VERIFICATION TEST OF
A 25kW CLASS SOFC COGENERATION SYSTEM

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ABSTRACT

Osaka Gas and Tokyo Gas have high expectations for natural-gas-fueled Solid Oxide Fuel Cell (SOFC) cogeneration systems. SOFC offers many advantages for on-site cogeneration systems, such as high electrical efficiency, high quality by-product heat and low emissions. They are now executing a joint development program with Westinghouse Electric Corporation (hereinafter called as WELCO). This program is aimed to verify a 25kW class SOFC cogeneration system. This system, which was modified by replacing previous zirconia porous support tube cells (PST cells) with newly designed air electrode supported cells (AES cells), commenced operation on March 21, 1995. The system has been successfully operated for 13,100 hours as of February 7, 1997. This paper presents the performance evaluation of the new AES cells and the results of system operation at WELCO.
INTRODUCTION

A 25 kW class cogeneration system was developed to verify SOFC performance for on-site cogeneration system. The system was operated for 817 hours at Osaka Gas test facility in 1992.

In 1995, the 25 kW class cogeneration system was modified by replacing two generator modules consisting of PST cells with one AES cells generator module. This system has been successfully operated for 13,100 hours as of February 7, 1997. In this report, the performance of the 25 kW class cogeneration system and the evaluation of new AES cells utilized after generator module are discussed.

A 25 kW CLASS COGENERATION SYSTEM

The 25 kW class SOFC cogeneration system was the first system in the world incorporating a high temperature fuel cell generator unified with pre-reformer and heat recovery system (Figure 1). The unit packaged the heat recovery system, the control system and the fuel supply system with the fuel cell generator and integrated pre-reformers to yield a very simple configuration. Overall dimensions of the system are 4.9m length, 2.0m width and 2.2m height. Fuel cells, pre-reformers and combustion plenum are integrated into one module, which has 576 tubular type AES cells with active length of 50 cm each as shown in Figure 2.

The pre-reformer is designed to reform approximately 75 % of the incoming desulfurized pipeline natural gas before it is introduced to the cells. The steam for reforming is supplied solely by the recirculation of anode exit gas. Heat for the reforming reaction is supplied both by heat exchange of the exhaust gas out of the combustion plenum and heat of the recirculated anode exit gas. Recirculation of the high temperature(900°C) anode exit gas is achieved by utilizing an used by utilizing an ejector (jet pump) driven by pressurized fuel gas. As a result, no steam and heat need to be supplied from outside of the generator module.

The heat recovery steam generator (for cogeneration) is located between the high and the low temperature recuperators. An auxiliary air preheater is used to heat the generator module during start-up and to keep the thermal balance under partial load operation. Maximum output (DC) of the system with one generator module (576 AES cells) is 25 kW. The specifications of the system are shown in Table 1. The system flow schematic is shown in Figure 3.
PERFORMANCE COMPARISON BETWEEN AES AND PST CELLS

The 25 kW class cogeneration system was installed with a new type of cell named the air electrode supported cell (AES cell) with improvement in durability against thermal cycles. The air electrode supported cell utilized in this system is shown schematically (not to scale) in Figure 4. The previous porous zirconia support tube cell (PST cell) is shown in Figure 5. Outside diameter of the AES cell is 16 mm, which is the same as that of PST cell. Figure 6 shows voltage vs. current performance curve for AES cells and PST cells. The voltage of AES cells exceeds by about 20% that of PST cells. This voltage performance shows that the electrical resistance of the air electrode side is reduced compared with that of PST cells. This superior voltage stability of AES cells is shown in Figure 8. AES cells also have been able to withstand 10 thermal cycles during an operation period of 13,100 hours. The durability and voltage performance of AES cells is demonstrated to be remarkably improved over the previous PST cells.

OPERATION STATUS

The important objectives of the operation test were to verify the performance of new cells and to evaluate the system for on-site cogeneration. Operation of the system started on March 21, 1995 at WELCO's factory. At the beginning, the temperature difference among four quadrants of the module increased. After 950 hours operation, the cell voltages decreased significantly due to pre-reformer's deactivation. As a result, the system was stopped, pre-reformer catalyst was replaced, and air flow adjustment valves were installed. On August 7, 1995, the system was restarted with balanced inlet air flow to the generator module. Since then, the system has operated well in spite of 4 stops due to failures of ancillary equipment. Four thermal cycling tests were conducted effectively after 10,000 hours. As of February 7, 1997, the total operation time reached 13,100 hours. A peak power output of 25kW DC was achieved on August, 1996 at a current of 222 amperes and a fuel utilization rate of 82% as designed. Steam recovery of 5kWt at a pressure of 9 kg/cm²G was achieved with an inlet water temperature of 90°C. Table 2 shows the operation test summary, and Figure 7 shows system performance.

Figure 8 shows the terminal voltage of two systems (the generation system of reference 3 with 576 PST cells and the cogeneration system with 576 AES cells). The voltage of the cogeneration system is about 20% higher than that of the PST generator system because of the improved cell structure. The terminal voltage of AES cells shows
excellent stability compared with that of PST cells. The degradation rate of the voltage for the AES cells was less than 0.1% per 1,000 hours. The data for generating efficiency are shown in Figure 9. The DC efficiency of the 25 kW class cogeneration system is over 50% (LHV) in the output current range from 120 to 180 ampere as designed. The efficiency is almost the same even after 10,500 hours operation.

SYSTEM PERFORMANCE AS COGENERATION

A steam output test was conducted for 100 hours in August, 1996. Steam can be taken anytime the current exceeds 160 Amperes by giving a set point for steam superheat. The results of the steam output test is shown in Figure 10. 27 kWt of maximum steam output at 9kg/cm²G was designed to be provided by the 25 class cogeneration system with two generator module installed each with 576 PST cells. In this cogeneration system with one generator installed, 4.7 kWt of superheated steam was produced at 9kg/cm²G (260°C). The high temperature steam is expected to be utilized for industrial usage as on-site cogeneration.

CONCLUSIONS

The 25kW class SOFC cogeneration system with a simple and compact design has been successfully demonstrated. The performance of the system for cogeneration was verified as designed. The voltage performance of AES cells was remarkably improved from that of PST cells, and the durability against thermal cycle of AES cells was much advanced compared with the previous PST cells. The system has been operating satisfactorily in cooperation with WELCO. The development of an advanced on-site cogeneration system with AES cells is a significant step forward for the practical use of SOFC systems. Osaka Gas and Tokyo Gas expect significant cost reduction by WELCO in the near future. Osaka Gas, Tokyo Gas and WELCO will further evaluate the performance of AES cells against thermal cycle.

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Table 1. The specifications of 25kW class SOFC cogeneration system

| Generator | Cell | AES Cells (Active length 50cm) 576 cells (1 Module) |
|-----------|------|--------------------------------------------------|
|           |      | 43W/Cell |
|           |      | 3 parallel x 6 series = 18 (1 Bundle) |
|           |      | 8 bundles x 4 = 576 (1 Module) |
|           |      | Internal with pre-reformers (75% pre-reforming) |
| Fuel, Oxidant | Pipeline natural gas (Pittsburgh city gas), Air |
| Operation condition | Temperature | 1,000°C |
|                     | Pressure   | Atmospheric |
|                     | Fuel utilization | 85% |
|                     | Air utilization | 15% |
| Output | Electric | DC 25 kW at Max |
|         | Steam    | 6 kW (9kg/cm²G) |
| Operation Control | Automatic |
| Dimensions | 4.9m length x 2.2m width x 2.0m height |
Figure 3. System flow schematic of 25kW class SOFC cogeneration system

Figure 4. AES cells

Figure 5. PST cells

Figure 6. V-I performance

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Table 2  Operation Test Summary

| Operation period | March 21, 1995 - February 7, 1997 * |
|------------------|-------------------------------------|
| Operation time   | 13,100 h*                           |
| Electricity      |                                     |
| Ave.             | 21.3 kWe                            |
| Max.             | 25.0 kW DC at 222A                  |
| Steam            | 4.7 kWt                             |
| Startup/Cooldown | 11 times / 10 times                 |
| Partial Cooldown | 1 time                              |
| Major Problems   |                                     |
|                  | - Reformer catalyst deactivation    |
|                  | - Fuel compressor failure           |
|                  | - Air blower failure etc.           |

*Operating

Figure 7  Power, Current, Voltage vs. Operating time
Figure 8  Voltage vs. operation time (at 150 amperes)

Figure 9  Output power vs. DC efficiency
Figure 10  Steam recovery test (100 hours)