DEVELOPMENT OF TUBULAR TYPE SOFC MODULE

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ABSTRACT

TOTO Ltd. has been developing solid oxide fuel cells (SOFCs) for more than 10 years. The cell structure is tubular type manufactured by a wet process (1-3). We have also been developing technologies for bundles and modules using these cells. SOFCs are thought to achieve high electrical efficiency in power generation systems from kW-class to several 10 kW-class sizes (4). This paper discusses development of a several-kW-class thermally sustainable module at TOTO Ltd.

INTRODUCTION

SOFC is one of the key technologies to solve the energy problem because of its high electrical efficiency. TOTO Ltd. (TOTO) has been developing SOFCs for more than 10 years with its own ceramic technologies. Technologies for manufacturing single cells, bundles and modules have been developed. Figure 1 shows a history of SOFC development at TOTO.

Figure 1. History of SOFC development at TOTO.
TOTO, with Kyushu Electric Power Company, Inc. and Nippon Steel Corporation, completed a 3 kW module test successfully in a national SOFC project by NEDO from 1998 to 2000 (5). Figure 2 shows an appearance of the 3 kW module and Table 1 shows specifications of the 3 kW Module. The objective of the test was a confirmation of bundle technologies. Electric heaters were used to maintain the operation temperature because the 3 kW module was not designed to be thermally sustainable.

In the next stage of the SOFC module development, a thermally sustainable kW-class module is now under development in a new NEDO project since 2001. The first thermally sustainable module (1st module) was constructed in the last part of 2001 and tested. The results of the test are given in this paper.

DEVELOPMENT OF THE 1st THERMALLY SUSTAINABLE MODULE

Planned Specifications

The planned specifications of the 1st module are shown in Table 3. The power output should be 6.7 kW DC using natural gas as fuel, with a degradation rate of less than 0.25 %/1000 hr. The number of cells in the module is 240.

| Fuel                  | Natural Gas (Town Gas 13A) |
|-----------------------|----------------------------|
| Power Output          | 6.7 kW DC                  |
| Fuel Utilization      | ≥75%                       |
| Degradation Rate      | ≤0.25%/1000 hr             |
| Number of Cells       | 240                        |

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Cell and Bundle

The structure of the cell is a tubular type. Table 2 shows materials and fabrication processes of the cell. Conventional materials suitable for high temperature operation (900-1000°C) were used. A feature of our cell is a 'wet process' fabrication method. Cathode tube is formed by extrusion molding and the other components are formed by slurry coating.

Table 2. Materials and fabrication processes of the cell.

| Component   | Material       | Fabrication       |
|-------------|----------------|-------------------|
| Cathode tube| (La, Sr)MnO₃   | Extrusion Molding |
| Interconnect| (La, Ca)CrO₃  | Slurry Coating    |
| Electrolyte | YSZ           | Slurry Coating    |
| Anode       | Ni/YSZ         | Slurry Coating    |

For the development of the 1st module, the configurations of cell and bundle were improved to make a compact module. Figure 3 shows the structure of a new bundle. The new cell is 16 mm in diameter and 0.6 m in length and is smaller than the previous one. The new bundle has 3 x 5 cell arrangement and the pitch of the cells is smaller than in the previous one.

Figure 3. Structure of the new bundle.
Main Module

Figure 4 shows the appearance of the main module and a sub-module. The sub-module consists of 4 bundles with a total of 60 cells. The sub-module is a fundamental unit for construction, and the main module consists of 4 sub-modules.

System

Figure 5 shows the system configuration of the 1st module. Two start-up burners are located at the bottom of the main module. They supply heat and reducing gas for the start-up of the system. In the air supply line, there is an air heat exchanger for pre-heating air, using heat of exhaust gas. In the fuel supply line, there is a desulfurizer, which is operated at room temperature, an electric vaporizer, a fuel heat exchanger for pre-heating fuel using heat of exhaust gas, and a reformer which is located in a combustion room. In the combustion room, exhaust gases from anode and cathode mix and burn. Then the high temperature combustion gas supplies heat for reforming.

An appearance of the 1st module is shown in Figure 6. The height of the main module is 1.8 m and there are heat exchangers above it.
Figure 5. System Configuration of the 1st module.

Figure 6. Appearance of the 1st module.
TEST RESULTS OF THE 1st THERMALLY SUSTAINABLE MODULE

I-V Characteristics Using Hydrogen

Figure 7 shows I-V performance of the 1st module using hydrogen in test 1 and test 2. With increasing current, the power of the burners was decreased to keep the module temperature between 900°C and 1000°C. The maximum power output was 3.2 kW DC at a fuel utilization of 65%. The power output was lower than planned, but the module indicated no degradation between test 1 and test 2 in spite of thermal cycling to room temperature.

![Figure 7. I-V performance of the 1st module using hydrogen.](image)

I-V Characteristics Using Natural Gas (Town Gas)

Figure 8 shows I-V performance of the 1st module using natural gas in test 3. The result in Figure 8 was obtained with a half module because the system had some trouble in air supply during test 2.

The maximum power output was 1.5 kW DC at a fuel utilization of 41%. The fuel utilization was lower than in the hydrogen case. Figure 9 shows an energy balance. It reveals that a large amount of heat radiated from the system. Because of the large heat loss, it was necessary to use extra fuel to supply heat for reforming in the combustion room. That was the reason for low fuel utilization in the natural gas case.

In this test, an electric heater was used for vaporization, but the energy balance shows the feasibility of obtaining a thermally sustainable module by using the heat of exhaust gas and heat loss for vaporization.
Figure 8. I-V performance of the 1st module using natural gas.

Figure 9. Energy balance of the 1st module using natural gas.
SUMMARY

The 1st SOFC module was constructed and tested to develop a thermally sustainable kW-class module by TOTO Ltd. The performance of the 1st module did not satisfy the planned specifications because of a large amount of heat loss from the system. The 2nd module is going to be constructed in the last part of 2002. It is expected to demonstrate maximum performance because of its compact module design and decrease in heat loss.

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