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A study on the operation method of high-temperature solid oxide electrolysis(SOEC) using nuclear power and waste heat

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1. Introduction

The abundant use of fossil fuels within the current global energy system accounts for about 70% of CO2 emissions, which contribute significantly to global warming and climate change. The Intergovernmental Panel on Climate Change (IPCC) recommends reducing CO2 emissions to zero by 2050. High-temperature SOEC is a promising device to convert H2O to H2 through electrolysis using renewable electricity. In addition, high-temperature SOEC is a system that requires not only electrical energy but also thermal energy. By utilizing the cheap electricity and waste heat generated by nuclear power plants, the cost of producing carbon-free hydrogen can be significantly reduced. In this study, the characteristics of high temperature SOEC according to the use of nuclear waste heat were analyzed.

2. Results

The state of the heat source supplied to high-temperature SOEC is a very important factor determining the operating conditions of high-temperature SOEC. The heat source supply method can be divided into a method of supplying water vapor generated in the Rankine cycle to some water electrolysis and a method of supplying heat generated by electric power. As a method of supplying water vapor in the Rankine cycle, there is a method of supplying water from the front or rear end of the turbine (Fig. 1). Supplying steam to high-temperature water electrolysis reduces the amount of nuclear power generation. Therefore, in order to design an appropriate heat source supply method, an understanding of thermodynamics is required.

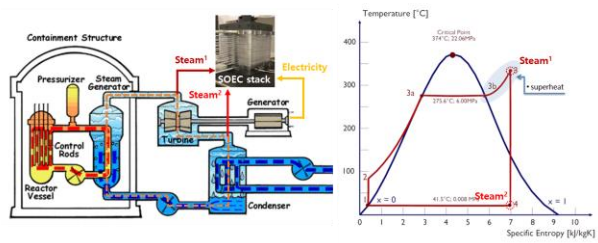
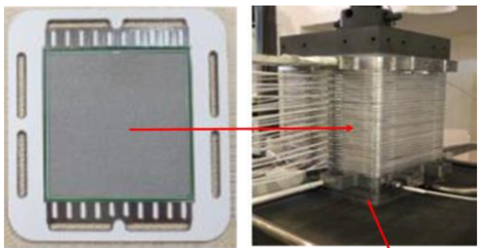


Fig. 1 Schematic diagram of the concept of high-temperature water electrolysis associated with nuclear power generation [1,2].

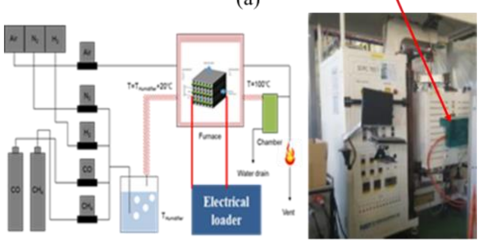
2.1 Solid oxide electrolysis electrochemical characteristics

In high-temperature SOEC, two-dimensional flat cells are stacked to form a stack, and the stack capacity is determined by controlling the cell area, number of stack layers, and operating current (Fig. 2 a). In this study, electrochemical performance evaluation was conducted with manufacturing a stack with a reaction area of 10x10 cm2 and 40 layers. The high-temperature electrochemical performance evaluation equipment consists of an electric furnace capable of controlling the stack temperature, a flow system capable of controlling the flow rates of water vapor and air, and a power supply capable of supplying power and measuring stack voltage (Fig. 2 b).

In high-temperature SOEC, the endothermic and exothermic characteristics are determined by the reaction current and voltage. Endotherm is caused by a reversible process of an electrochemical reaction and exotherm is caused by an irreversible process (Fig. 3 a). The voltage at which the sum of endothermic and exothermic is zero is called thermo-neutral voltage (Fig. 3b). The stack tested in this study satisfies the thermo-neutral condition at about 80A(0.8A/cm^2).

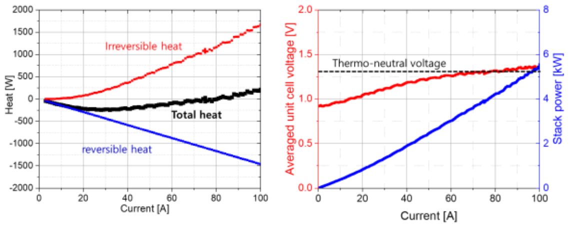


(a)



(b)

Fig. 2 (a) High-temperature SOEC stack manufacturing, (b) high-temperature electrochemical evaluation equipment.



(a) (b)

Fig. 3 (a) High-temperature SOEC endothermic and exothermic characteristics, (b) High-temperature SOEC electrochemical performance curve

2.2 Thermodynamic analysis and hydrogen productions

A high-temperature SOEC thermodynamic analysis was performed using waste heat from a 1.4 GW nuclear power plant. The turbine inlet pressure for the Rankine cycle was assumed to be 50 bar and saturated steam. The turbine was assumed to be an isentropic process and an outlet pressure of 0.06 bar. Case 1 is a case where saturated steam is applied to high-temperature water electrolysis at the front end of the turbine. At this time, it was assumed that the high-pressure steam was adiabatically expanded to 1.5 bar and supplied at 160 ℃. In case 1, the heat supplied to the turbine was lost, so about 106.6 MW of power was not generated. Case 2 is a case in which water vapor is supplied from the rear end of the turbine. It was assumed that the pressure was increased to 1.5 bar using an isentropic compressor. The power consumed by the compressor is about 40.1 MW. Case 3 assumes that the high-temperature SOEC is operated using only electricity without using waste heat.

As a result, Case 1 had the highest system electrical efficiency, but Case 2 had the highest total hydrogen production. This is because Case 2 consumes less power. When waste heat is not used at all (Case 3), hydrogen production can be expected to be about 14% less than when waste heat is used (Case 1& Case2). Since the heat demand due to the latent heat of water becoming water vapor is large, it is expected that it will be advantageous to receive heat for electrolysis of water at high temperature.

Table I: Parametric study of thermodynamic analysis according to thermal input

	Steam temperature [℃]	Vapor quality [-]	Operating voltage [V]
Case 1	160	1	1.285
Case 2	111	0.22	1.297
Case 3	n/a	0	1.541

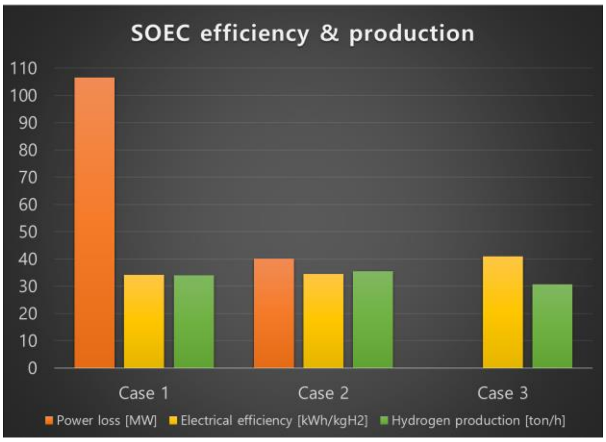


Fig. 4. The characteristics of high temperature SOEC according to the use of nuclear waste heat

3. Conclusions

In this study, an appropriate heat source supply method was reviewed through conceptual analysis neglecting heat loss. In the future, we plan to study an appropriate heat source supply method according to the cooling medium of the nuclear reactor. Higher hydrogen production can be expected by using helium as the cooling medium to supply a higher temperature heat source than the stack.

REFERENCES

[1] https://en.wikipedia.org/wiki/Pressurized_water_reactor.
[2] https://www.nuclear-power.com/nuclear-engineering/thermodynamics/thermodynamic-cycles/rankine-cycle-steam-turbine-cycle/