of wick, which is dominated by the membrane resistance, indicates that the conductivity of bulk electrolyte (membrane) is decreased due to relatively lower humidity. However, charge transfer resistance represented in Table 6 for configuration B and C is decreased in comparison with configuration A due to maintenance of required amount of humidity for electro-osmotic drag and back diffusion processes. Whereas in configuration D, the charge-transfer resistance is increased due to the decrease in accessibility of fuel streams for the catalyst.



Configuration	Ohmic Resistance (Ohm-cm ²)	Charge Transfer Resistance (Ohm)
A	0.140	5.23e-3
B	0.160	4.08e-3
C	0.184	4.65e-3
D	0.281	7.76e-3

Fig. 6: Electrochemical Impedance Spectroscopy comparison for Configurations A, B, C and D.

Table 6. Impedance Data for different configuration

4. Conclusion

A passive humidification technique was developed for a stable performance of PEMFC aimed at lower power density applications. The reduced performance of cell at 0.6 V for configurations B and C can be covered up by adding a cell for every 10 cell stack which leads to just 10 % cost increment for the stack. Reduced performance for configuration D can be covered up by adding two cells for every 10 cell stack with a cost increment of 20 % for the overall stack. The increment in cost due to this technique adds only to the capital cost. However, the operational costs of pumps, external humidification units etc. can be totally avoided which is a huge advantage considering the overall systems operational cost, complexity and feasibility for scale up.

It is further hypothesized that the same technique could render benefits of thermal management in multiple cells stack where thermal management becomes very crucial for stable and consistent performance. However, the concept is still under validation stage and needs further inclusion of heat and mass transfer principles for determining the effectiveness of wicking in thermal management. If validated, the technique would be greatly useful in PEMFC system's cost and complexity reduction providing stable performance.

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