CFD Analysis of One-sided Heating on the First Wall of TBM

Jun-Soo Lee, Jin-Hwa Yang and Goon-Cherl Park
Department of Nuclear Engineering, Seoul National University, San 56-1, Shillim-dong, Kwanak-Gu, Seoul 151-742, South Korea
yijunsu2@snu.ac.kr

1. Introduction

One of the main functions of Test Blanket Module (TBM) is to remove heat of the first wall and energy from plasma under the normal and off-normal operational conditions. The design of TBM imposes a peculiar condition for cooling of the first wall that is one-sided heating from the fusion plasma. It can cause large temperature gradient in the first wall and induce a strong thermal stress. In order to ensure the thermal margin of TBM and obtain high efficiency of power conversion system, it is necessary to investigate this phenomenon. Despite this importance, there are not many studies for TBM condition. Thus in this study, the CFD analysis is performed to understand the TBM heat transfer phenomenon and the heat transfer coefficient. Since the conventional TBM design concepts adopt 80 bar helium gas as the coolant, the CFD analysis is conducted at 20, 40, 60, 80 bar with the inlet velocity of 25, 50m/s helium gas, respectively.

2. One-sided Heating on the First Wall of TBM

For the TBM design, the special situation in the first wall occurs that the dominant heat flow is coming from one side only. Figure 1 describes the heat transfer phenomenon from the plasma to the first wall.

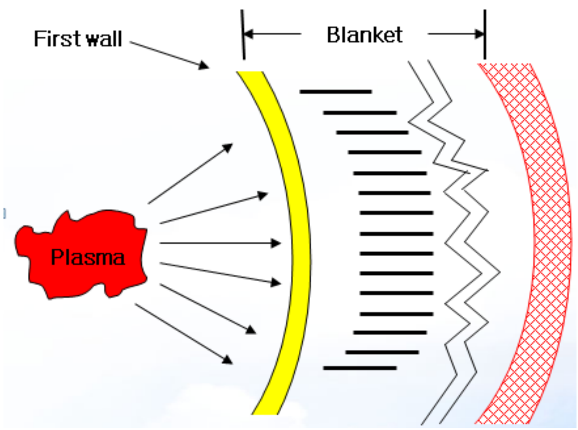

Fig. 1. Schematic diagram of the test section

The first wall is the component of TBM that faces the plasma. Since the one side of the first wall is heated, it can result in large temperature gradient and the strong thermal stress. It is designed to withstand neutron and heat flux from the plasma. The first wall is U-shaped and has the inside cooling channels. Its material is Ferritic Martensitic Steel (FMS). In order to maximize the cooling capability of TBM and keep the first wall temperature below the safety limit, rectangular cooling channels are adopted.

3. CFD Analysis

3.1 Geometry of Test Section

Figure 2 shows the geometry of test section.

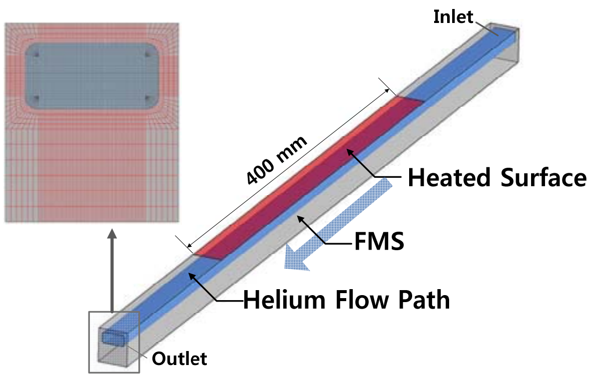

Fig. 2. Test section geometry and mesh structure

Total length of the test section is 770 mm including two 185 mm ducts and 400 mm heated surface. Helium gas of 573 K flows into the rectangular cooling channel. 4 edges of rectangular channel have the radius curvature of 2 mm, because the simple rectangular channel is not suitable for high pressure condition.

3.2 Analysis Condition

The mesh was constructed by using GAMBIT 2.3.16, and the numerical analysis was performed by FLUENT 6.3.26. The CFD analysis condition is tabulated in Table 1. The working fluid was helium gas that is same as the actual TBM coolant. Standard k-ε model was selected as the turbulence model. Material of test section is FMS. The material property of FMS is obtained from ITER MPH and that of helium (isobaric condition) from NIST web. Surface Heat flux of heated surface was set up to 50 MW/m^2.

Table 1. CFD analysis condition

Operating fluid	helium
Inlet Temperature	573 K
Inlet Velocity	25, 50 m/s
Operating Pressure	20, 40, 60, 80 bar
Surface Heat Flux	50 kW/m^2

4. Results and Discussion

The heat transfer coefficient of helium gas is obtained from the bulk temperature of helium gas and the wall temperature and coefficient is calculated from following equation .

$$h = \frac{q''}{T_{wall} - T_{bulk}} \quad (1)$$

Figures 3 and 4 show that heat transfer coefficients increase as the operating pressure increases. Since the density of helium gas varies with the pressure, the variation of the pressure has a significant influence on the heat transfer coefficient of helium. While helium coolant passed through the heated channel, the inlet velocity was dominant factor of heat transfer.

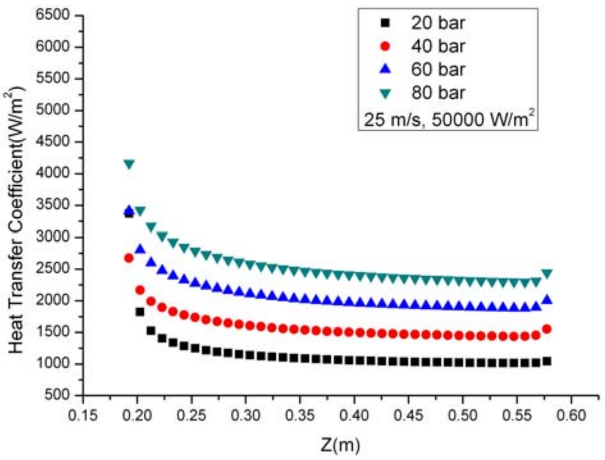

Fig. 3 Heat transfer coefficient of helium gas with pressure variation (inlet velocity: 25 m/s)

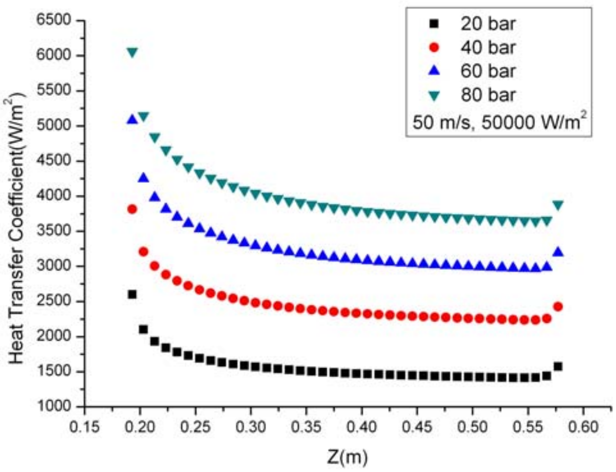

Fig. 4. Heat transfer coefficient of helium gas with pressure variation (inlet velocity: 50 m/s)

Figure 5 shows the average heat transfer coefficient according to the inlet velocity and the operating pressure. This figure shows the effect of inlet velocity on heat transfer coefficient. The value of heat transfer coefficient in the inlet velocity of 50 m/s is about one and half of that in 25 m/s. As a result, the heat transfer coefficient was proportional to the pressure.

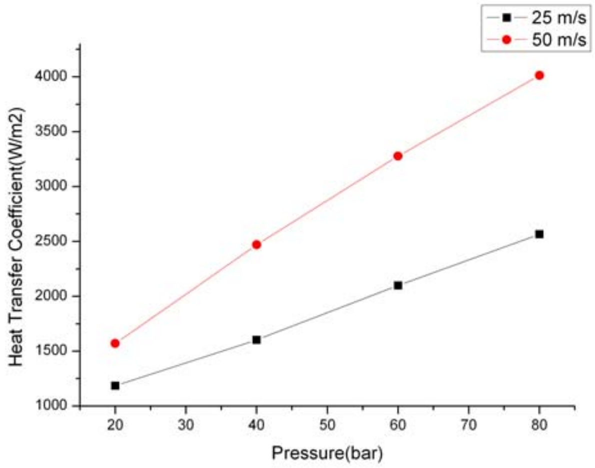

Fig. 5 Heat transfer coefficient with pressure and inlet velocity

5. Conclusion

CFD analysis was carried out to assess the heat transfer phenomena on the first wall of TBM. The analysis was conducted at several pressures and the inlet velocities of helium gas. As the result of the simulation, the heat transfer coefficients of helium gas are obtained. The heat transfer coefficient was enhanced by increasing pressure and inlet velocity of helium gas. This study will be applied to the design of experiment for TBM cooling capability.

REFERENCES

[1] G. Aiello, F. Gabriel, L. Giancarli, G. Rampal, “Thermo- hydraulical and thermo- mechanical analysis of the HCLL-TBM breeding unit”, Vol. 83, pp. 1227-1231, Fusion Engineering and Design, 2008

[2] L.V. Boccaccini, J. F. Salavy, R. Lasser, A. Li Puma, “The European Test Blanket Module systems : Design and integration in ITER”, Vol. 81, pp.407-414, Fusion Engineering and Design, 2006

[3] M. Ilic, B. Kiss, T. Ihli, “Thermo- hydraulic experimental design for the European Helium cooled pebble bed Test Blanket Module”, Vol. 83, pp. 1253-1257, Fusion Engineering and Design, 2008