Experimental validation of key components in the Helium Cooling System for fusion reactors

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1. Introduction

The breeding blanket system for tritium proliferation in nuclear fusion reactors plays an essential role in maintaining a stable fuel supply. For this purpose, the helium cooling system (HCS) creates a high temperature environment of more than 500°C and effectively removes the heat generated by the blanket and transfers it to the heat sink [1]. In addition, the helium cooling system must operate reliably under various operating scenarios during plasma operation and maintenance. To this end, the HCS consists of a complex system that includes a helium circulator, economizer, water cooler, and control valves.

The objective of this study is to experimentally evaluate the performance of the main components of the HCS and analyze the optimization possibilities depending on the operating conditions. For this purpose, the performance verification of the helium circulator and heat exchanger was performed using the HeSS built at the Korea Atomic Energy Research Institute (KAERI) as shown in Fig. 1, and the pressure drop and temperature change characteristics were experimentally analyzed [2].

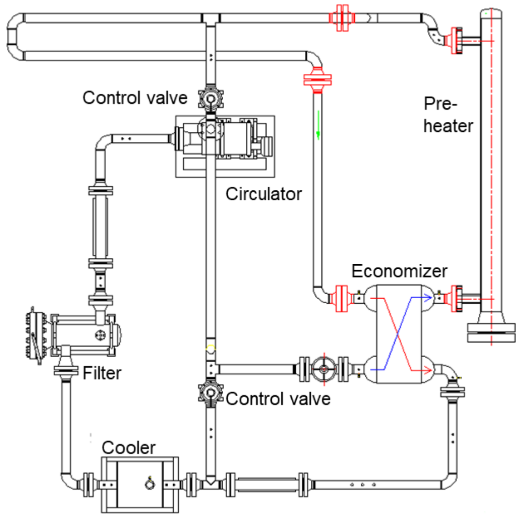

Fig. 1. Detailed diagram and apparatus of HeSS

2. Test facility and methods

The HeSS is a test device built at KAERI to verify the performance of the main components of the HCS and experimentally evaluate the operation scenarios. The HeSS consists of a helium circulator, PCHE economizer and water cooler, and various control valves, and the experiments allow the individual performance of each element and the operating characteristics of the system as a whole to be analyzed.

In this study, HeSS was utilized to perform the following experiments. First, to evaluate the helium circulator performance, the compression ratio and circulating flow characteristics of the helium circulator were analyzed, and the vibration and stability during operation were evaluated. Second, the heat exchanger performance was verified by analyzing the pressure drop and thermal efficiency of the PCHE. In addition to these individual performance tests, the upcoming operational scenario tests will analyze temperature and pressure changes under normal and transient conditions as well as the system response to control valve manipulations.

The HeSS experiments were performed under various flow and temperature conditions. The tested helium circulator was designed to maintain a flow rate of 1.5 kg/s under an operating pressure of 8 MPa, with a compression ratio of approximately 1.1. In addition, a newly designed PCHE heat exchanger was applied to minimize the pressure drop inside the system.

For temperature control, an economizer was used to separate the high-temperature (500°C) and low-temperature (50°C) loops, and the temperature at the inlet of the helium circulator was designed to maintain a stable 50°C. During the experiment, the pressure drop, temperature distribution, and heat exchange efficiency were measured to evaluate the performance of each component.

The experimental results showed that the new helium circulator was designed to optimize power efficiency by operating at high RPM and showed high pressure ratio performance under medium pressure conditions. Even during 8 MPa operation, it was found to operate stably without significant vibration. Validation tests under some high-pressure, high-RPM conditions remain and are ongoing. The experimental results of the PCHE heat exchanger confirm that the pressure drop after the new design is very low, below 50 kPa. However, it shows the possibility of optimizing the heat exchanger by reducing its size, and related research is underway.

3. Conclusion

In this study, experimental performance verification of the main components of the HCS in a fusion reactor was performed. It was found that the compression ratio and stability of the newly developed helium circulator were improved, and the pressure drop was reduced and the thermal efficiency was increased by the application of the optimized PCHE heat exchanger. In addition, the operation optimization of the control valve was verified through the operation scenario experiment.

In future research, further experiments and optimization studies will be conducted to improve the long-term operational reliability of the HCS based on the experimental results.

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