ABSTRACT

This dissertation focuses on numerical studies exploring the lattice Boltzmann method (LBM) for investigating pool boiling process and different means of enhancements including surface modifications, inclusion of porous matrix and introduction of induced vibrations in the liquid pool. The first study is conducted to examine the pool boiling heat transfer from a surface with protrusions using a single component pseudo-potential phase change model of LBM. The surface protrusions are assumed to be rectangular in shape with a given height and width. The effects of the protrusion height, width, shape, and thermal property on surface heat flux have been investigated in order to arrive at an optimal design for maximum heat transfer. Spatial and temporal averaged heat flux from all these protruding surfaces are found to be 3 to 4 times higher than that of a plane surface. Nucleation of more bubbles and their earlier departure are considered to be reasons for such higher surface heat flux.

The next study investigates the enhancement of pool boiling heat transfer inside a solid cylinder array representing an idealized/regular porous medium. The array has been conceptualized by placing square shaped solid structure inside the pool of liquid. The same numerical technique is used with an improved temperature distribution function and source term. The entire saturated pool boiling curve for the flat surface comprising different nucleate boiling regimes from boiling incipience (BI) to critical heat flux (CHF), transition boiling regime between CHF to Leidenfrost point (LP) and the film boiling regime is obtained numerically. The effect of the solid cylinder array is quantitatively evaluated and expressed in the form of its corresponding boiling curve. It is found that the boiling incipience in presence of solid cylinder array occurs at a lower surface superheat compared to that of a plane surface. Further, the solid array effectively delays the onset of film boiling. Qualitative analysis of the pool boiling phenomenon shows the bubble dynamics in such solid structure including bubble nucleation, coalescence, growth, entrapment, splitting and escape to be very different compared to a flat surface. Finally, two different cylinder arrays of porosity 90% and 98% are studied to examine the effect of porosity. The sensitivity of the heat transfer rates on porosity is found to be significant especially at higher values of surface superheat.

In the final study, we have used a single component multiphase multiple relaxation time (MRT) based lattice Boltzmann method (LBM) to study the effect of induced vibrations in a liquid pool for enhancement of pool boiling heat transfer. The ebullition cycle of bubble from a single and multiple nucleation sites with different nucleation densities are modelled in a liquid pool in quiescent condition (SQ) and in fluid motion with aid of the moving solid boundaries (SMSB), in periodic motion with a particular frequency (f^*_{MSB}) and amplitude(A^*_{MSB}). The numerical results throw an insight into the bubble dynamics, viz. nucleation, growth and departure in both of these media. It is found that the induced vibrations in the liquid pool leads to a higher growth rate and bubble departure frequency (f^*) due to additional forces acting on the bubble that facilitates its growth and early detachment. This results in a higher heat flux in SMSB for a given surface superheat. The evolution of the bubble and its shape with time (t*) is represented by the area-equivalent bubble diameter (D^*_e) and height (h^*). A force balance analysis on the bubble is conducted to explain the growth rate and shape evolution for both SQ and SMSB. A sensitivity study of the induced frequency (f^*_{MSB}) and amplitude (A^*_{MSB}) of the MSBs show that the bubble departure frequency (f^*) increases to a maximum value, and then decreases with continuous increase in both f^*_{MSB} and A^*_{MSB}. Subsequently, another sensitivity study is conducted to investigate the effects of unequal sizes of nucleation sites, unequal surface superheat (Ja), distance between the nucleation sites and surface wettability. In all these cases, the SMSB was found to exhibit improved heat transfer due to faster nucleation and growth of bubbles. The sizes of the bubbles are impacted by the size of nucleation site as well as surface superheat. For a given surface superheat (Ja) and configuration of nucleation sites, f^* is found to reduce after a threshold value of wetting angle (θ^*) in SQ while the same reaches maxima in SMSB before coming down. It was further observed that if the hydrophobicity of the surface is increased from $\theta^* = 1.0$ to 1.1 in SMSB, f^* remains high till a threshold Ja beyond which it reduces drastically due to higher rate of generation compared to detachment.