Large-Eddy Simulation of IFMIF Liquid-Metal Target flow

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The International Fusion Materials Irradiation Facility (IFMIF) [1] is an accelerator based deuteron-lithium neutron source to simulate the neutron irradiation field in a fusion reactor. As a target of 40-MeV, 2x125- mA deuteron beams liquid lithium (Li) free-surface jet flow is proposed. The free-surface of the Li target is subjected to the low gas pressure in the beam tubes. To generate a radial pressure distribution within the lithium layer, which increases the boiling point of the fluid, a concave curved leading back plate is the preferred design option. Before entering the target domain the lithium flow is conditioned by a nozzle, which has to form a lithium jet with a uniform velocity profile and minimal turbulence intensity at the exit.

The concave shaped nozzle wall and back-wall curvature of the IFMIF liquid-metal target can lead to the appearance of secondary motions in the lithium flow caused by Taylor-Görtler (TG) instabilities. These motions can influence significantly the hydrodynamic stability of the jet flow and the heat transfer from the hottest region in the target to the back plate. Their existence can cause an irregular flow separation at the nozzle edge. The TG vortices increase the wall shear stress and thus can accelerate the corrosion/erosion of the target structure.

Recent validation analyses [2] have shown the suitability of the Large Eddy Simulation (LES) technique for the simulation of transitional and turbulent boundary layer flows accompanied by the TG vortices.

The objective of this paper is to present the results of the LES of the IFMIF liquid-metal target flow conducted using the wall-adapting local eddy-viscosity Subgrid-Scale model [3]. The simulations were performed for the lithium velocity at the nozzle exit of 10 m/s.

The detailed numerical investigation is focused on the development and formation of the large-scale TG vortex structures in the nozzle and back-wall boundary layer flows. Two main effects associated with TG instabilities: the change of the near wall flow structure and interaction of the TG vortices with the lithium free-surface, were analysed. Two back-wall design concepts have been compared.

The simulation results show the appearance of the longitudinal coherent vortical structures in the boundary layer near the concave surfaces of the nozzle and back-wall, which are responsible for strong organization of streamwise and wall-normal velocity fluctuations, and contribute significantly for the Reynolds stress.

The simulations show that the TG vortices on the free-surface side are transported with the flow downstream the nozzle outlet. The interaction of the remaining TG vortex structures with the free-surface induces propagation of longitudinal waves on the lithium free-surface.

[1] IFMIF Comprehensive design report. The International Energy Agency, 2004.
[2] S. Gordeev, V. Heinzel, R. Stieglitz, Analysis of Görtler instabilities in liquid metal target flow, Proceedings of the Sixth Int. Symposium on Turbulence, Heat and Mass Transfer, Rome, Italy, 14-18.09.2009, pp. 189-192
[3] STAR-CCM+ Version 4.02.011, CD adapco, 2008.