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Concept of Pebble Feeding Procedure for HCCP TBM in KO

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1. Introduction

Test blanket module (TBM) is to be installed at the equatorial port of ITER to demonstrate the production and transport of tritium, as well as heat removal in high temperature environments [1,2]. Helium Cooled Ceramic Pebble (HCCP) TBM is developed in KO which a lithium based ceramic breeder and a beryllium multiplier are used with helium coolant. The pebbles of these functional materials are filled inside the TBM in the form of a 1 mm diameter pebble bed and used for tritium and neutron generation, respectively [3].

In this study, we investigated how to fill the part structure containing functional materials, called the Breeding Unit (BU), in the HCCP TBM and the thermo-hydraulic effects of changing the cooling channel by adding injection hole.

2. Key concerns

The functional materials inside the TBM are breeder and multiplier. The breeder is a lithium based ceramic material and the operating temperature should not exceed 920 °C. The temperature was limited to 100 degrees below the melting temperature of the ceramic breeder. The operation temperature limited is related thermos-mechanical properties, tritium release and thermal expansion [4]. The multiplier is made of beryllium and has a maximum temperature limit of 650 °C to prevent vaporization at high temperatures and swelling issues [4]. These temperature limits affect the assembly process of the TBM structure. The TBM structure is made by continuous welding and post-heating. Considering that the post-heat treatment temperature of RAFM steel, the TBM structure, is typically above 700 °C [5], the breeder limit temperature is much higher than the post-heat treatment temperature. Therefore, the breeder can be easily injected into the BU during TBM fabrication and assembly. However, due to the higher post-heat treatment temperature than the limit temperature of the multiplier, the injection of the multiplier into the BU is considered to be done carefully at the final stage of TBM fabrication and assembly.

Figure 1 shows the TBM-set geometry [6]. There are three possible directions to inject the Be pebbles inside the BU. Each can be considered by penetrating the First Wall (FW), Back Manifold (BM), and Side Cap (SC) to access the interior space. The FW is the part of the structure that faces the plasma and is subject to high temperatures. Therefore, a design that avoids the formation of separate mechanical machining or welding areas is prioritized. Access to the BU through the back manifold is limited by the complexity of the back manifold itself. Injecting the multiplier inside the BU through the SC is the simplest approach if the plate can be penetrated without affecting the cooling channels inside the SC. It is possible to inject the multiplier inside the BU without significant changes to the existing fabrication and assembly procedures. It is necessary to check the location and number of injection holes and the resulting change in thermo-hydraulic characteristics. The candidates for the hole location is shown in Fig. 2.

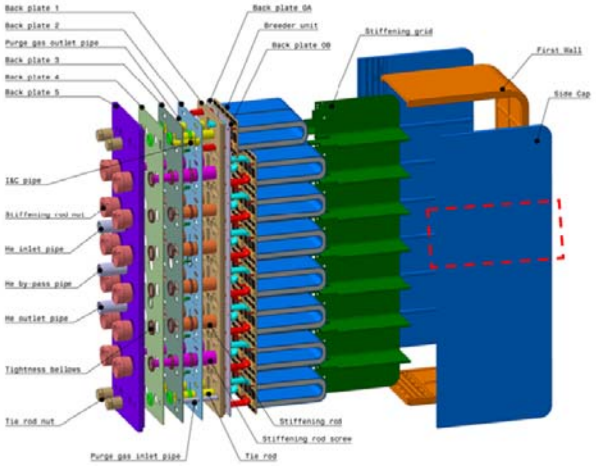


Fig. 1. Exploded view of the HCCP TBM

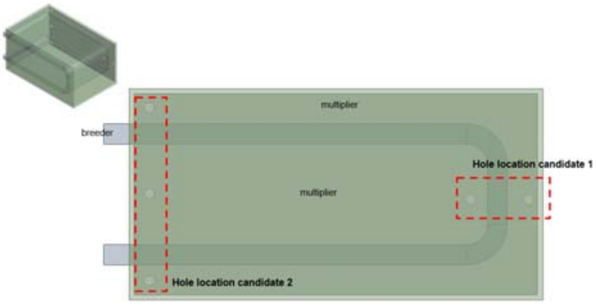


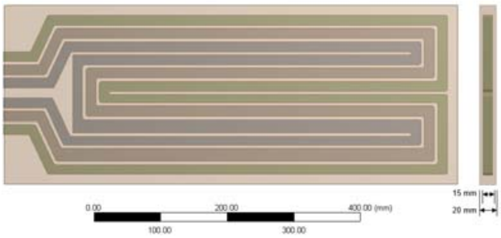
Fig. 2. Geometry of breeding unit (BU) & hole location

3. FEM analysis

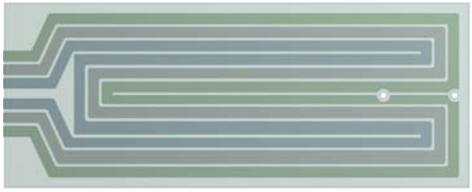
FEM analysis using ANSYS was performed to check the thermo-hydraulic characteristic changes due to the creation of the injection hole.

3.1 Geometry Model and material

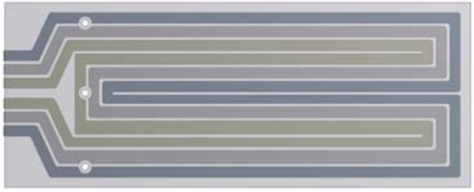
Figure 3 shows the SC geometry models used in the analysis. Model (a) does not include the injection holes, while models (b) and (c) include the injection holes in different locations. The multiplier must fill two independent spaces even within one BU. The spaces for the multiplier is separated in a BU. Therefore, a minimum of two injection holes are required, and up to three injection holes may be required depending on the injection location for the high pebble packing ratio. The material for the BU structure is Eurofer 97 [7]. The multiplier material is beryllium in 1 mm diameter [8].



(a) base model without injection holes



(b) case 1 model with injection holes



(c) case 2 model with injection holes

Fig. 3. Side Cap (SC) geometry model for analysis

3.2 Boundary condition

Heat is generated through nuclear reactions between functional materials and neutrons in the SC structure. Since there are no accurate nuclear analysis results for the HCCP TBM model, we used the results of the nuclear analysis for the HCCR TBM performed in Korea as boundary conditions for the analysis [9]. The coolant flowing inside the structure is helium at 8 MPa. Figure 4 shows the location of the inlet and outlet of the coolant channel.

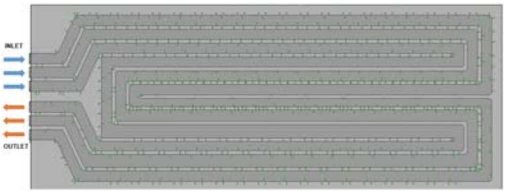
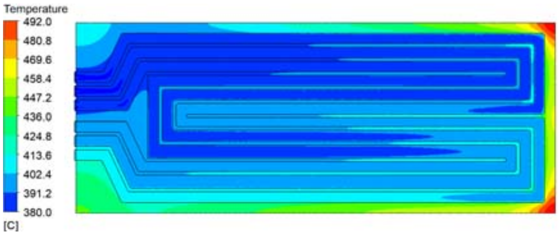


Fig. 4. Coolant inlet/outlet

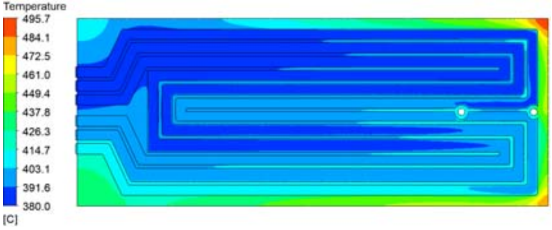
The coolant temperature at the inlet is 380 ℃. The helium coolant entering the TBM is 1.3 kg/s, but 30% of the flow cools the FW and then exits the TBM through a bypass pipe. The remaining 1.0 kg/s flow is directed to the 16 BUs simultaneously. Assuming equal flow to all BUs, one BU will have a flow rate of 0.057 kg/s.

3.3 Results

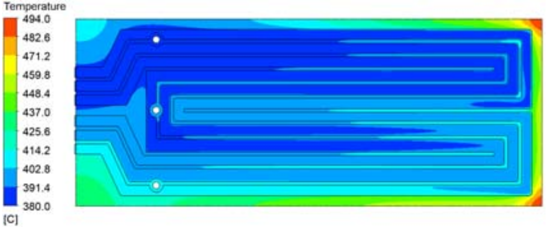
Figure 5 shows the maximum temperature of the structure for each model. Without the injection holes, the maximum temperature is 492 ℃. Even with the injection holes included, the maximum temperature is 495 ℃, which does not make a significant difference. Although the flow cross-sectional area of the cooling channel decreased due to the injection hole, the difference in maximum temperature was insignificant by about 3 degrees because the flow rate itself was not large. The difference in temperature distribution according to the location of the injection hole also changed slightly. Since it was confirmed that the location and quantity of injection holes do not have a significant effect in terms of the results of the thermal-hydraulic analysis, it is necessary to select the final injection holes in consideration of the manufacturing and assembly process.



(a) base model without injection holes



(b) case 1 model with injection holes



(c) case 2 model with injection holes

Fig. 5. Temperature distribution

4. Further work

In order to inject the multiplier inside the HCCP TBM, the penetrating the SC structure was considered. The candidates for the location and number of holes were proposed. Through thermo-hydraulic analysis, the temperature distribution formed in the SC structure was confirmed and the effect of changing the injection holes was analyzed. In the future, DEM analysis will be performed to check the feeding procedure, possible problems, and time required when the pebbles enter the BU inner space through the injection holes.

Acknowledgment

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