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Thermal-hydraulic performance analysis for the conceptual design of Korean HCCR TBM-set

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1. Introduction

The purpose of this document is to provide the thermal-hydraulic (TH) analyses results of the Helium Cooled Ceramic Reflector (HCCR) Test Blanket Module (TBM) including TBM-shield, which is called TBM-set. The analyses were performed for Electro-Magnetic Module (EM-TBM) and INTegral Module (INT-TBM) including TBM-shield, respectively, with the same model and meshes according to the ITER operation conditions of H/He and D-T phases, respectively. For each TBM-set, temperature distribution, flow rate and pressure drop were investigated to meet the design requirements and the temperature data were directly provided to mechanical analysis.

2. HCCR TBM-set description

The HCCR TBM shall be installed in the equatorial port #18 of ITER inside the Vacuum Vessel (VV) directly facing the plasma and shall be cooled by a high-temperature He coolant of 300 °C. A low-temperature water-cooled (70 °C) shield shall be placed behind the TBM and it shall be connected with the water-coolant system of the frame. TBM and shield shall be connected by bar-type keys. TBM-set refers the TBM and associated shield and keys, as shown in Fig. 1. The TBM is composed of four sub-modules and a common Back Manifold (BM). The associated shield is a water-cooled 316L(N)-IG block with internal cooling channels [1,2].

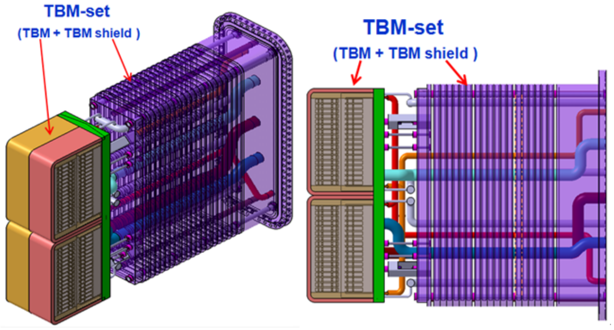
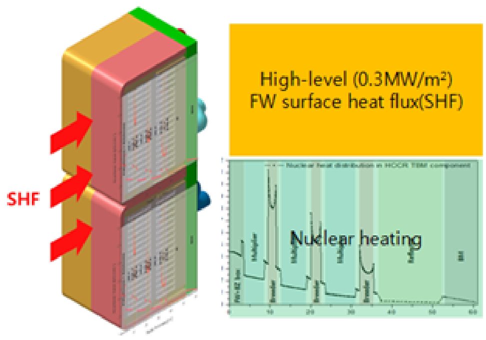


Fig. 1. HCCR TBM-set configuration.

In this analysis, both of INT- and EM-TBMs are considered using the surface heat fluxes and nuclear heating. Heat load was referred from IO document, Heat Loads on TBM First Walls (2LGNJK v2.2) [3.2]. The main considerations are summarized herewith. All loads, static and transient, for the main scenarios, including active and non-active operation phases, have been compiled in a dedicated TBM Heat Load Specification document, which also contains explanations of the physics basis for each load.

For INT-TBM (D-T phase), due to the recess of the TBM front end behind the FW radius, the TBMs will not receive any direct plasma thermal load. Steady state loads will be due only to photon impact from plasma radiative losses and the impact of charge exchange neutrals generated by recycling processes at the plasma edge. For the baseline, 15 MA inductive scenario and at the TBM outer midplane location, these loads are estimated to be at most 0.25 MW/m^2 from photons and a further 0.05 MW/m^2 from charge exchange, for a total of 0.3 MW/m^2.

For EM-TBM (H/He phase), heat load assumes 60% Ptot for 15 MA L-mode by photonic radiation, in which (max. heating power in DD phase 73 MW) and for H-mode requirement to stay in H-mode at 7.5 MA (PLH ~30 MW (D), ~40 MW (He)). Peaking factor of 2 included. The resulting heat flux during plasma current plateau during normal plasma operation is about 0.17 MW/m^2 [3].



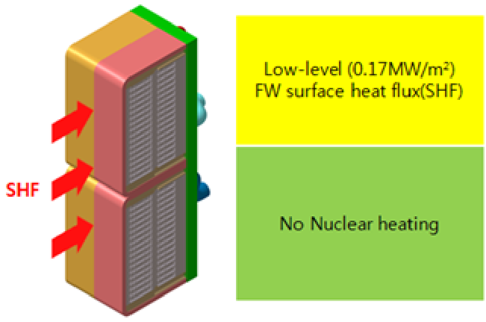


Fig. 2 Boundary conditions for INT- and EM-TBMs

3. Analysis results

Material properties for solid region and He coolant were used in the form of table in ANSYS-CFX 14.5 [4]. For water coolant of TBM-shield, default water properties in CFX code were used. Standard k-ε model was used for turbulent flow under y-plus control to be 20~200 near the wall region [5, 6].

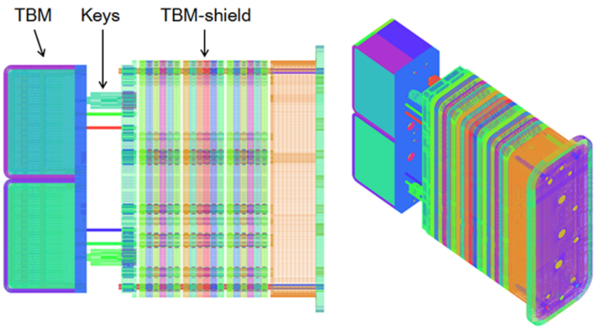


Fig. 3 Structure mesh for TH analysis

2.1 INT-TBM analysis

For INT-TBM analysis, surface heat flux of 0.3 MW/m^2 and nuclear heating were considered as mentioned in Chapter 3. In ANSYS-CFX 14.5, all materials were distinguished as separate domains and the maximum temperature of each material was obtained from these domains. Table 1 shows the obtained maximum temperature at each component comparing with the requirements.

The maximum temperature of structural material (RAFM steel) is 520.1 ^{o}C at BZ plate in group A sub-module but it is lower than the temperature limitation of the RAFM steel (550 ^{o}C). The maximum temperature of Be multiplier is 636.9 ^{o}C at the 2nd Be layer in group A sub-module but it is lower than the temperature limitation of Be pebble (650 ^{o}C). The maximum temperature of Li breeder is 864.9 ^{o}C at the 3rd Li layer in group A sub-module but it is lower than the temperature limitation of the Li pebble (920 ^{o}C). The maximum temperature of Gr reflector is 546.3 ^{o}C at the last Gr layer in group A sub-module but it is lower than the temperature limitation (1200 ^{o}C). For TBM-shield, the maximum temperature of structural material of 316L(N)-IG is 280.0 ^{o}C and it is lower than the requirement (400 ^{o}C).

Table 1 Bulk temperature results for both cases and their requirments

Components		Max. bulk temperature [^{o}C]		Temperature requirements [^{o}C]
		EM-TBM	INT-TBM	
TBM	Structure	397.6	520.1	< 550
	Be	330.7	636.9	< 650
	Li	330.7	864.9	< 920
	Gr	334.7	546.3	< 1200
TBM-shield	Structure	70.0	280.0	< 300

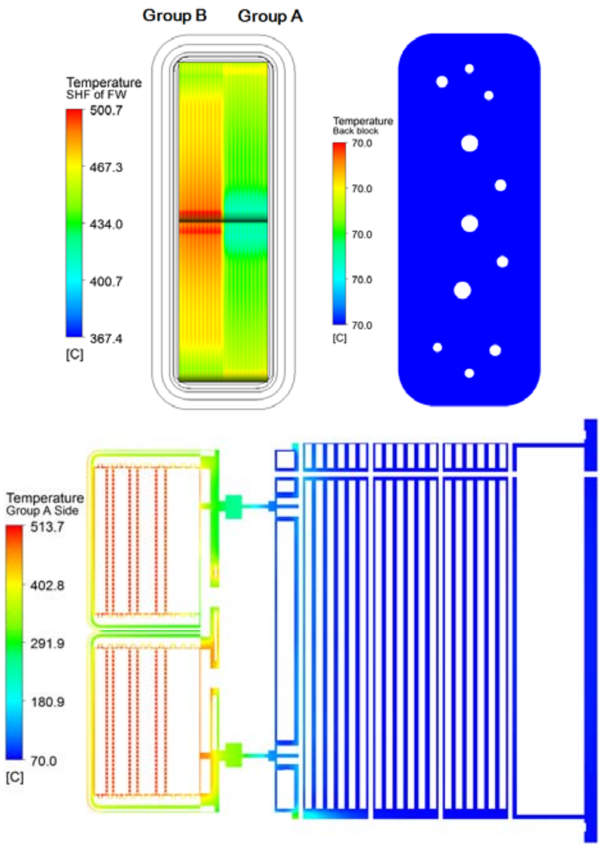


Fig. 4 Temperature distribution of INT-TBM

2.1 EM-TBM analysis

For EM-TBM analysis, surface heat flux of 0.17 MW/m^2 was considered without nuclear heating as mentioned in Chapter 3. In the same way as the case of INT-TBM, the maximum temperature of each material was obtained from the separate domains corresponding to each material.

Table 1 shows the obtained maximum temperature at each component comparing with the requirements. The maximum temperature of structural material (RAFM steel) is 397.6 ^{o}C at FW in group B sub-module but it is lower than the temperature limitation of the RAFM steel (550 ^{o}C). The maximum temperatures of Be multiplier and Li breeder are 330.7 ^{o}C in group A sub-module, which is the same temperature of He coolant due to no heat source and it is lower than the temperature limitation of Be pebble (650 ^{o}C) and Li pebble (920 ^{o}C), respectively. The maximum temperature of Gr reflector is 334.7 ^{o}C at the last Gr layer in group A sub-module and it is lower than the temperature limitation (1200 ^{o}C). It is also the same temperature as the He coolant. For TBM-shield, the maximum temperature of structural material of 316L(N)-IG is 70.0 ^{o}C and it is lower than the requirement (400 oC).

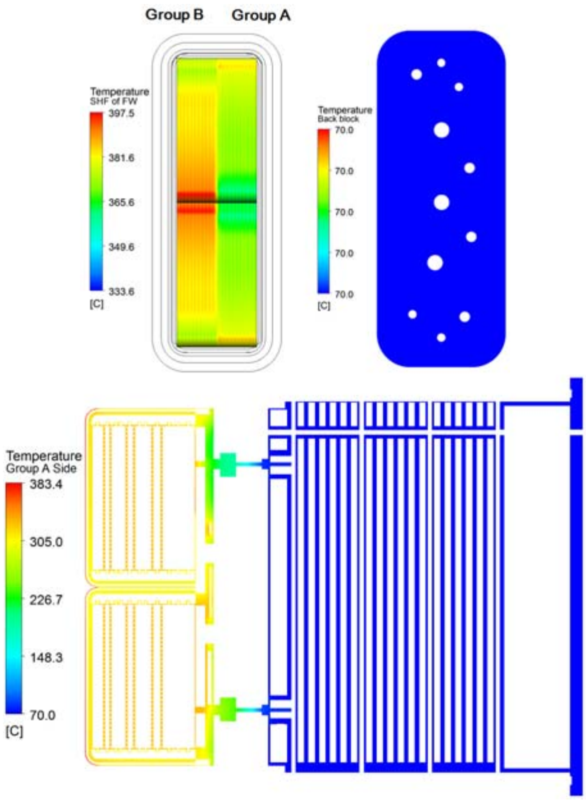


Fig. 5 Temperature distribution of EM-TBM

3. Conclusions

Thermal-hydraulic performance of the EM- and INT-TBM-sets were analysed using the fixed CATIA model for CDR. Fine mesh with 15.9 million elements for solid and 44.7 million elements for fluid was used for ANSYS-CFX 14.5 simulation and coarse mesh with 7.6 million elements for solid is prepared for the thermo-mechanical analysis. The boundary conditions such as heat flux, nuclear heating, and coolant conditions were determined considering the ITER operation condition and designed cooling scheme.

The analysis results and conclusions are as follows;

(1) It is confirmed that both EM- and INT-TBM performance results meet the design requirements, which were determined by the material characteristics.

(2) The obtained temperature difference of He coolant was used for estimation of the total power of TBM, and the pressure drop and flow distribution of TBM-set were investigated.

(3) The temperature results with fine mesh of both EM- and INT-TBM-sets were successfully transferred to those of coarse mesh for the thermo-mechanical analysis.

REFERENCES

[1] TBM Port Plug (TBM PP) System Load Specifications (BKXK75 v2.6)

[2] HCCR-TBS Conceptual Design Description (QQ2R5R v1.0)

[3] Heat Loads on TBM First Walls (2LGNJK v2.2)

[4] ANSYS-CFX 14.5, 2014, User Manual, ANSYS-CFX

[5] HCCR-TBS Material data summary for the design and analysis of CDR (QABFQ5 v1.0)

[6] J.-P. Robertson et al., Gibson Irradiation testing of austenitic stainless steels (26Q7X7 v1.0)