# Design and Thermal-hydraulic Analysis of the Integrated Model of the KO HCCR TBM

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## 1. Introduction

One of the main engineering performance goals of the ITER is to test and validate the design concepts of the tritium breeding blankets relevant to a power producing reactor. The tests will focus on modules including a demonstration of the breeding capability that will lead to a tritium self sufficiency and extraction of heat suitable for an electricity generation. In Korea a Helium Cooled Ceramic Reflector (HCCR) Test Blanket Module (TBM) for the ITER TBM program was chosen as a leading concept in the National Fusion Committee considering the unique concept of using the graphite reflector [1-3].

Up to 2012, the overall design by optimizing its performance analysis separately according to the main components such as the First Wall (FW), Breeding Zone (BZ), Side Wall (SW), and BZ box [4]. In the present paper, the integrated design and analysis results were introduced for one submodule.

## 2. Current TBM Design

Considering the design requirements such as (1) KO DEMO relevancy [5], (2) compact size for delivery for PIE (Post Irradiation Examination), (3) adopting a graphite reflector as a unique feature of the concept, (4) TBR > 1.4 under local assumptions. Finally, a new vertical HCCR TBM concept was developed, in which the four sub-module concept was taken for manufacturing and easy Post Irradiation Examination (PIE) aspects. The TBM has the following major components; a First Wall (FW), Side Wall (SW), Breeding Zone (BZ) in each sub-module, and common Back Manifolds (BM), as shown in Fig. 1. The FW has a role of facing a high level of a heat and the fast neutrons from the plasma side and protecting the other components. The SW was considered having a function of the cooling flow distribution from FW cooling channels to BZ, and it should sustain the internal coolant operating pressure of 8 MPa. And the combined FW and SW is the outer structure of the TBM. The sub-module dimension of the KO HCCR TBM is 1670 mm in height and 462 mm in width.

It adopts Reduced Activation Ferritic Martensitic (RAFM) steel as a structural material, $Li_4SiO_4$ (or $Li_2TiO_3$ as optional) as a breeder, beryllium as a multiplier, graphite as a reflector, and helium as a coolant. All functional materials are packed in a pebble-bed form. Helium coolant for cooling the TBM is at an operating pressure of 8 MPa with an inlet temperature 300 $^oC$ and an outlet temperature up to 500 $^oC$ depending on the operating conditions. As a purge gas for extraction of tritium from the breeding zone, helium with 0.1% hydrogen is used. In the design, the temperature limits of the RAFM structure and Li pebbles were assumed to be 550 $^oC$ and 920 $^oC$, respectively, considering its operating windows of the structural and functional pebble materials. In the design, structural analysis was performed with 10 MPa of design.

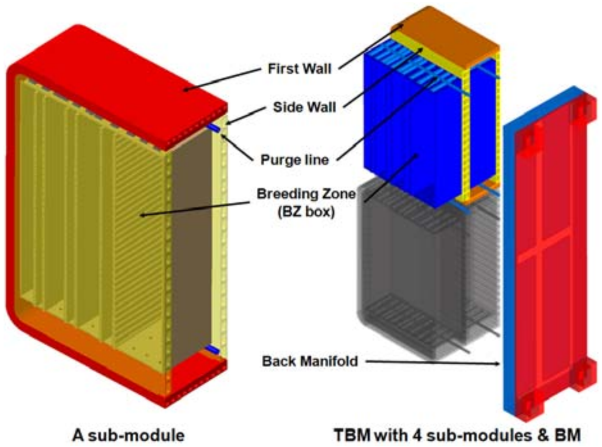


Fig. 1. Concept of KO HCCR TBM and its sub-modules.

## 3. Analysis model

### *3.1 Previous Separate model*

A separate design and analysis were performed for each functional component by using the conventional CFD code, ANSYS-CFX-13 [6], as shown in Fig. 2: (1) FW performance and flow schemes were updated by updating the neutron analysis; (2) BZ performance analyses were updated according to the design optimization; (3) the SW design concept was proposed, and its flow distribution was analyzed, (4) the BM design was performed for distributing the coolant to the FWs, and (5) a flow distribution analysis of a BZ box with a He purge line was performed. However, it did not consider the flow distribution by connected components by manifolds such as BM and SW.

| Part | BM | | FW | BZ | | | SW |
|---|---|---|---|---|---|---|---|
| Case | 03 | 03 | 08.1 | 08.1 | | | 07 |
| P_inlet | 35.556 | 6.474 | 22.121 | 2.630 | 2.555 | 2.498 | 85.143 |
| P_outlet | 26.733 | 2.237 | 0.006 | 0.002 | 0.002 | 0.002 | 8.302 |
| △P | 8.823 | 4.236 | 22.115 | 2.629 | 2.553 | 2.496 | 76.841 |
| Sum △P | 8.823 | 8.473 | 88.461 | 30.714 | | | 307.364 |
| Remarks | x1 | x2 | x4 | x4 | | | x4 |

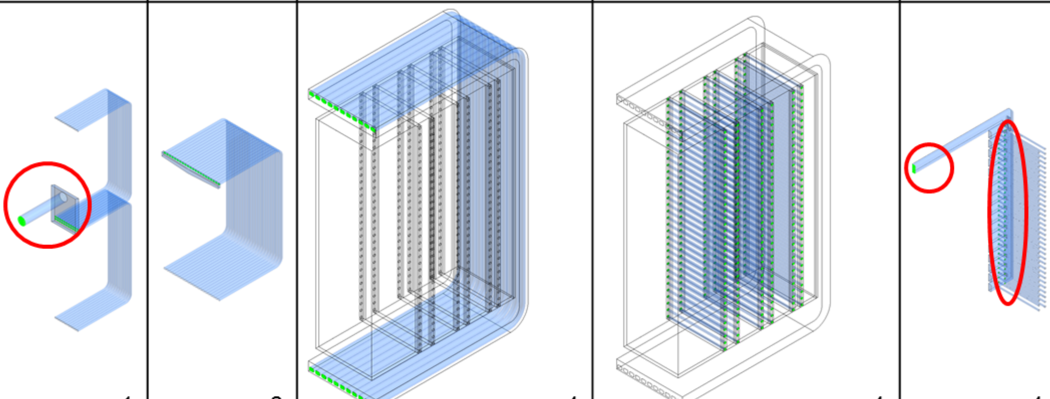

Fig. 2. The previous separate analysis models and their hydraulic results.

*3.2 Preparation of the Integrated Model*

Using the separate models and meshes, the integrated models were assembled. First, the submodule model was prepared and tested. Then, the whole TBM model was prepared with submodule and BM. Total 13,594,762 elements were used in the whole model with minimum and average qualities of 0.007 and 0.829, respectively. The minimum quality was too low and it should be improved in the near future.

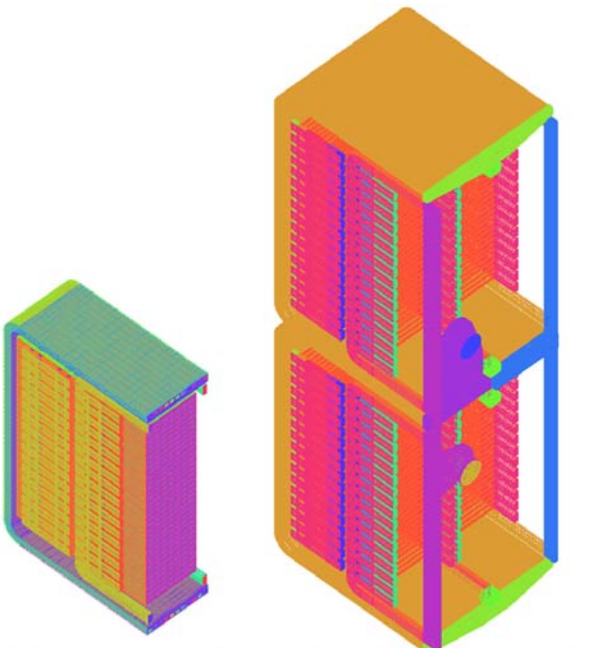


Fig. 3. Integrated models and meshes for submodule and whole model

## 4. Design and Analysis with Integrated Model

The designed flow scheme and the results by the current whole model were shown in Fig. 4, in which the fluid temperature, mass flow rate, and outlet pressure were also shown. The flow procedure and results are summarized as follows; (1) A He coolant of 1.14 kg/sec mass flow rate flows to the BM and it divides first two FW of 11 channels (group A); the mass flow rates divided into upper and lower FW in group A are 0.458 and 0.682 kg/sec, which is not the same but it can be optimized through the BM design. (2) Through BM, coolant in group A of FW flows to group B of FW and is collected in BM and flows to the SW in order to cool down the BZ. (3) BZ has 3 paths through SW and the coolant in BZ is collected in BM again. The temperature increase and pressure drop are expected to be about 176 $^{o}$C (outlet temperature is 476 $^{o}$C) and 0.5 MPa, respectively.

In more detail, the distribution of FW channels was investigated as shown in Fig. 5. As well as difference of the mass flow rate in each group of FW, the flow rate of each channel is also different. It causes the FW temperature difference as show in Fig. 6, in which the FW surface temperatures were compared with the old analysis with the flow distribution in FW using the integrated model. In old analysis, uniform flow was assumed in the 11 channels of FW, the maximum temperature was 522.6 $^{o}$C, however, the actual calculation shows the different temperature distribution although the optimization of the BM design for uniform flow. Since some regions of FW exceeds 550 $^{o}$C of the limitation of the structural material, the BM design should be updated.

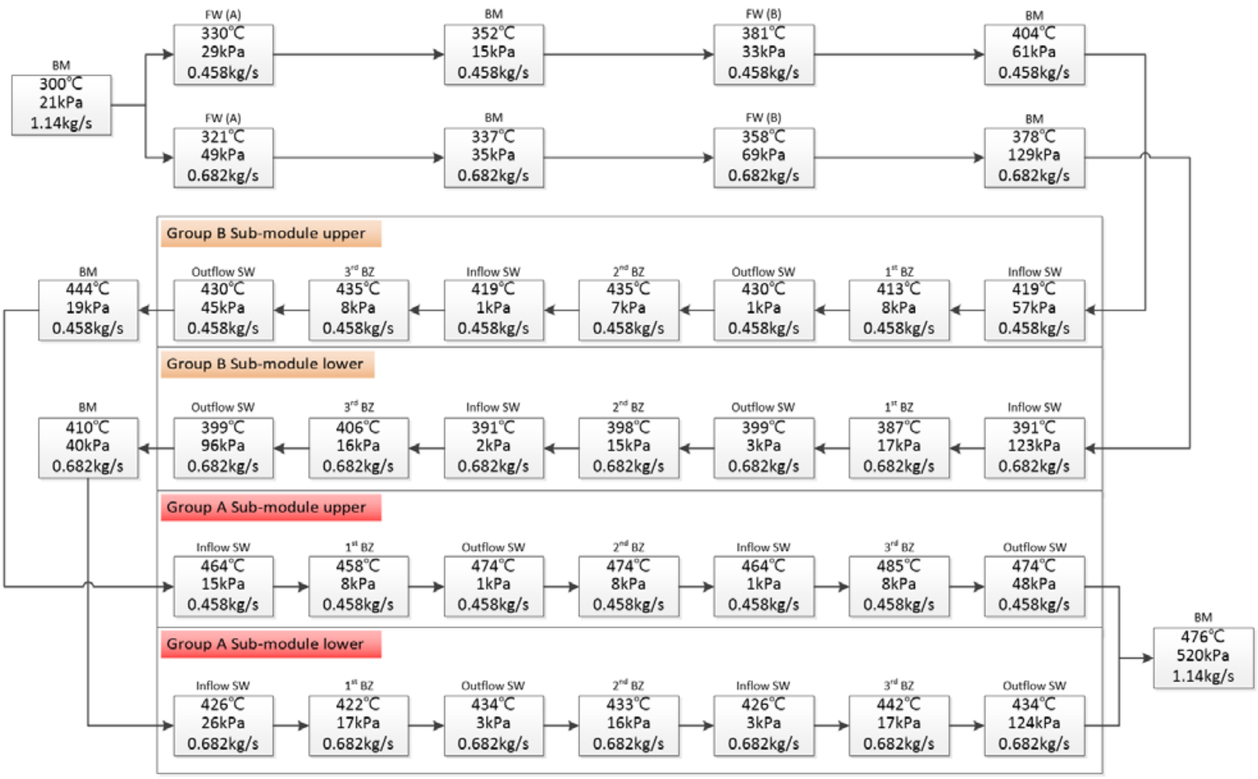


Fig. 4. Flow scheme and coolant information by integrated analysis.

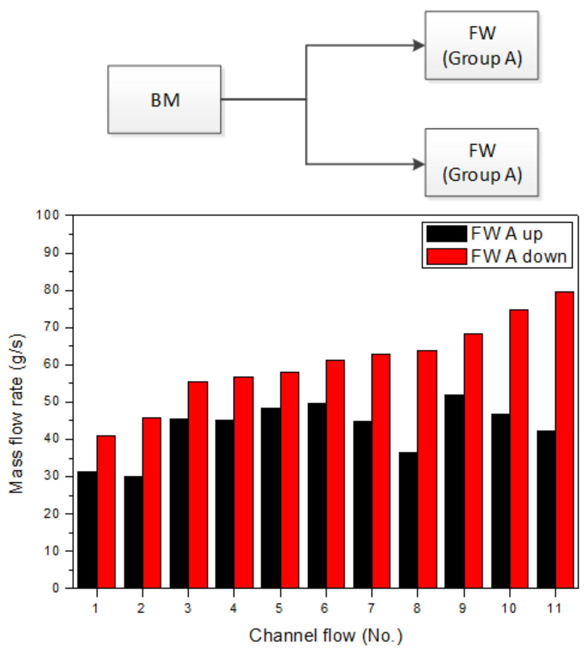


Fig. 5. Flow distribution in FW channels.

In the same way to the FW, the distribution of cooling holes in the BZ plates was investigated as shown in Figs. 7 to 9. The different flow rates in the BZ plates cause the different temperature distribution compared to the old analysis considering uniform flow in the BZ plates, as shown in Fig. 10, which shows the the BZ temperatures in the centered region with the flow distribution in BZ plates using the integrated model compared with the old analysis.. The maximum temperatures were lower than the current integrated analysis about 30 °C was 522.6 °C, however, the actual calculation shows the different temperature distribution although the optimization of the BM design for uniform flow. Sinice some regions of FW exceeds 550 °C of the limitation of the structural material, the BM design should be updated.

Figure 11 shows the structure temperature in BZ. The temperture in the structure in the first BZ plates between the first Be and the first Li exceeds 550 °C in the upper region and it should be reflected in the next design optimization.

## 5. Conclusion

To develop a Fusion Reactor, we have participated in the TBM program in the ITER. Based on the separate analysis with the functional components such as FW, BZ, SW, and BM by 2012, an integrated analysis model was prepared and preliminary analysis was performed. Considering the flow manifold like SW and BM, more actual flow distributions were obtained and it is confirmed that the structure temperatures were different with the old analysis considering the uniform flow rates. Some regions exceeds the design limit (550 °C) and design optimization with SW and BM will be performed.

After the thermal-hydraulic optimization, structural analysis with ANSYS-mechanical will be performed considering the internal pressure of 10 MPa design pressure.

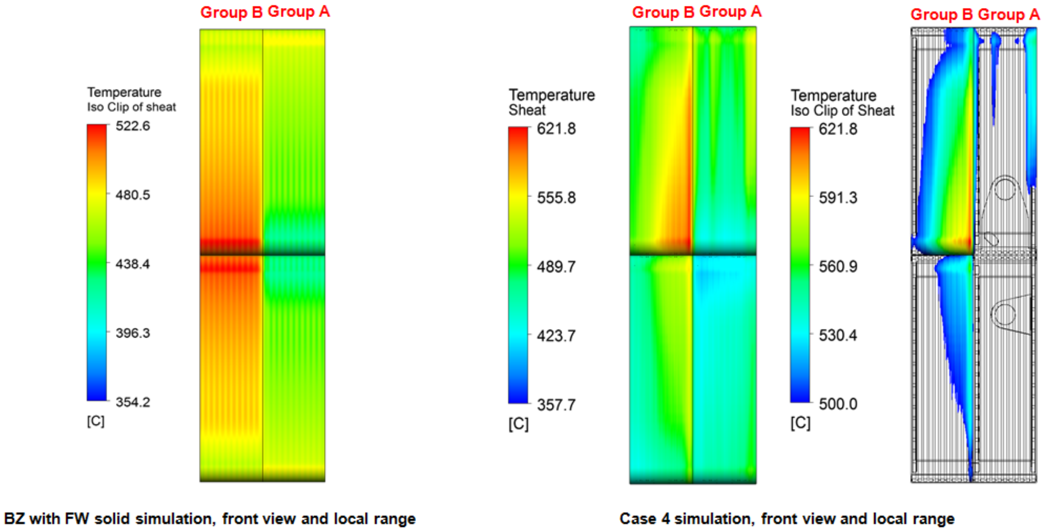


Fig. 6. Flow distribution in FW channels.

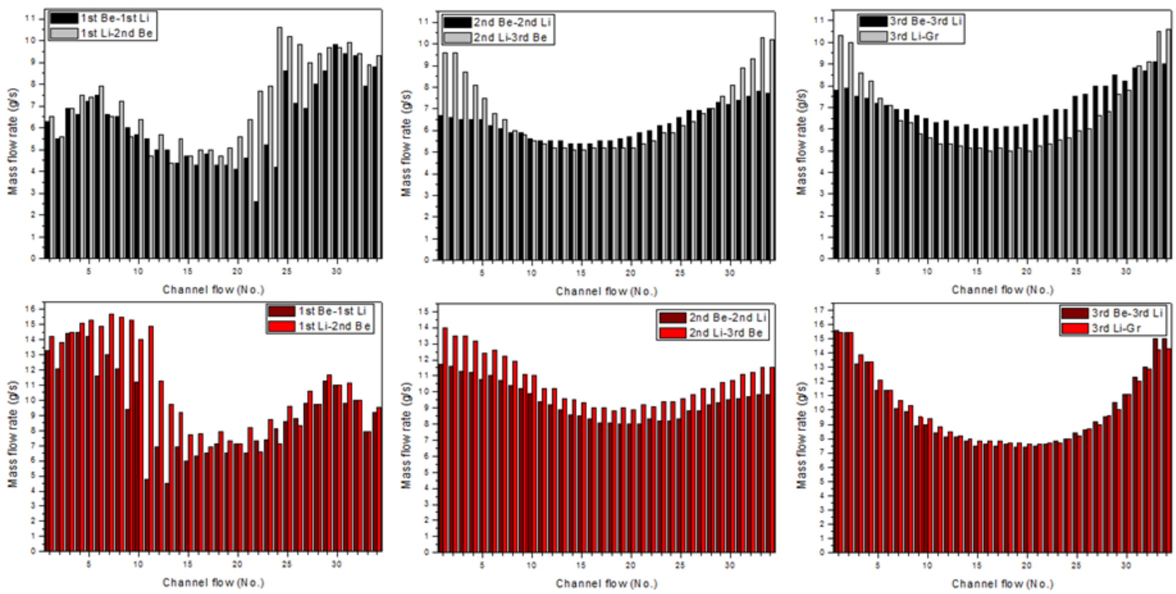


Fig. 7. Flow distribution in the BZ plate.

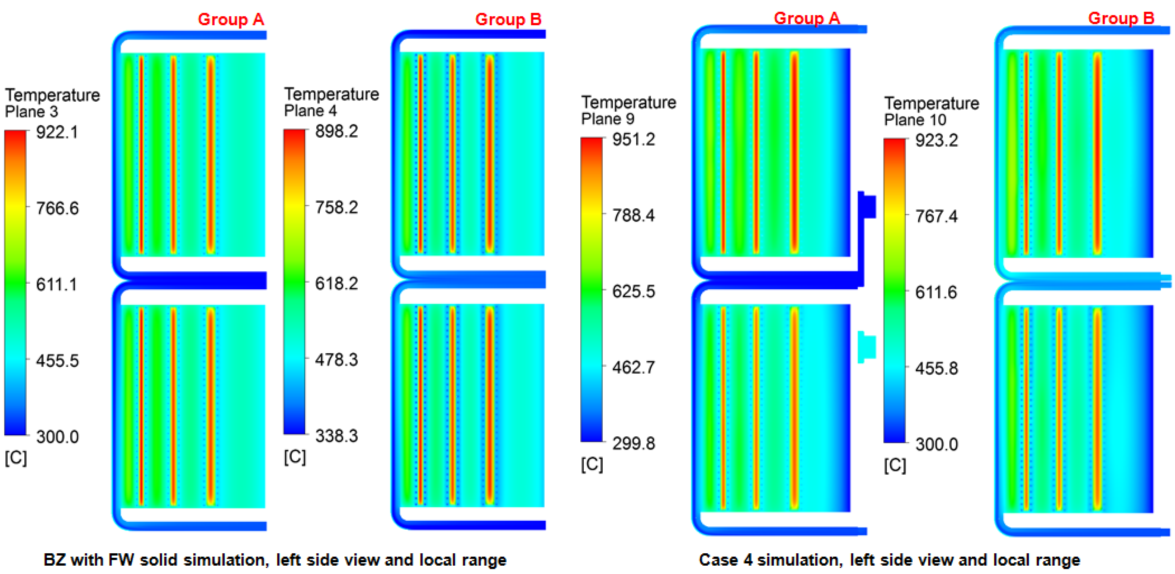


Fig. 10. BZ temperatures by separate (old) and integrated (new) models.

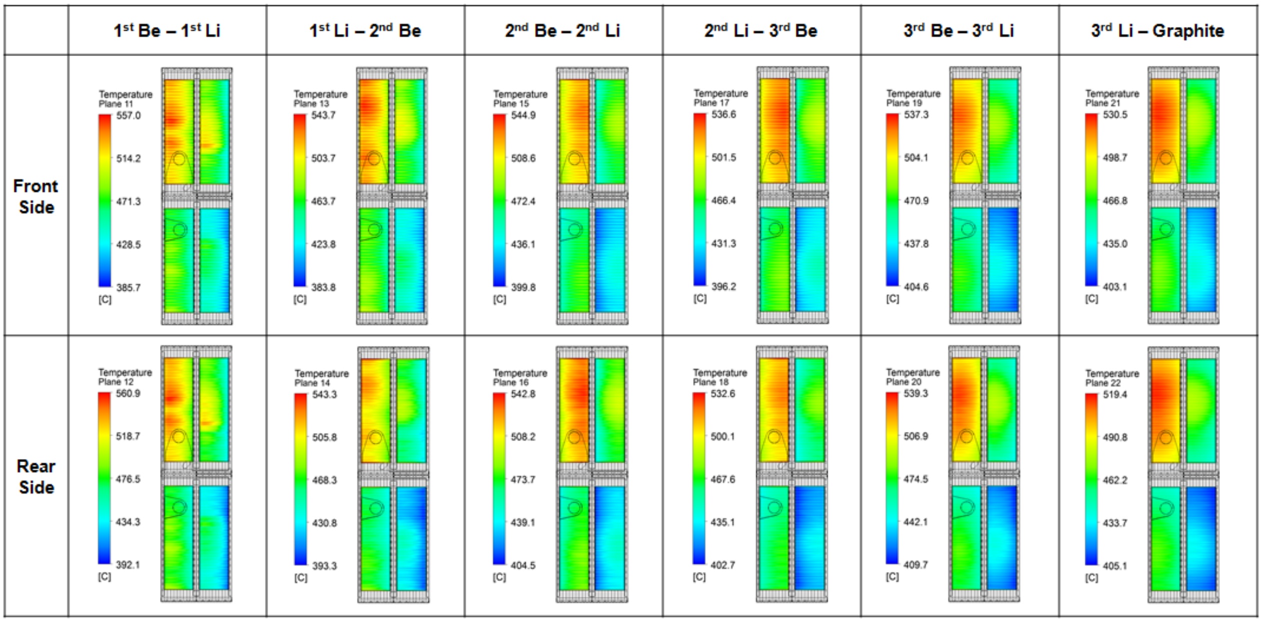

Fig. 11. BZ structure temperatures according to the location

## Acknowledgment

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