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PARALLEL NUMERICAL SIMULATION OF CONJUGATE HEAT TRANSFER IN THE TARGET SYSTEM OF AN ADS BY DOMAIN DECOMPOSITION METHOD

K. ARUL PRAKASH, B. V. RATHISH KUMAR, AND GAUTAM BISWAS

Abstract. Accelerator Driven Sub-critical nuclear reactor System (ADS) are envisaged to enhance neutronics of reactors as well as safety physics. The spallation target module or target system is the most innovative and key component for an ADS. In the target module, a high energy proton beam from the accelerator irradiates a heavy metal target like Lead Bismuth Eutectic (LBE) to produce spallation neutrons, which initiate the fission reaction in the sub-critical core. The removal of the spallation heat by the same LBE is a challenging thermal-hydraulic issue. Also the presence of any recirculation or stagnation zones of LBE in the flow path may lead to local hot spots either in the window or in the flowing liquid metal which is detrimental to the performance of the target. The beam window, a physical barrier separating the liquid metal (LBE) from the proton beam, is a critical component as it is subject to high heat fluxes as well as thermal and mechanical stresses. In addition to heat deposited in the bulk of LBE in the spallation region, large amount of heat also gets deposited on the window. To incorporate the physical situation in a more realistic way, a conjugate heat transfer problem (solving the conduction equation of the beam window in conjunction with the energy equation) is accomplished. As the conjugate heat transfer problem is found to be computationally very demanding, the energy equation module is parallelized following the paradigm of domain decomposition method using MPI (Message passing Interface) library. In this study, the equations governing the axisymmetric flow and thermal energy are solved numerically using a Streamline Upwind Petrov-Galerkin (SUPG) Finite Element (FE) method. The turbulent kinetic energy and its dissipation rate are modeled using k-ϵ model with standard wall function approach. The interface temperature as a result of conjugate heat transfer and Nusselt number distribution at the interface with a reasonable speedup is computed and quantified.

Key words. ADS, Thermal Hydraulics, Conjugate heat transfer, Streamline Upwind Petrov-Galerkin technique, Parallel Computing

1. Introduction

In the near future, ADS will play a significant role in nuclear power generation due to their ability to enhance both the neutronics of reactors as well as safety physics (Rubbia *et al.* [13]). The target system is the critical part of an ADS which is shown in Figure 1 (i). In the target system, a high energy proton beam from the accelerator irradiates a heavy metal target to produce spallation neutrons which initiates fission reaction in the sub-critical core. The protons are induced on the target through vacuum pipe closed by a window at the end. Therefore, the beam window is exposed to a huge amount of thermal and mechanical load and suffers from radiation damage due to spallation neutrons. Lead-Bismuth Eutectic (LBE) is preferred as the target material due to its high production rate of neutrons, effective heat removal rate and a very small amount of radiation damage properties. In addition, it can be used as a reactor coolant simultaneously. Thus the spallation target module is the most innovative component of ADS which constitutes the physical interface between the accelerator and the sub-critical core.

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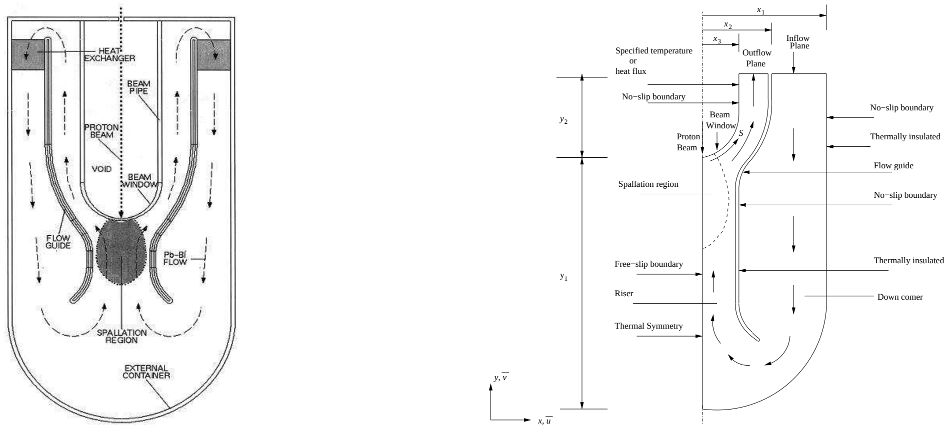

(i) (ii)

FIGURE 1. (i) Schematic diagram of the target module of an ADS (ii) Domain of Interest with boundary conditions.

Even though it is relatively easy to take away the total spallation heat by the LBE, what is crucial is that this has to be achieved without target temperature exceeding the stipulated temperature in any region of the flow. There should not be any re-circulation or stagnation zones leading to the hot spots, inadequate window cooling, generation of vapors etc. This necessitates detailed flow analysis in the spallation region, flow region near the entrance of the annular zone along with the temperature distribution on the window. Investigations concerning the development of target system of an ADS have been summarized by Maiorino *et al.* [9]. A review of the recent literature reveals that there have been few investigations focussing on the design of the target system of an ADS. Dury *et al.* [6] have analyzed the spallation zone near the beam window of the European Spallation source liquid-metal target facility numerically using CFX-4. They considered liquid mercury as the spallation target. Cho *et al.* [4] have computed the heat transfer and flow characteristics in a simplified version of the target system model called HYPER using ANSYS and CFX packages. Recently, window based target modules, such as, XADS (Batta *et al.* [1]), with nozzle shaped flow guides have been proposed. In the ADS model considered in this study, the downcomer part of the ADS is separated from the riser part by using a flow guide. The flow takes a 180^o turn around the tip of flow guide. In order to simulate the target system an in-house SUPG-FE code based on the projection scheme of Chorin [5] has been developed and validated. The two equation k-ϵ model with standard wall function approach is used for analyzing turbulent flows. Further, we account for the high energetic proton beam impingement on the window surface by introducing isothermal condition on the window. Simulations have been carried out to analyze the flow and heat transfer characteristics in the target system of an ADS for a wide range of Reynolds numbers. The optimization of the target modules are also carried out based on the suitable design of flow guide which separates the hot rising flow from the cold one. In the region where the flow takes a 180^o turn different shapes of flow guide are introduced. Initially a straight flow guide with cylindrical bottom container is simulated (Prakash *et al.* [11]). Finally a funnel shape flow guide with spherical bottom container is designed in order to accelerate the liquid metal and thereby enhance the cooling of the window (Prakash *et al.*