Modeling of Alkali-Metal Thermal to Electric Converter (AMTEC) with Thermoelectric Generator (TEG) Using OpenModelica

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1. Introduction

Alkali-Metal Thermal to Electric Converter (AMTEC) is a static conversion technique that directly converts thermal energy into electricity, and can utilize high-temperature waste heat and other heat sources. It has advantages such as energy conversion, increased energy utilization through electricity and combined heat and power, and the ability to achieve large-scale AMTEC power generation by combining small cells. AMTEC experiments were conducted at KIER [1], and currently, KIER, KAERI, and KERI are jointly researching AMTEC technology. In this study, we make a model to analysis AMTEC with thermoelectric generator (TEG). As connecting thermoelectric generator, It has the advantage of being able to increase efficiency by producing additional electricity through extra cooling, beyond the electricity originally generated in the cell.

The thermoelectric conversion principle of AMTEC is as follows: Sodium inside the AMTEC evaporates in the evaporator and moves to the cell. In the cell, it passes through the solid electrolyte, losing and gaining electrons while undergoing ion exchange. During this process, electricity is generated as it passes through the cell. The electrons that pass through the cell recombine with ions and move to the condenser, Additionally, it is further cooled by a thermoelectric generator to produce electricity. After that, it has a circulation structure where it returns to the evaporator through a wick or EM pump.

This study aims to develop an AMTEC that connect with thermoelectric generator analysis model to calculate temperature distribution and power generation in experiments.

2. Method and Results

For this modeling, Dymola, a 1D analysis program based on OpenModelica, was used. Dymola model of AMTEC consists of STS case, Cell, and TEG, among which Cell and TEG are the electricity-producing parts designed to show the electricity generated according to the flow rate. When sodium inside AMTEC passes through the STS Case, its temperature rises due to the high-temperature sodium. Then, as it passes through the Cell, it generates electricity, and at the TEG, it loses heat and produces additional electricity. This is the model of the process.

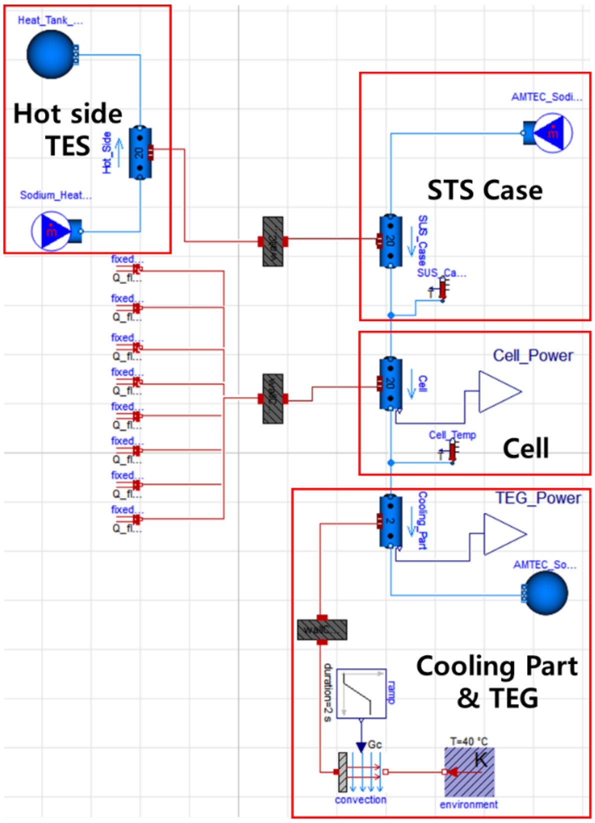

Fig. 1. Dymola model for calculating

AMTEC operates using a total of 100 units, and the evaporator can receive high-temperature energy through the TES (Thermal Energy Storage). In this setup, the sodium flow rate in the TES is set to 0.4 kg/s, while the sodium flow rate inside the AMTEC is 0.0002 kg/s. The electricity output from the Cell follows the following equation:

$$(1)\quad \{P = \frac{\dot{m}_i \times 1.602\times10^{-19}\times1.25}{3.8175\times10^{-26}}\}$$

The output of the TEG follows this equation [2]:

$$(2)\quad \{P_{max} = \frac{(\alpha_p-\alpha_n)^2(T_H-T_C)^2}{4(R_n+R_p+R_{met})},\ R_{met} = \frac{\rho_{met} l}{A_{met}}\}$$

The Cooling part was modeled using a convection model to simulate heat transfer, as it is exposed to air in the actual model. The external air temperature was set at 40 degrees, and the model was designed to lose a significant amount of heat initially, then gradually lose less heat as time progressed.

2.1. STS Case Design

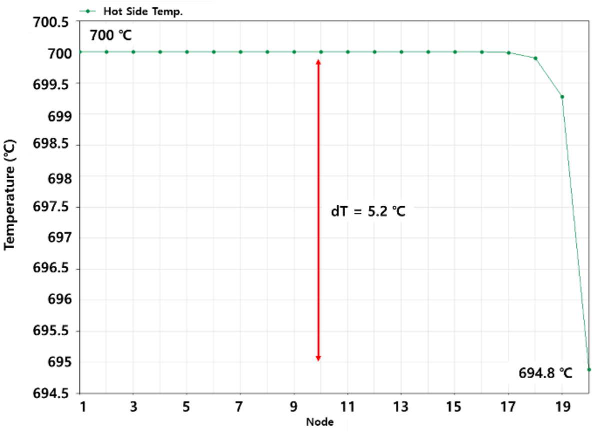

Fig. 3. Temperature graph of Thermal Energy Storage

The STS Case demonstrated that through heat exchange with 700 °C hig h-temperature sodium, the sodium in the high-temperature section dropped from 700 °C to 695.5 °C. Conversely, the internal sodium increased from its starting temperature of 400 °C to 695.5 °C. In the preliminary experiment, the difference was 4 °C, but in this model, it was 5.2 °C, confirming a discrepancy of 1.2 °C.

2.2. Cell and Cooling part Design

To calculate the heat loss when passing through the Cell, heat flow was used to model the heat loss. In fig. 4, the temperature decreased to 582°C while passing through the Cell. The temperature value was found to differ by approximately 2 °C from the cell temperature measured in the preliminary experiment. It shows that was found that approximately 1 kW of electricity was generated, based on an equation related to the mass flow rate. The Cooling part is the area where gaseous sodium condenses, modeled to decrease in temperature through convective heat transfer. In fig .5, The external wall temperature of the thermoelectric generator and the internal sodium temperature are shown, and the dT value of these two temperatures was inserted into equation (2) to display the electrical output. Through the convection model, it was confirmed that the temperature decreased from 580°C to 160°C, and approximately 56W of electricity was produced. This represents an efficiency of 6% compared to the AMTEC power generation.

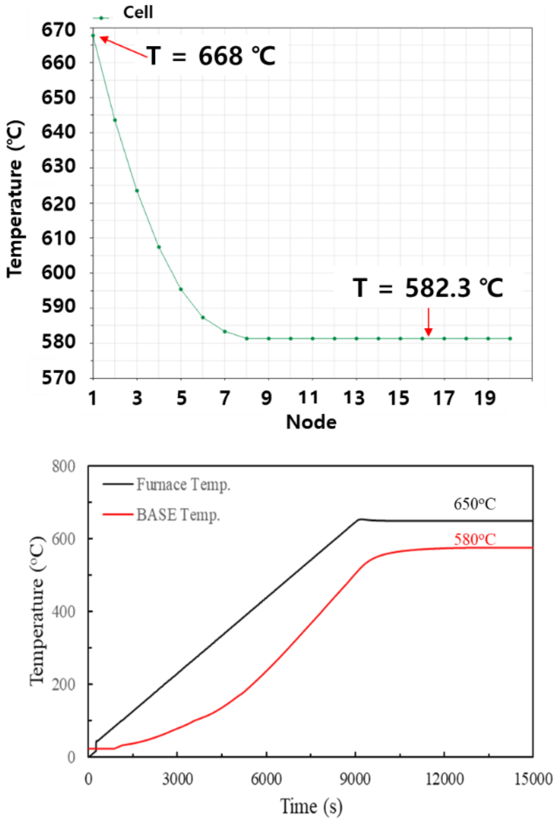

Fig. 4. Temperature graph of cell and experiment data

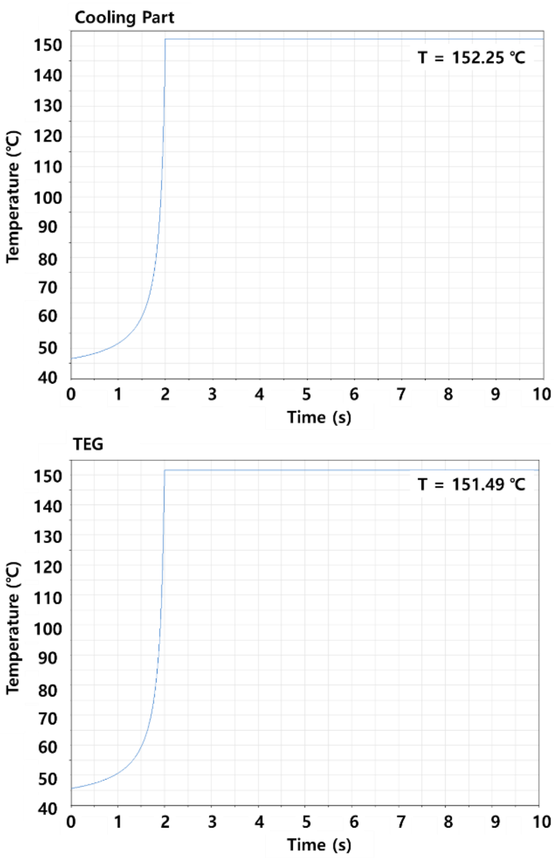

Fig. 5. Temperature graph of cooling part

3. Conclusion

Through analysis using the Dymola model, we were able to confirm that the sodium inside Amtec exchanges heat with the high-temperature sodium in the TES, and we could see that about 1kW of electricity is produced as it passes through the Cell. Additionally, we found that as the sodium temperature decreases in the Cooling part, additional electricity is generated, and the Cell can achieve an efficiency of about 5%.

In the future, we can improve the model by it with experimental results, and we expect to find ways to increase electricity production efficiency through additional analysis.

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