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Optimization Design of Bipolar Plate Flow Field in PEM Stack

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Abstract. A new design of bipolar plate flow field in proton exchange membrane (PEM) stack was presented to develop a high-performance transfer efficiency of the two-phase flow. Two different flow fields were studied by using numerical simulations and the performance of the flow fields was presented. the hydrodynamic properties include pressure gap between inlet and outlet, the Reynold's number of the two types were compared based on the Navier–Stokes equations. Computer aided optimization software was implemented in the design of experiments of the preferable flow field. The design of experiments(DOE) for the favorable concept was carried out to study the hydrodynamic properties when changing the design parameters of the bipolar plate.

1. Introduction

There are many fluctuant and unstable renewable energy on earth such as wind, geothermal, solar, tidal and etc. But how to store it at free time and release it when need is a problem we human beings faced. Hydrogen, as a renewable and clean energy, is considered the best means to store the electric energy which comes from the photovoltaic, and wind turbines [1, 2]. Unstable energy from solar and wind firstly was converted into electrical power, then the electrical energy can be used to electrolysis, converting the energy into chemical energy. To date, two main research points were focused on alkaline electrolysis systems and PEM electrolyzes. Compared with alkaline electrolysis, PEM electrolyzes has a high conversion efficiency above 70 % at high current densities (> 1 A.cm2), and also well-suited for working using intermittent power sources. But there still some issues such as the gas cross-permeation effects and related safety issues when operate at high pressure (in the 10-150 bars pressure range) and high current density [3], the lifetime of the proton exchange membrane when working in a terrible condition [4], the development of the bipolar plate and the stack [5].

As the first stage to distribute fluid in the stack, bipolar plates have great influence on the performance of PEM electrolyzes. Well-designed flow field which is uniform and have even pressure/velocity distributions for fluid contributes to high pressure operation and high current density in the stack [6]. Because plenty of heat which was generated by high current density will gathered in the stack if the heat cannot be taken away by the fluid, which will affect the performance and lifetime of the precious proton exchange membrane. Also, the optimized flow field which has low internal turbulence is suitable for high velocity fluid operation [7]. In order to achieve this goal, the optimized design of the flow field is once again of paramount importance.

In this study, a commercial parallel-serpentine bipolar plate and an optimized model were studied. The three-dimensional model of the two type bipolar plates were created, and the hydrodynamic properties include pressure gap between inlet and outlet, the Reynold's number of the two types were compared based on the Navier–Stokes equations. The design of experiments (DOE) for the favorable concept was carried out to study the hydrodynamic properties when changing the design parameters of the bipolar plate.

2. Model of the bipolar plate

The bipolar plate of the PEM electrolysis cell usually made of graphite, titanium or stainless steel, accounts for about half of the over cost of PEM stack for its platinum catalyst layer. According to the flow field channel patterns, the plate of the PEM electrolysis can be divided into three classed: pin-type, parallel channels, serpentine [8]. In this study, we adopted a commercial design using multiple serpentine with three channels. The dimension of the flow field area was 10cm×10cm, equal 100cm2 active area. It is formed by 18 channels which is 2mm deep and 3mm wide, with 2mm wide ribs between the channels. In order to decrease the turbulence in the flow field, an optimized plate with round corner was put forward. A schematic of the two investigated bipolar plates is shown in Fig 1.

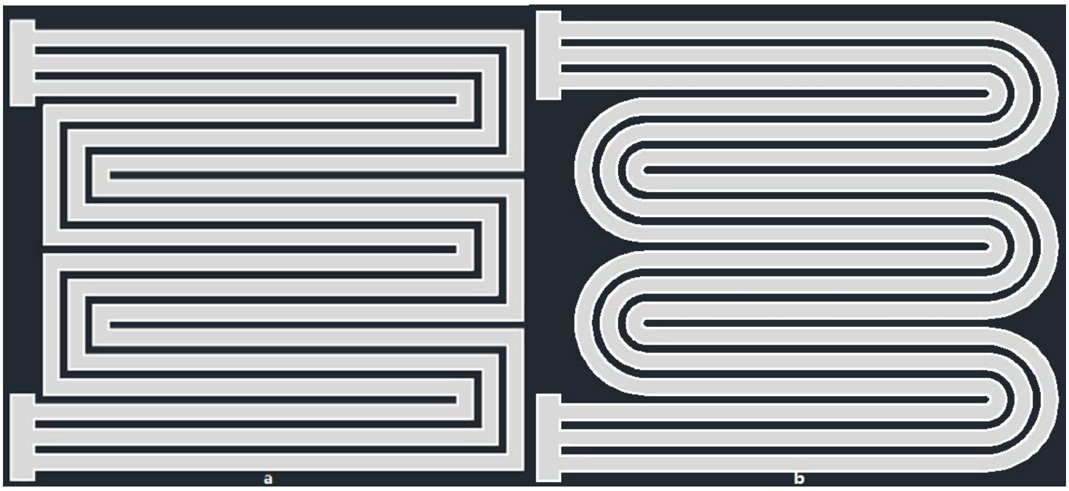


Fig. 1. Schematic of the two-investigated bipolar plate (a) the commercial plate with right-angle channels (b) the new design plate with round corner.

When creating the mathematic model, standard k-epsilon model was chosen to simulate flow in channels. Near-wall treatment was set in enhanced wall treatment. Hyper mesh 11.0 was used to generate the mesh and hybrid volume elements with the boundary layer are employed in the simulation, Ansys Fluent 14.0 was implemented in solving the velocity and pressure field.

3. Design of experiments for the favourable bipolar plate

3.1. Comparisons of the two investigated fields of the hydrodynamic properties

Simulations for the two different plate fields in the anode side were carried out to illustrate and validate the hydrodynamic properties between the commercial one and the newly designed one. Except the geometry and mesh, the model and boundary conditions used in the simulation were kept consistent. Independence tests of the grid were performed before they were used. For boundary conditions, the velocity of the inlet is 4.5m/s, the outlet is pressure outlet, and gage pressure is 0 bar.

It can be seen in Fig. 2 (a) (b) that the pressure distribution appears as decreasing gradually along the flow from inlet to outlet. The pressure drops between the field with straight corner and the field with round corner as shown in Table 1. The Reynold's number contour is shown in Fig. 3.

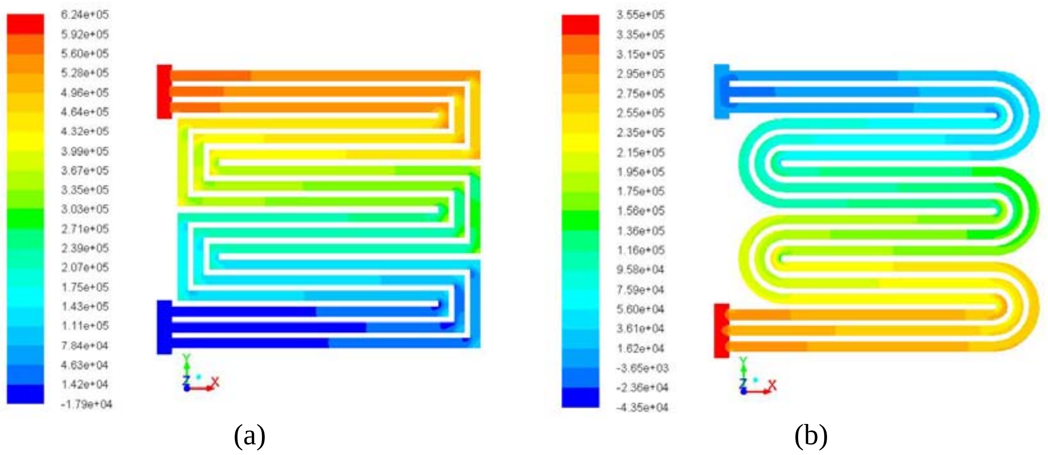


Fig. 2 Pressure distribution in the fields (a) field with right corner (b) field with round corner.

Table 1. The pressure drops between two fields

	Field with right corner	Field with round corner
Pressure in inlet (Pa)	611401	341267
Pressure in outlet (Pa)	-85	-62
Pressure drop (Pa)	611486	341329

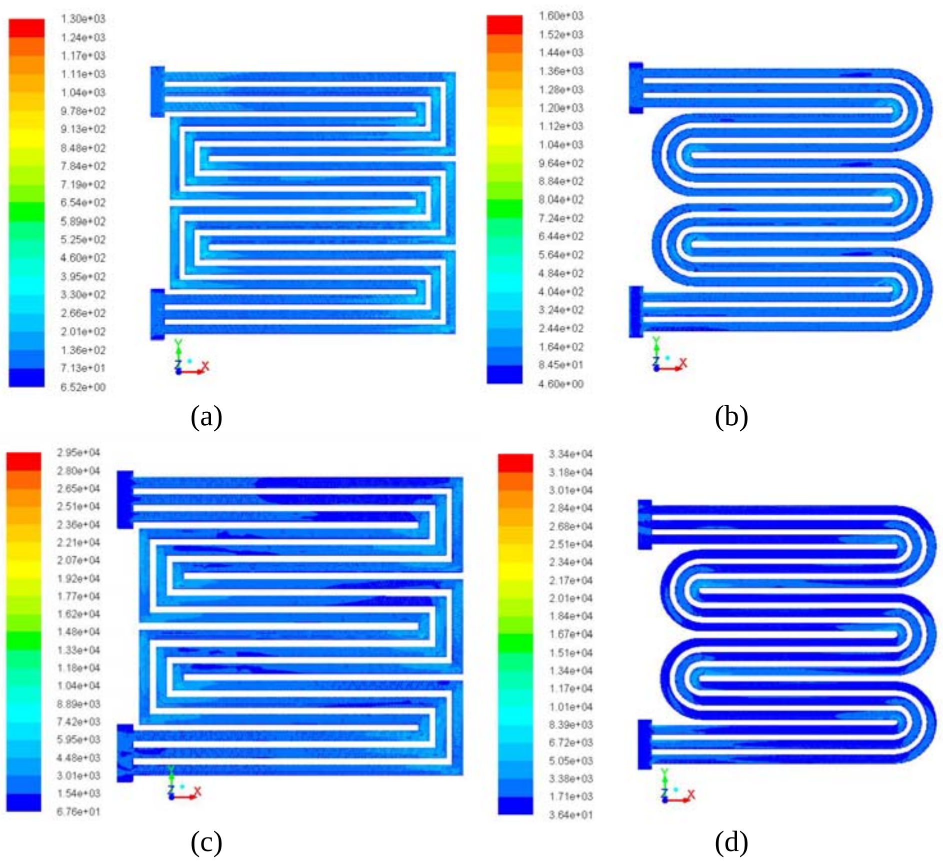


Fig. 3 Reynolds number in the field. (a) right corner, inlet velocity=4.5m/s (b) round corner, inlet velocity=4.5m/s (c) right corner, inlet velocity=100m/s (d) round corner, inlet velocity=100m/s

3.2. Design of experiments of the round corner field.

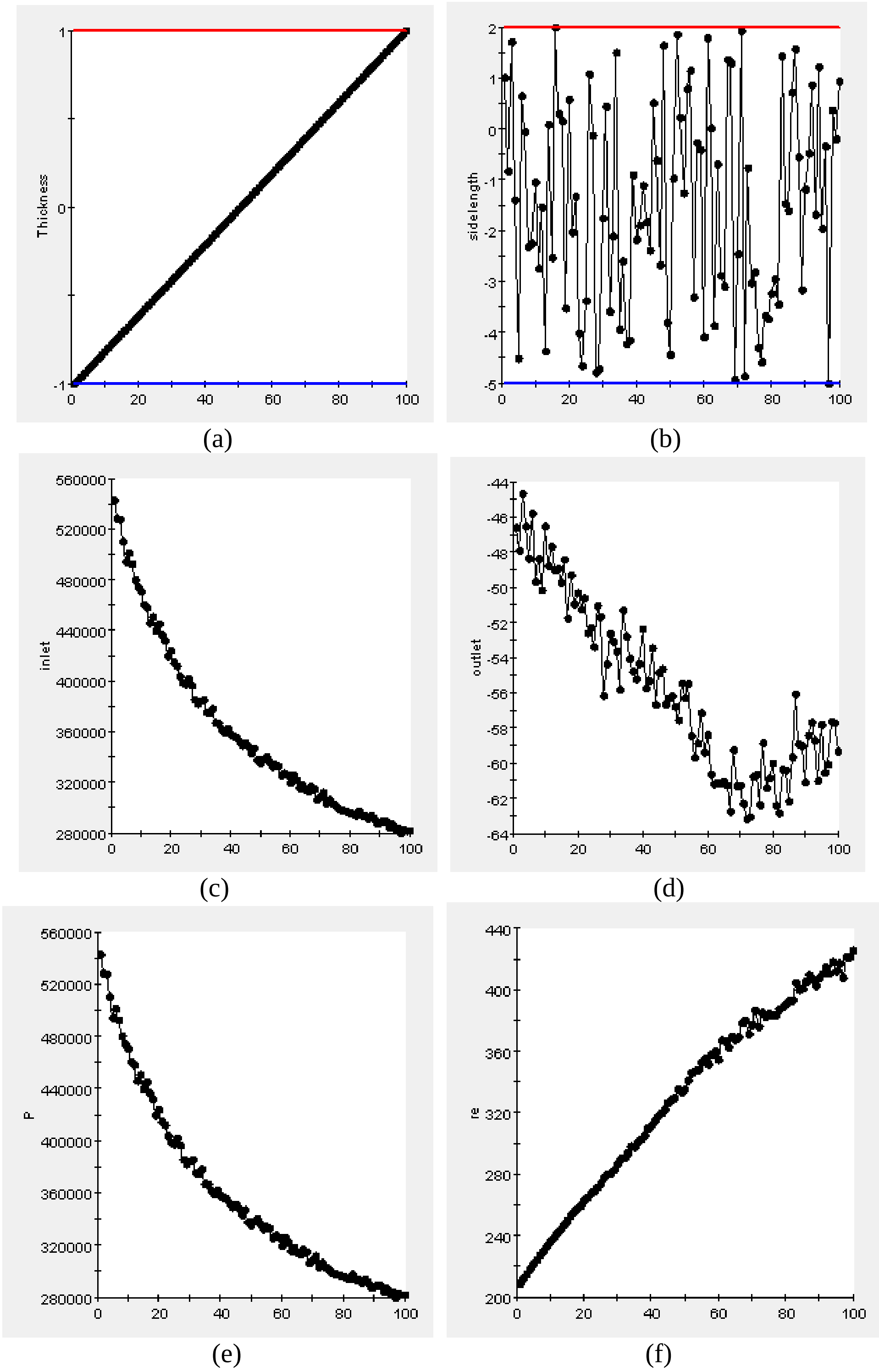
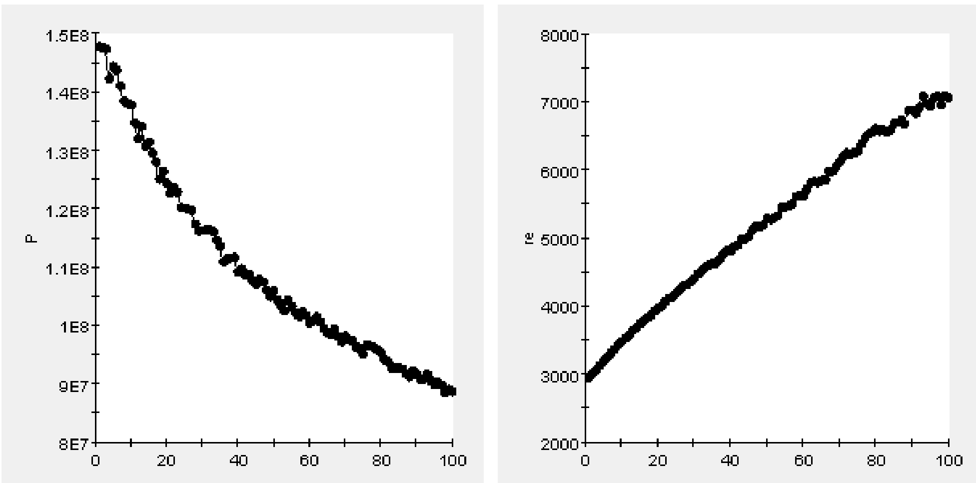


Fig. 4 Design of experiments for the field with round corner and inlet velocity 4.5 m/s. (a) design variable: thickness of the field (b) design variable: side length of the field (c) Area-Weighted Average pressure in inlet (d) Area-Weighted Average pressure in outlet (e) pressure drops between inlet and outlet (f) Volume-Weighted Average Reynolds number of the field.

In this study, a computer aided optimization (CAO) software was implemented to decide how the design parameters effect the properties of the field. To save time and reduce the calculate work, field with round corner was chosen to have design of experiments (DOE). The side length and the thickness of the field was set to be design variable. The pressure drops between the inlet and outlet, the Volume-Weighted Average Reynolds number was chosen as design objectives. Single-phase simulation of the field was implemented in the experiments.

The DOE results of the field with inlet velocity 4.5 m/s and pressure outlet are illustrated in Fig. 4, the pressure in outlet is 0 bar. The thickness of the field varied for-1mm to 1mm at the baseline 2mm, namely the thickness changed from 1mm to 3mm. side length of the field varied the same as thickness with a baseline 10mm and changed from -5mm to 2mm, namely side length changed from 5mm to 12mm. 100 points were set and Latin Hypercube technique was chosen to perform the DOE. When the design factors changed, the objective parameter changed as shown in Fig.4 (c) (d) (e) (f). It can be seen that when the thickness of the field enhanced, the cross-sectional area of the channel enhanced at the same time, then the pressure in inlet diminished. So, if we want a smaller pressure drop, we can increase the thickness or width of the channel, but at the same time, the Volume-Weighted Average Reynolds number of the field rise.

When the velocity in inlet is 100m/s, the corresponding parameter variation tendency is visible in Fig. 5 (a) (b).



(a) (b)

Fig. 5 Design of experiments for the field with round corner and inlet velocity 100 m/s (a) pressure drops between inlet and outlet (b) Volume-Weighted Average Reynolds number of the field.

4. Results and discussion

According the above data, we can find that the hydrodynamic properties between the two type fields. In literature, the magnitude of velocity in two passes is 150m/s while in single pass channel can reach 350m/s, in our simulation cases, 100m/s and 4.5m/s was respectively set to simulate the high speed and low speed flow in the field. From the comparison, pressure drop in right corner field is about 6atm, while which in round corner is about 3.4atm, Reynolds number between the two types shown nearly 300 and has small gap. It indicates that geometric feature we design has great influence on pressure drop while has less influence on turbulence intensity. In this way, we can change the geometry structure of the field to get less pressure drop, which will decrease input voltage on PEM stack and energy to compress the hydrogen [2].

For DOE results, thickness of the channels has an impact on the pressure drop and turbulence intensity. In general, less pressure drop is expected for less energy waste, but when enhancing the thickness, turbulence intensity of the flow grows up at the same time, which will lead to catalyst erosion. So, we need to balance pressure drop and turbulence intensity. In future, fellow-up experiments will be hold to elaborate the relationship between geometry parameter and hydrodynamic properties.

5. Conclusion

The results of the numerical simulations reveal the difference in hydrodynamic properties include pressure gap between inlet and outlet, the Reynold's number between the two flow fields. After comparing the two type fields, it seems that field with round corner has favourable properties to minimize the pressure drop to adapt high pressure electrolysis. Turbulence intensity of the two type fields shows basically consistent at different inlet velocity. DOE results validated the channel dimension's influence on behaviour of the flow, which gives future consideration of the bipolar plate. However, further validation includes experiments such as high pressure operational test, electrochemical test, diagnosis will be required in later experiments [9].

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