Abstract

The small spatial and temporal scales associated with boiling problems make experimental measurements very challenging. On the other hand, direct numerical simulations of boiling flow problems can resolve the small spatial and temporal scales associated with the problem. Therefore, in the past two decades many numerical models have been developed for simulating boiling flow problems. For modelling boiling flow problems, accurate interface capturing and accurate prediction of the interfacial heat and mass transfer is very important.

For numerical simulations of phase change problems, the front tracking method and the interface capturing methods are widely used. However, the front-tracking method is very challenging to implement for boiling flow problems as interface breakup, and merger is very common in boiling flow problems. Therefore, the interface capturing method is preferred for modelling boiling flow problems. The volume of fluid (VOF), the level set (LS), and the coupled level set and volume of fluid (CLSVOF) methods are the popular interface capturing methods preferred for simulating boiling flow problems. However, the use of the VOF method alone leads to unwanted spurious currents in the vicinity of the interface whereas the LS method suffers from the mass loss problem. Therefore, the CLSVOF method is preferred for the direct numerical simulation of boiling flow problems. However, most of the CLSVOF methods available in the literature use the operator-split advection method which is computationally expensive, as it requires interface reconstruction twice and thrice for 2D and 3D problems, respectively. Additionally, most of the numerical studies reported in the literature were performed using structured mesh. Hence, these studies were mostly limited to simple geometries. However, for real-life applications, geometries are complex, and it will be easy to mesh these geometries with unstructured meshes. Thus, in the present work, a CLSVOF method has been proposed for 3D unstructured polyhedral meshes with multi-directional advection. The proposed CLSVOF was thoroughly validated against a number of standard advection test cases. The interface error norms obtained using the proposed CLSVOF method compare well with the results available in the literature, which were obtained using higher-order interface reconstruction techniques. The accuracy and

performance of the proposed CLSVOF method were also checked for various two-phase flow test cases without phase change. Finally, the proposed CLSVOF method was used to simulate natural convection film boiling over a 3D flat surface and a 3D horizontal cylinder. The present heat transfer results are in good agreement with the results available in the literature.

Many analytical and experimental studies on flow film boiling over a sphere are available in the literature. However, most of these studies are focused on subcooled and saturated flow film boiling over a sphere in the natural and forced convection regime. For the natural convection regime, the effect of the surface tension force and the size of the heated spherical surface under reduced gravity levels is not very clear from the literature. Therefore, in the present work, the proposed multi-directional CLSVOF method was used to numerically study the effect of the size of the heated sphere on the interface evolution and the associated heat transfer characteristics for natural convection film boiling over a sphere under different gravity levels. For flow film boiling over a sphere, there is no proper heat transfer data available in the literature for the mixed convection regime as compared to the forced convection regime. Therefore, the proposed multi-directional CLSVOF method was used to numerically study flow film boiling over a sphere in the mixed convection regime. Simulations were performed for both the vertical and the horizontal flow configurations. The interface evolution, vapour wake dynamics, and heat transfer have been thoroughly investigated by varying the saturated liquid flow velocity, sphere diameter, and wall superheat for both flow configurations.

The experimental studies in the literature have reported that peculiar structures appear in the vapour film as the fluid approaches the critical pressure for film boiling over a wire. However, the exact physics behind this observation is not clearly explained in the literature. Therefore, this problem is studied numerically in the present work.

The mixed convection regime can also be important in some scenarios for film condensation over a bank of cylindrical tubes. However, the literature on condensation over a bank of cylindrical tubes in the mixed convection regime is very limited. Therefore, in the present work, the proposed multi-directional CLSVOF method was used to simulate flow film condensation over an inline arrangement of two cylinders in the mixed convection regime. The interface evolution and the associated heat transfer characteristics were thoroughly studied by varying various flow and geometrical parameters. The condensate removal from the top cylinder was mostly observed to be in the form of individual droplets. However, a liquid column is formed between the two cylinders as condensate from the top cylinder gets drained to the second cylinder. The number of droplet generation sites was observed to increase as the cylinder diameter is increased. Interfacial waves were evident in the liquid film around the bottom cylinder for the large diameter cylinder. These interfacial waves significantly affect the heat transfer for the bottom cylinder. As the wall subcooling increases, the condensate removal pattern between the top cylinder and the bottom cylinder changes from a combination of liquid droplets and columns to stable liquid columns.

Finally, a new multi-directional advection method based moment of fluid (MOF) method developed for 2D unstructured messh was extended to for 3D unstructured polyhedral mesh. The proposed multi-directional MOF method is computationally efficient and inexpensive than the multi-directional CLSVOF method proposed earlier in this work. The accuracy and performance of the proposed multi-directional MOF method were observed to be much better than the other multi-directional methods available in the literature.