Effect of Entry Conditions on Performance of a Proton Exchange Membrane Fuel Cell with Interdigitated Flow Fields

Yixiang Wang, Ruibo Shen, Zhe Sun and Mingge Wu*
College of Mechanical and Electrical Engineering, Wenzhou University, Wenzhou, China

*Corresponding author e-mail: wmg7810@wzu.edu.cn

Abstract. A three-dimensional two-phase mathematical model is used to investigate the entry conditions effects on performance of proton exchange membrane fuel cells (PEMFC) with an interdigitated flow field. Analogy with parallel and serpentine flow fields, interdigitated is better than the other two in comprehensive, and should be preferred. Comparison of different relate humidity (RH) indicates that RH significantly affect cell performance, while RH of cathode affect more. Current density increases with increased hydrogen flow of RH 100%, however, slightly reduces with that of oxygen.

1. Introduction
The study of proton exchange membrane fuel cell (PEMFC) has become a hot topic, among which the design of bipolar plate flow field is not only the most basic research, but also the most important one. The distribution of liquid water in the flow field has a great effect on the overall performance and stability of fuel cells. The cathode side of the battery is more prone to water flooding, while the anode side of the battery is more prone to dry. Interdigitated flow field has become a research hotspot for its excellent water management.

Yu [1], Wang [2] established a three-dimensional two-phase model to describe the effect of mass transfer in the diffusion layer and the distribution of liquid water on oxygen transport through different oxygen flow rates. Hu [3] verified that the flow form of reaction gas in the interdigitated flow field is mainly forced convection, while the parallel field is diffusion. Hwang [4] compared the temperature distribution between the interdigitated flow field and the parallel field. The new experimental device designed by S.Bell [5] measured the process of liquid water permeating freely into the membrane electrode in the interdigitated flow field for the first time, and took the serpentine flow field as a reference. Wang [6] proposed that the optimal depth-width ratio of the interdigitated flow field was 1:1, and the area was 1mm*1mm. Santamaria [7] proved through numerical calculation and experiment that the limiting current density of the short channel length of the interdigitated flow field is higher than that of the long channel. Kazim [8] and Yan [9,10] verified that the increase of porosity of diffusion layer, mole fraction of input oxygen, operating temperature and pressure are all conducive to the overall performance of the interdigitated fuel cell.

All the above researches focus on the mass transfer mechanism and influencing factors of the interdigitated flow field fuel cell. There are not too many quantitative analysis on the pros and cons of...
the three traditional flow fields at the same conditions. Therefore, this article focuses on investigating
the changes of performance of interdigitated PEMFC at different entry condition (parallel channel and
serpentine channel at the same conditions as reference), so as to provide some references for the design
of PEMFC flow channel.

2. Model description
The width and depth of each channel and the width of each rib in all considered flow fields are 1mm,
other geometric parameters were shown in Table 1, and operational parameters and electrochemical
parameters were shown in Table 2.

| Parameters | value |
|------------|-------|
| Active area | 51mm x 51mm |
| Thicknesses of GDLs | 0.254mm |
| Thicknesses of catalyst layers | 0.01mm |
| Thicknesses of membrane | 0.178mm |

| Parameters | value |
|------------|-------|
| Operating pressure/(Pa) | 202650 |
| Operating temperature /(K) | 353 |
| Exchange current density of anode volume/(A•m⁻³) | 2×10⁹ |
| Exchange current density of cathode volume /(A•m⁻³) | 1×10⁵ |
| Hydrogen diffusion coefficient / (m²•s⁻¹) | 5×10⁻⁵ |
| Oxygen diffusion coefficient /(m²•s⁻¹) | 3.5×10⁻⁵ |
| Water vapor diffusion coefficient/ (m²•s⁻¹) | 8×10⁻⁵ |
| Other diffusion coefficients/(m²•s⁻¹) | 3×10⁻⁵ |
| Open circuit voltage/(v) | 1.05 |
| GDL porosity | 0.4 |
| Catalyst layer porosity | 0.112 |

Because the high complexity of the fuel cell system, it is unrealistic to conduct numerical simulation
completely in accordance with the actual operation of the battery. Without affecting the simulation
results, the following basic assumptions are made for the fuel cell system in the process of model
establishment:
(1) All gaseous components (hydrogen, oxygen, water vapor) are ideal gases;
(2) Because the reaction gas velocity is low and the gas flow field cross-sectional area is small, the
gas flow inside the fuel cell is considered as laminar flow based on the low Reynolds number in the flow
process;
(3) All porous medium (proton exchange membrane, catalyst layer, gas diffusion layer) are
considered as isotropic homogeneous materials;
(4) The cooling of the fuel cell system consists of forced convection.
3. Results and discussions

3.1. Contrast between traditional flow fields

Fig. 1 shows the current density of PEMFC at the condition of 2atm, 353k, hydrogen flow 600ml/min, RH 100%, oxygen flow 300ml/min, RH 100%. The current density of three traditional flow fields decreases with the decrease of external voltage. In the case of low current density, the three are basically the same, which is a typical ohmic polarization region. The current density of the interdigitated channel is very close to that of the serpentine channel, almost coincident. However, when the external voltage of the parallel channel is 0.5v, it begins to decrease rapidly and deviates significantly with the decrease of voltage. This is because there is a certain amount of saturation, so there is not much difference in battery performance with the same area. With the decrease of external voltage, the electrochemical reaction is accelerated, and the formation and retention of liquid water increase. Because of the different flow and drainage characteristics of the three traditional flow fields, the battery performance changes.

![Figure 1. Polarization curve of PEMFC with traditional flow fields.](image)

The cathode water distribution of the three is shown in Fig.2. The gas conduction mode of the interdigitated flow field is forced convection. During the reaction process, the water generated is carried to the air exit channel by the oxygen through the diffusion layer by convection, and pushes the water flow to the air exit. Liquid water builds up at the far end of the gas entry, reaching a maximum at the exit, but does not block the flow channel. The obvious flooding phenomenon occurs in the parallel channel because of the parallel connection of its branches. When liquid water blocks some branch flow channels, the gas will automatically flow out of the exit to the unblocked flow channel with a small pressure drop, thus reducing the actual reaction area and current density. And as the reaction speeds up, the flooding becomes more pronounced, leading to the sharp drop seen in Fig.1. Serpentine flow because of its single flow channel, the reaction gas will constantly push the water in the blocked flow channel to keeping the flow path open, but at the same time, it will cause greater pressure loss. The pressure drops of the three are shown in Fig.3. The anode and cathode pressure drop of interdigitated flow field were 857.88Pa and 932.32Pa. Those of parallel flow field were 161.2Pa and 22.92Pa. Those of serpentine flow field were 3282.56Pa and 4592.08Pa. The pressure drop in the serpentine flow field is much higher than that in the interdigitated flow field and parallel flow field. In conclusion, considering the fuel cell as an energy generating device, the actual net energy output and stability of the battery cannot be ignored. Therefore, the basic structure of interdigitated is more suitable for the design of bipolar plate.
3.2. Effect of gas humidity
Many scholars have discussed the effect of humidification temperature on battery performance in previous studies, but increasing the entry temperature alone while maintaining the overall battery temperature has little effect on battery performance, especially when the flow channel is long or the flow rate is small. This section kept the temperature constant and changed the content of water in the entry gas to adjust the humidity of the entry gas. However, the change of total pressure caused by the change of water content in the gas must be ignored. The humidity of anode and cathode is respectively set to 0, 50%, 75% and 100%. Considering that the difference between the three is not obvious when the current density is low, only the current density when the working voltage is 0.3V is taken, as shown in Table 3. It can be seen from the table that when the anode or cathode side is not humidified, the current density of PEMFC is much lower than that of both sides, and when the two sides are not humidified, the performance of the interdigitated and serpentine flow fields is much lower than that of the parallel channel. This is because the multi-channel parallel characteristic of parallel channel allows more water to be retained in the flow channel, which is the cause of water flooding in the case of high current density. Comparing RH 1:0 and RH 0:1, it is not difficult to find that the humidification of the anode is more important than that of the cathode, because the water generated by the cathode reaction can humidify the membrane electrode to a certain extent.
Table 3. Current density under 0.3V of PEMFC with traditional flow fields

| Interdigitated/parallelserpentine (A/cm²) | 0  | 50% | 75% | 100%       |
|------------------------------------------|----|-----|-----|------------|
| Anode humidification                     |    |     |     |            |
| 0                                        | 0.286 / 0.913 / 1.234 / 1.207 / 1.684 / 1.370 / 2.126 / 1.536 |
| 50%                                      | 1.133 / 1.257 / 1.862 / 1.548 / 2.063 / 1.598 / 2.112 / 1.642 |
| 75%                                      | 1.651 / 1.520 / 2.120 / 1.600 / 2.211 / 1.631 / 2.232 / 1.666 |
| 100%                                     | 1.908 / 1.735 / 2.275 / 1.653 / 2.325 / 1.669 / 2.352 / 1.721 |

4. Conclusion
Considering current density, net output and stability, the PEMFC of the interdigitated flow field is better than the other two traditional flow fields, which should be preferred in the foundation selection of flow field design. When both sides of the bipolar plate are not humidified, the performance of parallel flow field is better than the other two. The current density of only one side humid is much less than that of both sides, and the humidification of anode is more important than that of cathode.

Acknowledgments
This work was financially supported by the Natural Science Foundation of Zhejiang Province (LQ20E060012).

Reference
[1] Yu, Li Jun, et al. Transport mechanisms and performance simulations of a PEM fuel cell with interdigitated flow field. Renewable Energy 34.3 (2009) 530-543.
[2] Wang, Xiaodong, et al. Transient response of PEM fuel cells with parallel and interdigitated flow field designs. International Journal of Heat and Mass Transfer 54.11 (2011) 2375-2386.
[3] Hu, G., J. Fan, and S. Chen. Three-dimensional numerical analysis of proton exchange membrane fuel cells (PEMFCs) with conventional and interdigitated flow fields. Journal of Power Sources 136.1 (2004) 1-9.
[4] Hwang, J. J., and S. J. Liu. Comparison of temperature distributions inside a PEM fuel cell with parallel and interdigitated gas distributors. Journal of Power Sources162.2 (2006) 1203-1212.
[5] Bell, S., et al. Humidity, Pressure, and Temperature Measurements in an Interdigitated-Flow PEM Hydrogen Fuel Cell. International Journal of Thermophysics 33.8-9 (2012) 1583-1594.
[6] Wang, Xiao Dong, et al. Effects of flow channel geometry on cell performance for PEM fuel cells with parallel and interdigitated flow fields. Electrochimica Acta53.16 (2008) 5334-5343.
[7] Santamaria, Anthony D., et al. Effect of channel length on interdigitated flow-field PEMFC performance: A computational and experimental study. International Journal of Hydrogen Energy 38.36 (2013) 16253-16263.
[8] Kazim, A., P. Forges, and H. T. Liu. Effects of cathode operating conditions on performance of a PEM fuel cell with interdigitated flow fields. International Journal of Energy Research 27.4 (2003) 401–414.
[9] Yan, Wei Mon, C. Y. Chen, and S. C. Mei. Effects of operating conditions on performance of PEM fuel cells with conventional or interdigitated flow field. Journal of Power Sources 162.2 (2006) 1157-1164.
[10] Yan, W. M., S. C. Mei, and C. Y. Soong. Experimental study on the performance of PEM fuel cells with interdigitated flow channels. Journal of Power Sources 160.1 (2006) 116-122.