PRELIMINARY ENGINEERING ANALYSIS FOR CN HCCB TBM REGARDING ITER NEW BASELINE SCENARIO

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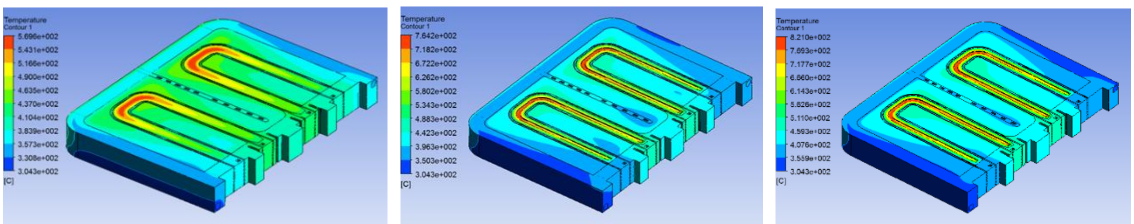
According to the ITER project objectives, some DEMO blanket relevant technologies, such as tritium self-sufficiency, extraction of high-grade heat, design criteria, safety requirement and environmental impacts will be demonstrated by testing of ITER Test Blanket Modules (TBMs) in dedicated equatorial ports.

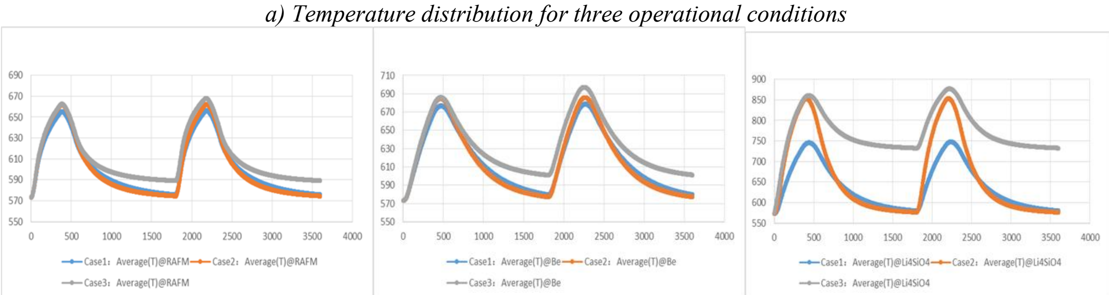
The conceptual design of CN HCCB TBM has been completed since 2015, which was composed of four sub-modules with back plate, and each sub-module consist of the first wall (FW), the cap, the rib, the breeding zone with Li_4SiO_4 and Be pebbles, and the back manifold zone, cooled by 8 MPa Helium [2]. During preliminary design phase, some design update for CN HCCB TBM has been carried out, considering engineering performance and manufacturing feasibility [3][4]. Since the new ITER Baseline has been under development since the beginning of February 2023 [5][6][7], due to some engineering and technical issues, i.e. replacement of Beryllium with Tungsten on first wall (FW) [8], further design optimization and engineering analysis was performed for CN HCCB TBM, including neutronics, thermo-hydraulic, tritium transport, and structural analysis [9][10], and the main results for each aspect are all included in this paper.

For neutronics analysis, preliminary results showed that for the 2024 baseline, the nuclear heating deposition and tritium generation on TBM was almost reduced in half, the maximum nuclear heating rate in Li_4SiO_4 pebble bed was about $4 MW/m^3$.

For thermo-hydraulic analysis, static analysis was firstly performed, it's found that the maximum temperatures of structural and functional materials have been largely reduced, especially for the tritium breeder Li_4SiO_4 pebble bed, whose temperature has been reduced for 20.6%. Transient thermo-hydraulic analysis was performed for sliced model, and three operational conditions were considered, including: i) without electric heater; ii) with electric heater, varied with plasma pulse; iii) with electric heater, continuous heating. The results (see Fig. 1) showed that the FW coolant temperature almost reached the peak value in one plasma pulse; the breeding zone coolant temperature couldn't reach the peak value, the outlet temperature could only reach 428~464℃, and thus the corresponding cooling plate, tritium breeder, and beryllium could not reach the peak value; through adjustment of mass flow rate of the bypass loop and adding electrical heater inside tritium breeder zone, the maximum temperature of Li_4SiO_4 could increase to 821℃, and the average temperature was increased to 604℃, which can basically meet the requirement of tritium release temperature.



a) Temperature distribution for three operational conditions



b) Variation of structure, breeder, multiplier peak temperature for three operational conditions

Figure 1 Transient thermal analysis results of CN HCCB TBM

For tritium transport analysis, system-level transient analysis was performed according to calculated temperature distribution for three operational conditions. The results (see Fig. 2) showed that for the 1st condition (without electrical heater), the tritium partial pressure couldn't achieve steady-state after 32 pulses, and the overall tritium concentration reduced for about 1 grade compared with previous baseline; for the 3rd condition (with electrical heater under continuous heating), the tritium partial pressure could achieve steady-state after ~15 pulses, but the overall tritium concentration was slightly lower than the 2nd condition. Therefore, it can be concluded that adding electrical heater inside tritium breeder zone was enough for tritium balance requirement, it's not needed to further add electrical heater inside neutron multiplier zone.

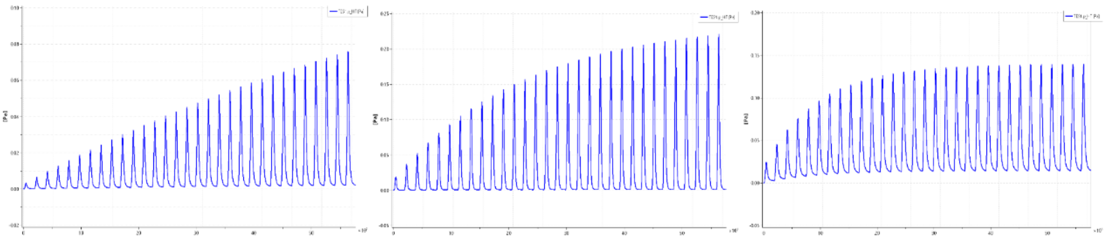


Figure 2 Transient tritium transport analysis results of CN HCCB TBS

For structural analysis, since there was no major change for overall temperature distribution of CN HCCB TBM after adjusting the bypass flow rate and adding internal electrical heater, especially for the FW region and breeding zone, the structural performance was generally the same with previous baseline, only with slight difference on TBM back plate and pipes inside TBM shield. Preliminary results showed that the primary and secondary stresses were well below the limit of structural material, which could ensure the overall structural integrity.

In the future, detailed analysis will be performed for CN HCCB TBS, considering the update design of internal electrical heater.

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