Thesis Title: Numerical simulations of film boiling and condensation over circular cylinders using interface capturing methods

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ABSTRACT

Phase change phenomena are used to efficiently transport energy in various thermal systems. This is due to the high value of latent heat associated with phase change processes. The phase change phenomena of boiling and condensation are encountered at a wide range of scales in industries from electronic chip cooling to cold storage refrigeration. High heat transfer rates are achieved in the processes involving nucleate boiling and drop-wise condensation. Owing to lower heat transfer rates, the film boiling and film condensation regimes are generally avoided in industrial applications. However, estimates of heat transfer in the film boiling and condensation regimes serve as the limiting cases in boiling and condensation processes. The spatial and temporal scales of the phase change phenomena of film boiling and condensation are small, making the experimental measurements difficult. The theoretical studies on film boiling and condensation involve several simplifying postulations on the interfacial, hydrodynamic and heat characteristics of the phenomena. Direct numerical simulations of two-phase flows with phase change would enable us to improve our understanding of the film boiling and condensation phenomena and will also eliminate the difficulties in the experimental and theoretical analysis of the phenomena.

Interface capturing techniques are one of the important direct numerical simulation methods to simulate multi-phase flows. These techniques capture interfaces on a fixed Eulerian grid, making them computationally cost-effective. Coupled level set and volume of fluid (CLSVOF) is one of the popular and widely used interface capturing techniques. In the present study, a numerical framework using the CLSVOF method is developed to simulate the film boiling phenomenon over circular cylinders. Hence, the two-phase flow solver is developed for two-dimensional unstructured grids, which enable simulations involving curved geometries such as cylinders. The advection of the volume of fluid data is achieved using a

multi-direction geometric algorithm and the advection of the level set field is done using a total variational diminishing (TVD) scheme. Post advection, the level set field is reinitialised using a geometric procedure based on the inteface obtained from the volume of fluid (VOF) method. The developed numerical framework is validated with regard to the advection of the level set and volume of fluid data, reconstruction of the interface, surface tension force calculation and phase change calculation on both structured and unstructured grids.

The developed CLSVOF based two-phase flow solver was used to study film boiling over a system of two inline cylinders. The effect of liquid Reynolds number, non-dimensional wall superheat and non-dimensional spacing between the cylinders on the interface dynamics, fluid flow characteristics and heat transfer characteristics were studied. Studies were performed for upward and horizontal liquid flow configurations in the mixed convection regime.

The moment of fluid (MOF) technique is another interface capturing method that has been gaining popularity in recent times. The MOF method can resolve fine interface structures. Hence, it is one of the important direct numerical simulation techniques used for multi-phase flows. In the present work, a numerical framework based on the MOF technique was also developed to simulate film boiling and condensation on two-dimensional unstructured grids. The MOF technique involves the advection of the centroid and volume fraction of one of the phases. The reconstruction of the interface in the MOF technique does not rely on the data from the neighbouring cells and requires only the centroid and volume fraction data of the corresponding cell. In the present work, a face flux based multi-directional advection of material centroid and volume fraction is proposed to enable MOF based two-phase flow simulations on two-dimensional unstructured grids. The developed MOF based two-phase flow solver is validated for its interface reconstruction, material moment advection and surface tension calculation. Using the developed MOF based two-phase flows solver, film condensation over a cylinder is studied. The effect of vapour Reynolds number and the degree of subcooling on the fluid flow and heat transfer characteristics is investigated for the case of downward flow of vapour.