Design of a fast response ZrCo bed

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1. Introduction

For the ITER SDS bed, several ZrCo beds have been developed [1-3]. Required performance of the ITER SDS bed is rapid recovery, rapid delivery of tritium and accurate measurement of the amount of in-bed tritium. From the ZrCo bed developed by T. Hayashi, 90% of hydrogen was supplied in 60 min at 350^{o}C and the amount of tritium was measured at ±1% accuracy within 24 hours [1]. M. Glugla reported that 90% of hydrogen was delivered in 17 min at 400^{o}C, but 30% of the recovery and delivery capacity was lost after 10 times of a hydriding/dehydriding by disproportionation of ZrCo hydride at high temperature at 400^{o}C [2]. Based on the study of two existing ZrCo beds, a new ZrCo bed was designed and fabricated in order to increase the delivery rate and minimize the disproportionation rate [3]. In this study, a more improved ZrCo bed design is presented.

2. Structure of a ZrCo bed

For the development of the ITER SDS bed, 1:1 scale ZrCo bed storing 70 g of tritium as a chemical form of ZrCoT2.8 was designed as shown in Fig. 1. The structure of this bed is almost the same as that of a previous ZrCo bed storing 50 g of tritium except for the following improvements [3]. Two heaters (Watlow cable heater, Outer heater: 5 kW, Inner heater: 5.8 kw) including one spare heater were installed on the outer surface of the primary vessel and the inner surface of the filter cylinder. If one heater fails during 20 years of ITER plasma experiments, the other heater can be used. Two hydrogen inlet filter tubes (3 ㎛, 6 mm O.D. × 320 mm Len.) were installed in the ZrCo layer between the primary vessel and the secondary vessel, and a hydrogen outlet tube (25.4 mm O.D.) inside the filter cylinder. For the He-3 recovery from ITER SDS beds, tritium containing He-3 can be circulated from the hydrogen inlet filter tubes to the hydrogen outlet tube through the ZrCo layer. In, addition, hermetic seals were designed to be installed at the ends of the heaters and thermocouples in order to prevent tritium leakage from the SDS bed to the glovebox.

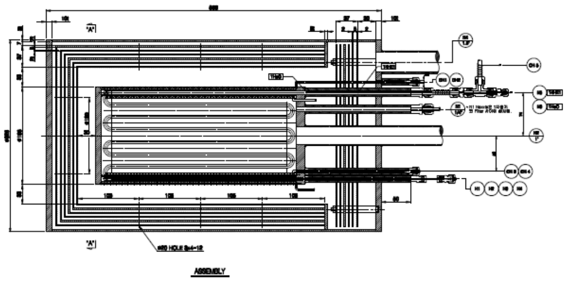

Fig. 1. Horizontal cross-section view of the ZrCo bed

3. Mechanical design of the bed

We carried out a mechanical design for this bed using ASME section VIII Div. 2 code as follows. Design temperature and design pressure of the primary vessel (SS 316) are 575^{o}C and 0.5 MPa and those of the secondary vessel (SS 304) are 100^{o}C and 0.4 MPa, respectively. Minimum thickness of the plates and shells under the design temperature and pressure was calculated using equations (1) and (2). Table 1 shows the minimum thickness and the selected thickness of the shells and plates, and the maximum allowable pressure under the selected shells and plates. From this, this bed is mechanically stable under the design temperature and pressure.

$$t_{shell} = D/2(\exp[P/S\cdot E]-1) \quad (1)$$
$$t_{plate} = d\cdot\mathrm{sqrt}(C\cdot P/S\cdot E) \quad (2)$$

t : minimum thickness of shell or plate
S : Allowable stress value
D, d : Shell inner diameter
E : Welded efficiency (=1.0)
P : Internal design Pressure
C : Plate attachment factor,
C = 0.33 for cover welded to shell

Table 1. Required Minimum Thickness and the Maximum Working Pressures of the Shell and Plate

Components		Minimum thickness (mm)	Selected thickness (mm)	Pmax. (MPa)
Primary vessel	Shell	0.40	1.8	2.23
	Plate	6.4	10	1.22
Secondary vessel	Shell	0.46	3	2.56
	Plate	9.9	10	0.41

4. Heat transfer from the heaters to the ZrCo hydride

Heat transfer from the heaters to the ZrCo hydride during a hydrogen delivery was evaluated by the following heat analysis. Fig. 2 shows the two-dimensional heat analysis model. In the ZrCo bed, 45 g of tritium was absorbed to 1251 g of ZrCo as a chemical form of $ZrCoT_{1.8}$. It was assumed that 90% and 8% of 45 g of tritium was supplied firstly in 14 min and secondary in 10 min. Temperature of heaters was assumed to be increased to 270°C for 5 min during preheating and from 270°C to 350°C for 3 min and kept at 350°C during delivery. Heat generation and consumption rates of the ZrCo tritide were calculated to be 26,475 W/m^3 (tritium decay heat during preheating), − 1,231,995 W/m^3 and − 153,315 W/m^3 during delivery of 90% and 8% of tritium [4].

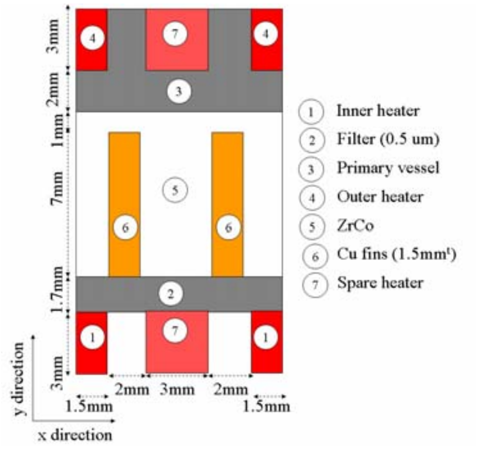

Fig. 2. Cross section and dimensions of the ZrCo bed heat analysis model

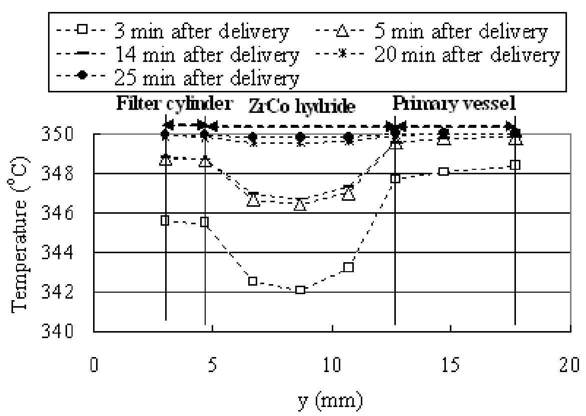

Fig. 3. Temperature profiles in the ZrCo bed during rapid delivery.

Fig. 3 shows a change of the temperature of the ZrCo hydride during delivery. Temperature of the ZrCo hydride was calculated to be 342~346°C during a delivery. From this, it was estimated that the heat transfer from the heaters to the ZrCo hydride on this bed was effective.

5. Conclusion

Based on the previous design of a ZrCo bed, a second ZrCo bed was designed with some improvements. For long-term operation of a ZrCo bed, a redundant heater was applied. For a He-3 recovery from the ZrCo bed, the positions of the hydrogen inlet and outlet tubes were separated. Hermetic seals were applied to the thermocouples and heaters in order to prevent tritium permeation from the bed to atmosphere. With these design improvements, a ZrCo bed was mechanically designed by applying ASME VII Div. 2 code. Also, it was evaluated that the heat transfer from the heaters to the ZrCo hydride during delivery was effective by a heat analysis. This second ZrCo bed will be fabricated and tested.

Acknowledgements

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