Development of Polymer Electrolyte Fuel Cells

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1. Introduction

Polymer electrolyte fuel cells (PEFC) use an ion exchange membrane as the electrolyte.

Fuji Electric initiated research on PEFC cells and fuel cell stacks in 1989. We have conducted fundamental research and development of PEFC cells and the fuel cell stack and have accumulated data, which allows us to evaluate the reliability of the power generating system[1].

To promote the practical use of PEFC system, we worked on the demonstration and verification of the 1 kW class stationary PEFC system from 2000 through 2001. We produced the prototype stationary PEFC system, which consists of a power generation unit, a hot water unit and an inverter unit. In addition, we evaluated the performance of the system. The problems, which needed to be solved, were defined and the fundamental data necessary for the system upgrade were collected.

In this paper, we will discuss the prototype system and the results of the evaluation. In addition, recent developments of reformed gas fuel cells will be presented.

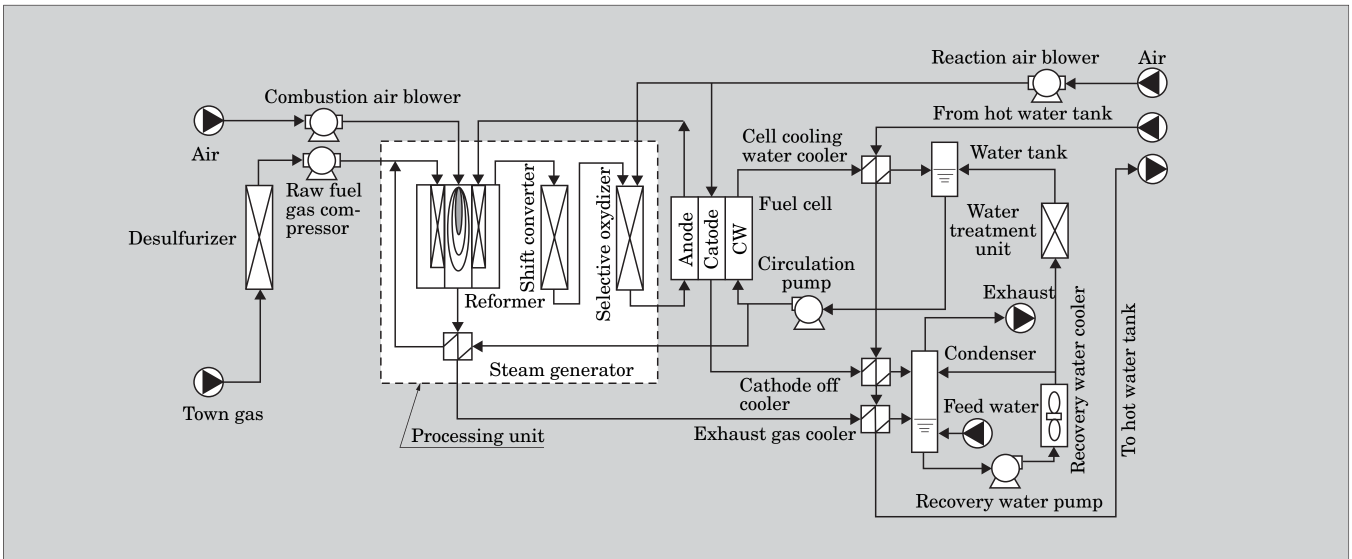
2. Development of the 1 kW System

2.1 Description of the system

The power generating system consists of a fuel processing unit, a fuel cell stack, and auxiliaries, such as a heat exchanger and a rotating machine. All of these components are self-contained in a package. Figure 1 shows the system flow diagram. Appearance of the package is shown in Fig. 3, “Fuel Cell Development Trends and Future Prospects” in this special issue.

Supplied town gas will be reformed to a hydrogen rich gas, which has a CO content less than 10ppm. This process is mediated by reforming devices, which consist of a desulfurizer, a reformer, a CO shift converter, and a CO remover. Following this process, the gas is introduced to the fuel cell stack. In the fuel cell stack, 60 to 70 % of the hydrogen in the reformed gas will be consumed during power generation. The balance of the hydrogen will be burnt in the burner and will be utilized as the heat source of the reformer. Throughout this process, the heat balance will be maintained. Electrical output will be converted into 200 V AC via an inverter unit and this electricity will

Fig.1 Process flow diagram of 1 kW class PEFC system



be supplied to the grid of the electric system. Waste heat will be recovered from the reformer exhaust gas, cell stack cooling water and cathode off gas, which pass through a heat exchanger. Heated water (60°C) will be stored in the hot water tank. Table 1 shows the specifications of the system.

The system is fully automated and can reach the power generating condition just by pressing a start button. The electrical output can be adjusted at any value between 30 and 100 % via a touch panel.

The control system is based on technology established by phosphoric acid fuel cells. Thus, the reliability and stable operation of the system is ensured.

2.2 Fuel processing unit

The fuel processing unit consists of the following four reaction devices, a desulfurizer to remove the sulfur in the town gas, a reformer for the steam reforming reaction, a CO shift converter to reduce CO content down to less than 1 %, and a CO remover to reduce CO content down to below 10 ppm. Table 2 shows the specifications of the fuel processing unit.

Table 1 System specifications

Output power	1 kW class (AC)
Electric connection	1 phese 3 wires 200 V AC
Heat recovery	60°C
Fuel	Town gas
Operation	Full automatic
Dimension Width,Height,Depth	1,100 × 1,100 × 400 mm

Table 2 Specifications of the fuel processing unit

Desulfurizer	Fuel	Town gas 13 A
	Catalyst	Zeolite
	Operating temp.	Ambient temp.
	Outlet sulfur concentration	Less than 10 ppb
	Exchange cycle	8,000 h
Reformer	Fuel	Town gas 13 A
	S/C	2.5 to 3.0
	Catalyst	Precious metals
	Operating temp.	650 to 680°C (Outlet)
	Outlet CH_4 concentration	Less than 2.0 dry %
CO shift converter	Catalyst	Cu-Zn
	Operating temp.	320°C/180°C (Inlet/outlet)
	Outlet CH_4 concentration	Less than 1.0 dry %
CO remover	Processing gas	Reformed gas (CO concentration 1.0 dry %)
	O_2 to CO mol ratio	1.0 to 1.5
	Catalyst	Precious metals
	Operating temp.	220°C/80°C (Peak/outlet)
	Outlet CH_4 concentration	Less than 10 ppm

An ambient temperature desulfurizer was adopted in order to simplify the system. The cartridge was filled with the quantity of desufurizing agent required for approximately one year of full operation.

A steam reforming system, which was used for onsite fuel cells, was adopted. This allowed for the size to be reduced, due to the fact that in this system the reformer and CO shift converter are combined. Steam for the reformer is superheated in the CO shift converter. Figure 2 shows the appearance of the reformer/CO shift converter.

A selective oxidation CO removal method was adopted. This procedure oxidizes CO by mixing air in the pre-stage in proportion to the CO concentration in the reformed gas. Previously, the reaction tank consisted of two layers. However, we used a single reaction layer type to achieve a more compact size.

Because the operating temperature of the fuel cell stack is relatively low on PEFC power generating system, it is not possible to obtain the necessary steam required for the reformer from the fuel cell stack. Consequently, the steam had to be provided by a steam generator. This generator produced the steam from the combustion of the reformer's exhaust gas. The steam generator is an important component of the fuel processing unit.

The steam was generated by a steam generator without pulsation and the temperature of combustion exhaust gas from the reformer was lowered to 110° at the outlet of the steam generator. Thus, efficient heat utilization was achieved.

With the exception of the desulfurizer, the fuel processing unit (inside of the dotted line in Fig. 1) was integrated and its size is only ϕ300 × 650 mm (including thermal insulation material).

2.3 Test results

2.3.1 Start-up/shut-down, load changing and rated load performance tests

Start-up time required to achieve the rated output was about 110 minutes for the cold start and about 60

Fig.2 Appearance of the reformer/CO shift converter

minutes for the hot start.

Figure 3 shows the catalytic layer temperature of the fuel processing unit during the start-up from the cold condition and the corresponding load change. The load changed from a rated load of 100 % to 30 %, and then back to 100 %.

Temperature of each part was controlled properly and the load change was able to be done in a stable manner.

Electrical efficiency was 38 % (LHV: lower heating value) at the DC generating output end on the rated load.

2.3.2 Continuous operation tests

To verify the temperature of each component, gas composition and water quality after a long period of operation, we performed the continuous operation tests from June to July of 2001. Figure 4 shows the test results on temperature, and pressure for the fuel processing unit.

Temperature and pressure of each part were controlled properly. We utilized a small direct contact heat exchanger in the water recovery section and achieved a closed-loop, self watering operation (water required for the steam reforming is obtained from the water contained in the combustion exhaust gas and the operation can be done without an external water supply). This process was previously believed to be difficult to conduct during the summer. Because the closed-loop, self watering system does not rely on an external water supply, the quality of recovered water can be improved. Therefore, the life of the water treatment equipment may be extended. This represents an economic advantage of this system.

Fig.3 Start-up and load changing test results

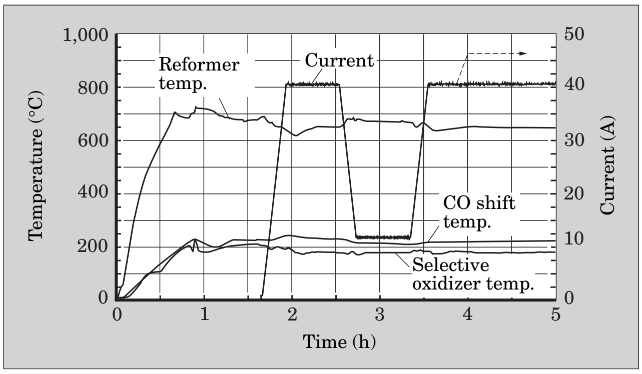
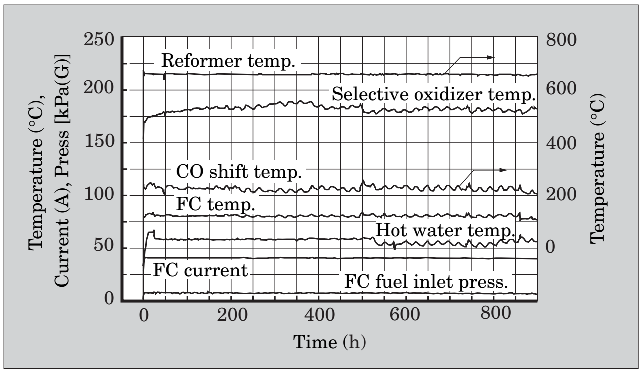


Fig.4 Continuous operation test results



2.3.3 Repeated start-up/shut-down tests

To verify the effect of repeated start-up and shut-down of the system, we conducted a 50 cycle start-up and shut-down (one or two cycles a day) operation. Any abnormalities were detected by inspecting the fuel cell voltage and the reformed gas composition. After 50 cycles of operation, the gas tightness was maintained and the temperature distribution of each catalytic layer of the fuel processing unit remained unchanged. From these test results, we were able to verify that the fuel processing unit was not damaged or deformed after 50 cycle start-up and shut-down operation.

3. Development of the Fuel Cell Stack for the Reformed Gas

3.1 PEPC fuel cell stack

The PEFC fuel cell stack is constructed from fuel cells connected in series, which comprise the power generating unit. These cells are bolted together. Each cell consists of a fuel electrode, an air electrode, and an ion exchange membrane. The reaction gas will supplied to each electrode. Each electrode consists of a catalyst layer and a gas diffusion layer. Catalyst layers consists of a catalyst (platinum or its alloy particles supported on carbon black particles) and a persulfonate ionomer solution. In the cell, water must be controlled in order to ensure that the reformed gas passage is not impeded. In contrast, the ion exchange membrane must be maintained in a continuously wet condition in order to ensure proper functioning.

When the reformed gas is used as fuel, a small amount of CO is contained. The catalyst of the fuel cell electrode can be poisoned by CO. Such poisoning can be relieved by conducting this procedure at a high temperature or by using an alloy catalyst.

Fuji Electric has performed a detailed study[2] on water management technology and has unique knowledge on non-humidifying operation. As an example, the 1 kW class fuel cell stack, which generates pure hydrogen fuel, is currently being operated successfully after 10,000 total hours with this technology[3]. Based upon the experience of this operation, we reexamined the operating temperature of the reformed gas fuel stack and improved the water management conditions. In addition, we evaluated the ability of the electrode catalyst to resist CO poisoning and we selected the most appropriate catalysts.

3.2 Long life tests of the single cell for reformed gas

We are evaluating the durability of a single cell based on the test results obtained to date. Figure 5 shows the change in cell voltage after a long period of operation under typical operating conditions (cell tem-

Fig.5 Long life test results for the single cell

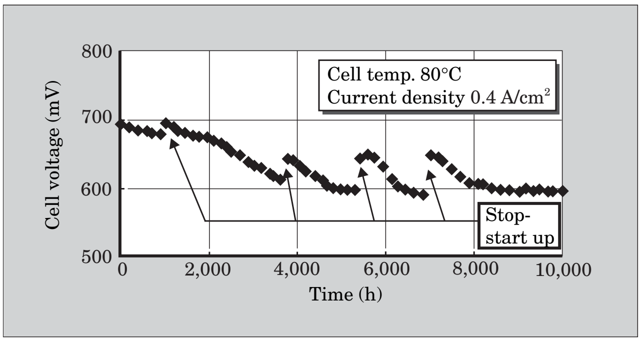


Table 3 Specifications of 1 kW class fuel cell stack for reformed gas

Fuel	Reformed gas
Oxidant	Air
Humidification	Internal humidification for air
Operating temp.	80°C
Operating pressure	Atmospheric pressure
Electrode area	100 cm^2
Number of cells	60
Current at 100 % load	40 A
Output power at 100 % load	1.6 kW DC

perature: 80°C, current density: 0.4 A/cm^2). From Fig. 5, it can be seen that cell voltage increases after restarting, and cell voltage gradually recedes before shut-down. This phenomenon is assumed to be caused by changing water conditions in the cell when restarting. When the system is continuously operating, the voltage will stabilize after 5,000 total hours.

We are studying the possibility of improving the electrode in order to enhance its initial performance and endurance. The results of this study are currently being evaluated.

3.3 1 kW class fuel cell stack for reformed gas

Table 3 shows the major specifications of the 1 kW class fuel cell stacks. The appearance of the fuel cell stack is shown on Fig. 6. Air will be humidified inside the fuel cell stack. As a consequence, the reformed fuel gas without humidification will be supplied to the fuel cell stack.

The fuel cell stack was subjected to component power generation tests and then assembled into the power generating system. Figure 7 depicts I-V performance of the component and performance of the power generating system at rated power. The I-V characteristic was satisfactory and the performance at rated power satisfied design requirements.

4. Conclusion

We evaluated the 1 kW class PEFC system and stack for reformed gas and verified that these can be operated in a stable manner for a relatively long time.

Fig.6 Appearance of 1 kW class fuel cell stack for reformed gas

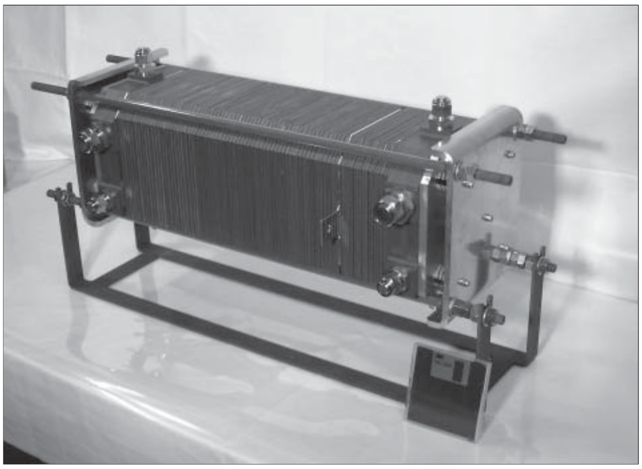
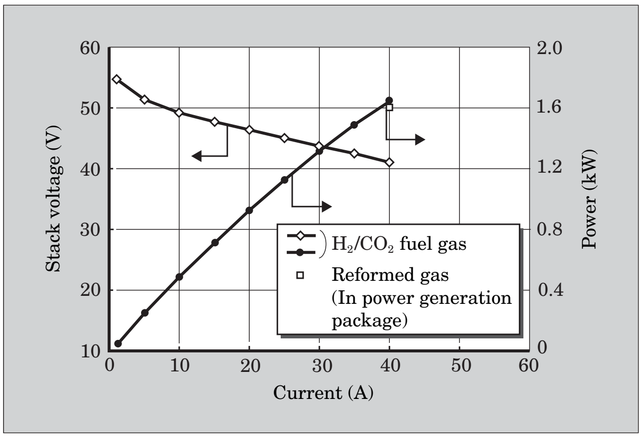


Fig.7 Performance of 1kW class fuel cell stack for reformed gas



We will continue to study practical applications of the PEFC power generating system. The following aspects will be the focus of future research:

(1) Creating long life reformed gas fuel cells and at lower costs
(2) Cost reduction by the simplification of the system
(3) Improve efficiency by reducing auxiliary power loss and heat loss
(4) Optimizing the generating capacity and developing reformed gas fuel cells with larger electrode area

References

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(3) Wada, T. et al. Development of PEPC Stacks in Fuji Electric, 7th Grove Fuel Cell Symposium Delegate Manual. 2001, p.2a.11.