Optimization of Flow Rate in Lead-Bismuth Target System with Dual Injection Tube

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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. Recently there have been some intensive studies on the design of LBE spallation targets.[1][2] However, they are mainly focused on spallation neutron sources or experimental scales of ADS targets. 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.[3][4] 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.

The main objective of the present paper is to show the possibility of designing a 20 MW lead-bismuth spallation target with a beam window.

In the previous work, basic target system offers sufficient beam current to sustain a $1000MW_{th}$ power level of ADS.[5] 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. Sensitivity studies for the DIT have been performed for the HYPER target system and the results are provided in this paper.

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 $1000MW_{th}$ 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 4.4 code for the beam window diameter of 35cm and the beam window thickness of 2mm.

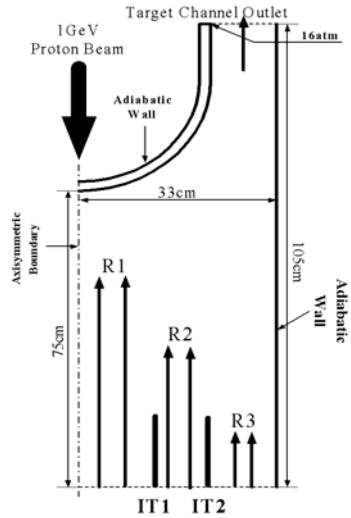

Fig. 1. Computational domain and boundary conditions

In the thermal hydraulic analyses, 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.

4. Results

With a dual injection tube of a 10cm inner tube diameter and a 30cm outer tube diameter, the allowable maximum beam current is 14.0mA for a parabolic beam that is about 159% higher than that of the target system without an injection tube and calculation results are shown in Figure 2..

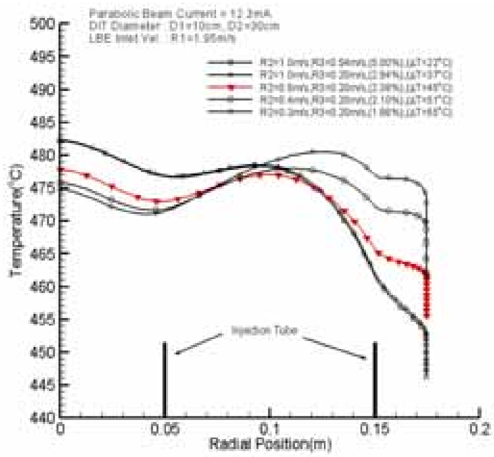

Figure 2. The Temperature distribution at the wetted surface of beam window with parabolic beam.

Also, with a dual injection tube of a 20cm inner tube diameter and a 30cm outer tube diameter, the allowable maximum beam current is 21.27mA for a uniform beam that is about 111% higher than that of the target system without an injection tube and the calculation results are shown in Figure 3.

From the viewpoint of the thermal hydraulics, the results show that a smaller diameter of the inner injection tube would be appropriate for the parabolic beam and a wider diameter of the inner injection tube would be appropriate for the uniform beam.

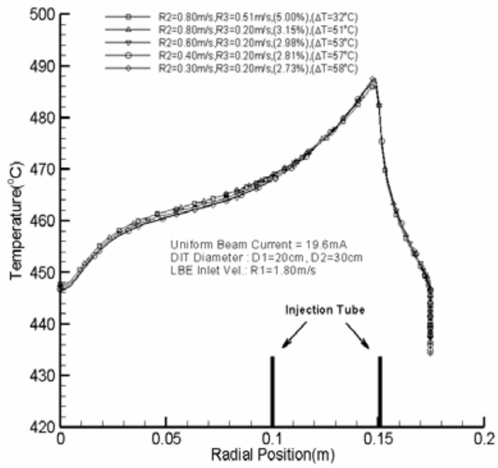

Figure 3. The Temperature distribution at the wetted surface of beam window with uniform beam

5. Conclusion

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 inlet velocity of R3 is further reduced, the LBE flow rate could be decreased without reducing the maximum allowable beam current and to achieve this a related study is underway.

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