Thermal Hydraulic Analyses of Lead-Bismuth Spallation Target System with due regard to Core Temperature Distribution

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1. Introduction

In an ADS, a high energy proton beam is impinged on a heavy metal target to produce spallation neutrons that are multiplied in a sub-critical blanket. Therefore, the spallation target is one of the most important units of an ADS.

The key issue in the target design is how to design an appropriate beam window and LBE flow so that the system can sustain thermal and mechanical loads as well as radiation damage. It is well known that a proton beam power of 15-25 MW is inevitable for the practical size (about 1000 MWth power) of the ADS.[1][2] The design of a 20 MW spallation target is very challenging because more than 60% of the beam power is deposited as heat in the window and a small volume on the target system.

In the previous work, basic target system offers sufficient beam current to sustain a 1000MW_{th} power level of ADS.[3] However, it was found that the LBE flow rate was too high, almost 10% of the total coolant flow rate, and also the average LBE temperature rise in the target outlet was too low, compared to the LBE heat up in the core. These problems result in an increased pumping power of the coolant, potential thermal striping of the core upper structures, and a decrease of the thermal efficiency of the system. Thus, there is a big necessity to reduce the LBE flow rate in the target channel, without hampering the target performance.

For this purpose, we introduce a dual LBE injection tube(DIT), which controls the LBE velocity distribution at the target inlet.

The main objective of the present paper is to show the possibility of flow rate reduction with DIT and the thermal hydraulic analyses result with due regard to core temperature distribution.

2. Target System

Korea Atomic Energy Research Institute (KAERI) has been developing an ADS called HYPER. HYPER is expected to need about 20 mA proton beam of 1 GeV to sustain a 1000MWth power level. Lead-bismuth eutectic (LBE) is the target material and the target coolant. The beam window material is chosen as 9Cr-2WVTa. The cylindrical beam tube and hemi-spherical beam window are adopted in the basic target design of HYPER. The temperatures of LBE at inlet and outlet are 340 ^{o}C and 490 ^{o}C, respectively. The total flow rate of HYPER is 45506.26 kg/s.

3. Numerical Simulation

The heat generation inside the beam window and LBE is calculated using the LCS 2.7 for the two kinds of proton beam distributions, parabolic, uniform, considered. The thermal-hydraulic analyses of the target system are performed using the CFX 5.7 code for the beam window diameter of 35cm and the beam window thickness of 2mm. The thermal-hydraulic analysis of core is performed using the MATRA-LMR code, which is developed for LMR core analysis.

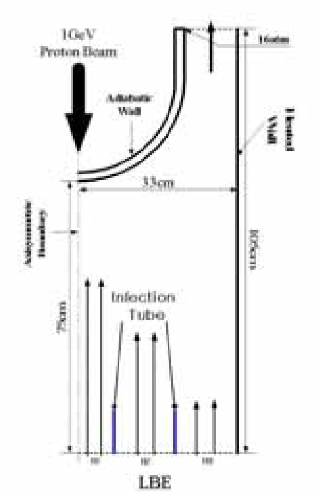

Fig. 1. Computational domain and boundary conditions

In the thermal hydraulic analyses of the target system, all the cases use the standard k-ε turbulence model to predict turbulent flow characteristics, and the logarithmic law-of-the-wall to predict near-the-wall characteristics. Sufficient mesh refinement is used in each case to obtain y+ values between 30 and 200 in the heated regions, indicating that the turbulence model can provide reasonable predictions in these regions. The calculation is performed as a steady state simulation using the SIMPLEC solution algorithm and higher upwind differencing scheme.

In the thermal hydraulic analyses of the inner core, the LBE properties are implemented and the Lyon-Martinelli[4] correlation and Novendstern[5] correlation are used for the correction of heat transfer coefficient and pressure drop, respectively.

4. Results

Figure 2 shows the axial temperature distribution of inner core which is mean value at the gap region and implemented to the wall boundary condition for the thermal hydraulic analyses of target system.

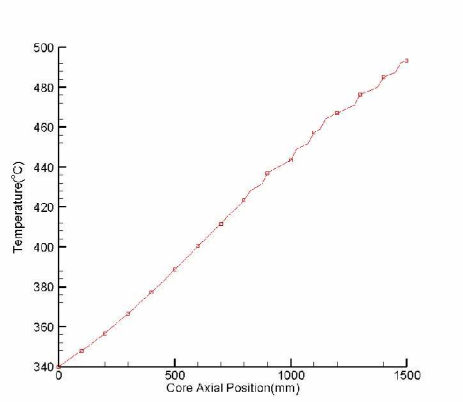

Figure 2. Axial temperature distribution of inner core

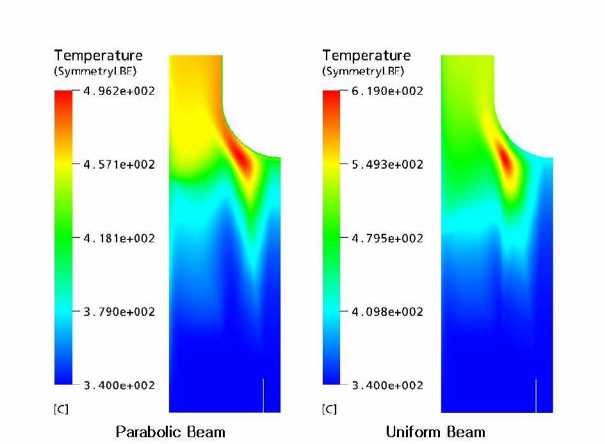

Figure 3. The temperature distribution in the target system

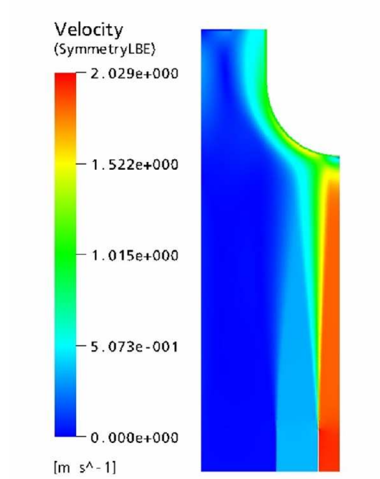

Figure 4. The Velocity distribution in the target system

Figure 3, 4 show the temperature and velocity distribution in the target system, respectively. In this case, the injection tube height is 10 cm, and the injection tube diameter are 10cm and 30cm, respectively. Also, beam currents of parabolic and uniform beam are 12.3mA and 19.6mA, respectively. The inlet velocities of R1, R2 and R3 are 1.95m/s, 0.3m/s and 0.01m/s, respectively.

Without an injection tube, the flow rate of the target system is 4560kg/s with inlet velocity 1.31m/s and outlet temperature is 355.5℃ in case the uniform beam current is 19.3mA. With a dual injection tube, the flow rate of the target system is 373kg/s and outlet temperature with heated wall boundary condition is 523.6℃ in case the uniform beam current is 19.6mA. Also, without the heated wall boundary condition, outlet temperature is 538.7℃. The result shows that the lower wall temperature than that of LBE in the target system cut down the temperature difference between the inlet and the outlet in the target system.

5. Conclusions

With a dual injection tube of a 10cm inner tube diameter and a 30cm outer tube diameter, the flow rate of the target system is 373kg/s that is about 91.8% loss than that of the target system without an injection tube. Also, the temperature difference between the inlet and the outlet is 183℃ that is about 1180% higher than that of the target system without an injection tube.

The results show that the target system with a dual injection tube offers not only a higher allowable beam current but also a significantly reduced flow rate at the target channel.

If the inner injection tube diameter is larger than that of this case, that is 10cm, the temperature of LBE and beam window will be further reduced, and the optimum design parameters for target system with DIT will be obtained and to achieve this a related study is underway.

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