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Design of a heater for the ITER SDS bed

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1. Introduction

A preliminary design concept of metal hydride beds for the storage and delivery system (SDS) and the long term storage system (LTS) in the ITER was reported by authors [1]. The SDS bed consists of a primary vessel containing ZrCoQx (Q=90T-10D, 50T-50D) and a secondary vessel for protecting and insulating the primary vessel. In the primary vessel, about 3.5kg of ZrCo absorb D-T at room temperature and desorb D-T at 250-350^{o}C. Twenty six nickel fins with a 1mm thickness and 106mm in diameter (2mm less than the inner diameter of the primary vessel) are attached at a 10 mm pitch to increase the heat transfer from the heater to the ZrCoQx. In the secondary vessel, four thermal barriers within the inner wall surround the primary vessel for insulation and an outer wall of the secondary vessel surrounds the inner wall of the secondary vessel with a vacuum layer. To meet ITER plasma experiment requirements, the SDS beds have to supply D-T gas at a delivery of ~ 20Pam^3/s (time average) delivery rate is required in order to supply 50Pam^3/s to the fuel injection system (FIS). The internal design structure of the LTS bed, which stores T_2 and/or 90T10D, is similar to that of SDS bed.

The present study describes design detail of the heater required for the SDS bed and the LTS bed and their heating performance analyzed by using the heating 7.3 program [2].

2. Methods and Results

2.1 Design of heater capacity

Table 1 summarizes the required heat capacity to heat ZrCo hydride such as ZrCo(90T-10D)x packed in the primary vessel of SDS and LTS beds. The endothermic heat of reaction (equations (1) and (2)), was calculated to be 1492.6kJ for delivery of 100g-T (107g 90T10D) [3]. The heat consumption rate at the delivery rate of 20Pam^3/s (for approximately 35 min) was specified to be 719W (=1492.6kJ/2073.9sec). The design power (Table 2) of the SDS and LTS bed heaters, which includes design margin of 50% for operation flexibility, were determined by adding the heat capacity for heating the primary vessel and the heat to compensate the endothermic reactions. In the inner wall of the primary vessel (30.1mm diameter, 290mm length), cartridge type heaters of 3kW or 2kW cartridge are applied to the SDS and LTS beds.

$$ZrCo + 1/2T_2 \rightarrow ZrCoT + 80.495kJ/mol(T_2) \quad (1)$$
$$ZrCo + 1/2D_2 \rightarrow ZrCoD + 81.54KJ/mol(D_2) \quad (2)$$

Table 1. Required heat capacity of the primary vessel of SDS and LTS beds

Materials	Mass (kg)	Specific heat Cp (J/kg/K)	Heat capacity (kJ)
SUS 316	5.025	509	844.05
Ni fins	1.85	518	314.25
ZrCo	3.5	355.3	410.37
Tritium	0.1	14,430	476.19
Total required heat			2044.86kJ
Power to heat the primary vessel from 20^{o}C to 350^{o}C for 30 minutes (SDS bed)			1136W
Power to heat the primary vessel from 20^{o}C to 350^{o}C for 60 minutes (LTS bed)			568W

Table 2. Design power of the SDS and LTS beds heater

	Required power	Design power*1
SDS bed	1855W	2782W (30 min heating)
LTS bed	1287W	1930W (60 min heating)

*1: Design power = Required power × 1.5

2.2 Analysis of the heating capacity for design maximum operating temperature

To evaluate the heater performance of heating the SDS and LTS beds to their maximum operating temperature (=500^{o}C for activation, regeneration and residual tritium minimization), temperature distribution was analyzed as shown in Figures 1 and 2. As the temperature of the heater increases to 500^{o}C in SDS bed, temperature of ZrCo packed in the primary vessel increases to 490-500^{o}C. In LTS bed, the temperature of ZrCo increases to 450-500^{o}C.

2.3 Heat transfer efficiency during delivery from SDS bed and LTS bed

Heater performance of the SDS bed for pre-heating delivery, which was proposed by authors to meet ITER plasma operation requirements [4], was analyzed. Figure 3 shows that the temperature of the ZrCo(90T-10D)x is raised to 240-250^{o}C in 60 min. Figure 4 shows the ZrCo(90T-10D)x temperature is raised to 340-350^{o}C from preheating temperature within 30min.

Meantime, rapid delivery is not required for LTS bed. Figure 2, the radial temperature distribution of the LTS bed, shows that ZrCo(90T-10D)x can be heated up to 340-350C in 2-2.5h for off-loading of DT gas, and the temperature can be further raised to 450-500°C for minimization of residual tritium in the bed.

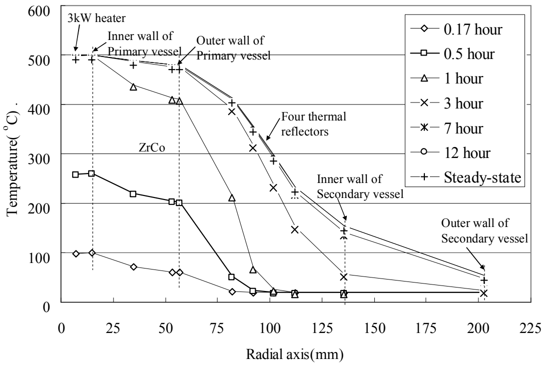

Figure 1. Radial temperature distribution in the SDS bed during activation or regeneration

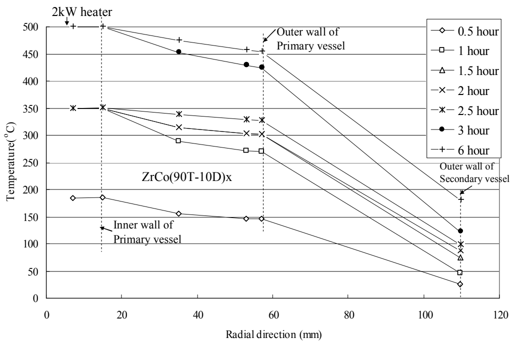

Figure 2. Radial temperature distribution in the LTS bed during a delivery at 350°C and a residual tritium removal at 500°C

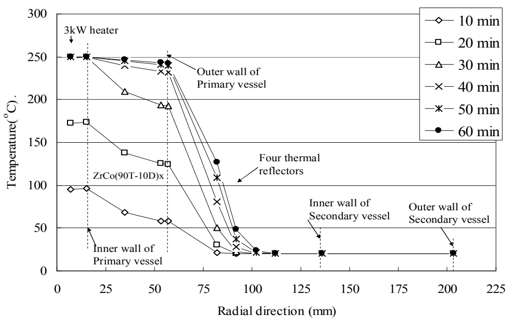

Figure 3. Radial temperature distribution in the SDS bed during a preheating at 250°C

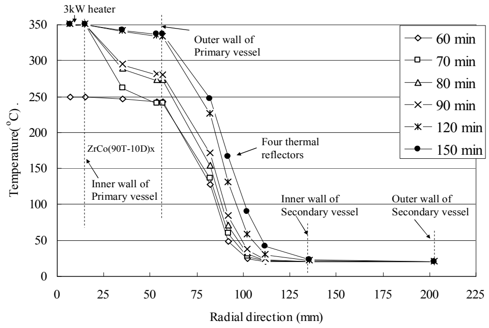

Figure 4. Radial temperature distribution in the SDS bed during a delivery at 350°C

3. Conclusion

A 3kW heater for the SDS bed and a 2kW heater for the LTS bed were designed based on their material heat capacity, endothermic reaction heat of ZrCo hydride and design heating rate for each bed. Heat analysis carried out by using system heating **7.3** program indicated that these heaters satisfy all operating temperatures required for activation and regeneration of ZrCo bed, rapid delivery from the SDS bed during plasma operation, and off-loading of DT from LTS bed.

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