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The numerical simulation for the heat transfer enhancement experiments of the HCCB-TBM first wall

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The first wall (FW) of helium gas Cooled Ceramic Breeder (HCCB) Test Blanket Module (TBM) for ITER need bear the loads like high power density heat flux from plasma, nuclear heat from neutron deposition on the structure, and the transient high heat loads like plasma disruption. The average heat flux density on FW of HCCB-TBM is about 0.3MW/m2 and the maximum partial transient heat flux may reach up to 1MW/m2. In current design schemes in ITER, Reduced-Activation ferritic/Martensitic (RAFM) steel is mostly selected as structural material, several groups of "radial-circular-radial"flow channels are placed inside FW, and 8MPa high pressure helium gas is applied as coolant to remove the heat flux on the surface and the nuclear heat by neutron deposition. As for smooth channel, required heat transfer efficiency and structural security can only be achieved after the flow velocity of helium gas reaches 50~80m/s (operating temperature of RAFM steel structure is lower than 550℃). High flow velocity of helium gas consumes a large amount of pumping power which lowers the net output power of reactor and increases greatly the equipment cost. Although roughness (less than 10μm) technique on the flow channel surface enhance heat transfer efficiency to some extent, the average heat transfer coefficient increases by less than 10% (from 2700 W/m2K to 2900 W/m2K). To enhance the helium gas cooling efficiency and security in FW, heat transfer enhancement technology needs improving and optimizing for the design scheme of helium flow channel to meet the functional requirements of FW. Based on this objective, the filling-evacuating HPHCL (High-Pressure Helium-Cooled Loop) were build to test and prove the heat transfer enhancement schemes of helium gas cooling FW. In this paper, the design scheme of the filling-evacuating HPHCL is presented, and the key issues of engineering manufacture and the test cases are calculated and analyzed. As for the first step, the CFD numerical simulation method is adopted to simulate the test cases of filling-evacuating HPHCL. The sustainable evacuating time under different mass flow rate of the He gas are estimated. On the basis of calculating helium gas cooling scheme of FW smooth flow channel, FW structural temperature gradient, maximum wall temperature, average heat transfer coefficient, and pressure drop of flow channel are selected as evaluation indexes. Three dimension numerical simulation results are compared to acquire optimizational heat transfer enhancement schemes like placing transversal ribs and V-shaped ribs in the flow channel of front wall of FW. The helium gas turbulence intensity and the heat transfer area are improved through optimizing the distance and angle between V-shaped ribs and other coefficients to enhance heat transfer. The calculation results are used as reference for the next verification experiments, which the 8~10MPa high pressure helium gas will be selected as coolant.

Eligible for student paper award?

No

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