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Study of Multiple 2:1 and Single 1:1 Inlet/Outlet Ratio for Serpentine PEMFC Performance

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ABSTRACT

Experimental analysis of channel inlet/outlet ratio assessment for a single cell PEM Fuel Cell (PEMFC) is presented in this paper. Two single cell fuel cells were compared with different channel inlet/outlet quantity of 1:1 inlet/outlet and multiple 2:1 inlet/outlet ratio. Fuel cell having single inlet has to overcome large pressure drop. Therefore, an additional inlet was introduced and compared. The two inlets of multiple 2:1 fuel cell were positioned far from each other to increase reactant distribution. The BPP were made from industrial standard carbon graphite. Nafion 112 PEM layer with an active area of 25 cm^2 *was used. Both fuel cells were subjected to similar experimental condition for comparison purposes. Both cathode and anode air condition supplied was dehumidified. Flow rates of 0.25 L/min, 0.5 L/min and 0.75 L/min were introduced at the cathode. Meanwhile, the anode hydrogen supplied was kept at a constant flow rate of 0.25 L/min. The results for each parametric condition was observed. The results show that polarization performance of 2:1 has improved over the 1:1 fuel cell. The 2:1 recorded average power improvement of 43.6%, 52.9%, and 47.2% over the 1:1 fuel cell for 0.25, 0.5 and 0.75 L/min cathode flow conditions. This shown that under similar operating conditions, additional inlet and the inlets positioning able to overcome pressure drop and promotes cell performance due to better reactant distribution.*

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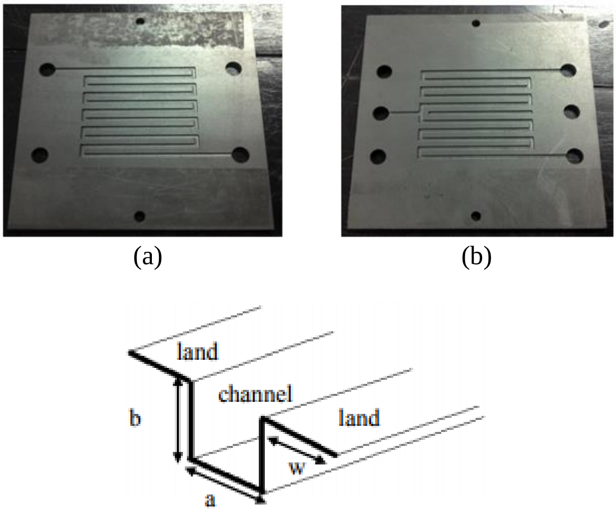
Introduction

The designs of the flow field are known to have a significant impact on the cell performance as provided in a lot of research projects [1],[2],[3]. The main function of the flow channel is to deliver reactant over the entire fuel cell active area for electrochemical reaction process. The most commonly used PEMFC flow channel is the serpentine design that always been regarded as industry standard. The design has long reactant flow path which causes substantial pressure drop and significant concentration gradients from the inlet to outlet [4]. Improper reactant distribution leads to inefficient performance. The introduction of additional inlets has been proven to improve cell performance. Through CFD simulation, serpentine design with a different number of reactant path and thus path lengths affect the species distribution and performance. Proper design to minimize the pressure drop can enhance the reactant distribution evenly [5]. Proton Exchange Membrane (PEM) requires the existence of uniform gas and water molecules over the membrane surface area. Too much water is unnecessary. However, at high load, the PEMFC produce liquid water thus blocking the channel path especially at the downstream. The multi inlet design able to reduce the liquid water generation at the downstream especially at high GDL porosity. The design has resulted in comparatively higher power because of uniform distribution of reactant gas and water [6]. Similarly, at high load, the pressure drop is increased further as a result of the electrochemical reaction process. More oxygen molecules are converted, therefore reduce the reactant concentration [7].

In this project, two PEMFCs have been developed with different flow channel design of 1:1 inlet/outlet and multiple 2:1 inlet/outlet ratio [8]. The proposed design was tested experimentally and compared.

Flow Channel Design

Serpentine flow channels exhibits combination of laminar and turbulent flow regime. Laminar flow regime is fully developed in the straight channel far away from turning region. Highest velocity occurs at the midway of the straight channel. When the flow approaches the turning region, separation occurs. The symmetric flow profile becomes asymmetric. The highest velocity occurs near to the inner wall. Then, the pattern of the asymmetric velocity profile remains when it leaves the turning region. The symmetric velocity profile becomes fully developed again far from the turning region and continues until the end of the channel [9]. Fig. 1 (a) shows the single 1:1 fuel cell bipolar plate. There is only one entrance into the BPP and one exit. The flow field has a total of 10 ‘U’ turn region. Fig. 1 (b) shows the multiple 2:1 fuel cell bipolar plate. There are two channel entrances and one exit. There are a total of 9 ‘U’ turn region. Both have a similar active area which is 25 cm^2. The cross sectional flow for the anode is 2 mm x 1.2 mm x 2 mm while for the cathode is 2 mm x 0.5 mm x 2 mm for a x b x w respectively. Theoretically, 1:1 fuel cell has larger pressure drop compared to 2:1 fuel cell. It has higher total number of serpentine ‘U’ turns and longer distance from the entrance to the exit which contributes towards losses. Therefore, higher pumping power needed to overcome the losses.



(a) (b)

(c)

Figure 1: The serpentine base flow field layout for (a) single 1:1 fuel cell, (b) multiple 2:1 fuel cell and (c) channel cross sectional dimension

Based on the Equation (1), the length of the channel, L is the only variable contributes towards the differences in major losses between both fuel cell. The friction factor, f, mass average velocity, u, channel hydraulic diameter, D_h and gravitational acceleration, g is remained the same throughout all three conditions analyzed. Equation (5) explains the losses occur when fluid is flowing through ‘U’ turn bends.

The major loss, h_L inside the channel is from Darcy-Weisbach equation [10]:

$$h_{L,major} = f\frac{Lu^2}{2gD_h} \tag{1}$$

where D_h is defined as

$$D_h = \frac{4A_c}{P} \tag{2}$$

A_c is the channel cross sectional area and P is the wetted parameter. The friction factor, f can be determined using Haaland equation [11]:

$$\frac{1}{\sqrt{f}} = -1.8\,log\left[\left(\frac{\varepsilon/D_h}{3.7}\right)^{1.11} + \frac{6.9}{Re}\right] \tag{3}$$

f is the BPP surface roughness and Re is the Reynolds number defined as

$$Re = \frac{\rho u D_h}{\mu} \tag{4}$$

where ρ is the reactant density and μ is the viscosity of the reactant. The loss due to the 'U' turn bends:

$$h_{L,bend} = K_L\frac{u^2}{2g} \tag{5}$$

Where K_L is the loss coefficient due to 'U' turn bends. The value taken is 0.2 [12] multiply by the number of bends. On the other hand, the loss due to entrance and exit are ignored because of the flow is considered fully developed as it approaches and leaves the fuel cell active area.

The total loss is calculated as

$$h_{L,total} = h_{L,major} + h_{L,bend} \tag{6}$$

The total loss, $h_{L,total}$ developed causing drop in pressure therefore need to be overcome for better reactant distribution over entire active area. The flow channel pressure drop is calculated by

$$\Delta P = \rho g h_{L,total} \tag{7}$$

Experimental Setup

A schematic diagram of the test bench facility use for the experimental analysis is shown in Figure 2. The facility was built to enable several parameters variations and measurement of output data. The test bench facility has four main subsystems. The nitrogen supply system, the reactants supply system, the humidifying system and the electrical power supply system. The nitrogen supply system was used to purge nitrogen gas into the fuel cell through the flow lines of hydrogen and air. Nitrogen is an inert gas and used as a blanketing agent and prevention from contamination. This to inert the flow lines and the fuel cell before activation of each set of experimental analysis. The gas supply systems consist of flow lines tubing which was set up to deliver the reactants of hydrogen and air into the fuel cell. The hydrogen gas line system is stored in the industrial tanks equipped with a pressure regulator in a gas room. The amount of gas fed into the fuel cell is monitored using gas flow meter controller RED-Y made by Vogtlin. The air supply line originates from an air compressor machine equipped with a pressure regulator. An air flow controller made by Dwyer was used to monitor the air flow rates. The humidifying system, on the other hand, consist of two bubble beaker humidifiers function to increase the water content of hydrogen and air. The beakers consist of a bubbler tube and a capillary thermostat that allows water temperature variation. Finally, is the electrical power supply system which consists of DC electronic load PRODIGIT 3353 to supply load variation onto the fuel cell. The DC load has the capability to read the voltage produced from the fuel cell as the load is varied.

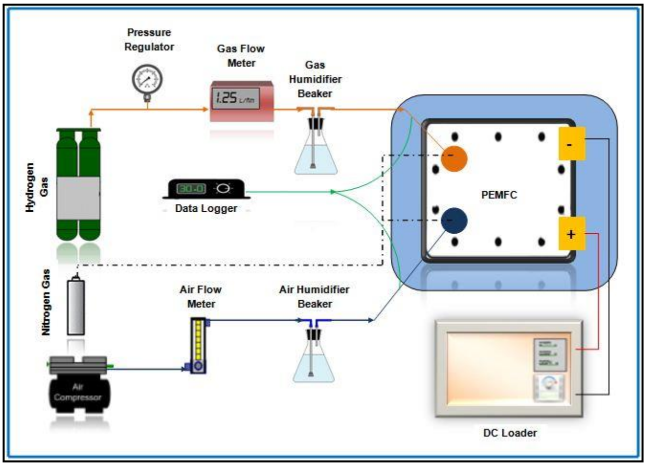


Figure 2: Fuel cell test bench facilities

The test bench able to operate up to maximum 2 bar absolute pressure; the pressure regulators used on both reactants controls the fuel cell operating pressure with accuracy ±2 %. The reactant temperature and humidity variation were measured using GRAPHTEC GL200 midi logger. There are four critical positions measured which include the both reactants inlet and outlet manifold. K-type thermocouple wire was used as the measurement sensor of the data logger. The recorded data were taken in real time using a dedicated data acquisition system incorporated with the midi logger. Table 1 explains the experimental parameter condition for both fuel cells.

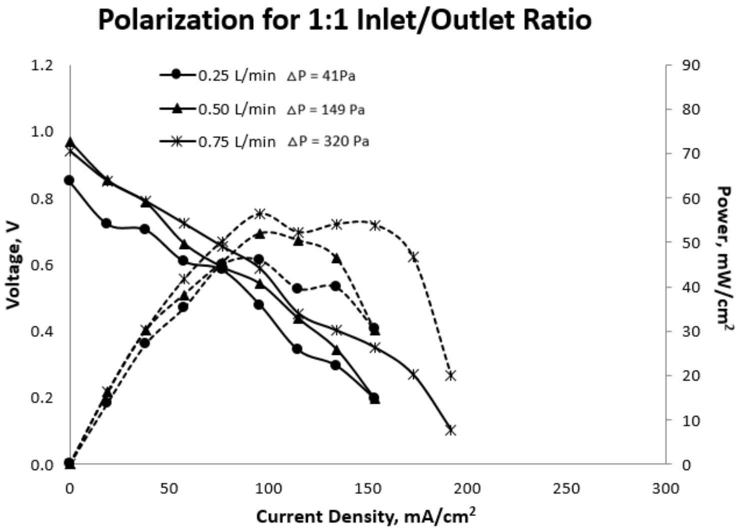
Table I: Design & Operation Parameters

Parameter	***1:1***	***2:1***	***Symbol***	***Unit***
Number of inlets	1	2	-	-
Number of outlets	1	1	-	-
Active area	5 x 5	5 x 5	A	cm^2
Anode cross section	2 x 1.2 x 2	2 x 1.2 x 2	a x b x w	mm
Cathode cross section	2 x 0.5 x 2	2 x 0.5 x 2	a x b x w	cm
Cathode flow rates	0.25, 0.5, 0.75	0.25, 0.5, 0.75	Q_{air}	L/min
Anode flow rates	0.25	0.25	Q_{H2}	L/min
Humidification	<30	<30	RH	%
Load	up to 1.0	up to 1.0	Icell	A

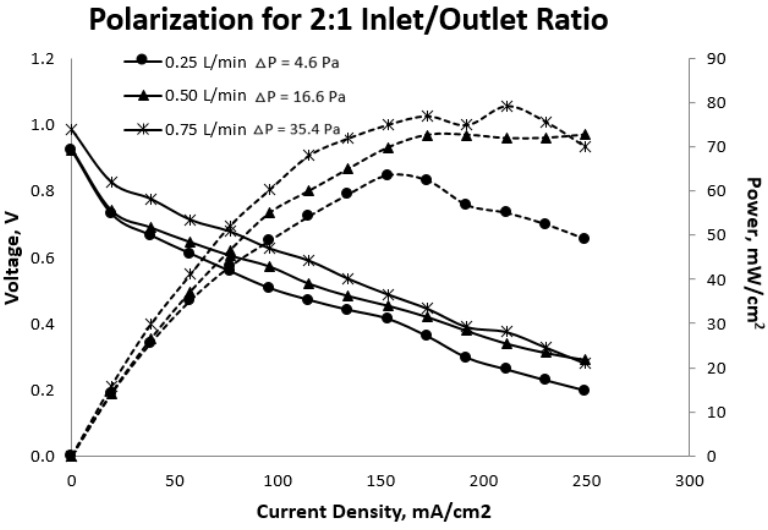
Results and Discussion

The results of the experiment are presented in terms of polarization curves. The effects of inlets quantity towards cell performance are observed and compared. Similarly, the effects of cathode flow rates change towards load changes were discussed as well.

Both fuel cells produced better performance when higher cathode flow rates were introduced as shown in Figure 3 (a) and Figure 3 (b). Highest power observed when cathode flow rates at 0.75 L/min with 23% and 25% improvement compared to lowest cathode flow rates 0.25 L/min. The anode flow rates were kept constant. Therefore the improvement solely because of the reactant within the cathode region. The cell performance increases as the cathode flow rates increased. Higher cathode flow rates add the amount of oxygen molecules into the channel thus improves the electrochemical reaction process. As the fuel cell load increases the amount of oxygen requires by the cell increases. Lower flow rates unable to feed oxygen sufficiently leads to cell starvation. Higher flow rates overcome this problem as more oxygen molecules were added and this was observed from both fuel cells. Average power recorded was 38.3 mW/cm^2 and 56.4 mW/cm^2 at 0.75 L/min for 1:1 and 2:1 fuel cells respectively. The power produced was higher than 30.7 mW/cm^2 and 44.1 mW/cm^2 recorded by 0.25 L/min flow rates.



(a)



(b)

Figure 3: Polarization performance (a) single 1:1 fuel cell and (b) multiple 2:1 fuel cell

The 2:1 fuel cell produced better performance compared to 1:1 fuel cell. In general, the 2:1 cell performance improves over the 1:1 for all the conditions tested. The fuel cell flow channel is intricate and small. High pressure drop is expected. For 1:1 fuel cell, the distance from channel entrance to the exit is 55 cm that contributes to the major loss. Add to the problem is the serpentine layout itself which is high in pressure drop because of the 10 continuous ‘U” turns at the channel edge that increases the losses. Therefore, the amount of air is less especially at the flow channel downstream thus reducing the active region effectiveness. The 2:1 has the advantages of having two inlets which allow better air supplied throughout the entire active area. The distance from the entrance to the exit is just 27.5 cm, therefore, has lower loss over the 1:1 fuel cell. The number of ‘U turns is one less compared to 1:1 fuel cell. This improves the air supplied especially at the downstream therefore increases the power produced. The 2:1 recorded average power improvement of 43.6%, 52.9%, and 47.2% over the 1:1 fuel cell for 0.25, 0.5 and 0.75 L/min cathode flow conditions.

Conclusion

In this study, the cell performance of single 1:1 and multiple 2:1 fuel cell were experimentally analyzed. The results show that the cell performance increases with higher inlet/outlet ratio. The increase in inlet quantity and positioning promotes better reactant distribution. On the other hand, the increase in cathode flow rates improves cell performance. Further investigation need to be carried out to justify the findings. The results implied that multiple inlets fuel cell has potential to be implemented in the future to overcome pressure drop inside fuel cell.

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References

[1] N. J. Cooper, T. Smith, A. D. Santamaria, and J. W. Park “Experimental optimization of parallel and interdigitated PEMFC flow-field channel

geometry," International Journal of Hydrogen Energy 41 (2), 1213 - 1223, (2016).

[2] X. D. Wang, Y. Y. Duan, and W. M. Yan, "Novel serpentine –baffle flow field design for proton exchange membrane fuel cells," Journal of Power Sources 173 (1) , 210-221, (2007).

[3] P. Martins Belchor, M.M. Camargo Forte, D.E Ortiz Suman Carpenter, "Parallel serpentine-baffle flow field design for water management in a proton exchange membrane fuel cell," International Journal of Hydrogen Energy 37 (16) , 11904-11911, (2012).

[4] X. Li and I. Sabir, "Review of bipolar plates in PEM fuel cells: Flow-field designs," International Journal of Hydrogen Energy 30 (4), 359-371, (2005).

[5] S. Shimpalee, S. Greenway and J. W. Van Zee, "The impact of channel path length on PEMFC flow-field design," Journal of Power Sources 160 (1), 398-406, (2006).

[6] S. Lee, T. Kim and H. Park, "Comparison of multi-inlet and serpentine channel design on water production of PEMFCs," Chemical Engineering Science 66 (8), 1748-1758, (2011).

[7] K. Imran Sainan, W. A. Najmi W. Mohamed and R. Atan, "Computational model analysis on a bipolar plate flow field design of a PEM fuel cell," Proceedings in Power Engineering and Optimization Conference (PEOCO) 5, 133-138, (2011).

[8] K. Imran Sainan, N. Arsyad, M. E. Salleh, and F. Mohamad, "Development of 1:1 And 2:1 Channel Ratio Bipolar Plates (BPPs) For PEMFC," Applied Mechanics and Materials 799-800, 105-109, (2015).

[9] N. Oshima and L. K. Saha, "Prediction of flow crossover in the GDL of PEFC using serpentine flow channel," Journal of Mechanical Science and Technology 26 (5), 1315-1320, (2012).

[10] Philip M. Gerhart, Andrew L. Gerhart, and John I. Hochstein, Munson's Fundamental of Fluid Mechanics, 8th ed. (John Wiley & Sons, Singapore, 2017), pp. 336 – 401

[11] S. E. Haaland, "Simple and explicit formulas for the friction factor in turbulent pipe flow," Transactions of the ASME, Journal of Fluids Engineering (105), 89-90, (1983).

[12] Yunus A. Cengel, and John M. Cimbala, Fluid Mechanics, 1st ed. (Mcgraw Hill Higher Education, Singapore, 2006), pp. 321 – 380