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Numerical Investigation about Low Flow Characteristics of Purge Gas in Pebble Beds

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1. Introduction

Helium cooled ceramic reflector (HCCR) test blanket module (TBM) has been designed to install in ITER and verify the tritium production and the heat extraction [1, 2]. HCCR TBM is composed of four sub-modules and a common back manifold. The TBM is cooled by a high-temperature helium coolant of 300 °C. The breeder, a neutron multiplier and reflector are included in the TBM. TBM is essential device to verify the tritium production and the heat extraction. The lithium ceramics is used as breeder with the form of sphere-shaped pebbles for the extraction of the tritium in TBM. A low flow of purge gas is designed in order to remove the generated tritium. Heat is also generated in the pebble beds, and the generated heat is removed through the wall surrounding the pebble beds. The purge gas is the helium gas with 0.1 % H_2. The purge gas flows through the pebble beds and removes the tritium. The tritium is extracted from the purge gas through the several processes in a tritium extraction system (TES). The purge gas flow is limited to small flow rate due to the components specification of the TES. The size of the pebble is about 1 mm in diameter. The volume of the smallest pebble beds in the HCCR TBM is about 3,750,000 mm^3. Thermal analysis is generally limited to simulating all pebbles independently. In the previous analysis, it is assumed that the pebble beds itself is simulated as a box, and the inside of the box is filled with the pebbles [3]. This box is porous structure, and has relatively low thermal conductivity compared to the pebble.

In this work, heat transfer characteristics of the pebble beds is studied when each pebble geometry and the purge gas flow are reflected. Thermal-hydraulic analysis was performed with a conventional CFD code, ANSYS-CFX.

2. Thermal Properties of Pebble

In HCCR TBM, lithium metatitanate (Li_2TiO_3) is used as the breeder material. Equation (1) and (2) are formulas for the calculation of the thermal conductivity according to the state [4]. The thermal conductivity of the pebble itself is calculated according to the temperature and the porosity by using the Eq. (1). In Eq. (2), the pebble beds which is porous structure is calculated according to the temperature and the smear porosity.

$$(1-\varepsilon)^{2.9}(5.35-4.78\times10^{-3}T+2.87\times10^{-6}T^2)$$
For $0.14 \le \varepsilon \le 0.25,\ 300 \le T \le 1400K$ (1)

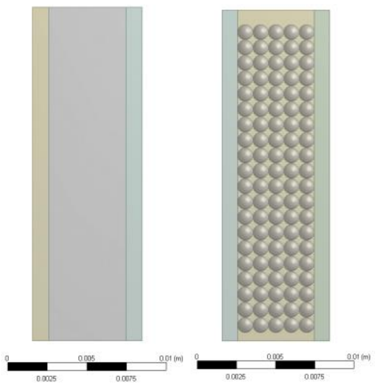
$$(1-\varepsilon)(0.74+0.0015(T-273)+3.3\times10^{-7}(T-273)^2)/0.52$$
For $0.43 \le 1-\delta \le 0.48,\ 300 \le T \le 1300K$ (2)

where ε is the porosity of the pebble. δ is the fraction factor.

3. Thermal Hydraulic Analysis

3.1 Geometry model & boundary

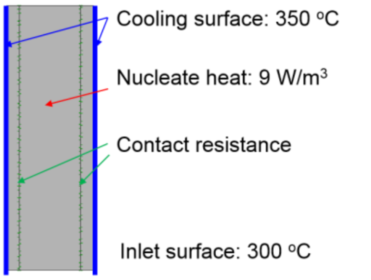
The geometry models was described in Fig. 1. The reference model in Fig. 1 (a) is the model which considered the pebbles as one box. The model that reflects each pebble is shown in Fig. 1 (b).



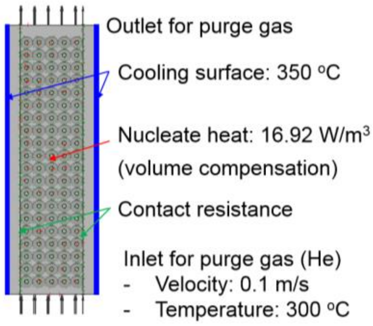
(a) Case 1 (b) Case 2
Fig. 1. Geometry of the pebble beds

The condition of the contact resistance between the pebble and the wall is applied in this analysis [5]. The value of the density of the pebble and the specific heat for the 2 models is same to clearly distinguish the effects of the thermal conductivity. Total number of the element is about 10,000. The element type is combined with the tetra and the hexagonal shape.

The boundary condition of the models is described in the Fig. 2. The temperate of the exposed outer wall is set to be low so as to remove the heat generated in the pebbles. The nucleate heat value is adjusted to equal the total generated heat in two models. The flow rate and the initial temperature of the purge gas is set in the model.



(a) Case 1



(b) Case 2

Fig. 2. Boundary condition in models

3.2 Temperature

Temperature distribution on vertical cross-section is described in Fig. 3. The layer thickness with relatively high temperature in the case 1 is higher than that of the case 2. This results would be caused by the thermal conductivity difference and the purge gas flow. The temperature distribution of the wall structure is difference. In the case 2, the locations with the high temperature value appear at the point form where it meets the pebbles. The purge gas temperature is directly affected by the pebble temperature in contact.

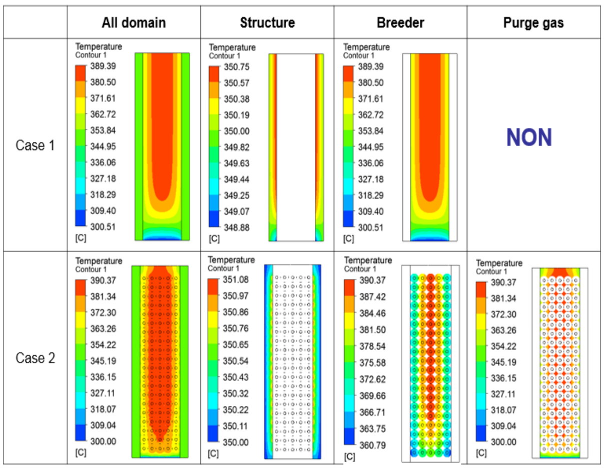


Fig. 3. Temperature distribution in the materials

3.3 Velocity

Temperature distribution according to the flow velocity of the purge gas is investigated. The mass flow rate is 2.46x10^{-7} kg at the 0.1 m/s flow condition. The temperature of the near inlet surface is different due to the initially cool purge gas. Since the total flow length in the HCCR TBM is about 0.8 m, the cooling effect in the early flow stage can be negligible. The heat removal effect caused by the purge gas flow is insufficient.

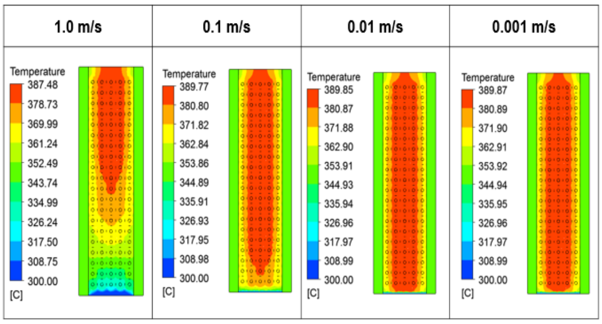


Fig. 4 Temperature distribution according the flow conditions

4 Conclusions

The thermal hydraulic analysis for the purge gas in the pebble beds is performed. The thickness with high temperature in the pebble beds is reduced when the simulation of the purgas flow is performed at same time. The effect of the velocity for the purge gas is minor to determine the maximum temperature. The heat removal effect caused by the purge gas flow is insufficient.

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