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Characteristics of Uranium-Hydrogen System

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1. Introduction

Nuclear fusion energy is considered one of the main energy sources for the future. Some countries, including Korea, are participating in the development of technologies used in nuclear fusion energy. Tritium and deuterium, which is a hydrogen isotope, is nuclear fusion fuel. To develop nuclear fusion technology, it will be necessary to store and supply hydrogen isotopes for a Tokamak operation because hydrogen isotope storage and delivery system (SDS) technologies have been studied for the storage and delivery of nuclear fusion fuels and other gases. SDS is used for storing hydrogen isotopes in a metal hydride form. A metal hydride bed, which is a key sub-system of an SDS, substantively performs the storage and delivery of nuclear fuels closely connected with the metal hydride bed. There have been many promising candidate materials, including zirconium cobalt (ZrCo), uranium (U), titanium (Ti), and lanthanum pentanickel (LaNi5), for the storage and delivery of hydrogen isotopes [1]. These materials have been extensively and widely studied for optimum SDS applications. Among these materials, uranium is chosen as a hydrogen isotope storage material for this study.

Uranium will form a hydride phase when exposed to molecular hydrogen. Some aspects of uranium with a hydrogen system have been characterized much less extensively than other common metal hydrides, particularly palladium with hydrogen, owing to radiological concerns associated with handling [2].

In this paper, the characteristics of uranium are introduced. A uranium-hydrogen system was suggested to evaluate the pressure drop by filtration, and the heat insulation by thermal reflectors. In addition, the system can be operated under high pressure and temperature conditions.

2. Chemical reactions in uranium

In this section, some chemical reactions in uranium are described, as well as the characteristics and reaction between uranium and hydrogen.

2.1 Characteristics of uranium

Uranium metal has a very high density of 19.1 g/cm^3 at 20℃. The melting and boiling points are 1405 K, and 4404 K, respectively. In addition, α-uranium is obtained at 298.15 K and changes into β-uranium and γ-uranium at 935.15 K and 1045.15 K, respectively [3]. Because α-uranium is an orthorhombic system with symmetry D_{2h}^{17}, the expansion coefficients for each vector value is different. At SATP condition, the alpha lattice constants are taken as a= 2.852 Å, b= 5.865 Å, and c=4.945 Å [4].

Uranium reacts with almost all non-metal elements by increasing the temperature. It has the largest atomic number that can be extracted in nature. The most abundant uranium existing in natural condition is ^{238}U, 99.2742% [3].

2.2 Reaction between uranium and hydrogen

The reaction for uranium hydride formation is given by the well-known equation

$$U + 3/2H_2 \rightarrow UH_3 \qquad \Delta H = -127\ kJ/mol$$

The enthalpy is observed at 25℃, 1atm. This reaction occurs at relatively low temperature and the reaction becomes reversible when the temperature goes higher.

Temperature(℃)	ΔG(kcal/mol)
400	-0.118
401	-0.070
402	-.0.022
403	0.026
404	0.074
405	0.121
406	0.169

Table. 1. Gibb's free energy in the temperature range 400℃ to 406℃ [5].

Table 1 shows the Gibb's free energy in the temperature range 400℃ to 406℃ [5]. It describes uranium and hydrogen have forward reactions, hydriding, during 402℃ and have reverse reactions which is dehydriding from 403℃. This result can be used as fiducial point to determine hydriding and dehydriding.

Since dehydriding begins above 403℃, some reactions can occur such as oxidation, nitrification, and hydration reaction. All three reactions are given below [5].

$$6UH_3 + 8O_2 = 2U_3O_8 + 9H_2$$
$$4UH_3 + 3N_2 = 2U_2N_3 + 6H_2$$

$$2UH_3 + 4H_2O = 2UO_2 + 7H_2$$

Oxidation occurs at room temperature and oxygen makes uranium catch on fire. The primary vessel should be thoroughly sealed. Nitrification and hydration occurs at temperature 250℃to 350℃ and nitrogen synthesize with uranium to decrease possibility to absorb hydrogen which decrease efficiency of uranium capacity. The water or steam can also make uranium oxide which easily burn itself. Therefore, the risk elements should be removed before operating this reaction [5].

3. Safety analysis of a uranium-hydrogen system using HAZOP

The uranium-hydrogen system is handling hydrogen and uranium which has potential explosiveness and intense chemical reactivity in hydrogen, and radioactive in uranium. Therefore, the HAZOP (hazard and operability study) technique is used to secure the safety in process. The HAZOP technique shown by Chung separates hydrogen isotope fueling system in fusion cycle process into 9 segments [6]. Our uranium-hydrogen system is focusing on hydrogen storage and delivery; however, the segments are more simplified. In this system, the segments will be separated in which at each node connected to vessel or gauge. Safety analysis will be operated by setting the variable in pressure, temperature, and flowing rate. For each run, the consequences and causes will be obtained. Eventually, the residual risk assessment will be dropped by reserving safety plan.

4. Uranium-hydrogen system

The advantage of using uranium as a hydride material is uranium-hydride has a low equilibrium pressure at room temperature, thereby minimizing tritium loss when the manifolds of the storage system are purged. This imply uranium decrease the load placed on the tritium waste management system. Also, the stored tritium can be dehydride quickly by heating up to 400~450℃. Despite the advantages, uranium hydride tends to break up into fine sub-micron sized particles which can contaminate system for the fragments. Since the filter is used to prevent small particles entering into the system. Figure 1 shows a schematic diagram of a performance test rig for a uranium-hydrogen system. Figure 2 shows uranium-hydrogen system. Two different beds, DU bed and ZrCo bed, are attached in this system at this moment. This bed will be replaced with DU tubing bed and the gas flowing routes will be changed. Figure 3 shows small DU bed which will be replaced with other bed. The small bed and measuring tank will be connected directly. The bed will contain approximately 1.9g of DU. Figure 4 shows the HMI system for uranium- hydrogen system. HMI is developed for efficient data acquisition and control. The LabVIEW software from National Instruments Company was used to develop this system. HMI send and save measured data, pressure and temperature, to computer at the same time.

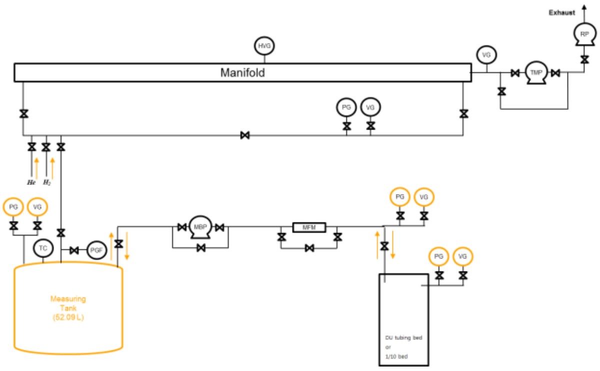

Fig. 1. Schematic diagram of a uranium-hydrogen system

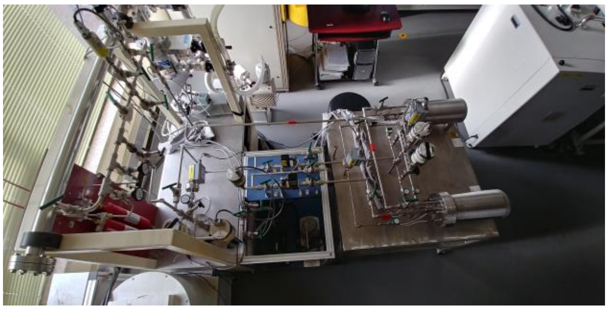

Fig. 2. Uranium-hydrogen system

Fig. 3. Small DU bed

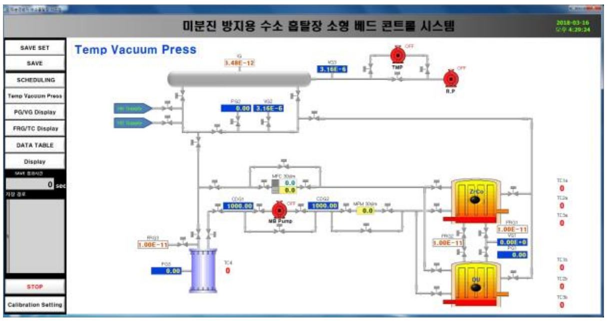

Fig. 4. Human Machine Interface (HMI) for uranium-hydrogen system

Fig. 5. Data Acquisition System (DAS)

5. Conclusions

The characteristics of uranium, including the properties of uranium, are introduced. Of three uranium modifications (alpha-, beta-, gamma-U), alpha-U is dominant and has an orthorhombic lattice under SATP. Since orthorhombic lattice has different expansion coefficient factors for each vector, the estimation calculation simulator for expansion has to be considered by measuring each vectors coefficient. Uranium has good affinity with all non-metallic elements. To evaluate the pressure, drop by filtration and the heat insulation by thermal reflectors, the schematics of the test rig have been suggested. Furthermore, a small DU hydride bed has been prepared to find the optimum operation conditions of the bed. HAZOP technique has been informed to analyze safety in uranium-hydrogen system. Each segment and node will be composed to discover the consequence and cause. HAZOP technique will decrease risk assessment and increase safety in experiment. Many experiments will be performed using the bed under various conditions.

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