International Journal of Heat and Mass Transfer 52 (2009) 5657–5659

Contents lists available at ScienceDirect

International Journal of Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ijhmt

Technical Note

Pressure drop on water accumulation distribution for a micro PEM fuel cell with different flow field plates

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ARTICLE INFO

Article history:
Received 20 December 2008
Received in revised form 6 July 2009
Accepted 6 July 2009
Available online 13 August 2009

Keywords:
Two-phase pressure drop
PEM fuel cell
Flowfield configuration

ABSTRACT

Time-dependent measurements of pressure drop in different flow fields on the cathode of a PEM fuel cell with different operating conditions of mass flow rates and cell temperatures on water accumulation were conducted. The results show that, among four flow fields studied herein, the interdigitated flow channel has the biggest pressure drop as well as the largest water accumulation at an early phase ($\leqslant$30 min) compared to those of the other three channels. In addition, the more water produced, the bigger the pressure drop that occurs. Similarly, the effects of mass flow rates at a fixed cell temperature were also examined and discussed.

1. Introduction

With the advances in MEMS technology, various micro-systems such as micro heat-sinks, micro-biochips, and micro fuel cells have been developed in recent years. Among these micro fuel cells, the proton exchange membrane (PEM) fuel cells are considered to be one of the most promising power sources, especially for 3*C* products, because of their high efficiency, clean, quiet, easy handling for fuel delivery, simple cell design, and fast start-up, even at low temperature [1–5].

So far, relatively few papers have reported on the study of the flow dynamics aspect in both anode/cathode flow field except Hsieh and Chu [6], in which pressure drop measurements in a serpentine flow channel for a micro PEM fuel cell were performed experimentally. In addition, Hsieh and Her [7], employed 3D mathematical model incorporated with Fluent computer code to simulate the developing laminar flow and heat transfer in a micro direct methanol fuel cell with serpentine flow channels.

In this paper, we report on in situ measurements of the pressure drop across the cathode flow field of a PEM fuel cell with four different flow fields. Time-dependent data were recorded as to how the pressure drop varied as current density increased as well as produced water accumulated at a fixed cell temperature of 25 °C. The reason for chosen such a low temperature of 25 °C is that the present design is aimed at providing useful information for cell phone application. The effects of various operating parameters, including: hydrogen and air (oxygen) flow rates on the pressure drop, and water accumulation were also examined and discussed.

2. Experimental

2.1. Test loop for pressure measurements

Following Hsieh and Huang [8], the pressure drop measurements were conducted in the test loop. The reactant gases are fed in series to the cells. Hydrogen (H_2) and air (oxygen) are conducted in parallel flow mode on both anode and cathode of the single cell. The purified hydrogen (99.99%) was supplied at different flow rates with a humidity of 70% at the anode with the corresponding air flow rates at the cathode. The cell operating pressure is fixed at 97 kPa on both anode and cathode, and the operating temperature is fixed at 25 °C. A pressure regulator (model 44-5200, TESCOM, USA) and a pressure transducer (model PSS-AE/BE/AF/BF, KYOWA, Japan) with a precision of 0.1% were employed to measure the pressure drop between the inlet and outlet of the cathode flow channel. A nitrogen purging system was used to clean the fuel and air reactant left in the test system tube-lines and fuel cells.

2.2. Data reduction/experimental procedure

The experiments were performed when the flow channels of the test fuel cell were oriented vertically. The reactant gases (H_2 and air) entered into the anode (cathode) flow channel from the upper (lower) left (right) corner and exited from the lower (upper) right (left) corner, respectively.

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doi:10.1016/j.ijheatmasstransfer.2009.07.010

Table 1
Measured friction factor in cathode side of four flow channels when operating 30 min at different operating temperatures.

Flow type	Interdigitated			Serpentine			Parallel			Mesh		
Air flow rate (sccm)	60											
Cathode inlet channel velocity (m/s)	16.7											
Temperature (°C)	25	50	75	25	50	75	25	50	75	25	50	75
Pressure drop (kPa)	8.5	8.9	9.9	38.7	42.7	44.2	8.5	9.2	9.8	7.1	7.5	8.0
Reynolds number	275.41											
Measured friction factor ($f = \frac{2D\Delta P_f}{\rho V^2 L}$)	0.224	0.242	0.270	0.239	0.263	0.273	0.232	0.252	0.267	0.234	0.248	0.265
$f\,Re$	63.8	66.8	74.3	65.8	72.6	75.2	63.9	69.5	73.6	64.4	68.3	72.9
Knudsen number*	2.85×10^{-5}	2.61×10^{-5}	2.67×10^{-5}	8.37×10^{-6}	7.59×10^{-6}	7.33×10^{-6}	1.72×10^{-4}	1.17×10^{-4}	1.11×10^{-4}	2.91×10^{-4}	2.75×10^{-4}	2.58×10^{-4}

* Mean particle size for air = 3.72×10^{-10} m, Boltzmann's constant = 1.38×10^{-23} J/K, conventional large channel $f = 59.4/Re = 0.216$, pressure drop due to interdigitated flow channel = 42.1 kPa channel characteristic length (D) = channel width.

Measurements were performed under three cell temperatures and four air flow rates on the cathode when ambient conditions were stable. The pressure drop was measured for each consecutive time interval, and after the cell reached a steady state, a polarization curve was measured. Following Hsieh and Huang [8], water accumulation measurements and the associated photo images of the area of 22.5 mm × 22.5 mm were taken at different times, upon disassembling the fuel cell, through a digital camera (Fuji film, FirePix F40fd) with 10 frames/min. Each measurement was repeated at least four times with the deviation between them being less than ±5%. Finally, average data were then taken and recorded.

3. Results and discussion

The friction factor deduced and calculated from the present pressure drop measurements can be read in Table 1 with 25 °C cell temperatures at different air flow rates for 180 min. Without considering the variations of thermophysical properties due to the temperature change, the corresponding Reynolds number and Knudsen number (λ/D) with gas molecule mean free path λ were also calculated and listed in Table 1. It is found that the present channel flows are all laminar with very small Knudsen number ($\sim 10^{-4}$–10^{-5}), which indicates that the continuum theory still holds in the present micro-channels. In Table 1, at 25 °C, the $f\,Re$ is also nearly constant of about 68, irrespective of types of flow channels except for interdigitated flow channels. This is mainly caused by the lateral convection in interdigitated flow channels as compared to serpentine, parallel, and mesh flow channels, especially when the air flow rate is changed, even though an "equivalent flow passage" concept was adopted and modified for the present interdigitated flow channels.

Based on the present study, the liquid volume fraction (β) of the produced water is a strong function of time, air flow rates, cell temperatures, and the channel configurations, as evidenced by one of the typical plots as shown in Fig. 1 at cell temperature of 25 °C. Roughly speaking, with four different flow channels at three different air flow rates of 30, 60, and 90 sccm, respectively, the liquid volume fraction (β) seems to have a definite slope at different times with a common initial gradual increase at the initial 30 min, with a larger slope following a slow increase with a little bit lower slope, and finally, reaching a saturated value at about 180 min. For a relative long operation (say 3 h), it is seen that the mesh and parallel flow channels have the bigger β

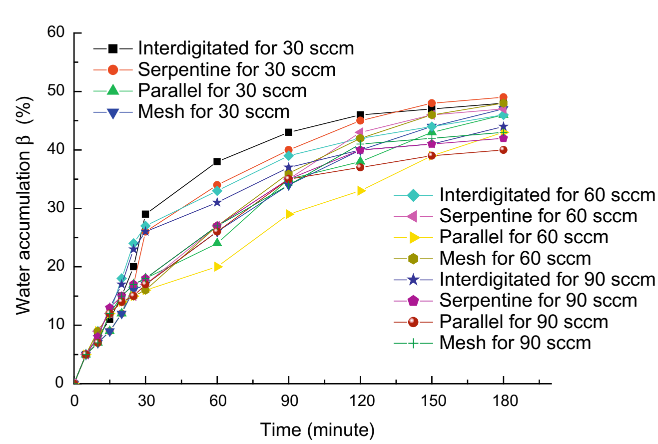

Fig. 1. Water accumulation in cathode side of four flow channels for different flow rate after different operating times at 25 °C.

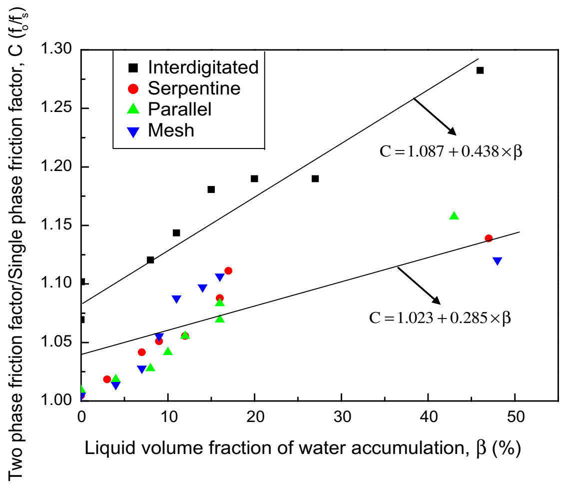

Fig. 2. Amplification factor C (=f_0/f_s) vs β.

(∼48%) as compared to those of serpentine and interdigitated flow channels, even at the lowest air flow rate of 30 sccm.

Fig. 2 presents the ratio C, amplification factor, of a two phase friction factor to that of single phase (f_0/f_s), as water accumulates in the channels in terms of the liquid volume fraction of β for four different channels. The present C is always bigger than 1, partly because the two phase mixture has a larger mixture density than that of single phase air and partly because the two phase flow maintains the acceleration pressure drop. Once the liquid volume fraction reaches saturation, the pressure drop seems not to change any more irrespective of the variation of the time, as expected. Two group data can be identified; one is for interdigitated flow configuration, and one is for the other three channels as one would expect; it is known that the flow in interdigitated channels is convective; while diffusion is dominant in the other types of channels, both groups appear to be approximately fitted with a linear function of liquid volume fraction (β). Two different slope straight lines are found as shown in Fig. 2 with all the amplification factors ($C = f_0/f_s$) ⩾ 1 as expected. In addition, these C are also found to be time independent.

4. Conclusion

The effect of pressure drop in different flow channels at the cathode on water accumulation and current distribution for a micro PEM fuel cell was studied at a cell temperature of 25 °C and air flow rates of 30, 60, and 90 sccm. Several salient features are discovered:

1. Among four different flow configurations the total pressure drop was found to be the biggest for interdigitated channels, followed by serpentine, parallel, and mesh types of flow channels.
2. Transient behavior for pressure drop, water accumulation, and local current density across the cathode flow channels was measured and the relevant data was extracted and examined via parametric analysis.
3. The total pressure drop was strongly influenced by the liquid volume fraction of the product water in the flow channels for a definite flow configuration.
4. It is found that water formation, accumulation, and flooding are strongly dependent on the cathode air flow rate and channel type. An amplification factor of C (f_0/f_s) was defined and found to be a linear function of liquid volume fraction (β) of water accumulation.

References

[1] R. Hahn, S. Wagner, A. Schmitz, H. Reichl, Development of a planar micro fuel cell with thin film and micro patterning technologies, J. Power Sources 131 (2004) 73–78.

[2] M. Kuhnke, T. Lippert, G.G. Scherer, A. Wokaun, Microfabrication of flow field channels in glassy carbon by a combined laser and reactive ion etching process, Surf. Coat. Technol. 200 (2005) 730–733.

[3] D.-E. Park, T. Kim, S. Kwon, C.-K. Kim, E. Yoon, Micromachined methanol steam reforming system as a hydrogen supplier for portable proton exchange membrane fuel cell, Sens. Actuators A 135 (2007) 58–66.

[4] P.-C. Lin, B.Y. Park, M.J. Madou, Development and characterization of a miniature PEM fuel cell stack with carbon bipolar plates, J. Power Sources 176 (2008) 207–214.

[5] S.-S. Hsieh, C.-F. Huang, C.-C. Feng, A novel design and micro-fabrication for copper (Cu) electroforming bipolar plates, Micron 39 (2008) 263–268.

[6] S.-S. Hsieh, K.-M. Chu, Channel and rib geometric scale effects of flowfield plates on the performance and transient thermal behavior of a micro-PEM fuel cell, J. Power Sources 173 (2007) 222–232.

[7] S.-S. Hsieh, B.-S. Her, Heat transfer and pressure drop in serpentine μDMFC flow channels, Int. J. Heat Mass Transfer 50 (2007) 5323–5327.

[8] S.-S. Hsieh, Y.-J. Huang, Measurements of current and water distribution for a micro-PEM fuel cell with different flow fields, J. Power Sources 183 (2008) 193–204.