Effects of the geometry of the air flowfield on the performance of an open-cathode PEMFC

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Abstract:
The present work performed an experimental study on a forced-air open-cathode PEMFC. The aim of this work is focused on the effect of the geometry, in terms of the flow area and the shape, of the cathode channel on the performance of the PEMFC. The single-cell open-cathode PEMFC with the active area of 100 cm2 is designed and fabricated for the study. A fan is used to supply an adequate flow rate for cooling and chemical reaction as well as to supply the pressure to overcome the pressure drop across the air flow channel. At low current density, the same performance was found regardless of the flow area and the aspect ratio. The performance at 0.6 V is about 180 mA/cm2. At higher current density, the performance increases with the higher aspect ratio. In contrast, the different flow areas exhibit mostly insignificant effect on the performance of the fuel cell. However, the larger flow area is more preferable due to the net system efficiency and the lower production cost.

Keywords: *PEMFC; fuel cell; open-cathode; aspect ratio; channel dimension; flowfield*

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1. Introduction

In response to the over-reliance on fossil fuel and the global warming problem, fuel cell is one of the clean technologies being developed and starting to reach commercialization. Polymer exchange membrane fuel cell or PEMFC is eminent due to its small size, lightweight, and high efficiency at low operating temperature (Wang et al., 2011; O'Hayre et al., 2008). Although the PEMFC is in practical use for limited commercial use already; the cost of its production is still obviously high. Numerous studies focus on the open-cathode PEMFC as an attempt to address the economy of the entire system (Squadruto et al., 2008). Without the air feeding and cooling system, the simplicity and cost advantages are expected. Its performance is limited because the air transfer by the natural convection is not sufficient for the high-current generation (Paquin and Frechette, 2008; Santa Rosa, 2007). The forced-air type using fans to force the air into the system are developed (Sasmito et al., 2012; Sasmito et al., 2010) to raise the level of performance.

Similar to the typical PEMFC, the air flow channel plays a crucial role in the performance. Studies show a different effect of the channel configuration to the performance between the typical and the natural-convection open-cathode PEMFC. For instance, the smaller channel area gives the better performance for the typical design (Wang et al, 2010; Shimpalee and Van Zee, 2007), while the larger channel area is more preferable for the natural-convection type (Sasmito et al., 2012; Sasmito et al., 2010; Kumar and Kolar, 2010; Tabe et al., 2006). The study on the forced-air type is, however, comparatively lacking and ambiguous. In studies (Sasmito et al., 2010; Kumar and Kolar, 2010; Ying et al.; 2005), various shapes of the air flow channel were simulated without the control over the flow areas. The results from the simulations might show the mixed influence of both the flow area and the shape of the channel.

The aim of this work is focused on the effect of the geometry, in terms of the flow area and the shape, of the cathode channel on the performance of the open-cathode PEMFC via the experiment. The single-cell open-cathode PEMFC with the active area of 100 cm^2 is designed and fabricated for the study. The aspect ratio is defined as the ratio of the width to the depth of the channel. In this study, the flow areas were kept constant at different aspect ratios. Using this strategy, the influence of the flow area and the aspect ratio can be separately investigated for the fuel cell performance.

2. Design and Fabrication

2.1 Single-Cell Open-Cathode PEMFC

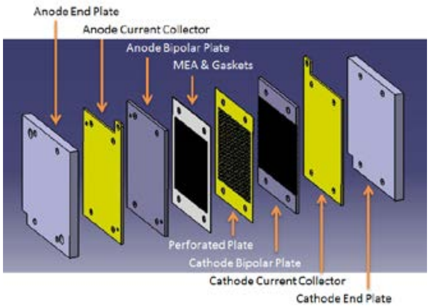
The single-cell open-cathode PEMFC is comprised of 5-layer membrane electrode assembly (MEA) for use in hydrogen/air fuel cell. The 0.002” Nafion® 212-membrane was coated with 410-µm thick carbon cloth GDL. The 60 wt%-platinum catalyst was also on the MEA. The platinum loading is 0.5 mg/cm^2. The activation area is 10 cm x 10 cm as a platform to the practical use at high power.
A perforated plate was fabricated from the gold-plating 0.5-mm copper plate to support the structure of the MEA, provide the air entrance to the MEA as well as electrical conductive. The construction and the function of this perforated plate is similar to the cathode separator in the planar air-breathing PEMFC. The staggered circular pattern in 60 degree angles was chosen. The diameter is 1 mm with 2-mm pitch; hence the open area is about 24%.

Bipolar plates were machined from the graphite plates. The anode bipolar plates were patterned with the parallel-serpentine flowfield. The width and depth are 9 mm. The cathode bipolar plates have the straight channels. The cathode channel configurations are varied for six different set of experiments as specified in Table. 1. Current collectors were made from the 2-mm thick copper plates. The machined plates were coated with the pure gold via the electroplating for low contact resistance. End plates are made from aluminum alloy 7075 with the thickness 13 mm.

Table 1 Details of the six cathode channel configurations.

Flow Area (mm^2)	Aspect Ratio	Width(mm)	Depth (mm)	No. of Channels
2.0	0.80	1.26	1.58	40
	1.25	1.58	1.26	40
5.0	0.80	2.00	2.50	25
	1.25	2.50	2.00	25
8.0	0.80	2.53	3.16	20
	1.25	3.16	2.53	20

The hydrogen flow is allowed by two hydrogen holes at the anode current collector. The 6-mm hydrogen inlet and outlet ports were screwed on the outside of the anode endplates. The hydrogen flow was designed as dead-end mode with a manual purging valve. The asymmetry shape was designed for the ease of the arrangement on the test rig. The order of assembly the single-cell PEMFC is as Fig. 2. All components were completely fastened with the 1-MPa clamping pressure.



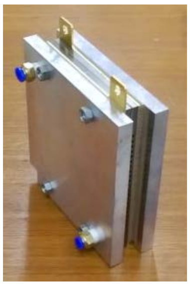


Fig. 2 Exploded view and the picture of the single-cell open-cathode PEMFC.

2.2 Fans

For a forced-air open-cathode PEMFC, fans are used to enhance the performance with minimal complexity and parasitic load. The flow rate has to be adequately generated for the desired electrochemical reaction at the design current density, for the cooling effect for the cell, and not to exceed the turbulent limitation for the sake of the compact design. From fundamental equations, the air flow rate for the cooling was determined to be much higher than that for the electrochemical reaction (the design current density at 300 mA/cm^2 in this case). The flow rate, therefore, has to be adequately delivered to maintain the acceptable temperature difference between the ambient and the cell (50°C in this case). As a result, at this predetermined flow rate, the fan outlet pressure also has to overcome the pressure drop of the air flow channel. An accurate formula (Kiattamrong and Sripakagorn, 2013; Barbir, 2007) to determine the friction of the fuel cell flowfield is

$$f = \frac{55 + 41.5e^{-\frac{3.4}{W/D}}}{\mathrm{Re}} \quad (1)$$

where f is friction coefficient, W is the width of the channel, D is the depth of the channel and Re is Reynolds number. With this equation, six flowfield curves were calculated from six channel configurations. Two curves from the same flow area are quite similar. So, one fan was shared for two test sets for the aspect ratio comparison at the same flow area. Finally, three fans, MC25100V1, MC17080V1 and MC17080V2, from SUNON® with three different characteristic curves were matched all requirements.

2.3 Experiment Procedures

The experiments were performed in the ambient operating relative humidity (60 – 70%) at the temperature 25 degree Celsius. At this atmosphere, the PEMFC can show the good performance (Jung et al., 2008). Each cathode bipolar plate with different air channel configuration was clamped inside the single-cell set as in Fig. 2 and placed in the test rig as in Fig. 3 with the connection on the auxiliary system.

The auxiliary system consists of the 5-VDC supply for the fan, hydrogen inlet valve, and the purging valve and its circuit as shown in Fig. 3. The hydrogen supply was set by the regulator outside the test rig to the value of 2 psi. The dead-end of the hydrogen flow channel was blocked with the solenoid valve for manual purging. The valve was designed to be normally closed and manually opened when the 12-volts direct-current was supplied for economical use and safety. The purging valve was set to operate before changing external load size and every three minutes.

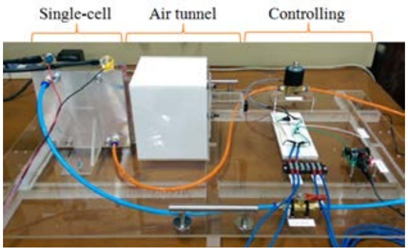


Fig. 3 Test rig.

3. Results and discussion

For the three different flow areas, the polarization curves are depicted in Fig. 4. At low current density, the same performance was found in terms of the voltage and power density regardless of the flow area and the aspect ratio. The performance at 0.6 V is about 180 mA/cm^2. This performance compares reasonably well with the commercial products. The performance of a forced-air open-cathode PEMFC, Horizon H-1000 PEM Fuel Cell, and a typical PEMFC, 1.2 kW Nexa™ Fuel Cell Module, are 250 and 300 mA/cm2, respectively, at 0.6 V. The maximum current density reached the design value at 300 mA/cm^2.

At higher current density, the aspect ratio has a strong influence on the performance. This result agreed with previous studies (Sasmito et al., 2010; Kumar and Kolar, 2010; Ying et al.; 2005) that the performance tends to increase with the higher aspect ratio. This part of the polarization curve is reported to be sensitive the mass transfer loss (Husar et al., 2012). The wide channel (and high aspect ratio) allows more oxygen to reach the MEA (Kumar and Kolar, 2010; Tabe et al., 2006).The drop in the performance of the fuel cell with lower aspect ratio can thus be attributed to the mass transfer loss.

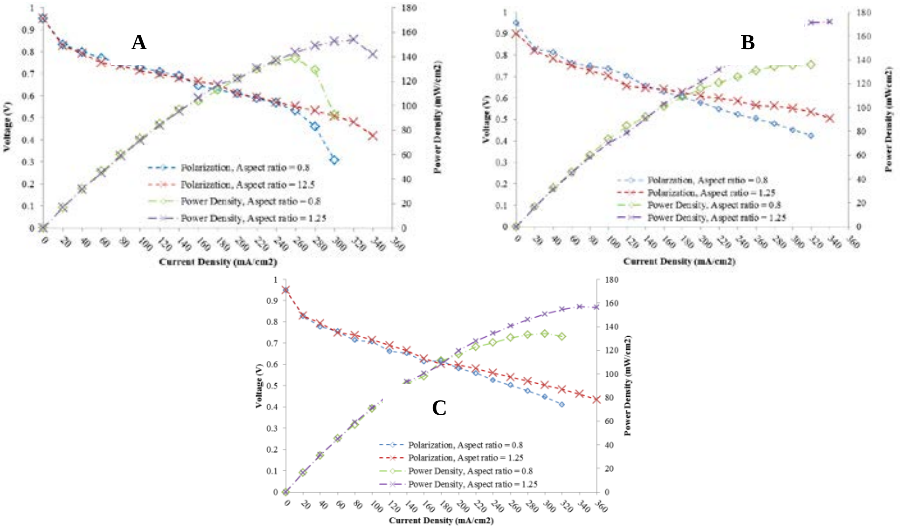


Fig. 4 Polarization curves show the comparison between the aspect ratio 0.8 and 1.25 at the constant flow areas; (A) 2 mm^2, (B) 5 mm^2 and (C) 8 mm^2.

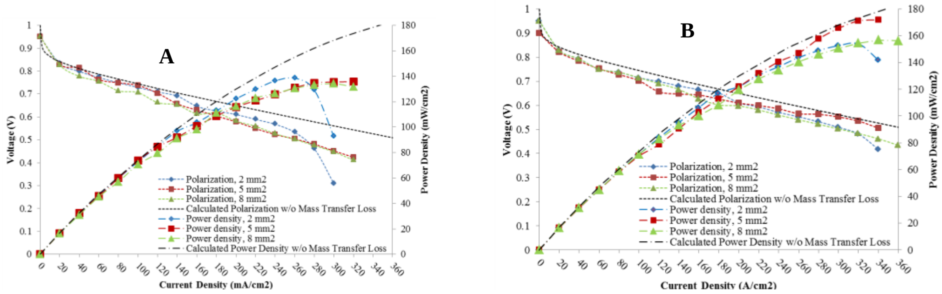


Fig. 5 Polarization curves show the comparison between the flow area 2, 5 and 8 mm^2 at the constant aspect ratios; (A) 0.8 and (B) 1.25.

Table 2 The operating flow rates for different flow area cases.

Flow area (mm^2)	Actual flow rate CFM)	Required flow rate (CFM)	% Excess flow rate
2	0.44	0.44	0
5	0.57	0.44	29.5
8	0.54	0.44	22.7

Fig. 5 illustrates the performance of the fuel cell for the different flow areas at a constant aspect ratio comparing to the calculated curve of the fuel cell loss model (Husar et al., 2012) with the negligible of the mass transfer loss. The different flow areas exhibit mostly insignificant effect on the performance of the fuel cell. Despite an abrupt drop found in the 2-mm^2 flow area case due to the operating flow rate at the minimum requirement, the peak power densities obtained from each test are not significantly different. The performance in case of the 5-mm^2 flow area performed a slightly better result than the others because of its maximum operating flow rate as in Table 2. Comparing the results from each aspect ratio to the limit curve, the lower aspect ratio was investigated that its performance lacks due to the mass transfer loss. Even though the flow area does not play the important role on the performance of the fuel cell, it should be concerned from the economy perspective. The small flow area causes the high pressure drop in the flow channel. A large fan with high power consumption and high cost is inevitably required for the fuel cell system.

Therefore, the larger flow area is more preferable due to the net system efficiency and the lower production cost.

Besides the electrochemical issues, the mechanical and thermal stress on both the MEA and the flowfield plate are to be concerned. The width of the rib and the channel has to be proper and balance (Tabe et al., 2006; Ying, 2005), and the ratio of the rib width over the channel width is recommended to be slightly more than unity. The optimum aspect ratio of the air flowfield, in the thermal stress and fuel cell performance conditions, should be determined and used as a basis towards the development of the forced-air open-cathode PEM fuel cell stack for the practical application.

4. Conclusion

The single-cell open-cathode PEMFC with the active area of 100 cm^2 is designed and fabricated for the study on the influence of the channel geometry on the performance of the fuel cell. In the present work, the flow areas were kept constant at different aspect ratios such that the influence of the flow area and the aspect ratio can be separately investigated for the fuel cell performance. The hydrogen supply is at 2 psi and was designed as dead-end mode with a manual purging valve. For this forced-air open-cathode PEMFC, a fan is used to supply an adequate flow rate for cooling and chemical reaction as well as to supply the pressure to overcome the pressure drop across the air flow channel.

The polarization curves are obtained for the three different flow areas. At low current density, the same performance was found regardless of the flow area and the aspect ratio. The performance at 0.6 V is about 180 mA/cm^2; the maximum current density reached 360 mA/cm^2. At higher current density, the performance tends to <u>increase with the higher aspect ratio</u>. The drop in the performance at lower aspect ratio can be attributed to the mass transfer loss. The different flow areas do not influence significantly to the performance of the fuel cell. Despite an abrupt drop found in the 2-mm^2 flow area case, the peak power densities obtained from each test are not considerably different. It was recommended that, for the benefit of net system efficiency and the lower production cost, the larger flow area is more preferable.

Due to the non-uniform load in the practical use as the <u>automotive application</u>, the effect of the geometry of the cathode channel on the performance of the open-cathode PEMFC for the transient load will be studied as the next step.

5. Acknowledgement

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