DEVELOPMENT OF TUBULAR TYPE SOFC

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ABSTRACT

Mitsubishi Heavy Industries, Ltd. (MHI) has been developing tubular type Solid Oxide Fuel Cells (SOFC) since 1984. A 1kW module of SOFC has been continuously operated for 3,000 hours with 2 scheduled thermal cycles at Electric Power Development Co., Inc.(EPDC) Wakamatsu Power Station in 1993. We have obtained of 34% module efficiency and deterioration rate of 2% per 1,000 hours in this field test. The next milestone of our tubular type SOFC development is an operation of the 10kW module in 1995, under a joint R & D project of EPDC & MHI.

INTRODUCTION

MHI has been developing SOFC since 1984. From 1986 to 1989, elementary technologies of tubular type SOFC stacks and module were developed with Tokyo Electric Power Co. (TEPCO). In 1989, TEPCO, EPDC and MHI developed 1kW SOFC module, and in 1991 we operated the 1kW module for 1,000 hours at Wakamatsu Power Station in EPDC. And in 1993, EPDC and MHI have developed the advanced type 1kW module and operated for 3,000 hours successfully.

DEVELOPMENT OF TUBULAR TYPE CELL STACK

We have applied the spray coating method to the tubular type SOFC. The cell stack has 15 cells connected in series, and the stack length is 500mm.

The overview of stacks is shown in Fig. 1. Fig.2 shows the structure of the stack. Main materials of films and film thickness are shown in Table 1. Most of films of this stack has been produced by atmospheric plasma spray coating method. However electrolyte film is produced by low pressure plasma spray (LPS) coating method, because it needs gas tightness.
We have been making efforts to improve cell performance. Major improvements are as follows;

1) Optimization of the spray conditions
2) Quality control of each material
3) Optimization of the cell configuration

Fig. 3 shows the example of I-V characteristics. Tests were conducted at 900°C, atmospheric pressure, using hydrogen as fuel and air as oxidant. MHI's cell-stack can be operated over 80% fuel utilization and the maximum efficiency reached 40% at the current density at 200mA/cm².

DEVELOPMENT OF 1kW MODULE

TEPCO, EPDC and MHI designed and fabricated a 1kW module in March 1990. Table 2 shows the specifications of 1kW module, and Fig. 4 shows the structure of the module. This module mainly consists of four parts, that is fuel plenum, spent fuel plenum, reactor chamber and air preheater.

We have adopted a pendant stack structure for relaxation of thermal stress and easy maintenance of stacks. Fuel is fed from the top of the module and introduced to the fuel plenum, distributed to each cell-stack through injection tubes and utilized for the cell reaction. The spent fuel is exhausted through spent fuel plenum.

Air is heated by air preheater, and is fed to a reactor chamber. Spent air is exhausted through the air exhaust tube, and its heat is exchanged to cold air in the air preheater. Current Collectors are made of metal and arranged in plenums with reducing atmosphere; one is in the fuel plenum, the other is in the spent fuel plenum.

The advanced type 1kW module was operated in Nagasaki Shipyard & Machinery Works of MHI and then in Wakamatsu Power Station of EPDC from May 1993. Fig. 5 shows the system flow diagram of the 1kW module. The fuel is hydrogen and the oxidant is air. The pressure difference of the fuel and the air is controlled by the pressure control valve in the fuel spent line. Some part of the spent fuel is recycled to inlet of the fuel.

The performance curve is shown in Fig. 6. The maximum power output was 1,416W, and the efficiency was 34% at 80% fuel utilization. Fig. 7 shows module power output at this test. This module was moved from Nagasaki to Wakamatsu after 500 hours operation, and was resumed to operate. Total operation time was 3,000 hours, and module power output was stable over all operation conditions. The deterioration rate was about 2% per 1,000 hours. After 3,000 hours operation, all cell tubes were unbroken. Current collector, the plenum and the preheater were all intact.
FUTURE WORK

EPDC and MHI are now developing 10kW module. The module follows the 1kW module in basic design, namely the structure of the module, seal method of the fuel and air, current collector technique and air preheat method. Fig.8 shows the structure of 10kW module. We are going to operate the 10kW module in 1995 at Wakamatsu Power Station of EPDC.

CONCLUSION

We believe SOFC can achieve the highest efficiency among all power generating systems using fossil fuel. So we will make our best efforts to realize the SOFC power generation system as soon as possible.

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### Table 1: Materials and Film Thickness

| Structure Film | Materials      | Film Thickness |
|----------------|----------------|----------------|
| Fuel Electrode | NiO/YSZ        | 80~100 μm      |
| Electrode     | YSZ            | 100~150 μm     |
| Air Electrode | LaCoO₃         | 150~200 μm     |
| Interconnector| NiAl/Al₂O₃     | 100~150 μm     |
| Substrate Tube| CSZ            | Outer Diameter 21mm |

### Table 2: Specifications of 1kW Module

| Power Output                  | 1.2kW D.C |
|-------------------------------|-----------|
| Open Circuit Voltage          | 180V      |
| Operation Voltage             | 120V      |
| Operation Current             | 10A       |
| Number of Stacks              | 48        |
| Operation Temperature         | 900°C     |
| Operation Pressure            | Atmospheric Pressure |
| Outer Size of Module          | 700mm Diameter 1634mm Height |

### Figures

- **Fig. 3** Example of Cell Performance
- **Fig. 4** Structure of 1kW Module
- **Fig. 5** System Flow Diagram of 1kW Module
Fig. 6  I-V Characteristic of 1kW Module

Fig. 7  3000hours Operation Results

Module Current : 10A
Fuel Utilization : 80%