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DEVELOPMENT OF A SOFC SYSTEM FOR SMALL-SCALE COMMERCIAL USE

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1. ABSTRACT

Solid Oxide Fuel Cells (SOFC) systems can produce the highest electrical conversion efficiency (45% to 60%) of the various kinds of fuel cell systems. Toho Gas has tackled the development of SOFC systems for small-scale commercial use.

Since 2006, Toho Gas has jointly developed SOFC system together with the Nippon Telegraph and Telephone Corporation (NTT) and Sumitomo Precision Products, Co., Ltd. (SPP). Up till now, we have developed a DC power 3kW SOFC power generation module and confirmed high electrical efficiency of 56% (LHV) at DC power of 3 kW.

After that, the SOFC power generation module was scaled up to 6 kW-class DC, and the AC power 5 kW-class SOFC system was developed that added an inverter and a unit controlling the supply of fuel, air, reformed water, etc.

The AC5kW-class SOFC system was developed and a 1000-hour electrical generation experiment was run. The AC electrical efficiency (initial) was 44%. After 1000 hours of electrical generation, the average was 42%.

TABLE OF CONTENTS

2. BODY OF PAPER

2-1. Introduction

In recent years, there has been global demand for ways to deal with the problem of global warming. At the G8 L'Aquila summit of July 2009, the goal was reconfirmed of cutting the world's total amount of global warming gas emissions by at least 50% by 2050. Of Japan's global warming gas emissions, the emission of carbon dioxide (CO_2) due to energy consumption accounts for 90% and there are great expectations for high-efficiency systems that can reduce CO_2 emissions.

On the other hand, in March 2011, Japan suffered a major earthquake. After this earthquake, from the perspective of energy security, attention turned to dispersed generating plants that can secure part of the required electrical power at homes and companies, rather than depend on nuclear power plants or thermal power plants, which are large-scale, centralized generating plants.

A cogeneration system which is an effective mean of reducing CO2 emissions, has been installed into large-scale industrial and commercial use. However, this system does not become widespread for small-scale commercial use, because a small-capacity cogeneration system has not caught on. Accordingly there is a need for such a high-efficiency system to be developed.

Fuel cell systems are one of the cogeneration systems, which can produce electrical power with high electrical efficiency. In Japan, Polymer Electrolyte Fuel Cells (PEFC) cogeneration systems for household were commercialized in 2009.

On the other hand, Solid Oxide Fuel Cells (SOFC) feature high operating temperatures and the ability to use exhaust heat for the reforming reaction of fuel, so SOFC systems can produce the highest electrical conversion efficiency (45% to 60%) of the various kinds of fuel cell systems. Many corporations and universities are involved in developing them, and the development of SOFC systems is accelerating with a national project that started in 2007 in Japan.

Given these circumstances, Toho Gas has tackled the development of SOFC systems for small-scale commercial use. This announcement reports on the development status for SOFC systems for small-scale commercial use.

2-2. Development of a 5kW-class SOFC system

2-2-1. Background to development

Since the 1990s, Toho Gas has been developed scandia-stabilized zirconia (ScSZ) electrolyte and succeeded in developing ScSZ electrolyte with great resistance to fracture and put it into practical use. After that, we put into practical use 12 cm-diameter planar electrolyte-supported cell (ESC) with developed ScSZ electrolyte.

Since 2003, Toho Gas has tackled the development of SOFC systems together with Sumitomo Precision Products, Co., Ltd. (SPP). Using the developed planar electrolyte-supported cells, we tackled SOFC system development and developed Japan's first 1 kW-class SOFC system. In 2005, we operated this system as a cogeneration system continuously for one half year at the 2005 World Exposition Aichi, Japan (Expo 2005).

Since 2006, Toho Gas has jointly developed SOFC system together with the Nippon Telegraph and Telephone Corporation (NTT) and Sumitomo Precision Products, Co., Ltd. (SPP). Up till now, we have developed a DC power 3kW SOFC power generation module and confirmed high electrical efficiency of 56% (LHV) at DC power of 3 kW.

After that, the SOFC power generation module was scaled up to 6 kW-class DC, and the AC power 5 kW-class SOFC system was developed that added an inverter and a unit controlling the supply of fuel, air, reformed water, etc (hereinafter referred to as BOP (Balance of Plant)).

2-2-2. System structure

Figure 1 shows the structure of the developed AC5kW-class SOFC system and Figure 2 shows its appearance. The SOFC system comprises the cell stack, power generation module, BOP, and inverter.

The cell stack is the section that generates DC power. The cell stack comprises 40 layers of "single cell stack" in which cells are sandwiched between metal separators. The DC power of one cell stack is 1.5 kW. The power generation module has four cell stacks and the DC power for the power generation module is 6 kW.

The power generation module comprises the cell stack, reformer, combustor, start-up burner, and heat exchanger (See Figure 3). The city gas introduced into the power generation module is reformed in the reformer by the addition of water vapor and becomes the reformed gas that is fed to the cell stack. After the air for the cathode is preheated in the heat exchanger, it is supplied to the cell stack. The reformed gas not used for power generation in the cell stack is combusted in the combustor and that combustion heat is used for the reaction of water vapor reforming and for preheating air. In this way, the fuel gas required for power generation in the power generation module is supplied to the cell stack, the temperatures required in the reformer and other sections are supported, and DC power is taken out from the cell stack.

The BOP is the section that comprises the pumps and controllers for supplying city gas, air, and water to the power generation module.

The inverter is the part that converts DC power taken out from the power generation module to AC power, and supplies the power generated by the SOFC to the power load.

In the power generation experiment this time, the inverter AC power is connected to an AC power supply that simulates a commercial power system. The BOP drive power is supplied from the AC power. Also, the power load for consuming the power generated by the SOFC is connected.

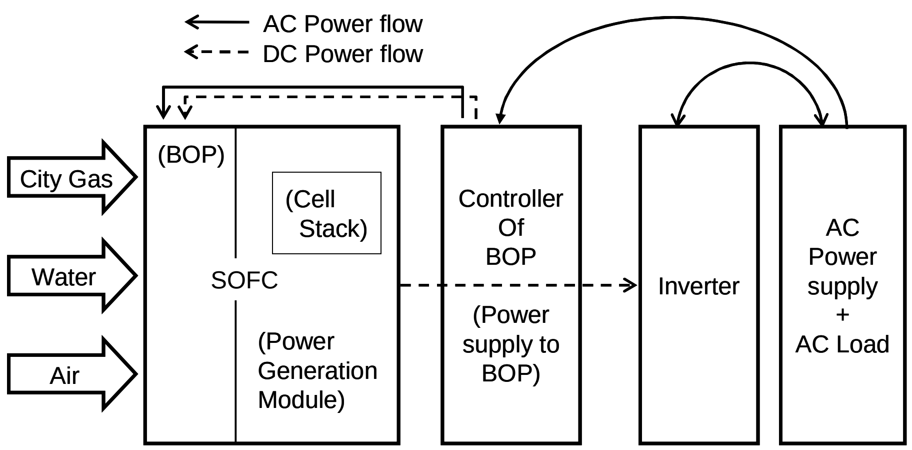

Figure 1: Structure of AC5kW-class SOFC System

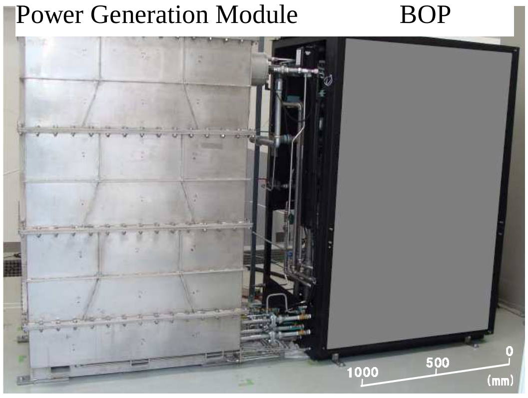

Figure 2: Appearance of 5kW-class SOFC system

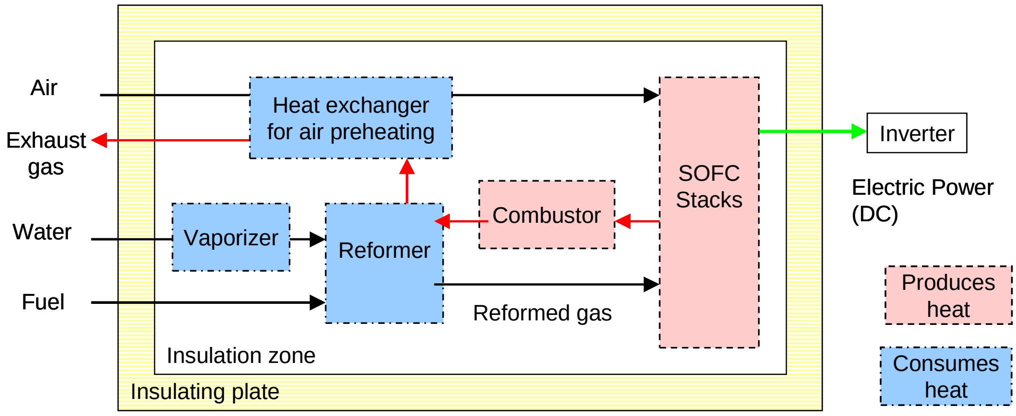

Figure 3: Flow diagram of SOFC power generation Module

2-2-3：SOFC system target value

Table 1 shows the main specifications of the AC5kW-class SOFC system. The system target value is an AC electrical efficiency of 45% (LHV). The DC power is the generated output taken out from the electrical generation module. The AC power is the generated output excluding the BOP power consumption and the inverter conversion losses. This corresponds to the power generation output supplied from the SOFC system to the outside (See Figure 4). Therefore, in order to attain an AC electrical efficiency of 45%, if the DC electrical efficiency is set to 54%, then it is necessary to attain an inverter conversion efficiency of 94% and BOP power consumption of 630 W. By the way, an AC electrical efficiency of 45% is 15% higher than the electrical efficiency of a gas engine type cogeneration system of the same capacity (which has an AC electrical efficiency of about 30%).

Table 1: Main Specifications of AC5kW-class SOFC System

Item	Designed value	Remarks
AC power : P_{AC}	5kW	-
AC electrical efficiency : η	45% (LHV) min.	Target value
DC power : P_{DC}	6 kW	1.5 kW x 4 stacks
DC electrical efficiency	54% (LHV) min.	-
BOP power consumption : P_{lose}	630 W max.	-
Inverter conversion efficiency : η_{INV}	94% min.	-
Reforming method	Water vapor reforming	Steam/carbon = 3.0
Exhaust heat used	No	-

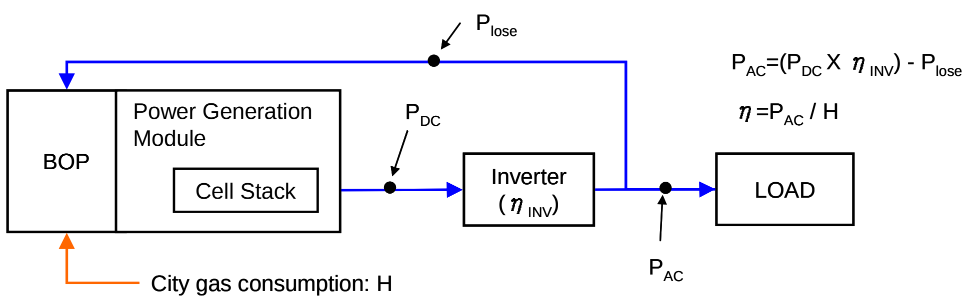

Figure 4: SOFC System Efficiency Evaluation

2-2-4. Experiment Results

The results of power generation experiment with the developed 5kW-class SOFC system for 1000 hours are shown below.

2-2-4-1. Power generation module output

Figure 5 shows the results of DC power at the power generation module. The DC power is 6.1 kW. The DC electrical efficiency is 56%. Also, during the 1000 hours of the power generation experiment, it was confirmed that the DC power and DC electrical efficiency were held constant.

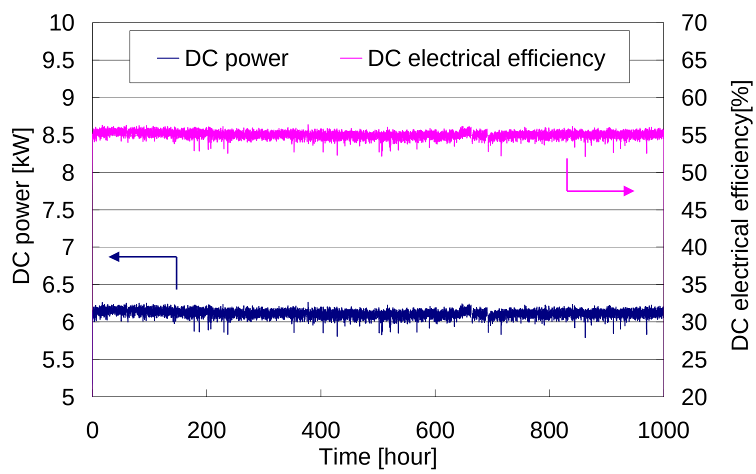

Figure 5: Power Generation Module DC Power and DC electrical efficiency

2-2-4-2. AC power

Figure 6 shows AC power results and Figure 7 shows the BOP power consumption. The initial AC power of power generation was about 5 kW and the AC electrical efficiency was 44%. As time passed, the AC power and the AC electrical efficiency decreased and the BOP power consumption increased. When the BOP power consumption increases, the electrical output that can be supplied to the outside decreases.

Investigating the details of the BOP power consumption, it was determined that the cathode air blower power consumption was increased. At the 400-hour mark, the operation sound from the cathode air blower became louder (Figure 7-①). At the 600-hour mark and 900-hour mark, the cathode air flow was decreased slightly and the experiment continued (Figure 7-②). The cause of the increased power consumption by the cathode air blower was an increase in pressure loss due to powder dust clogging in the flow meter downstream of the blower. Also, because the air blower continued to operate under a high load, the condition of the air blower deteriorated.

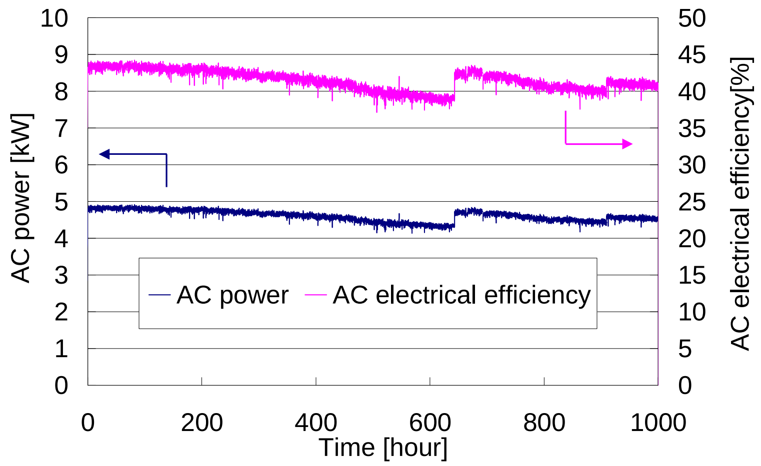

Figure 6: AC Power and AC electrical efficiency

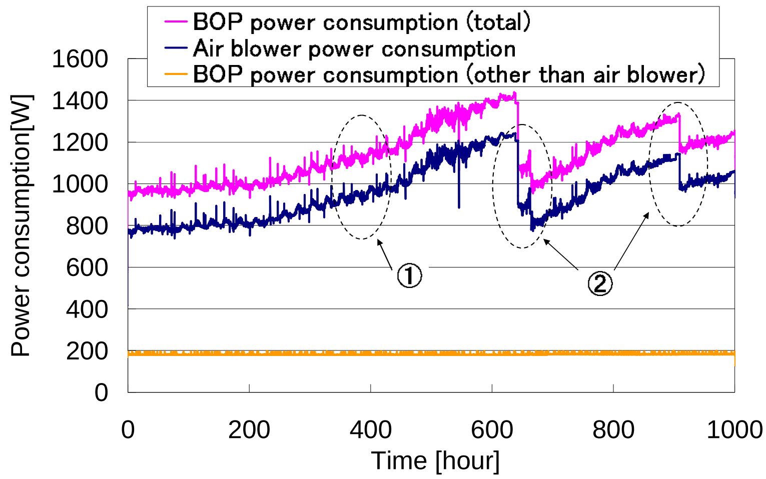

Figure 7: BOP Power Consumption

2-2-4-3. Comparison of Designed Value and Measured Values

Table 2 compares the SOFC designed value and measured values.

- The DC power and DC electrical efficiency for the power generation module satisfied the designed values.
- The measured value for inverter efficiency is 93-94%, which just about satisfies the designed value.
- The BOP power consumption (initial) is 950 W, which is 1.5 times the designed value. Of the BOP power consumption, that of the cathode air blower accounts for a large proportion. Thus, it is important to reduce power consumption of the cathode air blower.
- The AC electrical efficiency (initial) was 44%. After 1000 hours of electrical generation, the average was 42%. The designed value was not achieved.

Table 2: Comparison of SOFC System Designed Values and Measured Values

	DC power	DC electrical efficiency	Inverter efficiency	BOP Power consumption	AC power	AC electrical efficiency
Designed value	6 kW	54%	94%	630 W	5 kW	45%
Measured value	6.1 kW	56%	93-94%	950 W (initial)	5 kW (initial)	44% (initial)
Attainment	O	O	O	×	O	×

2-3. Summary

An AC5kW-class SOFC system was developed and a 1000-hour electrical generation experiment was run. Future issues are as follows.

- Reduce the BOP power consumption.
- Make the SOFC system smaller.
- Extend into cogeneration system by adding a heat recovery function.

3. LIST OF TABLES

4. LIST OF FIGURES