CFD Study of In-Core Partial Flow Blockage by Insulation Debris for a Typical Water Cooled Small Modular Reactor

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1. Introduction

Flow blockages differ from many other reactor core accidents as a consequence of their localized nature. The multitude of potential mechanism for causing flow blockage over a localized region of reactor core maybe divided roughly into two groups: debris swept against the core inlet structure by the coolant flow and failure of fuel or other component within the core [1-3]. This paper centers about the computational fluid dynamics (CFD) analysis of the partial core flow failures arising from blockage in the core.

2. Methods and Results

For the purpose of numerical analysis, the geometry and boundary conditions were taken from a typical small modular reactor (SMR). Analysis was performed using the commercial CFD code CFX 12.1 [4]. The Reynolds Averaged Navier-Stokes (RANS) equations were numerically solved for the mass, momentum and turbulence model. The flow cross section of the model represents ~1/7 of an actual fuel element, with a 5 × 5 rod bundle, 600 mm long as illustrated in Fig. 1. Each rod is 9.5 mm in diameter with a bundle pitch of 12.6 mm. The debris is spherical with a diameter of 8.3 mm (Fig. 2).

The standard *k*-*ε* turbulence model of Launder and Spalding was used in the current numerical analysis. It is practically useful and converges well for the complex turbulent flow in the subchannel geometry. Prevailing at the channel inlet is the uniform axial velocity of 6.79 m/s (*Re* = 65,000) at temperature of 570 K. The operating pressure and heat flux are 15.5 MPa and 250 kW/m^2, respectively. Unstructured fine meshes are used to discretize the computational domain (Fig. 3).

The velocity profiles are demonstrated in Fig. 4. The developed velocity profiles were found at $Z/D_h > 40$ after the spacer grid. The top peaks of the axial velocity profiles were located at the subchannel centers. The bottom peaks were matched with the gap centers. The pressure profiles at the center of channel B1 are shown in Fig. 5. The pressure loss is for the most part due to flow blockage area of debris. The swirling flow results in a pressure gradient being created in the radial direction, consequently affecting the boundary layer development. The cross flow between the flow paths adjacent to the individual fuel pins and flow from adjoining lattice cells tends to mix and cool the affected fuel pins, except for a stagnant wake area immediately downstream of the blockage. The flow was recoverd from the disturbance roughly 26 hydraulic diameters downstream of the blockage. The bulk temperatures at the center of channel B1 are shown in Fig 6.

Figure 7 shows the axial variation of turbulent kinetic energy at the center of channel B1. The results indicate a significantly increased turbulent kinetic energy due to blockage.

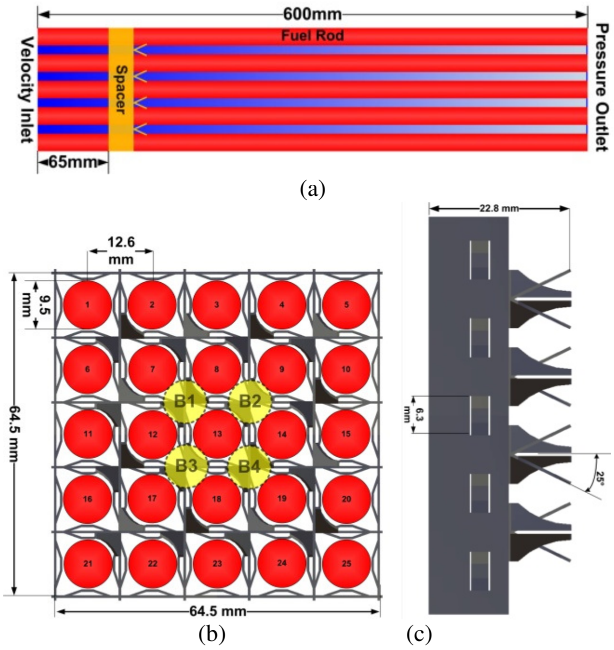


Fig.1 Computational domain (a) with details of the spacer grid (b) and the vanes (c).

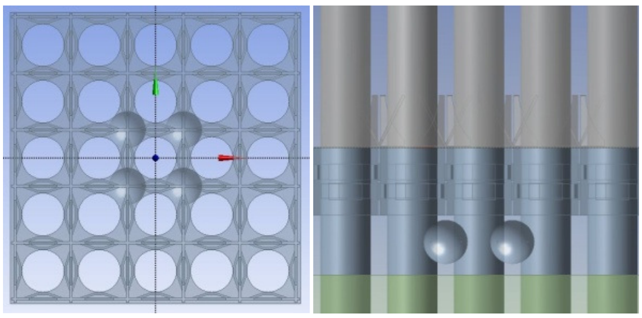


Fig. 2 Location of simulated insulation debris.

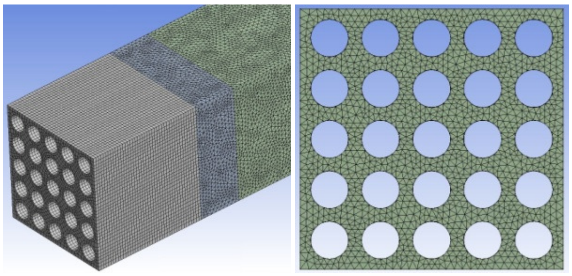
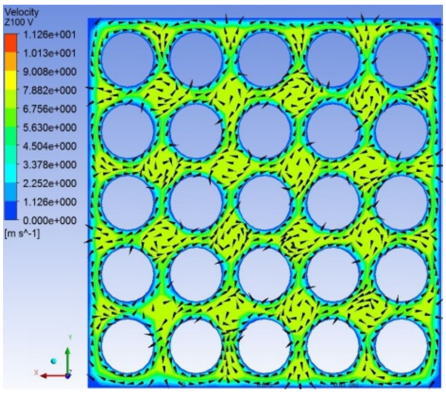
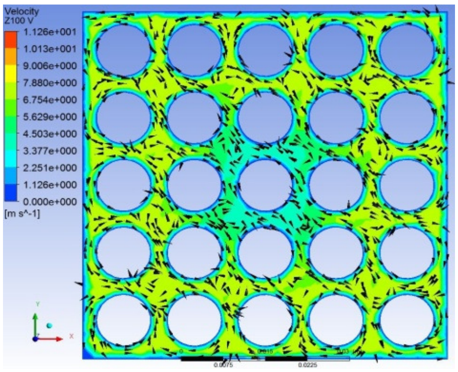


Fig. 3 Meshes in the computational domain (a) and velocity inlet (b).



(a)



(b)

Fig.4 Velocity vectors and profile at z = 100mm downstream the spacer grid without blockage (a) with blockage (b).

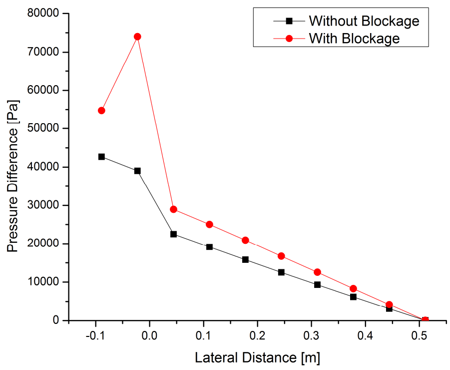


Fig 5. Pressure distribution at the channel B1.

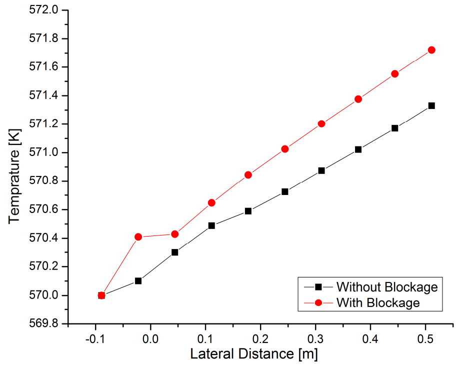


Fig 6. Bulk temperature profiles at the center of channel B1.

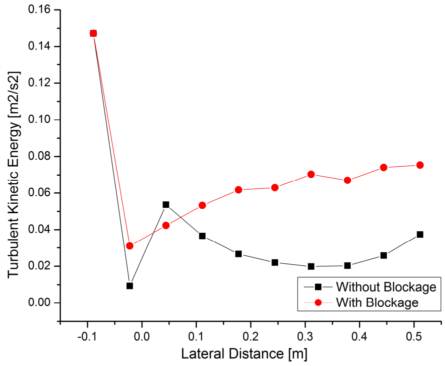


Fig 7. Turbulent kinetic energy profiles at the center of channel B1.

3. Conclusions

The purpose of the current study was to determine the effect of partial blockage on thermohydrodynamic parameters in a typical water cooled SMR. The flow blockages differ from many other reactor core accidents on account of their localized nature. The flow was recovered from the disturbance 26 hydraulic diameters downstream of the blockage. Thermohydrodynamics and neutronics coupling would indeed be interesting for more meticulous analyses of the partial flow blockage for SMRs.

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