THERMOELECTRIC POWER GENERATION USING H_2O_2 DECOMPOSITION FOR PORTABLE POWER SOURCE

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Abstract: The small thermoelectric power generation system with H_2O_2 decomposing reactor as a heat source was designed and fabricated. To maintain significant temperature difference across the thermoelectric module, the heat sinks with channels were attached on the cold side of thermoelectric module and they were operated by forced convection with water as liquid coolant. Using 87% of H_2O_2 solution, about 500 mW of electric power was generated with 27 cm^3 of power generator. Power consuming experiments were also carried out by connecting an electric load. It was found that the temperature on the hot side of thermoelectric module was affected by the electric current flowed through the closed circuit.

Key words: Thermoelectrics, hydrogen peroxide, micro-power generator, catalytic decomposition.

1. INTRODUCTION

A portable power source using chemical fuel such as hydrocarbons or alcohols, is attracting many researchers' attention as a promising alternative to the existing rechargeable batteries[1, 2]. To extract usable energy from fuel, an exothermic reactor such as a microcombustor is required essentially. Many research groups around the world attempted developing diverse micro-heat engines integrated with microcombustors. To achieve the micro-heat engines, miniaturized fast moving components and kinematics' mechanism to generate power must be fabricated and realized. However, these were difficult to be achieved in micro-scale devices; therefore development of micro-heat engines reached a deadlock.

Thermoelectric power generations were studied by a few research groups as an alternative to the micro-heat engines. Thermoelectric power generator is based on the Seebeck effect, and is a unique heat engine of which the working fluid is charge carriers. Merits of thermoelectric power generation in microsystem are absence of moving components and simple integration of components compared with heat engines.

$$H_2O_2 \xrightarrow{Catalyst} H_2O + 0.5O_2 \qquad (1)$$

Hydrogen peroxide (H_2O_2) is a promising fuel for a portable power source. Hydrogen peroxide releases heat when it is decomposed on the catalyst. It has advantages in storage and supplement since it is liquid at atmospheric condition and only one reactant is required. In addition, it is non-toxic and eco-friendly since it produces only oxygen and water.

Reducing the size of the heat sinks is important to miniaturize the thermoelectric power generation system. H_2O_2 has advantage since it can be used as a liquid coolant of heat sink (Fig. 1). In the system, H_2O_2 passes through heat sinks, and preheated H_2O_2 is supplied to the reactor.

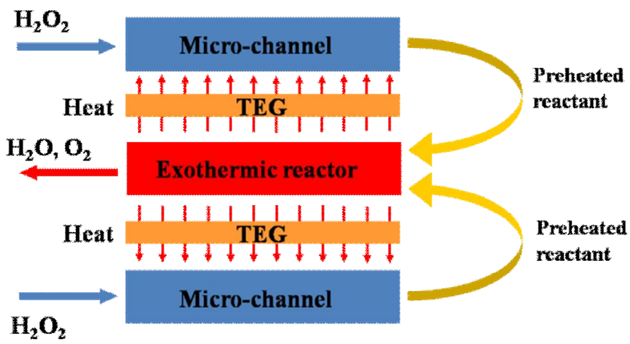

Fig. 1: Concept of the proposed system

In the present study, thermoelectric power generations with hydrogen peroxide decomposition were studied experimentally. The performances of system were tested and discussed in terms of open circuit voltages, power and efficiency.

2. EXPERIMENTAL

2.1 System integration

Fig. 2 illustrates the system integration. Reactor and heat sinks were made of aluminum by precision machining. The reactor and heat sinks were 30 mm long and wide, 6 mm high. Two TE module/heat sink pairs were attached on the both sides of the reactor. The two TE modules were connected in series. The reactor had 20 mm long and wide, 4 mm deep reaction chamber and contained the catalyst. The catalyst was

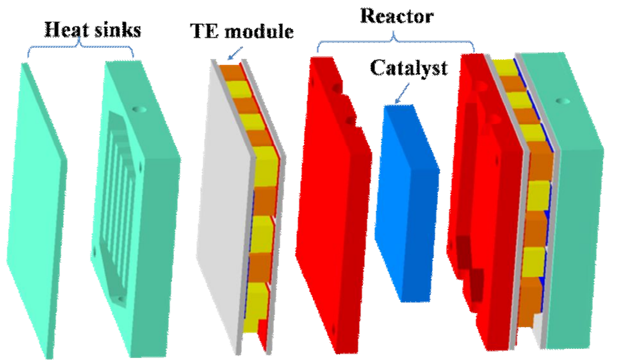

Fig. 2: Schematic of the system

prepared by silver electroplating on nickel foam. The porosity of nickel foam was 90-92% and the average pore diameter was about 1 mm. The channels of heat sink was 4 mm deep and 5 channel walls of which dimension was 16 (L) × 1.6 (W) × 4 (H) mm were located in it. 1/8" aluminum tubes were welded on the components.

Each component was assembled using thermal tape to fix overall components and to reduce contact thermal resistance between components. The thickness of the tape is 50 µm and it is sustainable in the range of -20 °C ~ 200 °C.

Thermoelectric modules used were HMG3730 from ACETEC Co., Ltd. (Daegu, Korea). The size of module is 30 mm long, 30 mm wide and 3.6 mm thick. It was made from Bi and Te. The required operating temperatures of the cold side and the hot side are 50 °C and 200 °C, and can generate 2.1 W with approximately 4.5 % of the thermal efficiency.

2.2 Experimental setup

Fig. 3 shows the experimental setup to evaluate performance of the system. In the originally proposed concept, the exhaust hole of the heat sinks must be connected with the inlet of the reactor. However, in the experiments, coolant of the heat sinks were supplied independently using syringe pump and as a coolant water was used for convenience. When the total flow rate was same with the flow rate of H_2O_2 which was supplied by a liquid pump, the system simulated the originally proposed system.

In the present study, 87% H_2O_2 was used with different flow rates. The flow conditions tested in the present study are listed in Table 1. Totally, 23 cases were tested with different H_2O_2 and water flow rates. The open circuit voltages (V_{OC}) and temperatures between each component were measured. 50 µm thick foil thermocouples were used to measure temperature. The conversions of H_2O_2 were obtained by measuring O_2 flow rates after removing H_2O among the product gas.

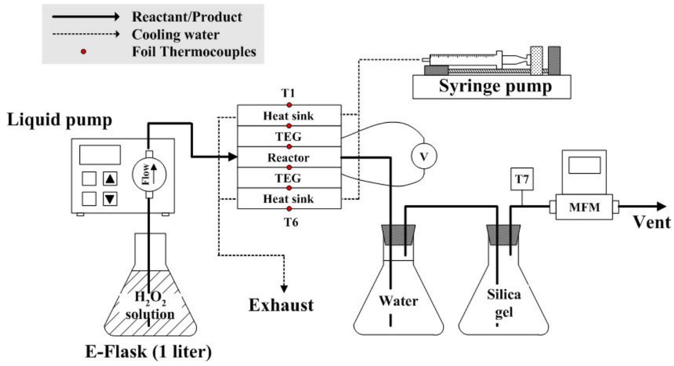

Fig. 3: Experimental setup

Q_{H2O2} (cch)	Q_{Water} (cch)
60	0, 60, 80, 120, 240, 360
90	0, 90, 120, 180, 240, 360
120	0, 120, 180, 240, 360
150	150, 300, 180
180	180, 360
210	210

Table 1: The flow conditions

3. RESULTS AND DISCUSSION

The conversions of H_2O_2 were almost 100% for all flow conditions. Fig. 4 shows the average value of temperatures on the hot side and cold side of two TE modules. Both temperatures increased as the H_2O_2 flow rate increased. However, increase in T_H was much higher than that of T_C. As a result, ΔT_{TEG} increased. Although water was not supplied, heat could be extracted through the heat sinks by natural convection on the outer surface of the heat sinks. Therefore, temperature differences could be obtained; however, the values were lower than those obtained with liquid coolant.

$$P_{max} = V_{OC}^2 / 4R_{INT} \qquad (2)$$

As the H_2O_2 flow rate increased V_{OC} increased. Using V_{OC}, the maximum output power could be predicted using Eq (2). The internal resistance of each TE module is about 7Ω. In the present study, 525 mW of the electric power was obtained. When the flow rate was low, the performance of the system did not increase even though water was supplied. As the flow rate increased, the generated electric power was much higher with water than without water. Fig. 5 is the efficiency and predicted P_{max} using Eq (2) for design condition. The efficiency was defined as the predicted P_{max} divided by the higher heating value of H_2O_2 decomposition. The efficiency was maximized with 180 cch of 90% H_2O_2 solution (0.27%).

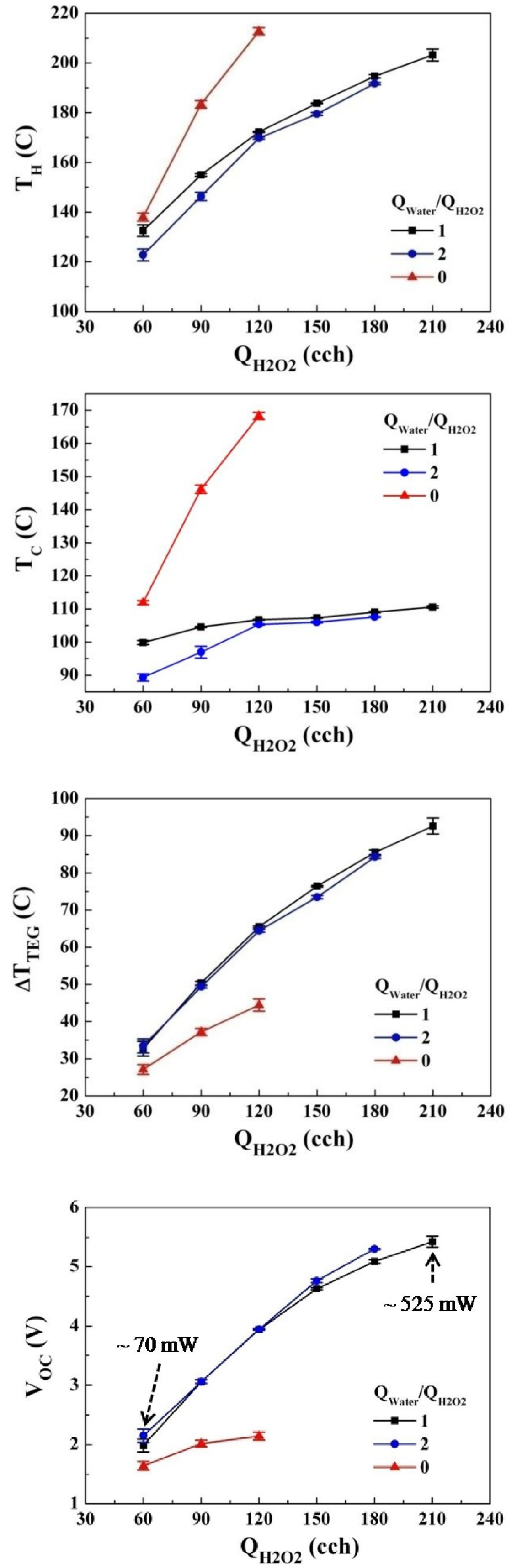

Fig. 4: T_H, T_C, temperature differences across the TE module and the open circuit voltages with respect to the H_2O_2 flow rates

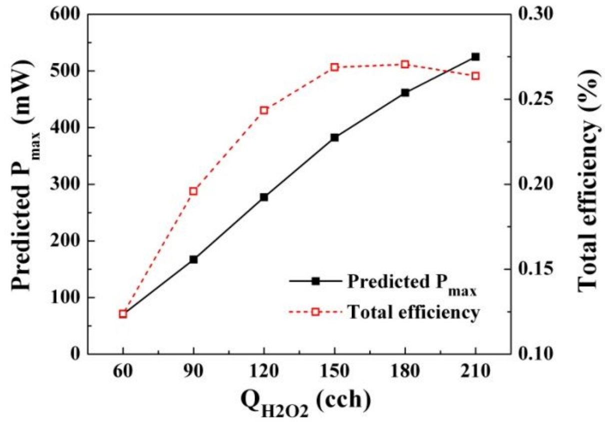

Fig. 5: Predicted P_{max} and total efficiency

The power consuming experiments were carried out with 180 cch of 90% H_2O_2 solution. Fig. 6 shows the variation of the voltage with respect to the time. When the electric load was turned on, current flowed through the closed circuit and voltage decreased. The voltage increased and was recovered to original V_{OC} when the electric load was turned off. Each value shown in Fig. 6 was the current for each condition. The red dashed line indicates the output voltage of mass flow meter and it stands for the O_2 flow rates and the H_2O_2 conversions. Although there was power consumption, the conversion was not changed.

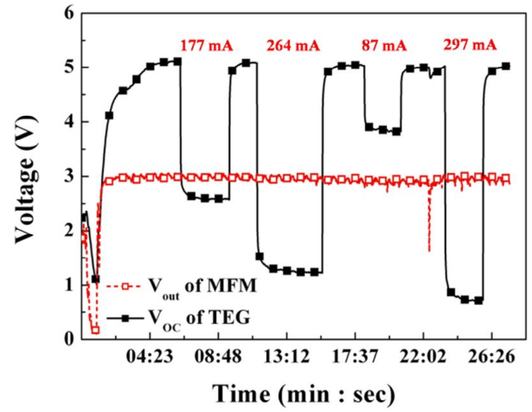

Fig. 6: Predicted P_{max} and total efficiency

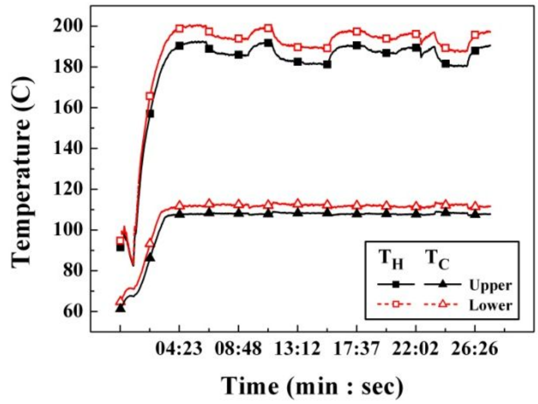

Fig. 7: T_H and T_C with respect to time

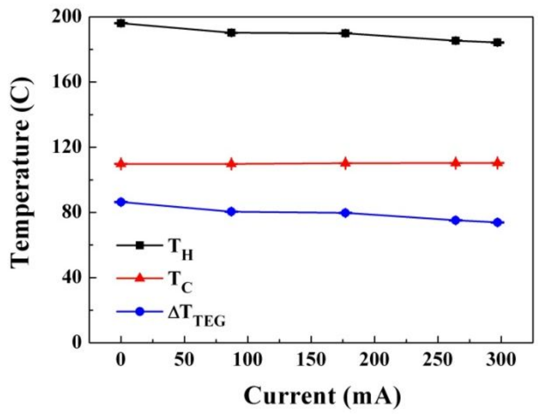

Fig. 8: T_H, T_C and ΔT_{TEG} with respect to the current

The temperature was changed when the current flowed through the circuit (Fig. 7). T_H decreased when the power was consumed; however T_C was not changed. As a result, ΔT_{TEG} decreased. As shown in Fig. 8, T_H and ΔT_{TEG} decreased as the current increased.

If ΔT_{TEG} decreased, V_{OC} also decreased. Therefore, the output power should be lower than predicted value with original V_{OC} for a given current. The lines shown in Fig. 9 are the calculated power curve with different V_{OC} and square symbols are measured data. The measured V_{OC} with 180 cch of 87% H_2O_2 was 5.09 V.

When the current was low, the output power was similar with the predicted value at 5.09 V of V_{OC}. However, when the current was large, the output power was approached to the values predicted using slightly lower V_{OC}. This phenomenon is due to the change in temperature difference when the current are flowed through the closed circuit as shown in Fig. 8. However, the P_{max} was almost same with the predicted value using measured V_{OC}. Therefore, it is reasonable to estimate the efficiency and to predict the P_{max} using the measured V_{OC}.

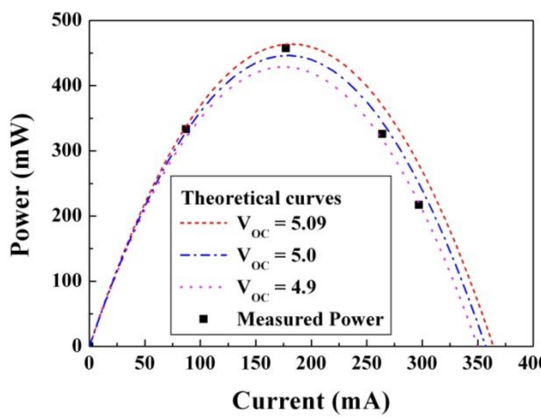

Fig.9: The predicted power curves with different V_{OC} and the measured output power with respect to the current

4. CONCLUSION

Thermoelectric power generation system with H_2O_2 catalytic decomposition was designed and fabricated. Temperature difference across the thermoelectric module was maintained by attaching heat sink on the cold side of thermoelectric modules and supply water. The compact power generation system was realized by the concept proposed in the present study. The volume of total system was 27 cm^3 and the system generated ~ 500 mW of electric power with 0.27% of total efficiency.

The temperatures between each component were measured in the experiments. Decrease in temperature on the hot side of thermoelectric module was observed when the generated power was consumed by an electronic device. Otherwise, temperature on the cold side was not changed.

ACKNOWLEDGEMENT

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