PAPER • OPEN ACCESS

Performance of PEM fuel cells stack as affected by number of cell and gas flow-rate

To cite this article: A Syampurwadi et al 2017 IOP Conf. Ser.: Earth Environ. Sci. 60 012029

View the article online for updates and enhancements.

You may also like

- <u>Multi-Objective Operating Parameters</u> Optimization for the Start Process of Proton Exchange Membrane Fuel Cell Stack with Non-Dominated Sorting Genetic Algorithm II

Zhao Liu, Huicui Chen, Tong Zhang et al.

- Impacts of Pore Scale Gas Diffusion Layer Deformation on PEMFC Performance at Sub Zero Operation Geethu Varghese, Venkatesh Babu KP, Thadathil Varghese Joseph et al.
- <u>Development of a PEMFC dynamic model</u> and the application to the analysis of fuel <u>cell vehicle performance</u> Wei Liu, Zhijun Peng, Bill Kim et al.





DISCOVER how sustainability intersects with electrochemistry & solid state science research



This content was downloaded from IP address 3.22.181.81 on 04/05/2024 at 06:28

Performance of PEM fuel cells stack as affected by number of cell and gas flow-rate

A Syampurwadi^{*}, H Onggo, Indrivati and R Yudianti

Research Unit for Clean Technology, Indonesian Institute of Sciences (LIPI) Jalan Cisitu 21/154 D, Bandung 40135, Indonesia *Email : anung.syampurwadi@lipi.go.id

Abstract. The proton exchange membrane fuel cell (PEMFC) is a promising technology as an alternative green energy due to its high power density, low operating temperatures, low local emissions, quiet operation and fast start up-shutdown. In order to apply fuel cell as portable power supply, the performance investigation of small number of cells is needed. In this study, PEMFC stacks consisting of 1, 3, 5 and 7-cells with an active area of 25 cm² per cell have been designed and developed. Their was evaluated in variation of gas flow rate. The membrane electrode assembly (MEA) was prepared by hot-pressing commercial gas diffusion electrodes (Pt loading 0.5 mg/cm²) on pre-treated Nafion 117 membrane. The stacks were constructed using bipolar plates in serpentine pattern and Z-type gas flow configuration. The experimental results were presented as polarization and power output curves which show the effects of varying number of cells and H₂/O₂ flow-rates on the PEMFC performance. The experimental results showed that not only number of cells and gas flow-rates affected the fuel cells performance, but also the operating temperature as a result of electrochemistry reaction inside the cell.

1. Introduction

Global demand for new and renewable energy has lead to several alternative energy resources & technology. One of them is fuel cell (FC) which convert chemical energy of hydrogen and oxygen (or air) directly to electrical energy. There are many kind of fuel cell technology, such as alkaline FC (AFC), proton exchange membrane FC (PEMFC), phosphoric acid FC (PAFC), molten carbonate FC (MCFC), and solid oxide FC (SOFC) [1].

Proton exchange membrane FC (PEMFC) is a promising technology due to its high power density, low operating temperatures, low local emissions, quiet operation and fast start up-shutdown. One of PEMFC application is as mini/portable power supply. For this purpose, the PEMFC is usually assembled as a stack of many cells. Investigation of PEMFC performance was conducted by assembling 1, 3, 5 and 7 cells, then evaluated the polarization curves yielded by fuel cell test device [2].

2. Experimental

2.1. Materials

Components of PEMFC stacks consisted of membrane electrode assembly (MEA), aluminum endplates, gold coated copper current collectors, silicon rubber gaskets (sheet thickness 0.5mm), FU4369 graphite bipolar plates and other accesories (Swagelok tubing fitting, rods, stainless steel nuts and bolts, ring, heat-resistants shells, silicone tubing). MEA consisted of Nafion 117 membrane, gas

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI. Published under licence by IOP Publishing Ltd 1

diffusion electrodes (GDE) with 0.5 mg/cm² Pt loading of 60% Pt/C and 5 wt.% Nation 117 solution. The reactant gases were hydrogen UHP (99.99% purity) and oxygen, with nitrogon as purging gas. In this assembly, the reactant gases flow configuration was Z type, as showed at Figure 1.



Figure 1. The Z type of reactant gases flow configuration.

2.2. Fabrication of some stack components

The bipolar plates were fuel cell grade FU 4369 graphite bipolar plates, dimension of 62 mm x 95 mm x 5 mm, with a 6-channel serpentine pattern in the hydrogen flow field and in oxygen flow field. Depth and width of the channels were 1mm, and width of the rib were 0.8 mm (Figure 2). The curent collector plates were gold coated (0.2μ m)-copper plates, dimension of 62mm x 120 mm x 1.0 mm). The aluminum end-plates had dimension of 80 mm x 115 mm x 16 mm.



Figure 2. Bipolar plates design, (a) schematic, (b) photo.

2.3. Preparation of membrane electrode assembly

The membrane electrode assemblies (MEAs) used for the experiment were prepared by hot-pressing of two commercial gas diffusion electrode (GDE) (60 wt% Pt/vulcan XC72 on carbon cloth, Pt loading 0.5 mg/cm²) on either side of a DuPontTM Nafion 117 membrane at 120°C, 20 kgf for 1 min. For effective contact between the GDE and the membrane, the Nafion 117 solution (5% solution of 1.0 mg cm⁻² (Neuroflash PTE Ltd)) was applied on catalyst surfaces of two GDE by screen printed methode[3]. Nafion 117 membrane was previously treated with 3% hydrogen peroxide (H₂O₂) at 70-80°C for 1 h to remove organic impurities. To get fully H-form, the membrane was boiled at 70-80 °C for 1 min 0.5 M H₂SO₄ that remain on the membrane surface.

2.4. Assembling single cell, 3-cells, 5-cells and 7-cells

The PEMFC stack consists of single cell, 3-cells, 5-cells and 7-cells with active area of 25 cm2. The MEAs, gasket, two monopolar plates (for hydrogen and oxygen flow), bipolar plates and current collectors were sandwiched between two aluminum end plates with eight threaded stainless steel rods, bolts and nuts. The gaskets are placed between electrolyte membrane and bipolar-plate which should have good elasticity, durability and corrosion resistant. During the stack assembling, two positioning rods were used for alignment. All components were aligned and stacked one by one. The sizes of SS 316 bolts are M6 x 0.8 mm with 58mm, 70mm, 90mm and 100mm length for the single cell , 3-cells, 5-cell and 7-cell stacks respectively. Equal clamping torque (20 kgf) was applied on each bolt to assemble the PEMFC single cell, 3-cells, 5-cells and 7-cells.

2.5. Measuringf PEMFC performances

In the cell testing, high purity hydrogen (99,99%) and oxygen gases were used as fuel and oxidant, respectively. Smart2 PEM/DM hybrid fuel cell test system (WonATech Co., Ltd.Korea) was used to test the performance of the stacks. The test station consisted of two main system: a gas feeding and a controlling system. A gas feeding system supplied and treated the fuel and oxidant gases fed to the cell, while the controlling system measured and controlled the operation conditions of the FC stack. The back pressure of the fuel cell could be varied with the help of mechanical valves in the test station, for each reactant.

2.5.1. Varying gas flow rate for single cell

At first step, number of cell was kept constant at single cell. Gas flow rate variation was applied, then each of its performances were evaluated. As addition, back pressure was also applied to show its effect. Table 1 shows each condition.

| | Condition 1 | Condition 2 | Condition 3 | Condition 4 |
|---|-------------|-------------|-------------|---|
| H ₂ /O ₂ volumetric | 100 / 140 | 60 / 140 | 100 / 100 | 100 / 100, with ³ ⁄ ₄ |
| flow rate (mL/min) | | | | psi back pressure |

Table 1. Variation of gas flow rate & back pressure for single cell.

2.5.2. *Varying number of cell*. At second step, number of cell was varied. In the other hand, gas flow rate were kept proportional to number of cells. Because of the fuel cell test device limitation, back pressure was not applied in this step. Each of its performance were then evaluated. Table 2 show each condition.

| | Single cell | 3-cells | 5-cells | 7-cells |
|---|-------------|-----------|-----------|-----------|
| H ₂ /O ₂ volumetric | 100 / 100 | 300 / 300 | 500 / 500 | 700 / 700 |
| flow rate (mL/min) | | | | |

 Table 2. Variation of number of cells.

3. Result and discussion

Figure 3 showed that for single cell, the best performance was achieved by condition of 100/100 with back pressure, followed by 100/100, 100/140, and 60/140, respectively.



Figure 3. Polarization and power output curves for single cell.

First, it showed that back pressure have positive effect on fuel cell performance, as already confirmed by many scientific books and journal papers [4][5][6]. Second, it indicated that 100/100 mL/min not only showed the saturated flow rate for the single cell, but also indicated that 1 : 1 ratio is the best stoichiometry ratio for these reactants. Theoretically, the mole ratio of hydrogen and oxygen gases for water formation is 2:1. The discrepancy between the experimental and theoretical ratios need to be investigated at futher research.



doi:10.1088/1755-1315/60/1/012029



Figure 4. Polarization and power output for (a) single cell, (b) 3-cells, (c) 5-cells, (d) 7-cells.

Figure 4 shows the performance test results for single cell, 3-cells, 5-cells and 7-cells. From these curves, it could be obtained data of Table 3 as follow.

| Parameter | 1-cell | 3-cells | 5-cells | 7-cells |
|---|---------|---------|---------|---------|
| H_2/O_2 volumetric flow rate (mL/min) | 100/100 | 300/300 | 500/500 | 700/700 |
| Open circuit voltage, OCV (volt) | 1.0 | 2.9 | 4.9 | 7.0 |
| Operational voltage, V _{op} (volt) | 0.6 | 1.8 | 3.0 | 4.2 |
| Operational current density, J_{op} (mA/cm ²) | 379 | 297 | 316 | 165 |
| Operational power density, P_{op} (mW/cm ²) | 227 | 535 | 948 | 693 |

Table 3. Extracted data from polarization and power output of 1-cell, 3-cells, 5-cells, 7-cells.

Table 3 shows that open circuit voltage values were normal for each cells, as it was predicted from theoretical study and confirmed by many research papers [7]. Operational voltage was determined by definition[8]. The results of operational current density were rather unexpected. The 7-cells indicated a fail or broken condition on operation/testing. It is normal if the expected values for J_{op} were same or similar for all of the 4 combination. But the results was different. The best J_{op} were 1-cell, followed by 5-cell, 3-cell, and 7-cell, respectively. This lead to irregular patern for operational power density P_{op} . There are many factors that could contribute to this unexpected results, from the quality of MEA assembling (hot-pressing), leakage of reactant gases, etc. The risk of defect is increased as number of cells increasing.

Figure 5 shows the correlation between cell temperature and current density for 1-cell, 3-cells, 5-cells and 5-cells.



doi:10.1088/1755-1315/60/1/012029



Figure 5. Correlation of cell temperature and J_{op}, (a)1-cell, (b)3-cells, (c)5-cells, (d)7-cells.

From Figure 5, it is clear that there exist some trends between cell temperature and current density. For 1-cell, the temperature was relatively steady at 45°C. For 3-cells and 5-cells, temperature increased as current density was growing up, but not exceed 90°C (usually known as temperature limit for Nafion membrane)[9]. Instead, by reaching 70-80°C, the stack could improve its performance, as this temperature range is the best values for Nafion performance[10]. For 7-cells, the increasing temperature could exceed 80°C, if current density was above 400mA/cm². This means that the stack need a cooling sytem to prevent from possibility of broken. On the other side, this results suggested that there was a possibility that the 7-cells temperature had exceeded 80°C, so triggering of Nafion defective during testing.

3. Conclusion

The reactant flow rate of ratio 1:1 yielded best stack performance. The polarization curves showed that before electronic loading, the OCV of each cells have normal values. This means that all stack worked normally at start point. As current density was increasing, some of the cells was going underperformance. Some considerations could be taken such as hot-pressing that based on determined spacing (thickness) rather than pressure gauge, cooling system for increased number of cells, changing value of clamping torque, etc. The risk of fail is increased as number of cell is increasing.

More number of the cells and higher current density had influence on the increasing of cell temperatures. On the other hand, this increasing temperature could contribute to higher performance of the stack if could be maintained between 70-80°C.

Acknowledgement

Authors would like to acknowledge Nanik Indayaningsih, Yuyun Irmawati, Dita Rama Insiyanda, and Achmad Subhan from Research Center for Physics, Indonesian Institute of Sciences for supporting PEMFC performance test.

References

- [1] Hoogers G 2003 Fuel Cell Technology Handbook.
- [2] Hirschenhofer J H, Stauffer D B, Engleman R R and Klett M G 1998 *Fuel Cell Handbook*, 4th edition.
- [3] Litster S and McLean G 2004 J. Power Sources. 130(1–2) 61–76.
- [4] Reshetenko T V, Bender G, Bethune K and Rocheleau R 2011 *Electrochimica Acta*. **56(24)** 8700–10.
- [5] Amirinejad M, Rowshanzamir S and Eikani M H 2006 J. Power Sources. 161(2) 872–5.
- [6] Sun H, Liu H, Guo L 2005 J. Power Sources. 143(1–2) 125–35.
- [7] Zhang J, Tang Y, Song C, Zhang J and Wang H 2006 J. Power Sources. 163(1) 532–7.
- [8] Yu P T, Gu W, Makharia R, Wagner F T and Gasteiger H A 2006 ECS Transactions 3(1)797-809

- Jung G, Weng F, Su A, Wang J, Yu T L, Lin H, Yang T and Chan S 2008 International [9] Journal of Hydrogen Energy 33(9) 2413–7.
- [10] Williams M V, Kunz H R and Fenton J M 2004 Journal of Power Sources 135(1-2) 122-34.