Development of an Experimental Apparatus for Performance Verification of Key Components and Scenario Simulations in a Helium Cooling System

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1. Introduction

In a nuclear fusion reactor, the primary function of the Helium Cooling System (HCS) is to sustain a specific high-temperature environment that supports efficient tritium breeding and concurrently transfer the heat generated during this process to a heat sink [1]. The HCS must operate effectively across various scenarios during both plasma operation and maintenance, ensuring system stability under all conditions. It is designed to function over a wide temperature range—from room temperature up to 500°C—under a pressure of 8 MPa. The HCS employs PCHE heat exchangers, filters, heaters, and helium circulators to ensure stable operation in such environments. Additionally, numerous control valves are utilized to meet the varying operational conditions required by different operating scenarios. This study aims to experimentally evaluate the performance of critical HCS components, considering their significant roles.

2. Test facility and methods

The Helium Supply System (HeSS), shown in Fig. 1, established at the Korea Atomic Energy Research Institute, is designed to experimentally verify the performance of key components within the HCS and to execute various operational scenarios [2]. Critical components of this system include the helium circulator, economizer, filter, preheater, water cooler, and control valves used for temperature regulation and bypass flow control. The pressure drop is significant not only in devices using microchannels such as filters and PCHE but also due to the complex structure of the blanket through which the helium flows for cooling. It is essential to validate the performance of the helium circulator to ensure an adequate compression ratio and stable cooling. The helium circulator in HeSS, a domestically developed device, is capable of circulating approximately 1.5 kg/s of helium with a compression ratio of about 1.1 under 8 MPa. The circulator is designed to withstand up to 10 MPa and 200°C. However, to maintain equipment integrity over prolonged operation, the HCS has been designed to keep the inlet temperature at 50°C. For this purpose, a PCHE-type economizer is employed, dividing the HCS into a high-temperature and a low-temperature loop in an 8-shaped configuration. A water cooler is applied upstream of the circulator to cool the helium down to 50°C, and the heat is transferred to a heat sink. Helium enters the HCS at 500°C and is cooled to 50°C before entering the circulator. After passing through the circulator, the helium then re-enters the blanket system at 300°C. The economizer, designed to minimize heat loss, enables significant temperature changes within the HCS.

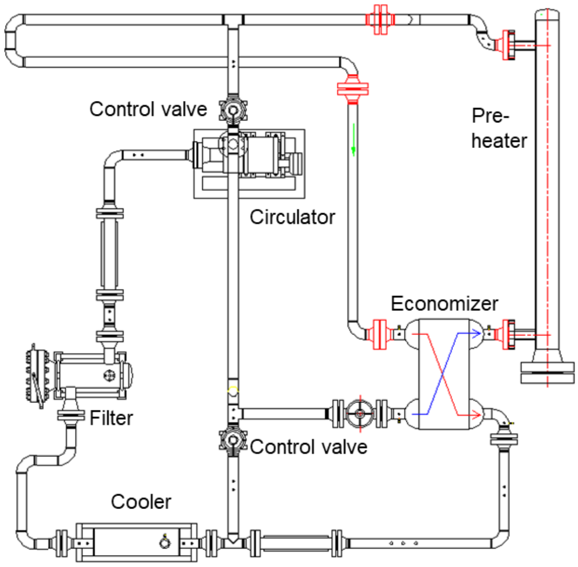

Fig. 1. Detailed diagram of Helium Supply System

The HeSS has been previously established and has conducted various tests. However, due to the aging of the equipment and the need for enhanced specifications of the circulator, the facility underwent an upgrade. The circulator has been modified internally to improve stability by reducing operational vibrations and now operates at higher RPMs, leading to an improved compression ratio. Additionally, the economizer and water cooler have been replaced to reduce the pressure drop occurring inside the heat exchangers. Therefore, the experiments initially focus on verifying the performance of individual devices, such as the circulator and heat exchangers. Subsequently, experiments will proceed to assess operational scenarios and conduct transient tests for the HCS.

3. Conclusions

The development of the Helium Cooling System (HCS), a crucial ancillary system for the breeding blanket, has involved performance validation of key components and scenario-based operations through the HeSS. Upgrades to the HeSS facility have been implemented, including the introduction of a newly developed circulator and heat exchangers. This reconstruction process is nearing completion. Through the planned experiments, we anticipate enhancing the reliability of the HCS design and optimizing the operating conditions for each component through detailed evaluations.

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