Effects of Reynolds Number and Shape of Manifold on Flow Rate in Separator for Polymer Electrolyte Fuel Cell (ICCAS 2004)

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Abstract: Recently, a great deal of research and development of a fuel cell have been carried out to solve problems on the drain of fossil fuel, air pollution and global warning. In order to improve the efficiency of a fuel cell, it is necessary to clarify the flow in separator. In this study, distributions of velocity flow rate and pressure, and streamlines are examined in detail from numerical analysis with CFD code. In the experiment the distribution of flow rate is measured and flow in the each grooves of the separator is visualized by dye method changing Reynolds number. Furthermore, effects of size of the inlet and outlet manifolds and shape of ribs near the inlet outlet on the distributions of flow and pressure are examined.

Keywords: fuel cell, separator, flow rate, pressure distribution, Reynolds number, flow visualization

1. INTRODUCTION

Recently, it is necessary to develop clean energy for using energy effectively, preventing lack of fossil fuel, protecting heat island and so on. One of the clean energy resources is fuel cell, which is developed actively. Many kinds of fuel cell are under developing. Above all, PEFC (Polymer Electrolyte Fuel Cell) has possibility to down size through developing new high polymer film and catalyst, and the development is improving not only energy of electric vehicle and portable equipment but also fuel cell of fixed type to utilize energy of electricity as well as heater used for house. Fuel Cell is complex system of which separator has junctions and branches of hydrogen and oxygen, and a large number of researches have been carried out about flow of junction and branch, but they are carried out only on high Reynolds number. However, in fact flow of single cell in separator is performed at low Reynolds number. There are many researches about the flow, but it is not enough to demonstrate details of the flow yet in separator.

In this study gas flow and pressure drop are investigated by numerical analysis, and flow and distribution of velocity in each groove of separator are visualized changing dimension of separator and shape of ribs. Effects of shape and size of the separator on equalization of flow rate distribution are made clear.

2. NUMERICAL ANALYSIS

In this experiment distribution of flow rate in separator is examined, but it is difficult to measure pressure distribution due to small amount of value. CFD2000 which is developed by Adaptive Research Co. Ltd. and uses FVM (Finite volume method) for discretion the differential equation is applied to numerical analysis of flow velocity, flow rate and distribution of pressure. Application of numerical analysis is useful for this study. In this study, chemical reaction is not taken into account.

The model for this simulation is shown in Fig. 1. Continuity equation and Navier Stokes equation are applied in this analysis. Directions of inflow and outflow are considered to only horizontal direction. Widths of inlet (D_i) and outlet (D_o) of manifolds are 4mm, 8mm and 20mm. Widths of the groove (W_g) and ribs (W_r) are same size of 4mm. Area for a reaction is set as 10mm x 10mm. Thickness of separator (H) is 4mm. The number of groove of the separator is 13, and the ratio of groove area to reaction area is 53%. Reynolds number of the flow is defined as follow.

$$Re=\frac{\overline{U}D}{\nu} \tag{1}$$

In this study, $\overline{U}$ and D are average inflow rate of inlet manifold and equivalent diameter of inlet manifold, respectively. ν denotes dynamic kinematics viscosity. A mean velocity at the inlet of manifold is applied for boundary condition. And it is assumed that there is no slippage between the flow and the surface of manifolds and ribs. Number of meshes are $198\times107\times4$ in case of separator of which equivalent diameter D of outflow and inflow manifold is 4mm.

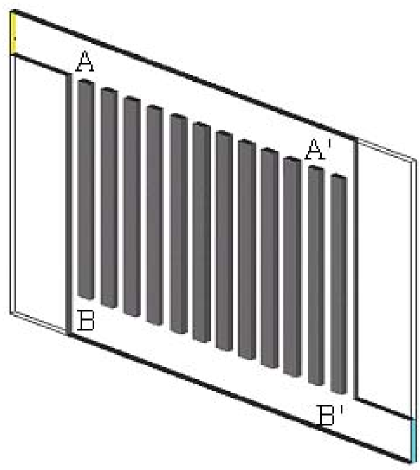


Fig.1 Model for simulation

3. EXPERIMENT AND MEASUREMENT

3.1 Experimental apparatus

In this study water was used in order to examine the flow in the separator instead of gas. Fluorescent sodium called "uranine" was infused into the water flow for visualization of flow and distribution of flow velocity. An experiment apparatus is shown in Fig.2. A model of the separator was made of acrylic material. That dimension in detail is shown in Fig.3.

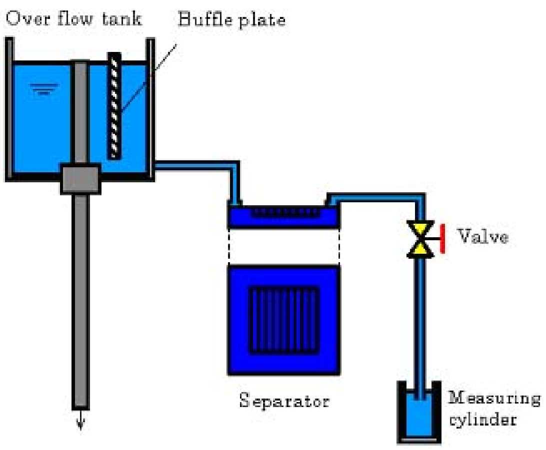


Fig.2 Experimental apparatus

D_i	4, 8, 20 mm
D_o	
W_g	4 mm
W_r	4 mm
H	4 mm
L	100mm

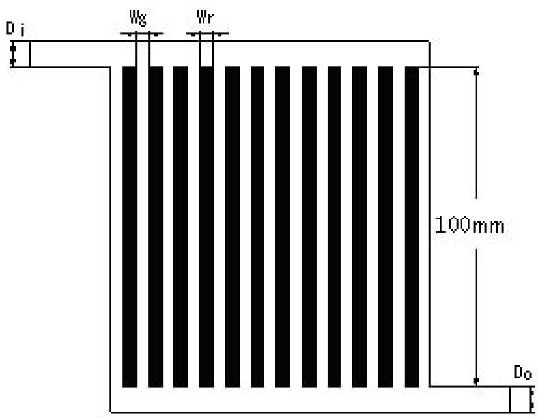


Fig.3 Dimension of separator

3.2 Measurements

Water supply to the separator keeps to constant water level by over flow tank. Flow rate is controlled by a valve in lower outlet. Photo of the flow in the separator is taken by video camera, poring fluorescent sodium into the water at inlet of separator. Flow velocity is calculated from taken an image of time interval and distance of relative movement of tracer in each groove.

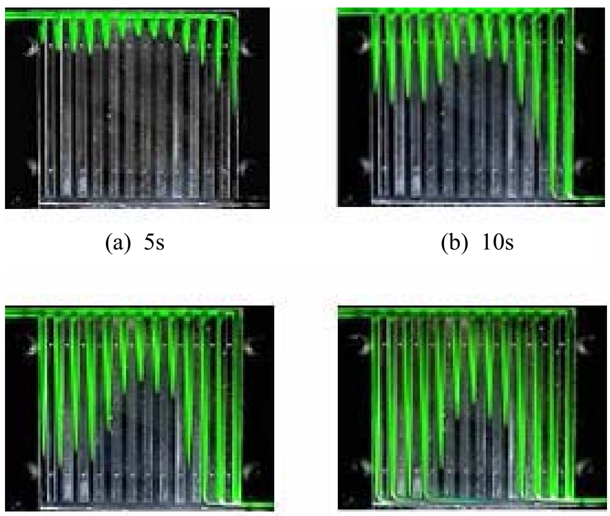
4. RESULTS AND DISCUSSION

4.1 Effect of Reynolds Number

At width of inlet and outlet D_{io} = 4mm and Reynolds number Re=180 in separator visualization picture of flow of tracer is shown Fig.4. Around inlet and outlet velocity of tracer is high, and around center of groove that is very low beside other area.

Distribution of pressure of the flow obtained by numerical analysis with CFD2000 produced by Adaptive Research at Re=180 in centerline (A-A') and (B-B') of inlet and outlet is shown in Fig.5. Flow streamed from A to A' blanch off and its velocity gradually decreases. It is considered that pressure recover is not caused in this experiment because flow rate is very small and width of inlet manifold is comparatively small compared with that of total inlet width of grooves. On the other hand, the pressure in outlet B-B' merely drops because increase of velocity due to joining of flow and friction decrease effective pressure energy of the flow. Flow rate of groove determines difference of the pressure between inlet and outlet of the separator. It may be considered that small pressure difference around center of the separator leads to comparatively small flow rate.

Fig.6 shows distribution of the flow rate obtained from visualization picture in separator. Each groove of the separator is numbered from 1 to 13. Flow rates of each groove are normalized by dividing it by averaged flow rate of all grooves. Results of distribution of flow rate by experiment and analysis are shown in Fig.7. When Reynolds number is small, flow rate around center of the separator is low, and that is approximately one third smaller than those around both sides of separator. When Reynolds number of the flow is increased, difference between flow velocities in the inlet side and the outlet side is high. But flow rate in center seldom influenced by Reynolds number.



(a) 5s (b) 10s

(c) 15s (d) 20s

Fig.4 Visualization of flow in separator

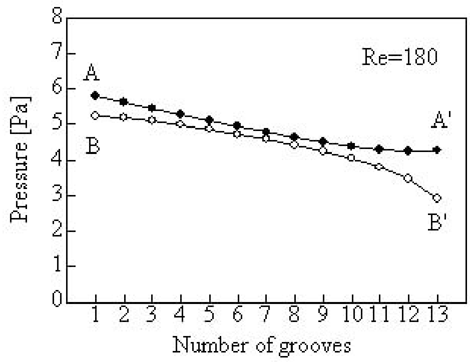


Fig.5 Pressure distribution in grooves of separator

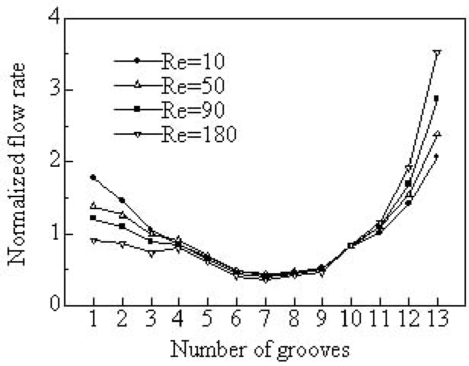


Fig.6, Flow rate distribution in grooves of separator

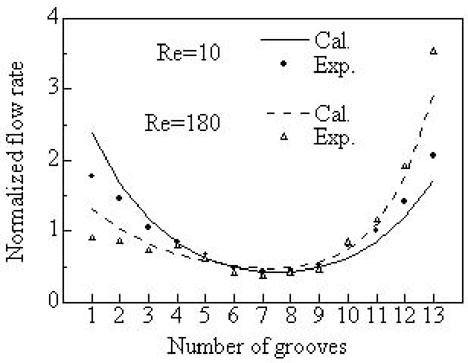


Fig.7 Comparison of flow rate in experiment and simulation

4.2 Effect of width of inlet and outlet

4.2.1 In Case of D_i=D_o

Result of pressure distribution on (A-A') and (B-B') in case of Re = 10 and $D_{i,o}$ = 4 ~ 20mm is shown in Fig.8. The pressure distribution on (A-A') and (B-B') is flat when the width of inlet manifold becomes wider. It may be considered that friction between fluid and wall has a small influence on pressure drop, and the pressure distribution also on B-B' is flat when width of outlet manifold increases. Difference of the flow rates among the each groove is small because difference of pressure between inlet and outlet is small.

Fig.9 shows comparison of flow rate of different width of manifold under same experimental conditions. Ratio of minimum flow rate to whole groove average flow rate is 58% in case of $D_{i,o}$= 4mm. while equality of flow rate progress 10% in case of $D_{i,o}$=20mm. And comparison of flow rate in Re=180 is shown in Fig.10. Flow rate difference between cases of $D_{i,o}$= 20mm and $D_{i,o}$= 4mm is small.

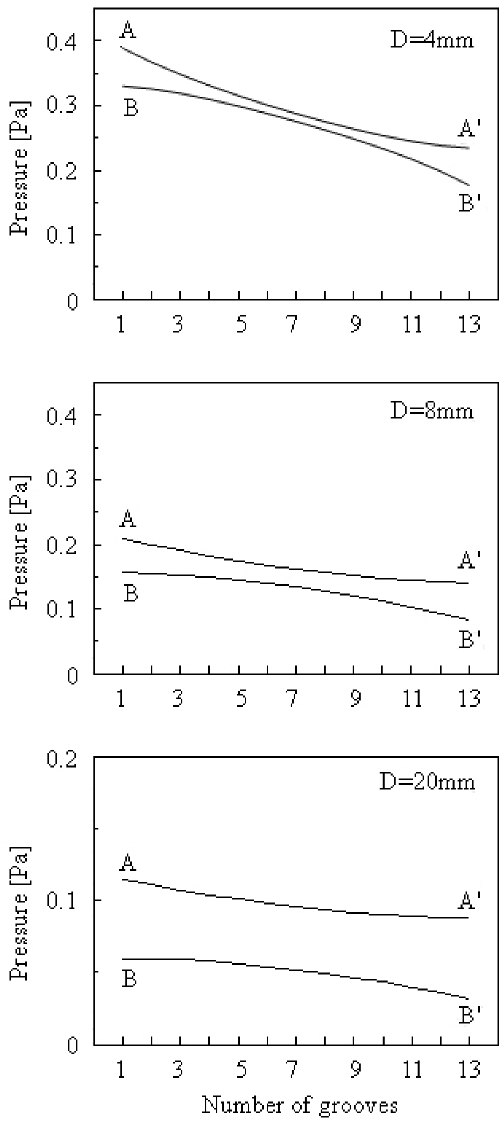


Fig.8, Pressure distribution for various manifold sizes

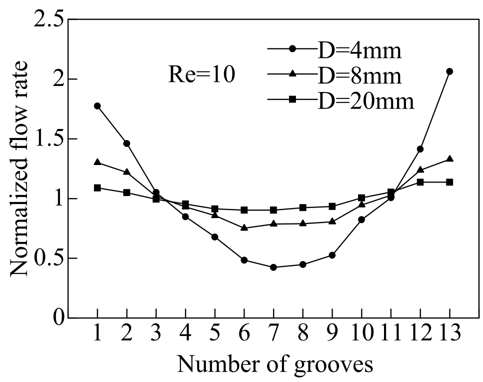


Fig.9 Flow rate distribution for various manifold sizes

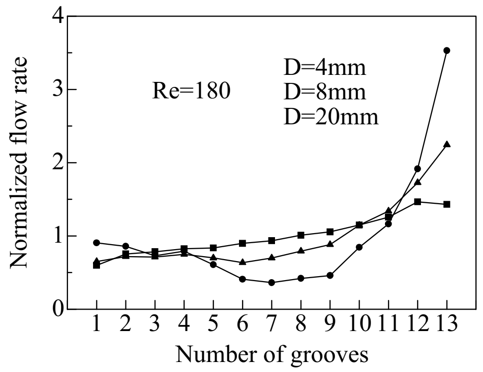


Fig.10 Flow rate distribution for various manifold sizes

4.2.2 In Case of $D_i \neq D_o$

It is made clear from results of experiment and numerical calculation that width of manifold leads to equality of flow distribution. It is necessary for making separator compact to realize optimum combination of inlet and outlet width. Fig.11 shows the result of flow distribution by experiment in case of Re=180. Pressure drop and difference of flow rate are relatively small in case of D_i=4mm and D_o=8mm, since increase of velocity by flow merging is suppressed by increased diameter of outlet manifold. On the other hand, in case of D_i=8mm and D_o=4mm, inflow velocity decreases by increased inlet width, but actual whole flow rate increases due to increased section area. Consequently, difference of flow rate becomes larger than case of D=4 due to larger pressure drop resulted by increased flow velocity in outlet manifold. Accordingly, it is considered that wider outlet is more influential than wider inlet for leading equality of flow rate.

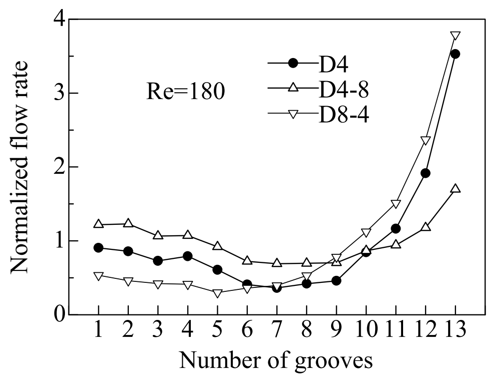
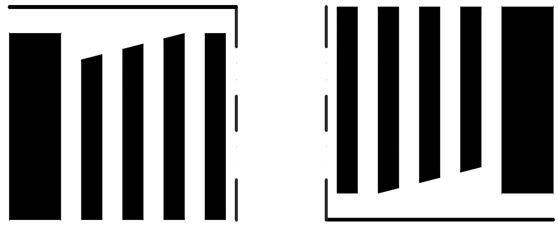


Fig.11, Flow rate distribution for various inlet and outlet size

4.3 Effect of shape of ribs

Shape of ribs (R_i, R_o) were changed around inlet and outlet of the manifold like Fig.12, and influence of that on equality of flow distribution progress is examined tentatively. Experimental result of flow rate distribution at Re=180 is shown in Fig.13. Despite increase of section area around inlet in case of inlet rib shape R_i, effect of that on the inflow velocity is comparatively smaller than that in case of $D_{i.}$ = 4. It is considered that in case of rib shape $R_{o,}$ increase of the flow velocity in junction is held by increase of section area in junction, and the pressure drop become small. Therefore, flow rate of groove around outlet is comparatively smaller than that in case of $D_{i.}$ =4.



(a) Inlet R_i **(b) Outlet R_o**

Fig.12 Shape of ribs

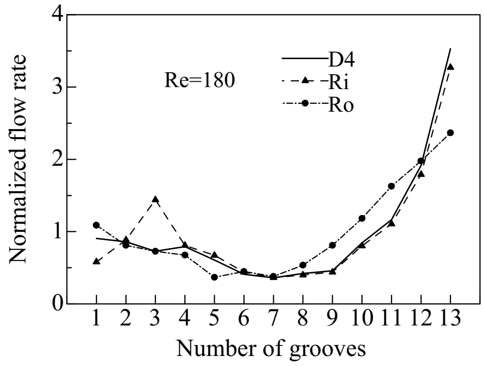


Figure.13, Flow rate distribution for various shapes of ribs

5. CONCLUSIONS

Flow characteristics in the separator of fuel cell were examined experimentally and theoretically when Reynolds number are changed from Re = 10 to Re = 180.

(1) Flow rate among each groove of the separator is not equality. Flow rate distribution depends on Reynolds number in inlet, and the flow rate in outlet increases as Reynolds number increases.

(2) When the width of inlet and outlet of the manifold becomes larger, flow distribution is quality. Increase of width of the outlet manifold makes out more equally flow rate distribution.

(3) It is possible to decrease the flow rate around there according to change of shape of ribs around outlet, but it does not contribute to equality of flow rate.

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