Status of R&D Activities on the ITER Tritium Storage and Delivery System

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Abstract. Korea is supposed to design, fabricate, deliver and install the ITER tritium storage and delivery system (SDS). For the successful procurement some major technologies have to be verified in the detailed design stage. Currently, have been invested the characteristics of several ZrCo storage materials, improvements of the getter beds to increase hydrogen delivery and recovery rates through small scale mock-up test of the beds, the fabricability of the bed designed considering the economical perspective, the performance verification for operation processes of the SDS using experimental apparatus and SDS bed simulator. The on-going R&D results are introduced in this paper. No difference was observed on the rates of hydriding and dehydriding for two bead and sponge type ZrCo samples. The hydrogen retention rates were measured using 1/10 scale bed and found to be dependent of the pressure of ZrCo hydride. The attachment methods of filters, heaters and flange to the primary and secondary vessels of the full scale bed were developed to minimize the cost satisfying the design requirements. Also, to determine the optimal thickness and to prove the robustness of the vessels structural and buckling analyses were performed. The in-bed calorimetry performance of the bed was investigated by using three dimensional thermo-hydraulic model. It was found that the volume of primary vessel and the cooling scheme are key parameters for high performing in-bed calorimetry. Prepared is an experimental apparatus capable of verifying the performance of several unit processes such as delivery and recovery, He-3 collection, in-bed calorimetry, etc. In order to simulate the various bed operation scenarios under normal and accident conditions a bed simulator has been developed. The pressure as a function of time was simulated perfectly and the tuning of mass flow rates are on-going.

1. Introduction

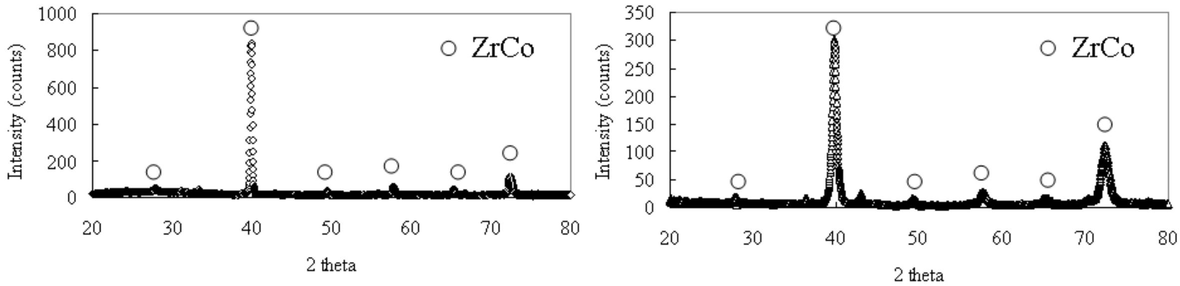
ITER is designed to operate at a nominal fusion power of 500 MW using deuterium and tritium as fuels delivered from a tritium plant. The tritium storage and delivery system (SDS) is one of the major components of the tritium plant. The SDS is designed to store and deliver the tritium and deuterium inventories in the ITER tritium plant. The system comprises several metal-hydride getter beds capable of in-bed calorimetry, a PVT-c loop for an accurate measurement of tritium inventory, a ^{3}He recovery system and other equipments for satisfying ITER fueling requirements. The long-term storage system (LTS) is included in the scope of the SDS. The LTS has several special glove boxes for unpacking the primary shipping containers of tritium, for accurately measuring the tritium inventory, for off-loading T_2 gas from the shipping containers to the SDS, and for packing solid waste [1].

For ITER construction, Korea Domestic Agency (KO-DA) will deliver tritium storage and delivery system. The system is currently in the detailed design stage for its procurement. This includes finalizing system composition and layout, completing detailed design of the metal-hydride getter bed, and the performance verification for the process design. To satisfy the rapid delivery and recovery target value of the ITER, several beds are designed and their performances are investigated [2, 3]. The verification of design-determining parameters is found to be important for optimal design of the bed. In this study some of these parameters are investigated through three dimensional (3D) thermal and structural analyses and small mock-up test of the beds. Also, since the operation procedures of the SDS proposed in Ref. [1, 4] have to be verified whether to satisfy the ITER fueling requirements, experimental apparatus for verifying the performance of unit processes is designed with SDS bed simulator developed for simulating various bed operation scenarios. The on-going R&D activities on the SDS are presented in this paper.

2. Design and Experiments of the SDS Bed

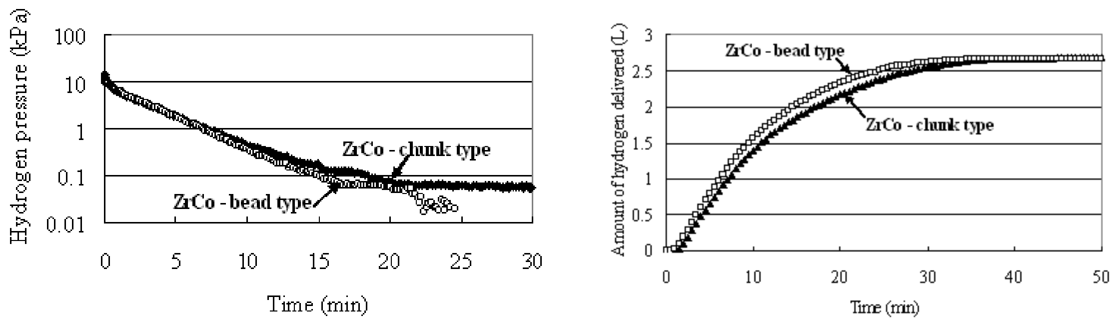
2.1. Investigation of the Characteristics of ZrCo

Two types of commercially available ZrCo were tested. The first is a bead type ZrCo, a particle size of 110 ~ 2214 μm (medium size : 778 μm) and apparent density of 4.6 g/cm^3. The second is a chunk type ZrCo, a larger particle size of 135 ~ 6655 μm (medium size : 2677 μm) and apparent density of 3.13 g/cm^3. Figure 1 shows no impurity peaks except for ZrCo peaks in the X-ray diffraction measurement. After powderization of the two ZrCo samples by several hydridings and dehydridings, rates of hydriding and dehydriding were measured. Figure 2(a) shows that the hydriding rates of the two ZrCo samples to form ZrCo hydride ($ZrCoH_{1.8}$) are almost the same. Figure 2(b) shows the amount of supplied hydrogen during preheating at about 250 °C and a delivery at 250 ~ 330 °C. Dehydriding rates of the two ZrCo samples were also almost the same. From these measurements, it was found that the performance of the two commercial ZrCo samples is almost the same.



(a) ZrCo – Bead Type *(b) ZrCo – Chunk Type*

FIG. 1. Results of the X-ray diffraction analysis of the two ZrCo samples

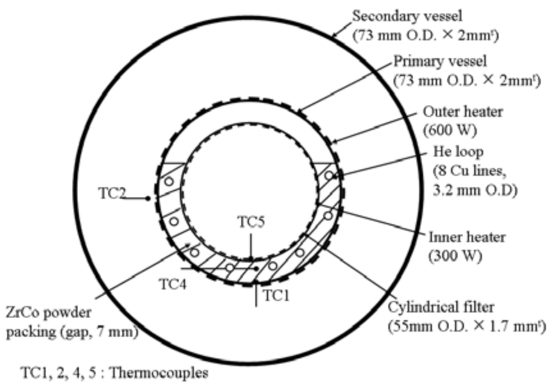


(a) hydriding behavior *(b) dehydriding behavior*

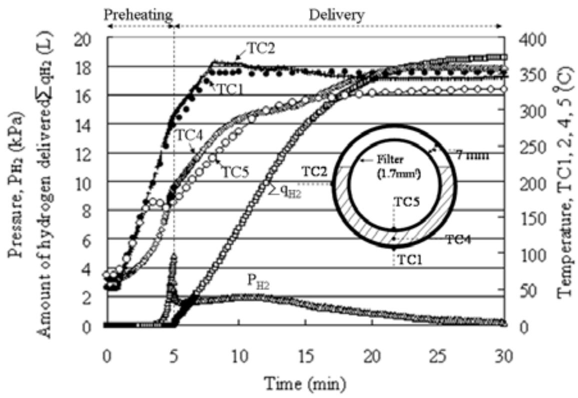
FIG. 2. Comparison of the hydriding and delivery behavior of the two ZrCo samples

2.2. Small Mockup Test of the Bed

For the development of an SDS bed with the performance of rapid recovery and delivery, we have estimated the design factors of a ZrCo bed [5-7]. Using a 1/10 scale ZrCo bed containing 127 g of ZrCo between the filter cylinder and the primary vessel, the performance of recovery and delivery were tested. Two heaters were attached to the outer surface of the primary vessel and to the inside surface of the filter cylinder as shown in Figure 3(a). This bed has a 7 mm ZrCo layer, a large filter surface area of 0.81cm^2/g-ZrCo and a large heating area of 1.83cm^2/g-ZrCo. During recovery, 99% of the hydrogen was absorbed in 8.8 min and the temperature of the ZrCo hydride was increased to about 270℃. Figure 3(b) shows the amount of supplied hydrogen, the pressure of the ZrCo hydride and the temperature of the bed during preheating and delivery. About 90% of the hydrogen was supplied in 17.6 min. During delivery, the peak value of hydrogen pressure of the ZrCo hydride was measured to be 2 kPa. Therefore we achieved rapid recovery and delivery in a ZrCo bed with a thin ZrCo layer, a large heating area and a larger filter surface area.



(a) Structure of the ZrCo bed

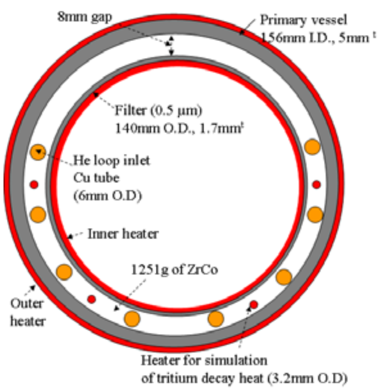


(b) Performance of the ZrCo bed

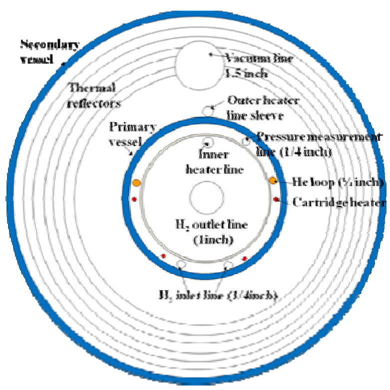
FIG. 3. Modeling and results of the 1/10 scale ZrCo bed

2.3. Design of a Full Scale SDS Bed

Based on these experimental results, a ZrCo bed for storing 70 g of tritium as $ZrCoT_{2.8}$ was designed as shown in Figure 4. About 1.25 kg of ZrCo powder (particle size < ~1 mm) was inserted in the interval of 8 mm between the primary vessel and the filter cylinder with a 8 mm ZrCo powder layer and a filter cylinder area of 1.12 cm^2/g-ZrCo. Helium loop with eight copper tube lines was installed between the primary vessel and the filter cylinder. The helium loop and ZrCo hydride have a contacting area of 0.38 cm^2/g-ZrCo. Four cable heaters were installed in the groove of the outer surface of the primary vessel and in the groove of the six supporters on the inner surface of the filter cylinder; two heaters for operation and the other two for a redundancy purpose. In order to maximize heat transfer from the heaters to the ZrCo hydride, copper fins with about 1.5 mm thickness were installed at an interval of 5 mm between the heaters and the filter cylinder.



(a) Primary vessel of the ZrCo Bed



(b) Secondary vessel of the ZrCo bed

FIG. 4. Radial cross-section view of the 1:1 ZrCo bed

Two hydrogen inlet filter tubes were installed in the ZrCo layer between the primary vessel and the filter cylinder, and a hydrogen outlet tube was installed inside the filter cylinder for a hydrogen flow path from the hydrogen inlet tubes to the hydrogen outlet tube through the ZrCo layer during He-3 recovery operation in the ITER SDS system. The size of the hydrogen outlet pipe was designed to have about 20 mm I.D. in order to minimize the gas conductance effect through the hydrogen outlet pipe so that disproportionation rate can be decreased by lowering pressure of ZrCo hydride during delivery. Hermetic seals were used for the thermocouples and heaters of the bed in order to prevent tritium permeation from the bed to the glove box. This bed is under fabrication and the performance of its recovery, delivery and in-bed calorimetry will be tested.

2.4. Design Study and 3D Thermo-hydraulic Analysis of In-bed Calorimetry

Another design concept of a full scale SDS bed has been proposed. It consists of the primary vessel and the secondary vessel which is a tritium confinement boundary. The primary vessel is a double-walled cylinder containing a thin double layers of annular type metal hydride (ZrCo) and filters. Two heaters are attached to the outer surfaces of the primary vessel. The helium cooling channels are drilled in the primary vessel for in-bed calorimetry measuring the tritium decay heat. Thermal reflectors are located in the vacuum layer formed between the primary and secondary vessels. The secondary vessel measures 585 mm in length and 300 mm in diameter. The configuration of the bed is shown in Figure 5 [8].

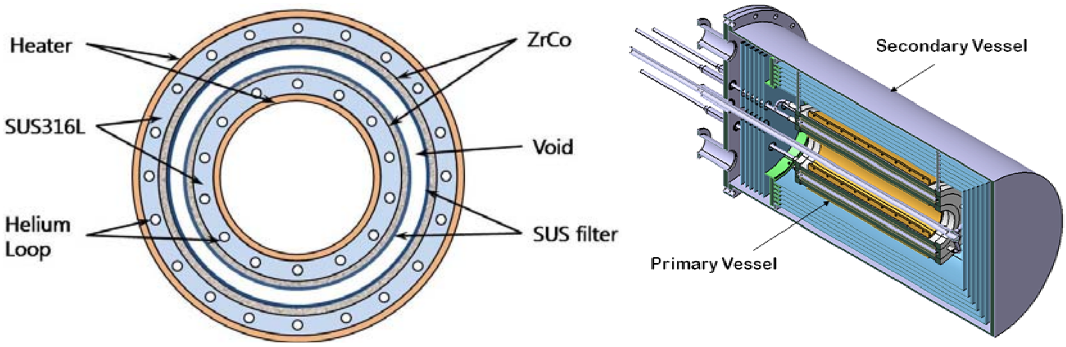
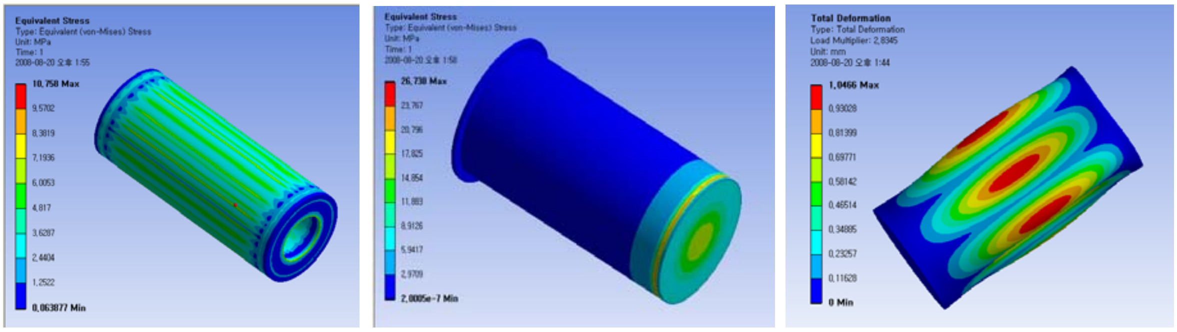


FIG. 5. Cross-section of the primary vessel and overall configuration of the SDS vessel

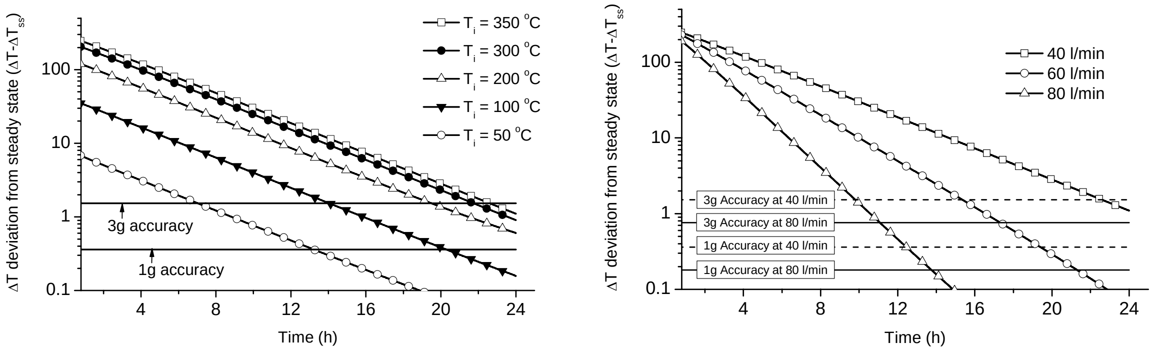
The design pressure of the primary and secondary vessels is 0.5 MPa. The thicknesses of the wall and flanges of the vessels are determined based on the 3D structural analysis using ANSYS [9] considering the fabricability. A conflex type flange was adopted to enhance the leak-tightness of the vessel. The stress analyses results show that the stresses are below than the allowable stress [10] of the vessel structural material as shown in Figure 6. Since a vacuum atmosphere exists inside the secondary vessel during normal operation, a buckling analysis was performed to investigate the robustness of the vessel. The results are also shown in this figure. The load multiplier of the first mode is about 28, which means the secondary vessel is structurally very strong and no reinforced structures are needed.

The in-bed calorimetry performance of the bed is investigated by 3D transient thermo-hydraulic analysis using CFX [9]. The change of temperature distribution of the bed, the temperature difference (ΔT) between the inlet and outlet of the helium flow and the time to reach the steady state ΔT are calculated. The effects of the initial temperature of the primary vessel and the various mass flow rate of helium on the time to steady state are investigated and the results are shown in Figure 7(a). When the bed is pre-cooled down to 50 ^{o}C before the in-bed calorimetry starts, the inserted helium-loop of the bed satisfies the reasonable accountancy [8]. In the case of the initial temperature of 350 °C, which is the most severe operation condition of performing the in-bed calorimetry right after the delivery process, it is estimated that the helium flow rate greater than 80 l/min is required to meet the accountancy as shown in Figure 7(b). The design optimization and the development of pre-cooling scheme are under progress.



(a) (b) (c)

FIG. 6. Stress variation in the primary vessel (a) and secondary vessel (b), buckling analysis result in the secondary vessel (c)



(a) (b)

FIG. 7. Time history of temperature difference between helium inlet and outlet in in-bed calorimetry with tritium inventory of 40 g (a) effect of initial temperature of the primary vessel, with helium mass flow rate of 40 l/min (b) effect of helium mass flow rate, with initial temperature of 350 ℃

3. Preparation of Unit Process Experiments

3.1. Experimental Setup for the Performance Verification of the Process Design of SDS

An experimental apparatus is designed for verifying the performance of unit processes of SDS. Based on new ITER environments, such as new fuelling requirements for plasma operations, site regulations for safety, and new reports for tritium compatible pumps, the process design of SDS should be modified and verified by the experimental activities and updated from FDR 2001.

The experimental apparatus consists of three major parts: gas delivery unit for hydrogen and helium gases, hydrogen storage unit using ZrCo bed, and experimental utility unit using gas cabinets and gas scrubber as shown in Figure 8.

The unit processes to be tested by these experiments are as follows: evacuation of all system, initial gas loading from gas bottles to vessels, delivery of gases using each pump from vessel to vessel, delivery of gases from getter bed simulator to vessel, examination of the procedure for He-3 collection using He-4, circulation of He for the in-bed calorimetry of storage bed, hydrogen storage and supply using hydrogen storage bed, examination of in-bed calorimetry using the heater to simulate tritium storage, and examination of cooling down for storage bed.

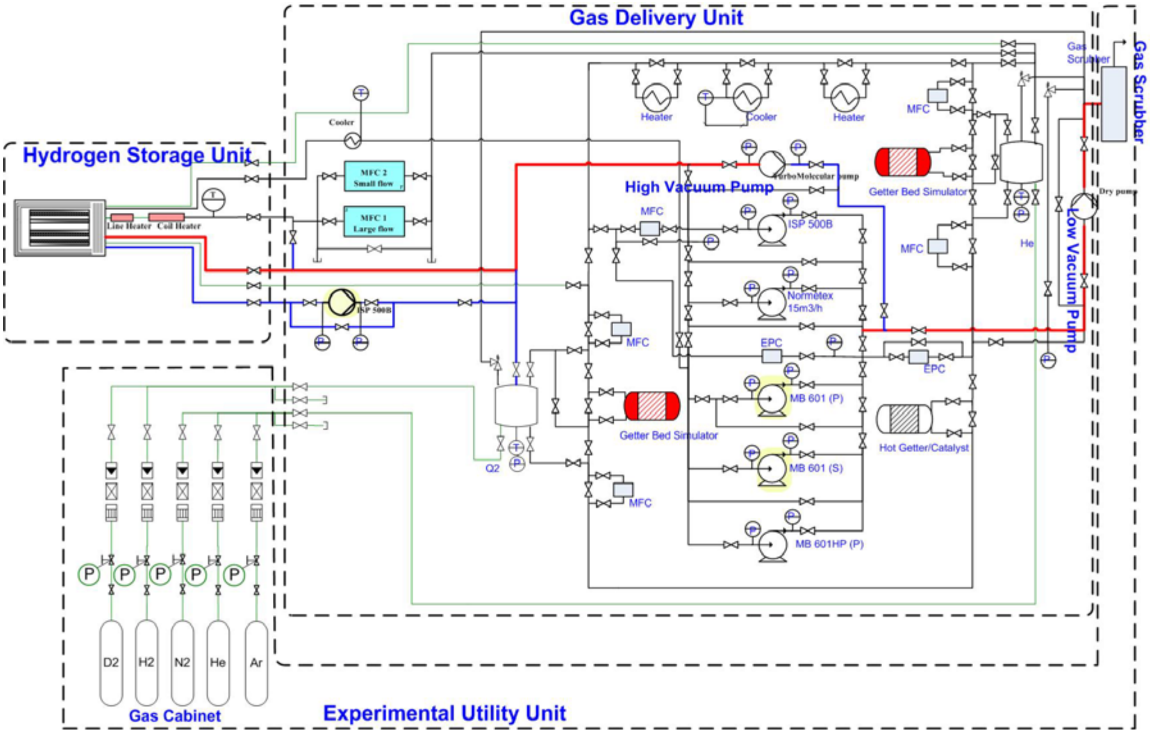
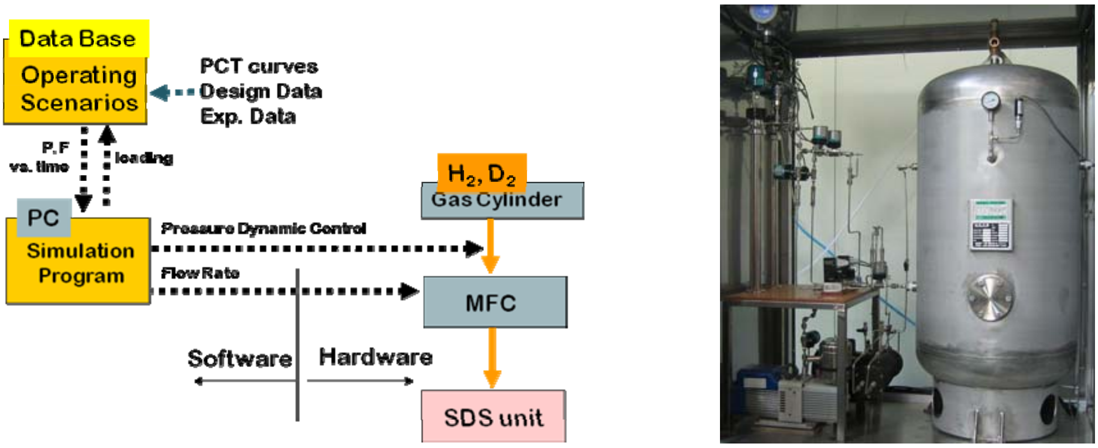


FIG. 8. Experimental apparatus for the verification of unit processes of SDS.

3.2. Development of an SDS Bed Simulator

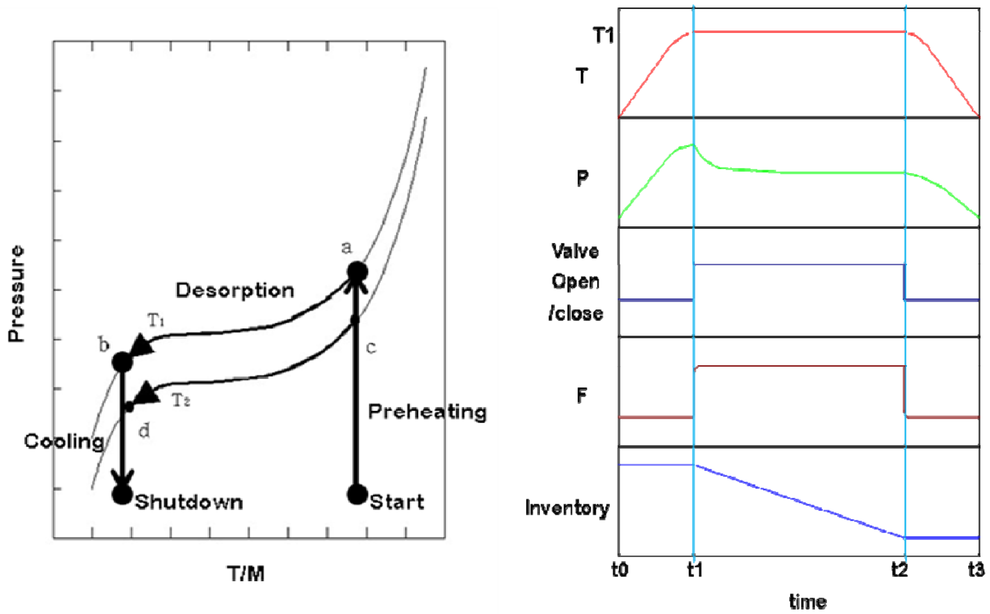
A reference bed was proposed to design and test the SDS process independently of the development of the storage bed. This bed, referred to as an SDS bed simulator, has been developed to simulate the various bed operation scenarios under normal/abnormal conditions [11]. It consists of a hardware part including pressure regulators, mass flow controllers, pumps and a tank, and an operating control part including simulation program and data acquisition system. The real storage bed for the fuel supply and storage is controlled by heating and cooling, however, the SDS simulator is controlled by the numeral values of pressure and flow rate generated by simulation program. Figure 9 shows the concept of the SDS bed simulator.

In order to simulate the delivery of deuterium and tritium from the storage bed to the supply tank, the storage bed is assumed to be operated along the pathway as shown in Figure 10(a), where the desorption pathway of the curve a to b or c to d shows an ideal behavior of constant temperature. The pathway on the PCT isotherm can be converted to the numerical values of control variables as a function of time, which is used for simulating an ideal storage bed. Simulation program generates control signals of pressure and mass flow rates as shown in Figure 10(b) according to a scenario having ideal or abnormal behavior. The tuning test of pressure regulators was completed and some tests based on the experimental data of a real bed obtained by KAERI [3] have been performed lately. It was found that the pressure as a function of time has been simulated perfectly, and the tuning of the mass flow rates is on-going.



(a) Concept of the SDS simulator *(b) Front view of SDS simulator*

FIG. 9. Concept and hardware components of the SDS bed simulator



(a) PCT isotherm and pathway *(b) key variables vs. time on pathway shown in (a)*

FIG. 10. Operating concept of the storage bed simulator on PCT isotherm

4. Conclusions

The on-going R&D activities for the detailed design of the ITER SDS have been addressed. The design of the getter beds to increase hydrogen recovery and delivery rates from ZrCo has been introduced with the experimental investigation of design variables. Also, a process flow diagram of an experimental apparatus for the performance test of the unit processes of the SDS is also introduced.

No big difference was observed on the rates of hydriding and dehydriding for two commercially available bead and sponge type ZrCo materials. Based on the hydrogen retention rate measurements using 1/10 scale bed, it was found that rapid recovery and delivery could be obtained in a ZrCo bed with a thin ZrCo layer, a large heating area and a larger filter surface area.

Two new bed configurations adopting these concepts were designed. The robustness and in-bed calorimetry performance were investigated with the 3D structural and thermo-hydraulic analyses. It was found that the volume of primary vessel and the pre-cooling are key parameters for high performing in-bed calorimetry. An experimental apparatus capable of verifying the performance of several unit processes of SDS is designed. In order to simulate the various bed operation scenarios under normal and accident conditions a bed simulator has been developed. The pressure as a function of time was simulated perfectly and the tuning of the mass flow rates are on-going. The SDS bed simulator will be installed into an experimental apparatus for the demonstration of ITER SDS unit process. A transportable simulator will be developed in order to perform factory acceptance test and site commissioning test ultimately.

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References

[1] ITER Design Description Document DDD 3.2.C, “Storage and Delivery System,” ITER doc. N32 (2001).

[2] Glugla, M., et al., “ITER fuel cycle R&D: Consequences for the design”, Fusion Engineering and Design 81, No. 1/7 (2006) 733-744.

[3] Chung, H.S., et al., “Korea’s progress on the ITER tritium systems”, the 25th Symposium on Fusion Technology, September 15-19, Rostock, Germany, 2008.

[4] Song, K.M., et al., “Development of Standard Operating Procedures for the SDS of the ITER Tritium Plant”, Fusion Eng. Des., in press, 2008.

[5] Shim, M., et al., “Characteristics of ZrCo Alloy for the Storage of Hydrogen Isotopes”, J. Korean Phys. Soc., 49 (2006) 369-373.

[6] Shim, M., et al., “Disproportionation characteristics of a ZrCo Hydride Bed under ITER Operating Conditions”, Fusion Sci. Tech., 53, (2008) 830-840.

[7] Shim, M., et al., “Experimental study on the delivery rate and recovery rate of ZrCo hydride for ITER application”, Fusion Sci. Tech., 54, (2008) 27-30.

[8] Kang, H.G., et al., “Thermo-hydraulic analysis on In-bed Calorimetry in a Thin Double-layered Annulus Metal Hydride Bed”, the 25th Symposium on Fusion Technology, September 15-19, Rostock, Germany, 2008.

[9] ANSYS, Inc., 201 Johnson Road, Houston, PA 15342, USA.

[10] RCC-MR (2007 Edition) – Section 1, Subsection Z : app A3 & A9.

[11] Song, K.M., et al., “Development of tritium storage bed simulator for the design and test of the SDS in ITER tritium plant”, the 25th Symposium on Fusion Technology, September 15-19, Rostock, Germany, 2008.