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Simulation of Reaction Distribution in PAFC Stack

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The short stacks studies as for the reaction distribution in the PAFC have been done. The measured values, such as temperature distributions and exhaust gases composition, were compared with calculated ones which obtained by simulation analysis. The large temperature deviations were observed along the air flow in the cell, but little along the fuel flow. Simulation results revealed that the deviation was caused by current distribution. The reaction distribution along the air flow is also confirmed by analysis of exhaust gases composition at the fuel outlet. The maximum current obtained at the air inlet is considered to be twice larger than the minimum at the air outlet.

1 INTRODUCTION

Kansai Electric Power Co. and Mitsubishi Electric Co. have been developing Phosphoric Acid Fuel Cell(PAFC) power generation system for both on-site generation use(ON-SITE use) and electric utility dispersed generation use(DISPERSED use). The PAFC short stacks with the electrode area of 4,000cm^2(rectangular shape) and 8,000cm^2(large square shape) have been made and tested respectively. The design was optimized by computer simulation and calculated results have been confirmed by comparing with short stack experimental data. As for the calculated results, some were given good fitness but the other showed difference from the experimental ones. In this work, research and analysis for the cell reaction distribution have been done to improve the simulation method.

It is important to estimate the cell reaction distribution with computer simulation, for the purpose of accelerating the improvement of the PAFC stacks design. Calculation of the cell performance and temperature distribution on the cell can reduce the testing term and cost.

In the plant size large cells, it is known that the reaction distribution shows non-uniformity since non-uniform distribution of the gas composition and the heat generation/conduction exist. Current distribution had been shown by Tsutsumi[1] for 3,000cm^2 size cell with 160mA/cm^2 as a mean current density. In their work, the maximum current density existed at the air/fuel inlet area, and the minimum at the air/fuel outlet area. Until now, to commercialize the fuel cell, cell size and current density have been increased. Larger cell size(up to 1m^2 class) and higher current density(300mA/cm^2 class) have begun to be adopted for a plant stack. It was worried that larger size or higher current would cause to expand the deviation of the reaction distribution, and might be reduced the cell life.

In our works so far, 4,000cm^2 or 8,000cm^2 cell size with 300mA/cm^2 current density have been testing and estimated with our computer simulation methods[2, 3]. Additional experiments for short stack cells with both sizes have been done, and calculated results were compared with them in this work.

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2 EXPERIMENTAL

Table1 shows the configuration of each short stack. The simulated reformed gas by mixing H_2 (80%) and CO_2(20%) with humidifying was supplied as the fuel gas.

To estimate the temperature distribution in the reaction area of stack cells, 25 thermo-couples had been set in the 5 by 5's grid point(same distance from each other) on the cell reservoir plate. The characteristics with the gas utilization for both type

Table1 The configuration of short stacks.

	ON-SITE use	DISPERSED use
Specification		
Current density	300mA/cm^2	300mA/cm^2
Cell size	4,000cm^2 class	8,000cm^2 class
Shape	Rectangle	Square
Number of cells	24cells/stack	20cells/stack
Construction	6cell/cooler	5cell/cooler
Operation mode		
Net power	15kW class	30kW class
Pressure	Atmospheric	Atmospheric
Temperature	205°C	200°C

use short stacks have been estimated.

The temperature distribution is influenced not only by the reaction distribution but also by the heat transportation through a cooling plate. To estimate the reaction distribution independently, the composition of exhaust gases obtained from gas flow path was analyzed by micro gas-tight syringe comprised of a long and thin SUS tube. The tube was fitted on the top of the syringe, and was put in the stack outlet manifold. To watch inside of the manifold and to approach the tube tip to the cell's gas flow path outlet, the glass window was set on the manifold. The gas composition analysis was done at the 10 points(same distance from each other) of the cell's gas outlet.

3 RESULTS AND DISCUSSION

3.1 The variation of Temperature Distribution

To make the analysis easier, typical points in the reaction area of the cell, that is each 5 points on the center line of the air and the fuel gas flows, were chosen. Figures 1 and 2 show the characteristics with AIR and FUEL utilization for ON-SITE use short stack respectively. The lines in these graphs are interpolation ones. The noticeable temperature deviations have been shown along the air flow, where the maximum point presents near the air inlet area and the minimum at the outlet one. The air temperature before the inlet is kept so lower than inside of the cell reaction area that the temperature near the inlet becomes lower. The deviations become larger with higher utilization of air but dose not change with the fuel utilization. Almost uniform temperature distributions have been shown along the fuel flow at any utilization conditions.

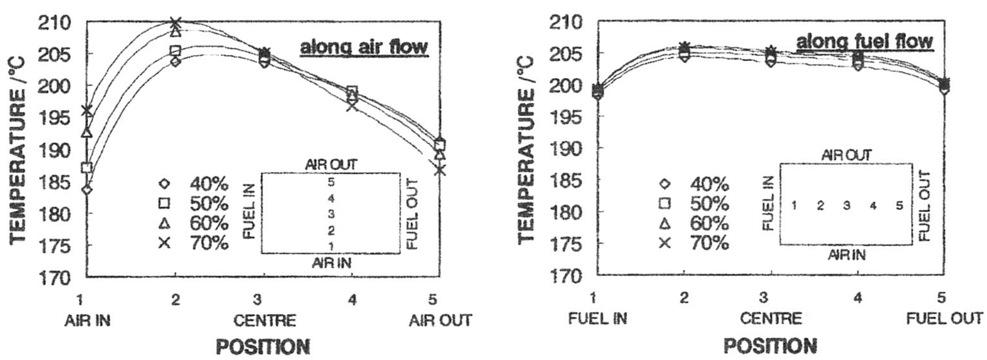

Fig.1 Plots of temperature distribution characteristics against AIR utilization.
ON-SITE use short stack, Current:300mA/cm^2, Fuel utilization:80%

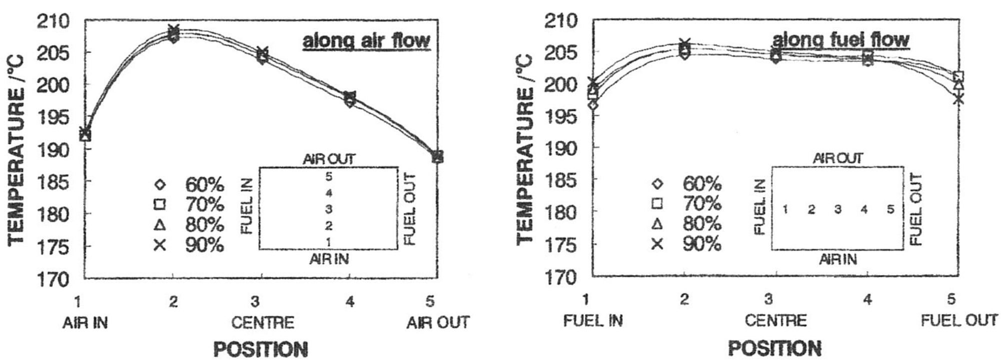

Fig.2 Plots of temperature distribution characteristics against FUEL utilization.
ON-SITE use short stack, Current:300mA/cm^2, Air utilization:80%

These temperature characteristics were shown similarly in DISPERSED use short stack.

Since the temperature deviation is mainly caused by variation of the heat generation, the cell reaction deviation is considered to exist only along the air flow, not along the fuel flow. The reason of this deviation could be explained by the variation of O_2 concentration. Namely, the rate of O_2 reduction is mainly controlled by O_2 concentration and the concentration is reduced as downstream along the air flow by its consumption. On the other hand, there is little deviation of the cell reaction along the fuel flow . It might be able to be concluded that H_2 concentration has little influence to the cell reaction.

With such characteristics, the simulation model has been built. Figure 3 shows the flow chart of the simulation program.

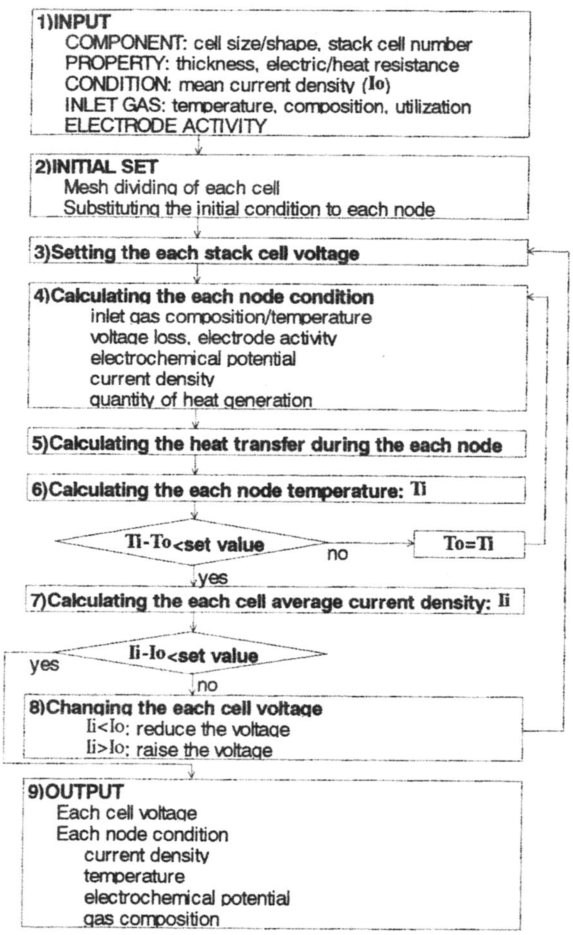

Fig.3 The flow chart of the simulation program.

The meshes, as shown in Fig.4, are divided as a 3-D model, up to 10 grids in horizontal and the number of stacking elements in vertical.

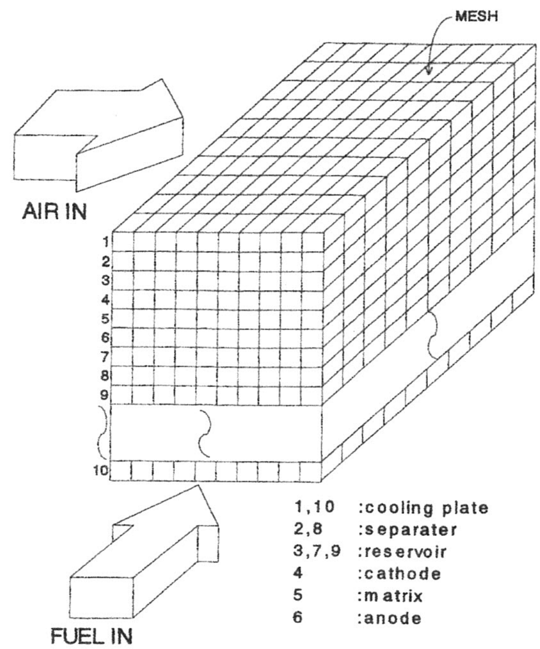

Fig.4 The Division of stack cell elements.

The results of measured temperature distribution and calculated one are compared as follows. Figure5 shows the distribution of ON-SITE use short stack and Fig.6 shows the DISPERSED use one. The temperature deviation along the air flow seems good fitness, though the detail shows difference from each other.

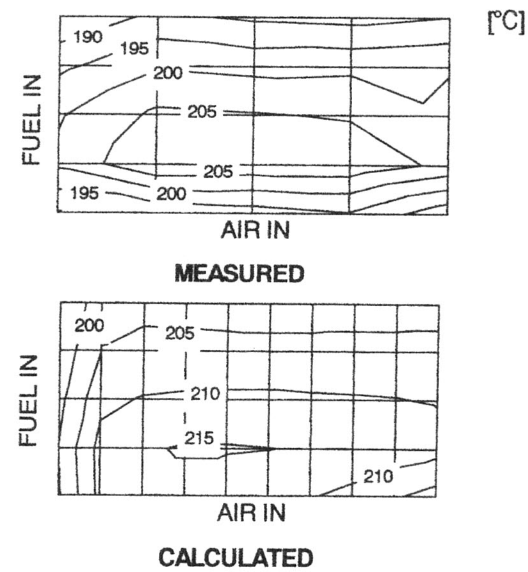

Fig.5 The temperature distribution in cell reaction area of ON-SITE use short stack cell.
Current:300mA/cm^2, Fuel utilization:80%
Air utilization:60%

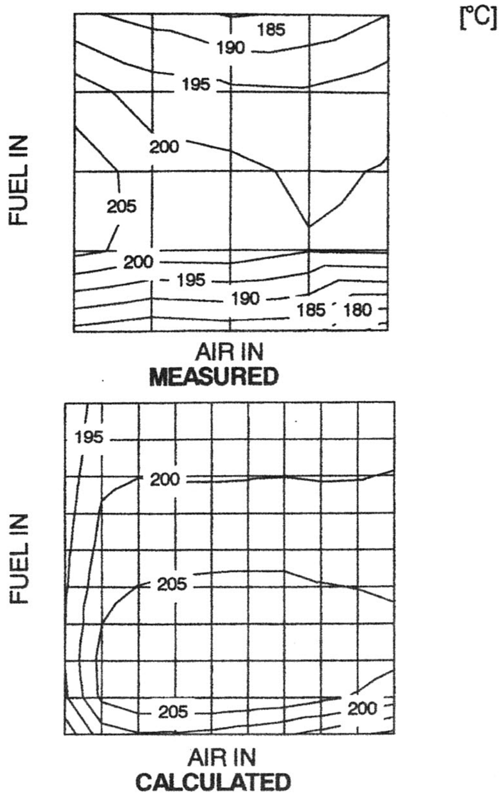

Fig.6 The temperature distribution in cell reaction area of DISPERSED use short stack cell.
Current:300mA/cm^2, Fuel utilization:80%
Air utilization:60%

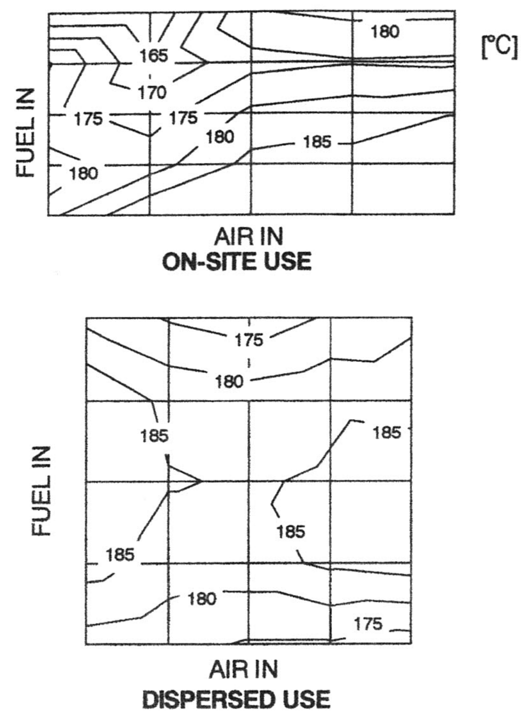

Fig.7 Measured temperature distribution in the cooling plate of short stack cell.
Current:300mA/cm^2, Fuel utilization:80%
Air utilization:60%

The main reason of the difference is supposed to be cause by the temperature distribution estimation in the cooling plate. The cooling plate for the simulation had to be assumed to have an even temperature distribution because the heat transfer behavior could not sufficiently be systematized and could not be expressed as an appropriate equation.

In fact, the temperature distribution in the cooling plate is not uniform as shown in Fig.7. To improve the precision of the calculation, the heat transfer model in the cooling plate would built in the next work.

3.2 The deviation of the composition in exhaust gases

In order to confirm the existence of the reaction deviation along the air flow, the analysis of the exhaust gases has been done. Since the anode with higher current would consume more amount of hydrogen, the reaction deviation along the air flow could be estimated by the exhaust H_2 composition at the fuel outlet. The results of both short stacks are shown in Fig.8, compared with calculated value. The H_2 concentration deviation, which shows the minimum at the air inlet and the maximum at the outlet, has been confirmed. Although the measured values contain some analytical errors, both short stack's data and calculated one have good correspondence.

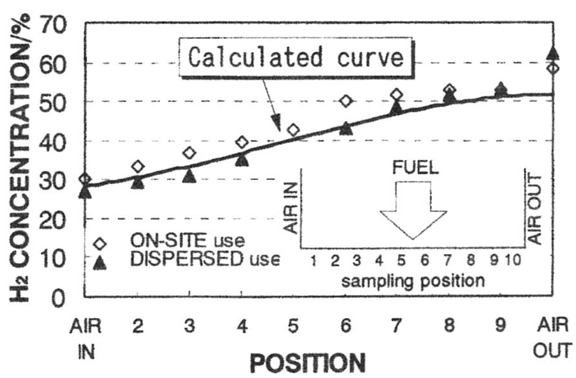

Fig.8 H_2 concentration distribution at the fuel outlet.
Current:300mA/cm^2, Fuel utilization:80%
Air utilization:60%

The calculated current distribution corresponded to this H_2 concentration are shown in Fig.9 . It shows that the current density at the air inlet is twice larger than that of the air outlet. This deviation is also considered to cause the temperature deviation.

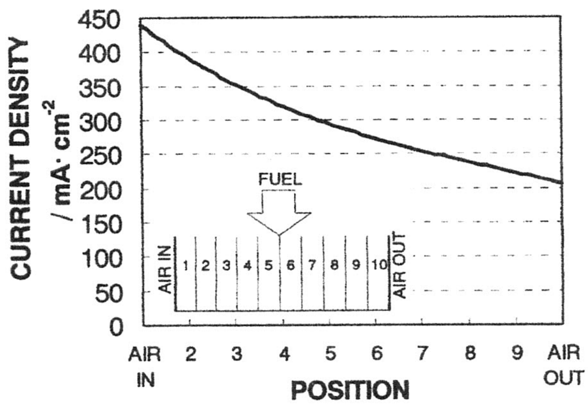

Fig.9 Calculated current distribution along the air flow.
Current:300mA/cm^2, Fuel utilization:80%
Air utilization:60%

4 CONCLUSION

Experimental and calculated results lead to following conclusion;

1)Temperature deviation exists along the air flow in PAFC stack, but little along the fuel flow .

2)Current deviation exists along the air flow and causes temperature deviation.

3)Current deviation along the air flow is considered to be twice at the maximum larger than the minimum.

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