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Status of fuel cells R&D activities at Sanyo

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Abstract

Sanyo is currently developing four types of fuel cell including phosphoric acid fuel cells (PAFCs), polymer electrolyte fuel cells (PEFCs), solid oxide fuel cells (SOFCs) and molten carbonate fuel cells (MCFCs). PAFC portable power units are fully developed. Such units are small, high performance, clean and quiet power sources which utilize a hydrogen absorbing alloy developed by Sanyo, as the fuel supplier. Their specific performance was maintained through 600 cycle tests. PEFC and SOFC R&D are being carried out under contract from the New Energy and Industrial Technology Development Organization (NEDO). Development of PEFCs with a high ion-conductive electrode is being carried out. A 1 kW module has been developed. Combined-cell stacking technology for planar SOFCs is being developed. A 160 $cm^2 \times 30$ cell stack was assembled and achieved a maximum output power of 1064 W; the decay rate was 4.4%/1000 h over the 1800 h of operation. A 30 kW class direct internal reforming MCFC system with light petroleum fuels was developed jointly with Tonen Corporation and Toyo Engineering Corporation, with the support from the Petroleum Energy Center (PEC). This system produced an output power of 30.5 kW.

Keywords: Fuel cells; Japan; Phosphoric acid fuel cells; Polymer electrolyte fuel cells; Solid oxide fuel cells; Molten carbonate fuel cells

1. Introduction

The fuel cell is the fourth power generating technology, following after hydro-power, thermal power and nuclear power. With respect to saving energy resources and protecting the global environment, it is expected to be one of the most promising technologies to be commercialized.

Sanyo has been developing fuel cells since the 1960s and the following types have already been put to practical use; methanol-air fuel cells, hydrazine-air fuel cells and zinc-air fuel cells. Building on these experience we are now developing four further types of fuel cell: phosphoric acid fuel cell (PAFC), polymer electrolyte fuel cell (PEFC), solid oxide fuel cell (SOFC) and molten carbonate fuel cell (MCFC).

This paper presents a status report of R&D activities of the four types of fuel cell.

2. PAFC

Sanyo had been engaged in the development of air-cooled PAFCs. There are two main themes aiming at developing small output power fuel cell products to be marketed: (i) portable power units, and (ii) small power units for consumer use. R&D has been concentrated on portable power units.

The portable power unit, which has an output power of several hundred watts, needs the following characteristics which are somewhat different from those of large-scale power plants [1]: easy handling (operation, fuel supply, storage etc.); long life in cyclic use (repeated start up/shut-down); quick start-up from ambient temperature; portability (small size and light weight); low cost (competition with battery systems), and safety.

2.1. Cell performances

The cell performance depends on the operating temperature as shown in Fig. 1. Although the performance is reduced by lowering the operation temperature, a cell voltage of about 670 mV (at 100 mA/cm^2) is obtained even at the low temperature of 100 °C by using pure hydrogen as fuel [2]. Such a performance offers the possibility of applying portable power units at low temperature.

2.2. Specifications of portable power units

A photograph of a 250 W class portable power unit is shown in Fig. 2 and specifications for the unit are given in Table 1.

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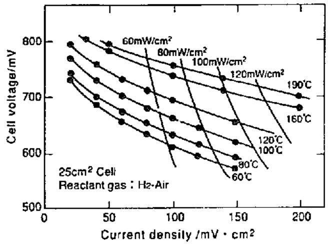

Fig. 1. Temperature dependence of the cell performance of a portable PAFC power unit.

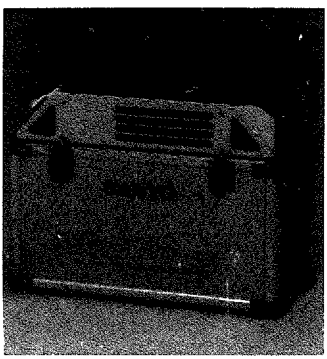

Fig. 2. View of a 250 W portable power unit.

Table 1
Specifications of a portable PAFC power unit [2]

a) *Power unit*	
Rated output	250 W
Voltage	12 V d.c.
Operation time	60 min at 250 W/1 tank
Dimensions $l\times w\times h$	433 mm × 212 mm × 340 mm
Weight	20 kg
Start-up operation	One-touch control
Start-up time	Several minutes
Fuel	Hydrogen
Fuel consumption	~5 l/min
b) *Fuel supplier vessel*	
Dimensions $l\times w\times h$	186 mm × 49 mm × 275 mm
Weight	4.5 kg
Condition of hydrogen	As metal hydride
Available hydrogen	> 300 l
Working pressure	< 9 kgf/cm²

This portable power units has a capacity of 12 V d.c. 250 W with a start-up time of several minutes. The dimension and weight of the power unit are 433 mm × 212 mm × 340 mm and 20 kg, respectively. It can start or stop by one-touch control.

2.3. Block diagram of portable power systems

The block diagram of the system is shown in Fig. 3. A 250 W d.c. portable power unit consists of a PAFC stack, a hydrogen supplier vessel using a hydrogen absorbing alloy, a controller and a DC/DC converter.

The fuel of the PAFC stack in this power unit is pure hydrogen supplied from the fuel supplier vessel. An alloy of misch metal, which is developed by Sanyo, is used as a hydrogen storage alloy. The weight of the fuel supplier vessel is 4.5 kg. The hydrogen evolution pressure of this alloy is higher than the atmospheric pressure at room temperature. The portable power unit can generate an output power of 250 W using this vessel for 60 min. The heat necessary for evolving hydrogen is supplied by the exhaust air from the PAFC stack.

The DC/DC converter keeps the output voltage at a constant value of 12 V d.c. and protects the fuel cell from connecting with an overload. A high conversion efficiency of 90% is capable in spite of the small capacity. Easy construction of software is achieved by using a general purpose 8 bit CPU. Both the DC/DC converter and, the control unit are purpose-designed for this power unit and they are integrated on one board [1].

2.4. Performances of portable power units

The operating performance of the fuel cell system is shown in Fig. 4. It was measured in terms of temperature (T_{cell}), voltage (V_{cell}) and current (I_{cell}) of the fuel cell stack. A load

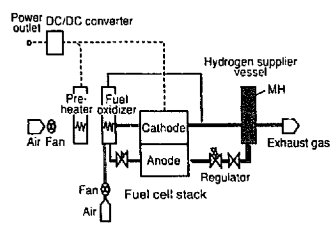

Fig. 3. Configuration of the portable PAFC power system.

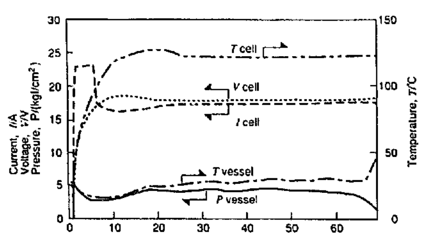

Fig. 4. Operating performance of the portable PAFC power system.

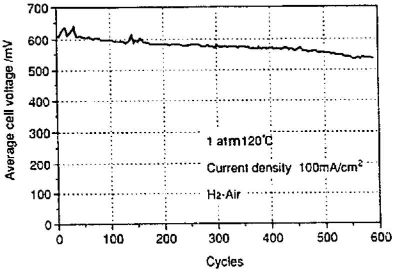

Fig. 5. Life test for the portable PAFC power unit.

was connected after 5 min from the start-up. The steady-state operation continued for about 60 min and the total electric generation was 309.2 Wh. The vessel pressure (P_{vessel}) fluctuated in accordance with vessel temperature (T_{vessel}), which reflects the fact that the hydrogen equilibrium pressure depends on the alloy's temperature [3].

2.5. *Life-test result of portable power units*

The result for the life test for the stack employed in the portable power unit is shown in Fig. 5. One operation cycle includes heating the stack with a load connected, continued operation at the rated output current, shut-down with no purge, and rest at room temperature. The degradation of the average cell voltage is relatively small with the average decay rate over 600 cycles of operation at less than −0.1 mV/cycle [2].

3. PEFC

PEFCs have a distinctive characteristic. Although they operate in a rather low-temperature range (from room temperature to 100 °C), they have a high power density. Making the best use of this characteristic, we have been developing PEFCs for portable power sources, etc.

3.1. *Development of cell unit construction technologies*

The effect of platinum catalyst loading and PTFE content on cell performance was studied in order to improve the cell unit performance using high ion-conductive electrodes. The cell performance was improved even with the same catalyst loading by increasing the platinum density on carbon-supported platinum catalyst (Pt/C). It would be possible for a cell with a loading of less than 1 mg/cm² Pt to achieve 0.3 W/cm² of power density (atmospheric pressure, 500 mA/cm²) by using 50 wt.% Pt catalyst [4].

The endurance of a 25 cm² single cell was evaluated by the test running for 4000 h as shown in Fig. 6. The catalyst loading of the electrodes was controlled to 0.5mg/cm², and the test was run under atmospheric pressure (but with sometimes pressurized to 3 atm), 80 °C, 500 mA/cm². The average degradation rate of the cell voltage was about 1%/1000 h.

3.2. *Performances of a 500 W module and a 1 kW module*

A 500 W module was operated in both atmospheric and pressurized conditions. An output power of 550 W d.c. was obtained at 50 A (current density: 500 mA/cm²) in the atmospheric conditions. More than 0.3 W/cm² of power density (output power: 610 W d.c.) was obtained in the pressurized operation at 3 atm.

A photograph of 1 kW module is shown in Fig. 7. The 1 kW module was tested at almost the same operating conditions as those of a 500 W module. The 1 kW module voltage–current and power characteristics are shown in Fig. 8. The voltage–current characteristics were equal to that of the 500 W module, and an output power of more than 1.2 kW d.c. (power density: 0.3 W/cm²) was achieved at 3 atm and with a current of 100 A (current density: 500 mA/cm²).

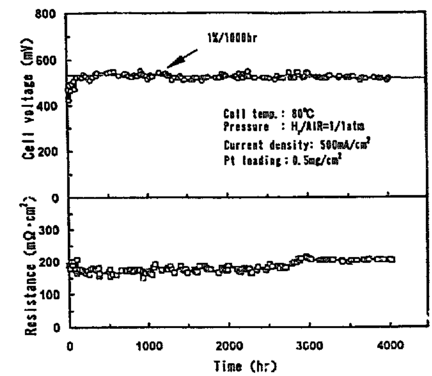

Fig. 6. Endurance of a 25 cm² single PEFC.

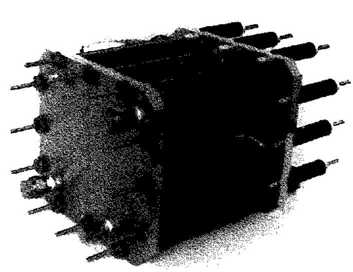
Fig. 7. View of a 1 kW PEFC module.

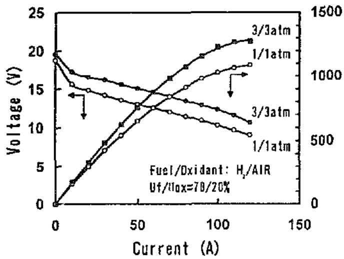

Fig. 8. 1 kW PEFC module: voltage–current and power characteristics.

4. SOFC

SOFCs are expected to yield high power density because of their high operating temperature, 800–1000 °C. We selected a planar type for compactness and aimed at small-scaled co-generation systems. Fundamental technologies, such as composite electrodes and melt-seal methods, were developed during the NEDO project in Phase I, 1989–1991. Now, we are undertaking R&D of a 'combined cell stacked module' under contract with NEDO in the New Sunshine Project.

4.1. Performances of a 1 kW module

In 1993, an output power exceeding 500 W was achieved with a 130 $cm^2 \times 20$ cell module. Gas distribution and temperature distribution were found uniform in this module. In 1994, a 160 $cm^2 \times 30$ cell module was developed in order to investigate a stacking technology and the effect of the cathode second layer. Moreover, a single layered combined cell module (160 $cm^2 \times 4$ cell parallel) was also tested.

Specifications of 160 $cm^2 \times 30$ cell module are shown in Table 2. A photograph of a 1 kW module is shown in Fig. 9. A maximum output power of 1064 W, and a power density of 0.22 W/cm^2 were achieved [5]. The voltage–current and power characteristics of a 1 kW module are shown in Fig. 10.

The endurance of a 1 kW module was evaluated for more than 1800 h, see Fig. 11; the module was operated at a constant current density, and its output power decay rate was 4.4%/1000 h.

Table 2
Specifications of the SOFC module

Electrolyte	$150 \times 200 \times 0.2$ mm^3
Active electrode area	160 cm^2
Stacking number	30 cells
Rated output power	960 W (0.2 W/cm^2)

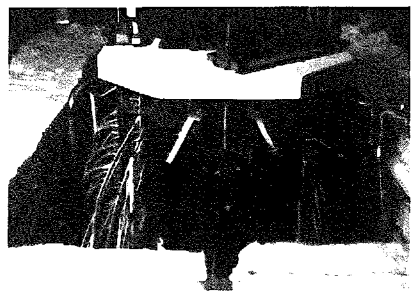
Fig. 9. View of a 1 kW SOFC module.

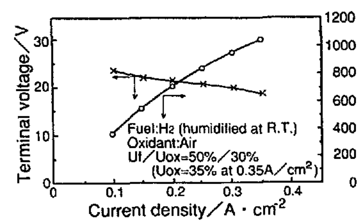

Fig. 10. Voltage–current and power characteristics of a 1 kW SOFC module.

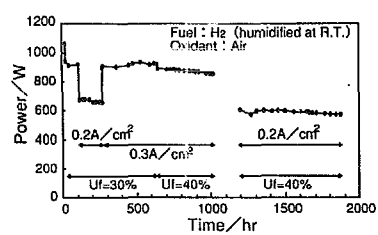

Fig. 11. Endurance of a 1 kW SOFC module.

5. MCFC

The internal-reforming MCFC is receiving a great deal of attention by virtue of its high efficiency and simple system configuration.

Sanyo has conducted research on MCFC stacks and systems. In 1990, a 10 kW, naphtha-fueled, external-reforming, MCFC system was demonstrated successfully. A 30 kW direct, internal-reforming MCFC system is being tested in order to evaluate the feasibility of petroleum-fueled MCFCs for co-generation applications.

R&D has been concentrated on the promotion of internal reforming technologies. With the support from PEC, jointly with Tonen Corporation and Toyo Engineering Corporation, a 30 kW direct internal reforming MCFC system with light petroleum fuels is under development.

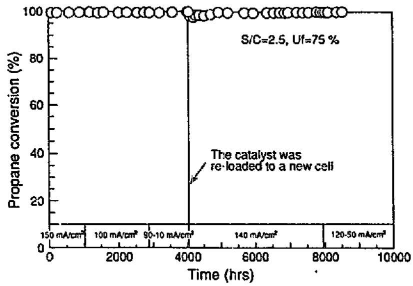

Fig. 12. Performance stability of Ru–ZrO_2 catalyst in an MCFC.

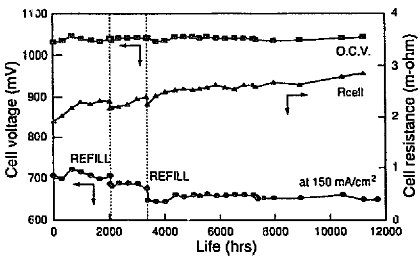

Fig. 13. Long-term stability test of 250cm² single MCFC cell.

5.1. *Performances of a 30 kW DIR-MCFC stack*

A 30 kW direct internal reforming (DIR-MCFC) system with petroleum fuel has been developed. The system is based on cell stack technology, DIR-catalyst technology and system technology.

A Ru–ZrO catalyst was developed for liquefied petroleum gas (LPG) reforming. The activity was tested in 25 cm^2 single cells. The catalyst activity had been stable for 8500 h as shown in Fig. 12.

A long-term stability of cell performance was confirmed with a 250 cm^2 single cell as shown in Fig. 13. The decay rate was 0.7 mV/1000 h in 11 700 h operation. The 1 kW DIR-MCFC stack (777 $cm^2 \times 10$ cells) was successfully operated with LPG for 5000 h as shown in Fig. 14. The specification of the 30 kW stack was based on that of this 1 kW stack.

To make a compact packaged system, plate fin types of heat exchanger were selected and combined with a separator. 0.5 m^2/kW of foot print has been successfully achieved. A photograph of the system is given in Fig. 15.

A 30 kW stack (4510 $cm^2 \times 66$ cells) was assembled and tested preliminarily in Osaka, then transported to Saitama. After process and control testing of the system, the stack was connected to the system and tested with LPG as fuel. There was no influence on the stack performance by transportation.

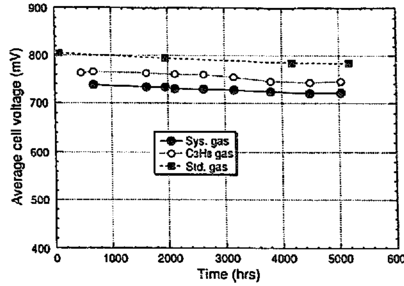

Fig. 14. Endurance of a 1 kW DIR-MCFC stack.


Fig. 15. View of a 30 kW MCFC system.

30.5 kW of output power and 50.0% of electrical efficiency were achieved [6].

6. Summary

We have developed PAFC portable power units. These units are small, high performance, clean and quiet power sources which utilize a hydrogen absorbing alloys developed by Sanyo as the fuel supplier.

PEFC and SOFC R&D are being carried out under contract from NEDO. Development is being carried out for PEFCs with high ion-conductive electrode. A 1 kW module was developed and an output power of more than 1.2 kW d.c. (power density: 0.3 W/cm^2) was achieved at 3 atm, with a current of 100 A (current density: 500 mA/cm^2). Combined-cell stacking technology for planar SOFCs is being developed. A 160 $cm^2 \times 30$ cell stack was assembled and achieved the maximum output power of 1064 W; the decay rate was 4.4%/1000 h over the 1800 h of operation.

A 30 kW DIR-MCFC system with light-petroleum fuels was developed supported by PEC, jointly with Tonen Corporation and Toyo Engineering Corporation. An output power of 30.5 kW and 50.0% of electrical efficiency were achieved.

Acknowledgements

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MCFC work was performed with the support of the Petroleum Energy Center (PEC) Technical Development Division, which is subsidized by MITI.

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