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Highly efficient heat recovery system for phosphoric acid fuel cells used for cooling telecommunication equipment

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Abstract

To protect the global environment by using energy more efficiently, NTT is developing a phosphoric acid fuel cell (PAFC) energy system for telecommunication cogeneration systems. Fuel cells are used to provide electrical power to telecommunication equipment and the heat energy is used by absorption refrigerators to cool the telecommunication rooms throughout the year. We have recently developed a highly efficient system for recovering heat and water from the exhaust gases of a 200-kW (rated power) fuel cell. It is composed of a shell-and-tube type heat exchanger to recover high-temperature heat and a direct-contact cooler to recover the water efficiently and simply. The reformer and cathode exhaust gases from the fuel cell are first supplied to the heat exchanger and then to the cooler. The high-temperature (85–60°C) heat can be recovered, and the total efficiency including the heat recovered from the fuel-cell stack coolant can be improved by supplying the recovered heat to the dual-heat-input absorption refrigerator. The water needed for operating the fuel cell is also recovered from the exhaust gases. We are currently applying this heat and water recovery system to the PC25C-type fuel cell. Maximum total efficiency including electrical power efficiency is estimated to be 78% at the rated power of 200 kW: composed of 17% heat recovery for the fuel-cell stack coolant, 21% from the exhaust gas by improving the heat exchanger, and 40% from electrical conversion. Next, we plan to evaluate the usefulness of this heat recovery system for cooling telecommunication equipment.

Keywords: Phosphoric acid fuel cell; Absorption refrigerator; Heat recovery; Cogeneration

1. Introduction

The amount of electrical power used for telecommunication services has reached 0.5% of the total electrical power consumed in Japan. The percentage will grow even higher as multimedia communications become even more popular. Therefore, the development of energy systems that generate power efficiently and cleanly is becoming more and more important for telecommunications [1].

A phosphoric-acid fuel-cell (PAFC) is expected to be a highly efficient and clean generator, and its exhaust heat can also be used in a co-generation system. We have developed a co-generation system in which the electrical power is supplied to a telecommunication system and the heat is used by absorption refrigerators, and field-tested it at two telecommunications buildings, NTT Yokohama branch and NTT Kansai network center [2–5]. The heat energy is used by the absorption refrigerators to cool the telecommunications rooms throughout the year even in winter because the amount of waste heat dissipated by telecommunication equipment is ever increasing. The heat recovery efficiency is expected to be improved by developing technology that can supply heat to the absorption refrigerator, even more efficiently than at present.

We have recently developed a highly efficient system for recovering heat and water from the exhaust gases of a 200-kW (rated power) fuel cell. This paper describes how heat is recovered from the fuel-cell exhaust gas to boost heat recovery efficiency, and how the system is applied to the PC25C-type fuel-cell system used for cooling telecommunication equipment.

2. Principle of heat recovery system

The configuration of the fuel cell energy system used for cooling telecommunication equipment is shown in Fig. 1. The system consists of equipment for recovering heat from the fuel cell coolant and from the fuel cell exhaust gas, a dual-heat-input absorption refrigerator, a refrigerant

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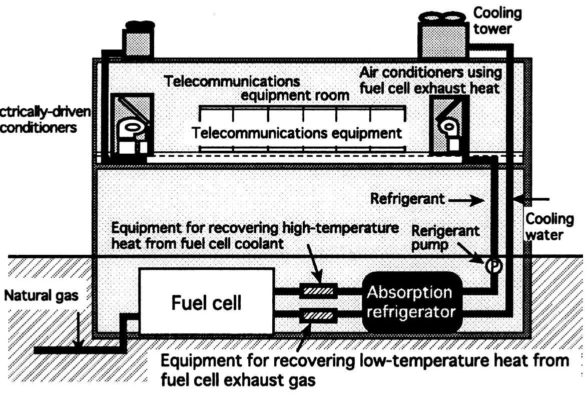

Fig. 1. 200-kW fuel cell system used for cooling telecommunication equipment.

pump, and an air conditioner using fuel cell exhaust heat. The rated power of the fuel cell is from 100 to 200 kW. Low temperatures produced by the absorption refrigerators are transmitted by means of a refrigerant to the air conditioner inside the telecommunications equipment room for cooling. To maintain the reliability of the air conditioning system, an air conditioner using the fuel cell exhaust heat is used in combination with an electrically-driven air conditioner.

The two types of recovered heat — high-temperature (about 160°C) heat recovered from the fuel cell stack coolant and low-temperature (about 60°C) heat recovered from the exhaust gas — are supplied to a new dual-heat-input absorption refrigerator having improved cooling performance. There are two generators, one each for high and low temperatures to produce cooled refrigerant for the air conditioners. The current version of the dual-heat-input absorption refrigerator operates all year round; when the outside air temperature drops, the temperature of the cooling water is also reduced. The absorption refrigerator is driven by the temperature difference between the heat-recovered water and the cooling water. Consequently, a heat recovery temperature of 60–65°C is sufficient for the low-temperature generator in winter, but it needs to be 80–85°C to maintain the cooling performance of the absorption refrigerator in summer because the outside air temperature is higher. Previously, this medium-temperature heat (80–85°C) was not recovered from exhaust gas; only the lower-temperature heat and the water contained in the exhaust gas were recovered. The main target of this system is to recover the medium-temperature heat more efficiently and to recover water inexpensively from the exhaust gas.

3. Heat recovery technology using the TFC 200-type fuel cell

3.1. Experiment

The configuration of the new system for recovering heat from the exhaust gases is shown in Fig. 2. This system is composed of a shell-and-tube type heat exchanger to recover the medium-temperature heat and a direct-contact cooler (DCC) to recover the water efficiently and simply. The reformer and cathode exhaust gases from the fuel cell were first supplied to the heat exchanger and then to DCC. The heat and water recovery properties of this system were examined using a 200-kW fuel cell (TFC 200, Toshiba). The temperature of the exhaust gas was about 160°C. The exhaust gas was composed of steam (about 25 mole%), N_2 (about 65 mole%), and a small quantity of CO_2 and ${}_{O}2$. The amount of recovered heat was evaluated by the product of (a) the flow rate of water circulating between the heat exchanger for heat recovery and the heat exchanger imitating the absorption refrigerator and (b) the water temperature difference between the inlet and outlet of the heat exchanger-imitated absorption refrigerator. The heat recovery temperature was controlled to within 5°C by controlling the flow rate of water circulating between the heat exchanger-imitated absorption refrigerator and the cooling tower. The amount of recovered water was evaluated from the sum of the measured amounts of water recovered from the heat exchanger for heat recovery and from the direct-contact cooler.

3.2. Results

As shown in Fig. 3, the amount of heat recovered from the exhaust gas of the fuel cell operating at the rated power of 200 kW increased with decreasing temperature of the heat-recovered water, because more condensed water was recovered from the exhaust gas when the temperature of the heat-recovered water was lower. The performance of the absorption refrigerator was affected by the temperature of the cooling water supplied from the cooling tower outdoors to the absorption refrigerator. The absorption refrigerator requires hotter heat-recovered water when the temperature of the cooling water is higher.

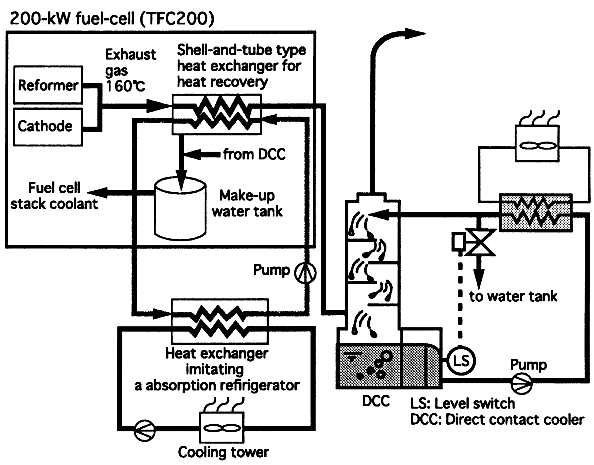

Fig. 2. Heat and water recovery system from 200-kW fuel cell exhaust gases.

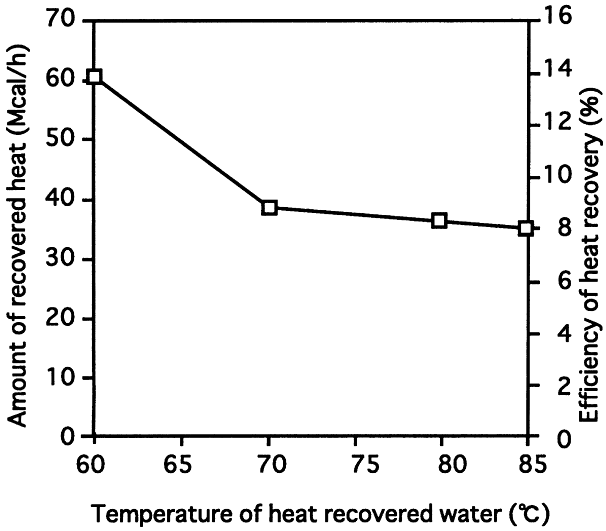

Fig. 3. Properties of heat recovery from the fuel cell exhaust gas (rated power operation: 200 kW).

Fig. 4 shows the amount of water recovered from the fuel cell exhaust gas for 200-kW rated power operation. When the temperature of the heat-recovered water was low (60°C), the amount of water recovered from the heat exchanger for exhaust gas was 30 kg/h (25% of the total amount of recovered water). When the temperature of the heat-recovered water was higher than 60°C, almost all the water from the exhaust gas came from the DCC. The total amount of the recovered water decreased with increasing temperature of the heat-recovered water and the water circulating in the DCC. Nevertheless, this system demonstrated that 120 kg/h of water could be recovered even under the severe conditions of summer (heat-recovered water temperature: 85°C; DCC water circulation temperature: 44–48°C). Since the amount of the water needed for reforming the fuel is only about 105 kg/h, this system can operate without any externally supplied water.

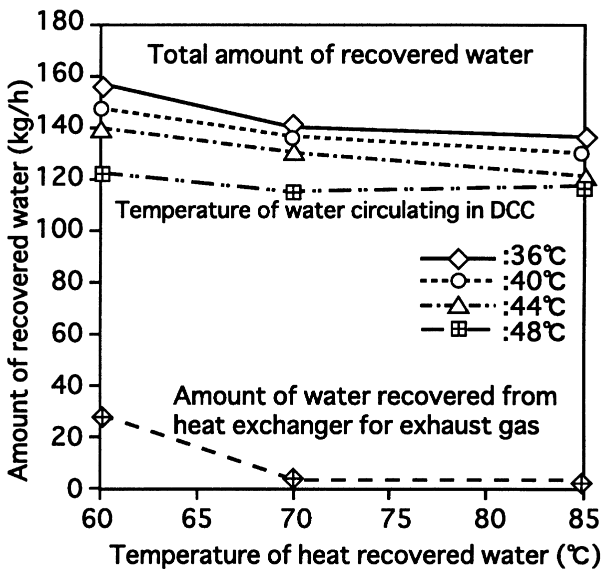

Fig. 4. Properties of water recovery from the fuel cell exhaust gas (rated power operation: 200 kW).

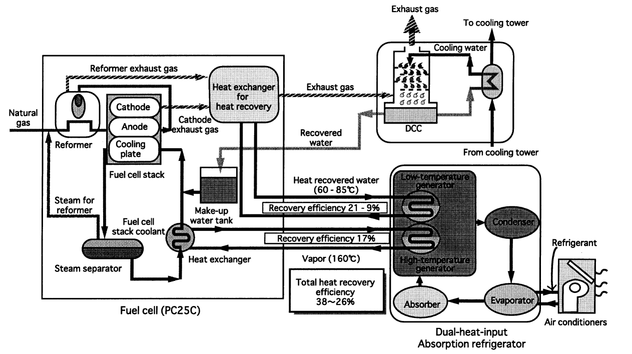

Fig. 5. New heat recovery and utilization system from 200-kW fuel cell.

4. Applying this technology to PC25C-type fuel cell

A new fuel-cell system incorporating the above-mentioned improved heat and water system was introduced at the NTT R&D center. Its system configuration is shown in Fig. 5 and photographs of it are shown in Figs. 6 and 7. This system was a modified 200-kW PC25C type fuel cell (ONSI-Toshiba). The reaction heat from the fuel cell stack is conducted to the cooling water and is fed into the steam separator. The steam produced here is supplied to a reformer, where it is used for reforming the fuel. Excess heat is fed indirectly into a high-temperature generator through the heat exchanger. The water that condenses in the generator is returned to the tank and used as make-up water. The steam supply temperature is very high, 160°C. The heat recovery efficiency from the fuel cell stack coolant was designed to be about 17%. On the other hand, the recovered heat from the reformer and the cathode exhaust gas is fed into a low-temperature generator. In this system, the capacity of shell-and-tube type heat exchanger for heat

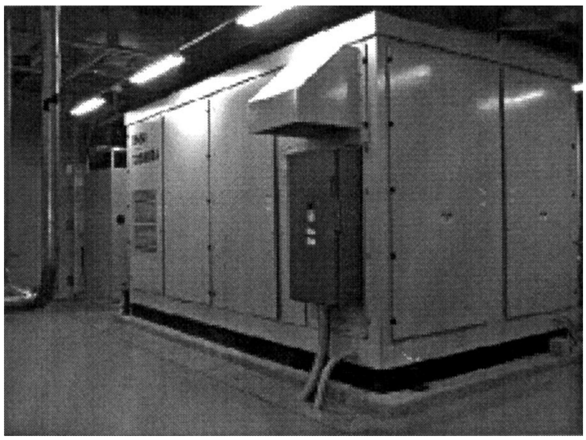

Fig. 6. Appearance of fuel cell.

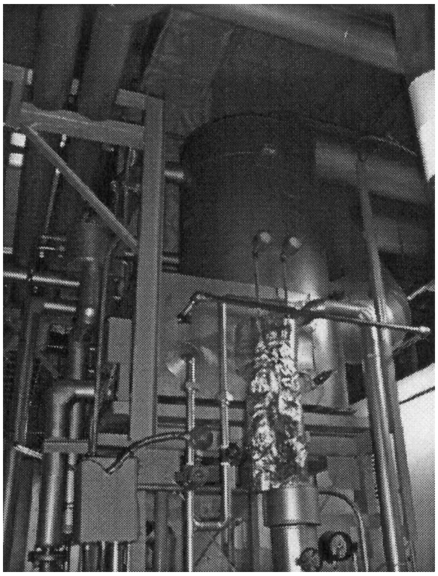

Fig. 7. Appearance of DCC.

recovery is 1.6 times that of the TFC200 system mentioned above. The heat recovery efficiency was designed to range from 9% (at the heat recovery temperature of 85°C corresponding to the summer peak) to 21%. The average heat recovery efficiency throughout the year is intended to be 18%. The maximum efficiency of the total recovered heat including that from the fuel cell stack coolant and the exhaust gas should be 38% in winter, and the maximum total efficiency including electrical power efficiency is estimated to be 78% under the rated power of 200 kW. Low temperatures produced by the absorption refrigerator are transmitted by means of refrigerant to the air conditioner inside the telecommunications equipment room for cooling. The coefficients of cooling performance were about 1.0 and 0.6 for supplying heat to the high- and low-temperature generators, respectively. This is the highest efficiency among existing air conditioning systems using absorption refrigerators.

5. Conclusion

An overview of the heat recovery and utilization technology of fuel-cell systems being developed by NTT was presented. Fuel cells are being used to provide electrical power to telecommunication equipment and the heat energy is used by absorption refrigerators to cool the telecommunication rooms throughout the year. We have recently developed a highly efficient system for recovering heat and water from the exhaust gases of a 200-kW (rated power) fuel cell. Field tests were conducted in NTT telecommunications buildings to evaluate the developed technology and to study its maintainability. These systems will enable heat energy to be utilized efficiently, thus helping to save energy.

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