PRESENT STATE OF SOFC IN JAPAN

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ABSTRACT

This review deals with the present state of solid oxide fuel cells (SOFC) in Japan. In a national project (Moonlight Project), feasibility study on SOFC started in 1989 and will last for three years. National institutes which promote R & D on SOFC are the Electrotechnical Laboratory and the National Chemical Laboratory for Industry; universities are Yokohama National University, Mie University, Kyoto University, Tottori University and Kyushu University; and the companies are Mitsubishi Heavy Industry, Mitsui Engineering and Shipbuilding and the Tokyo Electric Power Company. The research on SOFC operation is promoted in the Tokyo Gas and the Osaka Gas Companies.

1. INTRODUCTION

The R & D on fuel cells by research organizations and industrial firms in Japan has been underway for over 30 years. This R & D on fuel cells accelerated since 1981 when a national R & D program was started in the *Moonlight Project* by MITI (1). In addition, the activities of many industrial companies and organizations contributed to the recent progress in solid oxide fuel cells.

The Agency of Industrial Science and Technology, MITI, started research on fuel cells in Fiscal year 1981 as a part of "Large-Scale R & D Projects for Energy conservation" (Moonlight Project), and it is presently engaged in research mainly on the phosphoric acid and molten carbonate fuel cells, but also on the solid oxide fuel cells. Figure 1 shows the R & D program for developing fuel cell power generation technologies. The fuel cell R & D project is scheduled to be a 15-year program lasting until Fiscal year 1995 and the total R & D budget is estimated to be about ¥57 billion.

In the Moonlight Project, The Electrotechnical Laboratory is engaged in research to develop a 500-MW class solid oxide fuel cell based on a cylindrical configuration. The National Chemical Laboratory for Industry is conducting research to develop a planar type fuel cell in the same project.
Some private corporations are also very active in this field. Tokyo Gas and Osaka Gas Companies signed contracts in 1986 with Westinghouse to purchase 3 kW solid oxide fuel cell generators and have conducted demonstration tests on these generators since November 1987.

Fundamental research on SOFC is being conducted at universities such as Tottori University, Kyoto University, Mie University, Kyushu University and Yokohama National University.

A feasibility study on SOFC power generation system was conducted in FY 1987, and a report on this study published in March 1988 (2). The present status of SOFC research at various organizations is discussed in the following sections.

2. ELECTROTECHNICAL LABORATORY

The Electrotechnical Laboratory started R & D on SOFC in FY 1974; this R & D has continued as part of the Moonlight Project since FY 1981.

Figure 2 shows the cross-sectional view of a solid oxide fuel cell stack developed at the Electrotechnical Laboratory. Materials used in this cell design are:

- **Electrolyte**: $(\text{ZrO}_2)_{0.82} (\text{Y}_2\text{O}_3)_{0.18}$ (YSZ)
- **Air electrode**: $\text{LaCrO}_3$, $\text{La}_{1-M} \text{M}_M \text{CoO}_3$, $\text{La}_{1-x} \text{M}_x \text{MnO}_3$ ($M = \text{Sr or Ca}$)
- **Fuel electrode**: $\text{Ni}$, $\text{NiO}$ - YSZ
- **Interconnector**: NiAl, LaCrO$_3$
- **Gas-tight layer**: $\text{Al}_2\text{O}_3$
- **Substrate**: Calcia-stabilized zirconia or $\text{Al}_2\text{O}_3$

Gas-tight films are made by plasma spray and the porous films are made by flame spray or slurry painting method. Laser spray/vapor deposition and chemical vapor deposition using organic precursors are also under development.

Cell and stack performance tests were conducted for solving problems of cell materials and configuration and long-term tests of 1000 hours were conducted for the inspection of chemical reactions between the YSZ electrolyte and the electrode materials. In FY 1986, the 500 W power generation experiment was conducted to evaluate the plasma spray fabrication method and the performance of the SOFC. The specifications for the stacks developed for 500 W test were as follows:

- **Number of cells connected in series**: 15
- **Unit cell length**: 24 mm
- **Interconnector length**: 12 mm

The typical performance of a stack with 4 l/min hydrogen gas flow was as follows:

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Open circuit voltage: 0.986 volt per cell
Current density : 140 mA per square cm
Power output : 26.6 W at the cell voltage of 0.8 volt

The 500 W power generation test was conducted with 48 SOFC stacks connected in parallel. At the beginning of the test, the output power of 500 W was obtained at the cell voltage of 0.76 volt and the current density of 63 mA per square cm with hydrogen supply of 190 l/min and air supply of 1100 l/min.

3. NATIONAL CHEMICAL LABORATORY FOR INDUSTRY

The planar type SOFC is expected to be better suited than tubular type SOFC for large scale power plants because of its higher power generating efficiency, higher power density, lower production cost, etc. The National Chemical Laboratory for Industry (NCLI) has focused its research activity on planar type SOFC in the following fields:

(a) New separator material
(b) Design and feasibility of internal gas-manifold structure
(c) Material processing for cells with the above structure

The electrical resistances of the cells were measured with several Ni-Cr alloy separators in air at 1000° C with 100 mA per square cm current. It was found that the electrical resistance of the cell with Inconel-600 separator decreased during 600 hours testing. In this test, the YSZ membrane was reinforced by a framework and the gases sealed by inconel packing and silica cement; the evaluation of this design is presently under progress. Another type of internal gas-manifold was designed for a cell with corrugated lanthanum chromite separator as shown in Figure 3. The processing technology for this design is also presently under investigation.

4. TOKYO ELECTRIC POWER COMPANY, INC.

The Tokyo Electric Power Company, Inc. started investigating fuel cells in 1960’s and has already achieved many successes including that in the generation of 4.5 MW electric power by phosphoric acid fuel cells. In 1980’s, the company began the study of solid oxide fuel cells; at present, they are working on the development of this type of fuel cell jointly with Mitsubishi Heavy Industries, Ltd.

Their basic research efforts have concentrated on the investigation of cell component materials and their physical properties, methods for forming thin membrane and other flow fields, and trial production of cells. For the time being, these investigations employ tubular multi-cell type cell elements which can be made and evaluated easily in terms of basic technology. In the future, the development activities will focus on producing highly efficient and durable cells by improving
their electrical properties, preventing cracking, peeling and chemical changes, as well as by solving the problems of modularization.

5. MITSUI ENGINEERING AND SHIPBUILDING COMPANY, LTD.

With the aid of the Japan Shipbuilding Industry Foundation, Mitsui Engineering and Shipbuilding Company is currently developing SOFC, which is being considered for the next generation ship propellant power plant, jointly with the Japan Marine Machinery Development Association. SOFC is better suited as a power unit on board a ship because it is all solid state and composed only of ceramic materials. Maintenance of a SOFC is also very easy because there is no fear of outflow of any corrosive liquids as is the case with electrolytes in fuel cells of other types. A SOFC can utilize hydrogen, carbon monoxide and air, and also can tolerate more impurities in these gases than other types of fuel cells. Thus, SOFC is expected to be easy to handle and highly resistant to vibrations and oscillations on board a ship. If a power system composed of SOFC's with a DC motor is employed to propel a LNG ship, then the total weight can be reduced to about 30% of that of a conventional boiler and turbine system. Furthermore, the total volume will be reduced to about 20%.

SOFC's operate at a temperature as high as 1000 °C. This high operating temperature helps recover exhaust heat but it also could cause instability of materials and requires the selection of special materials for peripheral parts. It is therefore desirable to lower the operating temperature of a SOFC to accelerate its practical use. The operating temperature of a SOFC is determined by ionic conduction in the electrolyte and reaction kinetics in the electrodes. One objective of this research is to develop a SOFC that can operate at a lower temperature by using a suitable electrolyte material and improving the shape of the electrolyte film.

6. OSAKA GAS COMPANY, LTD.

Osaka Gas Company is interested in solid oxide fuel cell for on-site power generation because of its high electrical efficiency, high temperature exhaust heat and expected long life. They have tested a 3 kW SOFC generator system from Westinghouse Electric Corporation since 1987 to evaluate the state of the art SOFC. After test of the first generator was finished on March 18, 1988, a second generator was placed on test. This second generator has been running since its start-up on March 29, 1988 (2). The generator is shown in Figure 4. The results of the first generation operation were as follows:

Operating period: October 2, 1987 to March 18, 1988
Operating time : 3,012.5 hours
Availability : 97.9%
Average power : 2.02 kW

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REFERENCES

1. "The Moonlight Project," (1988), Japan Industrial Technology Association, Japan.

2. "FY 1987 Report on Coal Gas Utilization for High Efficiency of Electric Power Generation," (1988), Nihon Sangyo Kikai Kogyo Kai.

3. "Report of IEA Workshop on Advanced Fuel Cell," (1988), IEA.

4. "Fuel Cell News," (1984 onwards), Fuel Cell Association.

5. "FC News Letter," (1986 onwards), Fuel Cell Development Information Center, Japan.
### Figure 1. Timetable of the Moonlight Project

| R&D Item                  | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 |
|---------------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| 1. Phosphoric Acid Fuel Cell |     |     |     |     | 100kW class | 1000kW Plants | 1kW | 10kW |      |      |      |      |      |      |      |
| 2. Molten Carbonate Fuel Cell |     |     |     |     |      |      |      |      |      |      |      |      |      |      |      |
| 3. Solid Oxide Fuel Cell  |     |     |     |     |      |      |      |      |      |      |      |      |      |      |      |
| 4. Alkaline Fuel Cell     |     |     |     |     |      |      |      |      |      |      |      |      |      |      |      |

### Figure 2. 500 W SOFC generator

![Diagram of 500 W SOFC generator]
Figure 3. Gas-manifold for corrugated type planar SOFC

Figure 4. Westinghouse 3 kW SOFC generator