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Design of scale down test for an adsorption bed with molecular sieve

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1. Introduction

In fusion reactor, breeding of Tritium is necessary in order to maintain the fusion reaction. The heat generated in this process is continuously extracted by the helium cooling system (HCS). Helium, which has a higher conduction value compared to other gases, removes heat by circulating the breeding zone. Since the breeding zone is the environment of high temperature and high pressure, and has thin steal wall for effective heat transfer, small tritium continuously permeates to helium. If tritium reaches high concentration, it can be exposed to external environment through the secondary cooling system which extracts heat from HCS to external heat sink. Therefore, it should be removed in the HCS through Coolant purification system (CPS). 1% of helium flow rate bypasses CPS and is purified through several steps. In order to derive the design of the CPS, experimental devices are being manufactured and performed in many countries. KAERI and NFRI also compare and analyze several designs to be able to produce CPS, and the test facility is under construction now. In this paper, the design of test facility for adsorption bed is introduced.

2. Methods and Results

2.1. Coolant purification system

CPS consists of oxide bed [1,2], adsorption bed[3], impurity bed[4] and so on as shown in Fig 1. In this study, molecular sieves are utilized to physically capture tritium. Zeolite molecular sieves are crystalline with plentiful pores of precisely defined diameter. [5] However the tritium is too small to be captured by molecular sieves, it will pass through adsorption bed and the system cannot function adequately. Therefore, it is oxidized to Q2O before the adsorption bed and then a molecular sieve bed (MSB) captures. Since the diameter of helium and H_2O are 2 Å and 2.6 Å, respectively. H_2O with large size and polarity is adsorbed while on the other helium passes through the sieve. MSB has a high adsorption efficiency of 99% or more and is high efficiency at room temperature. In the impurity bed, only a few other impurities are filtered out using cold traps, and only pure helium is returned to HCS.

2.2 time to saturation of molecular sieve bed

The adsorption capacity varies depending on the adsorbent type, temperature, pressure and partial pressure of steam [6], and the saturation characteristic changes as well [7]. The concentration of Q2 in CPS is estimated as 0.3 Pa, which is very low compared to the Helium pressure of 8 MPa. Helium mass flow rate is 0.0114 kg/s which is 1% bypass flow from HCS. To design the size of MSB, the correlation of Nakashima [8] is used. MSB with the diameter of 0.1 m and the length of 1 m is calculated to be suitable size with about 265 days.[9] The equation for time to saturation is as follows,

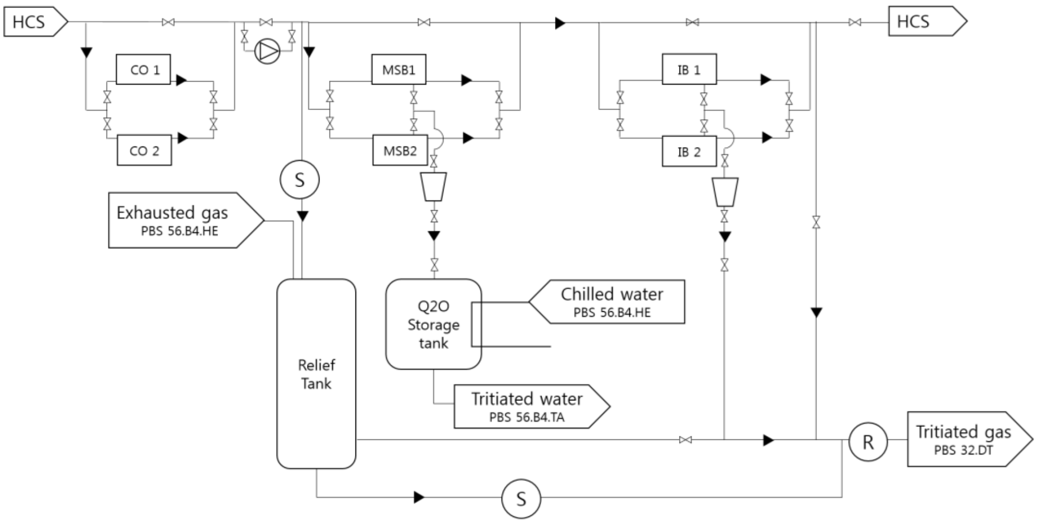

Fig 1 Schematic diagram of CPS (CO: copper oxide bed, MSB: molecular sieve bed, IB: impurities bed)

$$t = \left[\frac{Am}{vC_0}\right]\left\{l - \left[\frac{v}{2K \cdot Am}\right]\ln\left(\frac{C_0}{C_B}\right)\right\} \qquad (1)$$

Where,
A: Amounts of HTO adsorbed (mmol/ml)
Am: Maximum adsorption capacity (mmol/ml)
C: Concentration of HTO in the feed gas (mmol/ml)
K: Adsorption rate constant (ml/mmol/min)
v: Linear velocity of the feed gas (cm/min)
C_0: The initial concentration of HTO in the feed gas (mmol/ml).

2.3 scale down condition for adsorption test

Verification experiments should be performed to confirm the calculation results and adsorption rate of the MSB. However, as the concentration of Q2 is too low, the MSB of the same size takes long time, and the helium pressure is too high, making it difficult to build an experimental device. The low pressure experiment is planned through scaling.

Among the parameters in the above equation, the concentration of HTO and the linear velocity of the feed gas are influenced by fluid. In the experimental conditions, the pressure is lowered to 0.2 MPa, but the partial pressure of hydrogen is maintained at 0.4 Pa. In addition, the size of the MSB was reduced in order to keep the experiment run time within a few days. The minimum MSB diameter and height to minimize the effect of voids between the molecular sieve and the wall is 16 mm, which is 10 times the sieve, and 24 mm, which is 15 times the sieve, respectively. The linear velocity is adjusted by reducing the flow rate as the cross section decreased.

In addition, different diameters and heights will be used to determine the effect of design and concentration on the adsorption behavior of MSBs. Generally, the adsorption rate tends to decrease as the adsorption progresses. If the definition of general saturation is that MSB adsorbs all the absorbable water, in this study, the saturation time is defined as the time that can maintain 99% adsorption rate. The adsorption test conditions of this study were evaluated using Nakashima's equation. Figure 2 shows the ratio of water molecules that could not be captured by the MSB and passed as time goes by. It takes 147 hours for 0.4 Pa, 29 hours for 10 Pa, and 15 hours for 20 Pa.

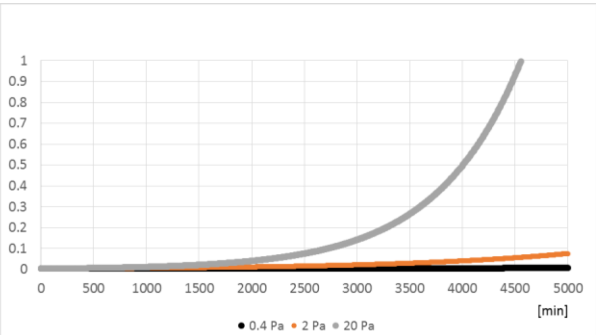

Fig 2 Percentage of water molecules not captured by the MSB and passed through

3. Conclusion and further works

The major components of CPS are oxide bed, adsorption bed and impurity bed. Tritium in helium is oxidized to water and captured be MSB. In order to design the MSB, literature review on the adsorbent characteristics and design study was carried out. In case of the actual MSB, it is designed to be used for several months. Due to the difficulty of long-term experiments, the size of the MSB was reduced to 16mm of diameter and 24mm of length, and the experimental pressure was reduced to 0.2 MPa. In this study, the saturation time is defined as the time to maintain 99% absorption rate. Using the Nakashima equation for the absorption experiment's condition, the time until saturation is 147 hours for 0.4Pa, 29 hours for 10Pa, and 15 hours for 20Pa. Verification experiment will be performed in the near future. The effect of geometry and concentration on saturation characteristics will be experimentally determined to improve the correlation and a more reliable MSB design will be derived.

REFERENCES

[1] F. Legros, K. Liger, M. Sardin, He purification system for GENIV nuclear reactor: study of H2 and CO oxidation on CuO, in: SFGP 2009, Marseille, 14–16 October, 2009
[2] F. Legros, K. Liger, C. Poletiko, O. Gastaldi, M. Troulay, M. Ollivier, Helium purification at laboratory scale, in: Proceedings HTR 2006, 3rd International Topical Meeting on High Temperature Reactor Technology, Johannesburg, South Africa, 1–4 October, 2006.
[3] A. Ciampichetti, k. Liger, d. Demange, "The coolant purification system of the European test blanket modules: preliminary design", Fusion Engineering and Design, Vol. 85, pp. 2033-2039, 2010
[4] I. Ricapito, A. Ciampichetti, P. Agostini, G. Benamati, Tritium processing systems for the helium cooled pebble bed test blanket module, Fusion Engineering and Design Vol. 83 pp. 1461–1465 2008.
[5] http://www.gracedavison.com/
[6] Yu Wang and M. Douglas LeVan, Adsorption Equilibrium of Carbon Dioxide and Water Vapor on Zeolites 5A and13X and Silica Gel: Pure Components J. Chem. Eng. Data Vol. 54, pp. 2839–2844, 2009.
[7] K.R Kim et. al., Adsorption tests of water vapor on synthetic zeolites for an atmospheric detritiation dryer, Radiation Physics and Chemistry, Vol. 76 pp. 1493–1496, 2007.
[8] Mikio Nakashima and Enzo Tachikawa, removal of tritiated water vapor by molecular sieves 5A and 13X, silica gel and activated alumina, journal of Nuclear science and technology No. 19 Vol.7 pp. 571-577, 1982.
[9] C.W. Shin et al., "Design of a tritium adsorption bed in the coolant purification system," the Korean nuclear Society Spring Meeting, May. 2019.