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Tritium measurement techniques for a metal tritide bed in hydrogen isotope storage and delivery system

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1. Introduction

Nuclear fusion is one of the major alternative energy sources for future society. For this reason, many basic researches have been conducted over half a century, and now seven countries including Korea are carrying out the International Thermo-nuclear Experimental Reactor (ITER) project to evaluate scientific-technological-economic feasibility and effectiveness [1, 2].

The hydrogen isotope storage and delivery system (SDS), which is one of Korea's procurement packages, must have the function to deliver fusion fuel up to 200 $Pa \cdot m^3 \cdot s^{-1}$ depending on the ITER operating scenario, which changes from time to time. In addition, it should be possible to measure the amount of tritium with an error of ± 3% for 8 to 12 h. Therefore, tritium accounting technologies have been continuously studied and developed for an SDS bed [3, 4].

The pressure, volume, temperature, and concentration method (PVT-c) is a standard tritium accounting procedure. It requires tritium in a gaseous form. It is necessary to heat the SDS bed to keep the tritium in a gaseous form. The tritium release and penetration probabilities might increase if the tritium is kept in a gaseous form. Therefore, tritium accounting technologies without any heating processes have been recommended. Calorimetry, used in the measurement of chemical energy, nuclear half-life, and nuclear material, is one of these techniques. It has been applied to some tritium facilities, providing robust and reasonable results. However, it is difficult to apply typical calorimetry into the SDS bed for ITER because the technique requires an additional SDS bed attaching/detaching system and a thermal measurement facility with large thermal insulation [5].

In this paper, as the tritium measurement techniques without any heating processes, static calorimetry, flowing gas calorimetry, and a radiation measurement were introduced and evaluated to employ into the SDS bed. In addition, our progress on tritium accountability and thermal-hydraulic code application into the SDS is presented.

2. Static calorimetry

The Los Alamos National Laboratory (LANL) has been developing a self-assaying tritium accountability and containment unit for ITER (STACI) to measure the amount of tritium stored in the SDS bed without any attachment or detachment of the SDS bed or any manipulation. Applying a static calorimetry technique into the SDS bed, they obtained a tritium quantity versus temperature curve [6]. The curve makes it possible to obtain the amount of tritium stored in the SDS bed through simple temperature measurements of the bed.

To obtain this curve, we also designed and fabricated our SDS bed using various sensors located at strategic positions. The SDS bed contains approximately 1.9 kg of depleted uranium. A simulation heater is employed for decay heat.

Figs. 1 and 2 show a performance test rig including STACI and a tritium quantity versus temperature curve, respectively [6]. Figs. 3 and 4 show the outer shape of our SDS bed and temperature change of the SDS bed by the heat producing source (approximately 22.5 W), respectively [7].

Fig. 1. Self-assaying tritium accountability and containment unit for ITER (STACI) [6].

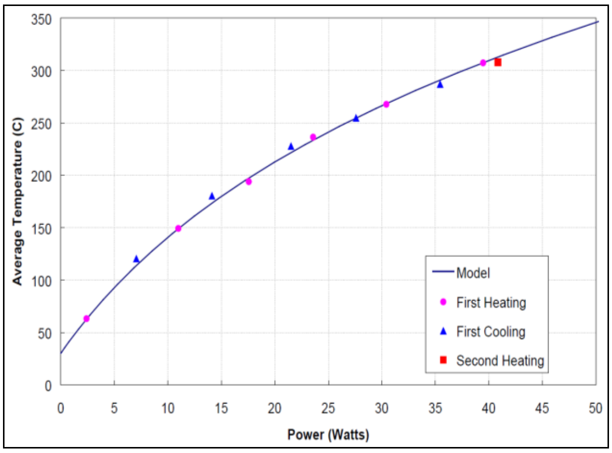

Fig. 2. Tritium quantity versus temperature curve of STACI [6].

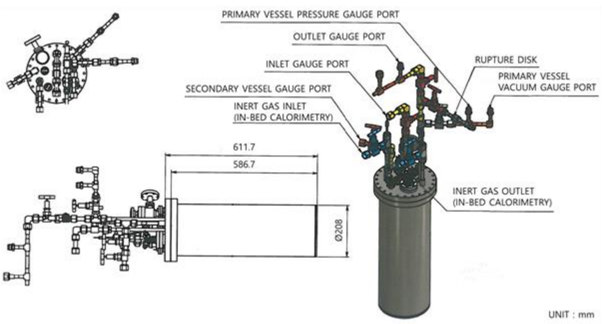

Fig. 3. Outer shape of our SDS bed [7].

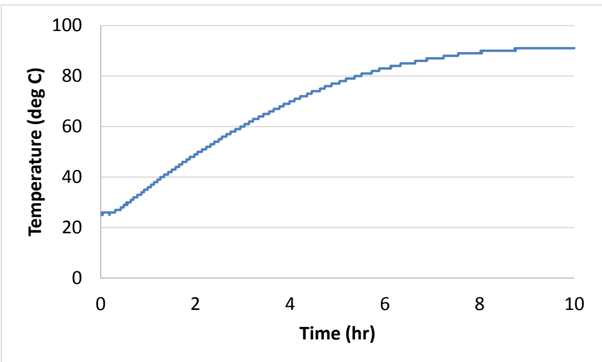

Fig. 4. Temperature change of the SDS bed by heat producing source (approximately 22.5 W).

3. Flowing gas calorimetry

The Savanna River Site (SRS) proposed static and flowing gas calorimetry techniques, which are capable of measuring tritium in real-time without a SDS bed attaching/detaching system. However, we applied the flowing gas calorimetry technique to our system because the results from the static gas calorimetry vary with the number of absorption/desorption cycles of the metal hydride and the gas composition in the metal hydride bed [8].

Fig. 5 shows a schematic diagram of a flowing gas calorimeter proposed by H. Chung et al. [9]. The flowing gas calorimetry loops consist largely of a SDS bed, circulation pumps, flow controllers, chillers, heaters, buffer tanks, pressure gauges, TCs, and RTDs. Fig. 6 shows a flowing gas calorimetry based on a schematic diagram proposed by H. Chung et al [5, 9]. Fig. 7 is a Human Machine Interface (HMI) of the SDS bed containing flowing gas calorimetry [5]. At present, the results of temperature and pressure sensors can be confirmed and stored in real time through a computer, and includes the control function of the heater to simulate the decay heat. In addition, the flow rate can be controlled using a mass flow controller. Fig. 8 shows a heater control system in HMI, and the results of simulation test of the heater operation [10].

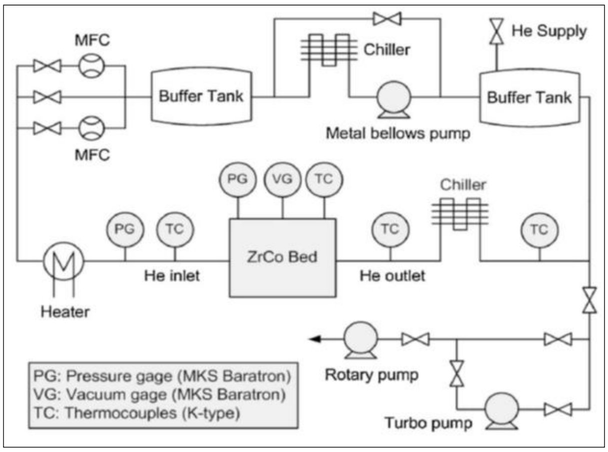

Fig. 5. Schematic diagram of flowing gas calorimetry [9].

Fig. 6. SDS bed performance test rig with flowing gas calorimetry [5].

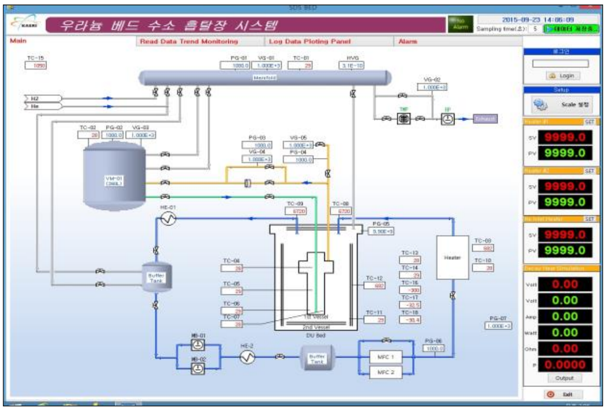

Fig. 7. HMI system for a SDS bed with flowing gas calorimetry [5].

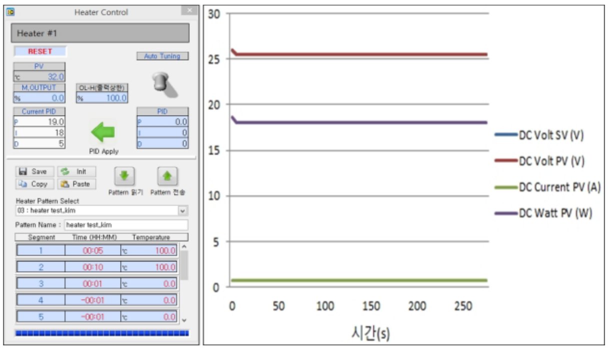

Fig. 8. Heater control system in HMI and simulation results of heater test run [10].

4. Radiation measurement

Beta radiation by tritium can be measured indirectly through electric signals amplified by diverse phenomenon, such as multiplying photoelectrons and an avalanche of electrons, which are used for various radiation counters. A liquid scintillation counter using the ionization of electrons or a proportional counter using electrons exciting by radiation energy can be a good example to understand the principle. In addition, the amount of tritium can be estimated by the measured intensity of beta rays. For now, however, radiation measurement devices cannot be applied directly into our SDS bed, because most of them need a sampling of radioactive nuclides in the form of various phases (gas, liquid, and solid), and the physicochemical conditions inside the SDS bed are quite harsh to use them. For this reason, we studied the development of a new electric amplifying device that can be employed into our SDS bed.

5. Thermal-hydraulic code application

A multi-dimensional analysis of a reactor system and safety code (MARS) has been selected to simulate the flowing gas calorimetry applied into the SDS bed. MARS can be used for any type of realistic multi-dimensional thermal-hydraulic system analyses under steady-state and transient conditions. It is a versatile, robust, and useful system analysis code based on multi-dimensional for a single-phase and two-phase model [11].

The entire system is mainly composed of an SDS bed, measurement tank, and flowing gas calorimetry, was set to a single-phase model because the fluid used in the system is only gas. Although there are various measurement parameters such as a pressure drop, void fraction, and mean accumulator tank wall metal temperature, the temperature, pressure, enthalpy and mass flow rate for gas were selectively presented. The characteristics of heat exchangers can be determined by measuring the temperatures and pressures. The heat exchangers were assumed as a horizontal and core heater. The heat exchange inside the SDS bed for the flowing gas calorimetry was assumed as a helical type core heater. The temperature difference of the inlet and outlet in the heat exchanger can confirm the heat exchanger characteristics and system performance. The heat transfer rate of the helical type in the SDS bed will be used to compare MARS-KS with the experiment results. The initial pressures of the system in MARS were set the same as in the experiment. The core heater power varied over time. The porous media was considered a long narrow pipe. The MARS code shows good agreement with the experiment results. Fig. 9 shows a MARS program execution screen while solving an example problem.

Fig. 9. MARS program execution screen while solving an example problem.

6. Conclusions

We designed and fabricated an SDS bed to measure the amount of tritium using two calorimetry techniques. The tritium accountability tests are progressing. The calorimetry techniques are thought to be useful and give a reasonable value based on our test results. However, we are still looking for a new and better method that can be employed into our system and account for tritium more quickly and safely. One of the alternative methods considered is radiation measurements. Until now, however, we were unable to find a good radiation measurement method because the physicochemical conditions inside the SDS bed are quite harsh and most of the radiation measurement devices need a sampling of radioactive nuclides in the form of various phases. Application of a thermal-hydraulic code to a nuclear fusion reactor has been attempted. The first step will be its application to our SDS including the SDS beds.

ACKNOWLEDGMENTS

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