Effect of Grooved Wall in TBM to Reduce the Maximum Temperature of the Breeder Pebbles

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1. Motivation

In Korea, the helium cooled ceramic reflector (HCCR) test blanket module (TBM) has been designed and developed to be installed in ITER for verifying the tritium production and the heat extraction [1]. The HCCR TBM is composed of four sub-modules and a common back manifold (BM) as shown in Fig. 1. The main components of the sub-module are a first wall (FW) and a breeding zone (BZ). The breeder and the multiplier material are located in the BZ in continuous layer structure. To cool the BZ, the cooling channels were formed inside the wall in contact with the breeder and the multiplier material to remove heat from the BZ. The cooling path of the BZ is shown in Fig. 1. The BZ was maintained with high temperature due to the nuclear heating of material. In the conceptual design phase of the TBM, the maximum temperature of the breeder material is about 917 oC and the limit was 920 oC. In the preliminary design phase, however, the temperature limit of the breeder material was lower to be 800 oC considering its sintering and creep phenomena for stable tritium extraction [2]. Therefore, it is necessary to improve the cooling performance to meet the new temperature requirement of the breeder material.

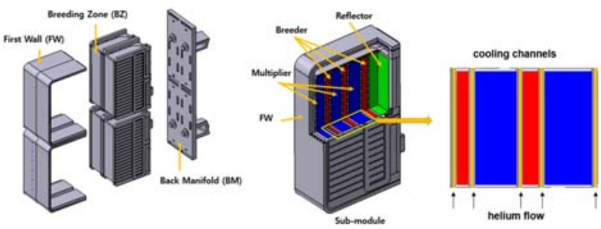
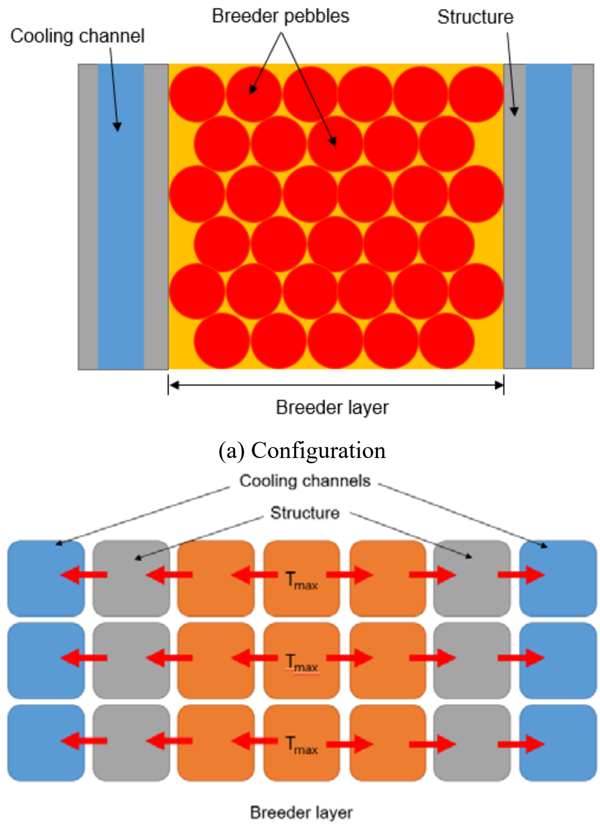


Figure 1. Exploded and internal view of the HCCR-TBM

2. Concept of the grooved wall

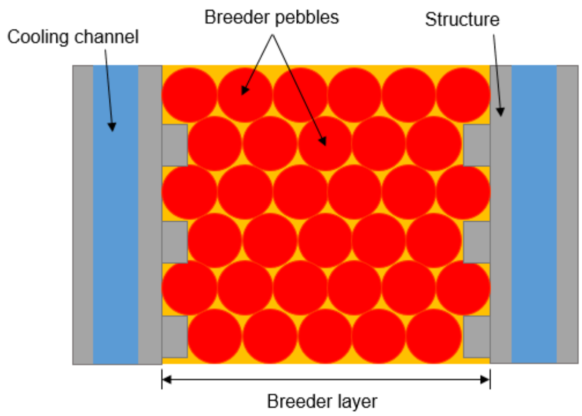
Figure 2 shows the heat transfer mechanism in the BZ in which the breeder consists of pebbles of 1mm diameter in the form of pebble bed. The location of the maximum temperature occurs is the middle of the breeder pebble bed. One of the solution to lower the maximum temperature of the breeder is to reduce its thickness. However, there is limitation for reducing the BZ layer thickness because it causes significant change of the neutron characteristics related to the tritium production. The grooved wall concept was considered to reduce the maximum temperature of breeder layer as shown in Fig. 3. The thermal conductivity of the structure is higher than the pebble bed. The heat of the breeder layer is quickly removed through the tip of the grooved wall.



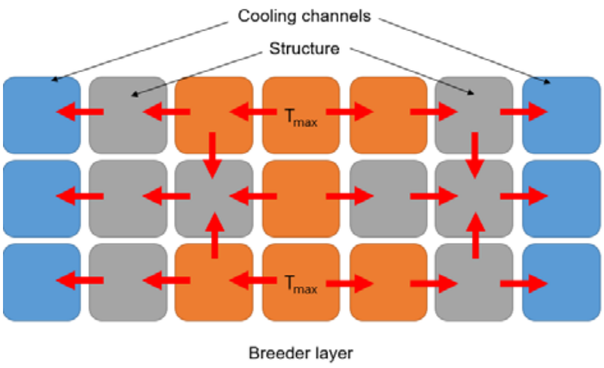
(a) Configuration

(b) Heat flow

Figure 2. Original heat transfer mechanism



(a) Configuration



(b) Heat flow

Figure 3. Heat transfer mechanism with grooved wall

3. Thermal-hydraulic analysis

Figure 4 shows the geometry of analysis model and boundary condition. In the current TBM design, 17 pairs of cooling channels are vertically located, but only one pair of cooling channel was simulated in the present study by using the symmetric wall condition. The volume of pebble bed is constant in all cases. The thickness of the breeder layer with the grooved wall was increased to compensate the reduced volume of the breeder due to the tips attached on the wall.

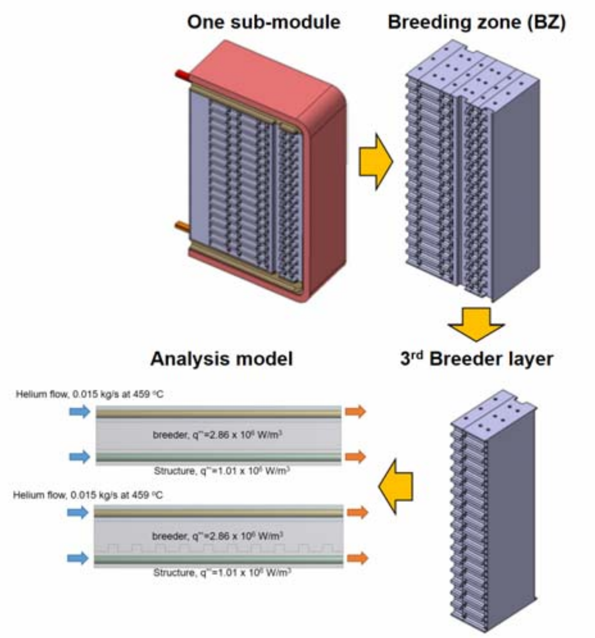
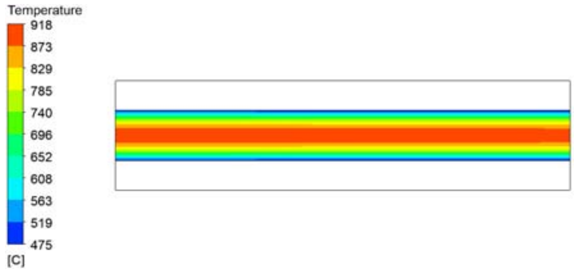
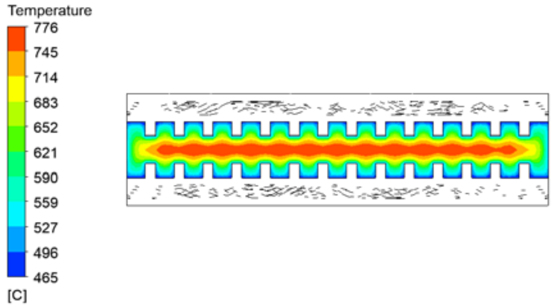


Figure 4. Geometry of analysis model

Temperature distribution on the breeder layer is shown in Fig. 5. The maximum temperature of the breather layer is reduced from 918°C to 776°C by the groove wall. In both cases, the maximum temperature of the structure does not exceed the design temperature of 550°C.



(a) Geometry without grooved wall



(b) Geometry with grooved wall

Figure 5. Temperature distribution in breeder layer

The thickness, length, and the number of tips can be selected as the design parameters in the grooved wall as shown in Fig. 6. Table I shows the maximum temperature of the structure and the breeder layer according to the design values. Installing grooved walls on both sides of the breather layer are more effective in lowering the maximum temperature of the breather pebble bed. The tip design should be more accessible to the middle of the layer, so a longer tip is suitable. A thin tip is recommended to avoid increasing the thickness of the breeder layer.

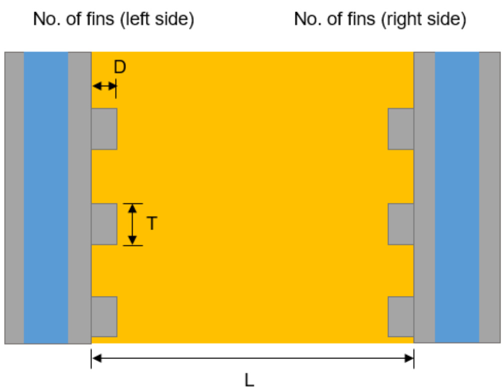


Figure 6. Design parameter of grooved wall

Table I: Temperature result of parameter study

	L	D	T	No. of fins (right side)	No. of fins (left side)	Max. Temp. of breeder
ref.	20	-	-	-	-	916
case 1	22	4.2	8.6	10	0	870
case 2	24	4.2	8.6	10	10	835
case 3	24	4.5	8	10	10	845
case 4	24	6	6	10	10	809

case 5	24	7	5.2	10	10	792
case 6	24	7	4.3	12	12	765
case 7	24	7	3.7	14	14	753
case 8	24	7	3.2	16	16	741
case 9	24	7	2.9	18	18	740
case 10	24	6	4.3	14	14	776
case 11	24	6	3.8	16	16	763
case 12	24	4.5	5.8	14	14	828
case13	24	4.5	5	16	16	821
case14	24	7	3.2	16	16	735

4. Conclusion

Considering the stable tritium extraction, the requirement of the breeder pebble temperature was lowered. Without change or reduction of the breeder amount, grooved wall concept was introduced in KO HCCR TBM as a heat transfer enhancing method. The various shapes as a parametric study were analyzed by CFD analysis. The grooved wall in TBM was designed under the condition of case 14, and the maximum temperature of the breeder pebble bed is 735 ^{o}C. It was confirmed that the temperature requirement for the breeder pebble bed was satisfied.

REFERENCES

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