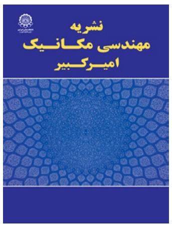

Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 50(4) (2018) 1-3
DOI:

The Effect of Surface Types on Bubble Dynamic Formation During Nucleate Pool Boiling by Use of Lee and Tanasawa Phase Change Models

S. A. Hosseini, R. KouhiKamali*

Department of Mechanical Engineering, University of Guilan, Rasht, Iran.

ABSTRACT: Numerical simulation of boiling has always been a challenging problem in terms of the variety and effectiveness of two-phase models. Boiling is one of the efficient methods in high heat transfer. In the boiling simulation, in addition to choosing an appropriate heat and mass transfer model, it will be important to evaluate the surfaces in which boiling occurs on it. A problem of nucleate boiling of saturated liquid is numerically simulated in this investigation by use of volume of fluid model together with the geo-reconstruction of the interface. One-dimensional Stephan problem as sucking interface problem is solved for verification the numerical solver. Two-phase change models of the Lee model and the Tanasawa model are used in order to calculate the rate of phase change and source terms. The results of nuclear boiling are investigated on the hydrophilic surface, hydrophobic surface, and the surface with contact angle 90 degrees. The results show that boiling on hydrophobic surfaces causes the detachment of larger bubbles with a larger heat transfer rate. Besides, bubble merging depending on the density of nucleation sites leads the nuclear boiling on the hydrophobic surface to film boiling.

Review History:

Received:
Revised:
Accepted:
Available Online:

Keywords:

Nuclear boiling
Numerical simulation
Surface contact angle
Phase change models
Heat and mass transfer

1. Introduction

The aim of this paper was to numerically simulate the boiling phenomenon. The heat transfer rate during boiling is more than high enough to be used in many industrial applications, including power plants and cooling of different electronic devices [1]. Over the past few decades, advances and breakthroughs in the field of boiling heat transfer, its related parameters, and the associated limitations in optimizing different applications of boiling heat transfer have led to a widespread study of boiling heat transfer fundamentals. Despite these efforts, due to a number of uncertainties, several aspects of this phenomenon are still not fully understood.

Among the multi-phase models in the Euler-Euler approach, the Eulerian two-phase flow model solves a set of n-momentum and continuity equations for each phase separately. This model has little success in boiling simulation, especially in accurate interface capturing, bubble generation and detachment. In contrast, the numerical methods that track the interface are more reliable. The Volume of Fluid (VOF) is a surface tracking method of the Euler-Euler approach, applied to a fixed mesh. So far, different models with their own special properties are presented for phase change. Tanasawa [2] presented a model by assuming the constant saturation temperature at both sides of the interface. Lee [3] also presented a phase change model which assumes that the boiling mass transfer occurs under constant pressure across the interface. Most researches have benefited one of the two above-mentioned phase change models to study boiling and condensation problems. While they have been less used to simulate the single-bubble nucleate boiling, as discussed in this paper.

In the present study, the effects of the surface type and fluid contact angle were assessed in each of the phase change models as an important parameter in the boiling process. The purpose of this study was to examine the effects of different types of surfaces on the bubble formation dynamics in the pool boiling phenomenon. This was achieved using Lee and Tanasawa phase change models on the hydrophilic, hydrophobic and 90-degree contact angle surfaces. The amount of vapor, and also the size of the bubble formed due to the boiling was evaluated in each of these conditions. Moreover, parameters such as the size and shape of the residual vapor on the surface, as well as the frequency and radius of bubble detachment were also investigated. Bubble merging and the effect of three distinct nucleate sites on the hydrophilic, hydrophobic and normal surfaces in our described phase change models were studied and the associated results were analyzed. A one-dimensional sucking interface problem, proposed by Stephan, was solved and the results were compared to the analytical solution in order to ensure the validity of the User-Defined Function (UDF) codes and the numerical solver. The numerical and

*Corresponding author's email: kouhikamali@guilan.ac.ir

analytical results were in a good agreement which verified the acceptable performance of the solver. Nevertheless, the authors of this paper have already verified the performance of this code and its solver in different ways in another article [4].

2. Methodology

In the present study, a 2-D nucleate boiling has been investigated numerically. A flat surface possessing the characteristics of a heater with a no-slip condition and constant temperature was considered as the geometry of our study. The temperature is ΔT higher than the fluid saturation temperature. An initially a 2-mm diameter bubble was placed at the surface center of the heater in order to initiate the boiling phenomenon.

Two continuity equations were utilized to determine the mass conservation of the liquid and vapor phase, and also the mass transfer rate between these two phases. The momentum and energy equations for the homogeneous fluid are applied for fluid flow and heat transfer simulation. Two widespread models of Tanasawa and Lee used in simulating the phase change problem are given in Eq. (1) and (2), respectively.

$$\dot{m}'' = \frac{2\gamma}{2-\gamma}\sqrt{\frac{M}{2\pi R}}\,\frac{\rho_g h_{fg}\left(T-T_{sat}\right)}{T_{sat}^{3/2}} \tag{۱}$$

$$\Gamma_v = \begin{cases} \lambda_v \rho_f \alpha_f \dfrac{(T_f - T_s)}{T_s} & ,T_f \ge T_s \\ 0 & ,T_f < T_s \end{cases} \tag{۲}$$

In the present study, the problem is simulated by Fluent software. All the source terms of the phase change process are defined separately as a UDF code. The Quadratic Upwind Interpolation for Convective Kinetics (QUICK) scheme is applied for discretizing the convection terms of momentum and energy equations. The PREssure STaggering Option (PRESTO) is employed for discretizing the pressure term of the momentum equation. This discretization method is usually applied for the flows involving steep pressure gradients or in strongly curved domains just like what exists at the bubble interface. The pressure-velocity coupling algorithm of the Pressure Implicit Splitting of Operators (PISO) is considered for pressure correction which is useful for unsteady flow problems. In the present numerical simulation of boiling, a structural uniform grid with 12288 quadrilateral cells is used. The number of cells is chosen according to the mesh independence study.

3. Results and Discussion

Fig.1 depicts the single-bubble formation dynamics on a flat surface in the pool boiling phenomenon. This figure essentially shows the numerical simulation output in the form of the volume fraction contours of vapor in equal time intervals.

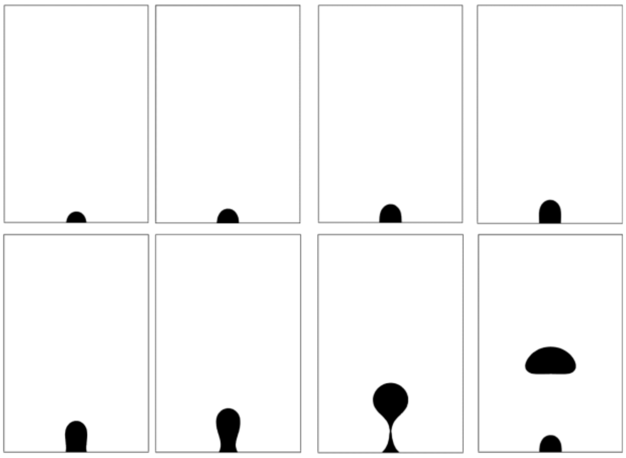

Fig. 1. . Contours of the volume fraction of a single bubble in nucleate boiling on the normal surface in Lee model

The amount of remaining vapor on the surface during bubble detachment, as well as the contact angle between the vapor and the solid surface, determines the size and frequency of vapor bubble generation in subsequent cycles of boiling. Therefore, the bubble root at the time of detachment from the surface, the amount of remaining vapor, and the angles between the vapor and the surface in Lee model are presented in Fig. 2.

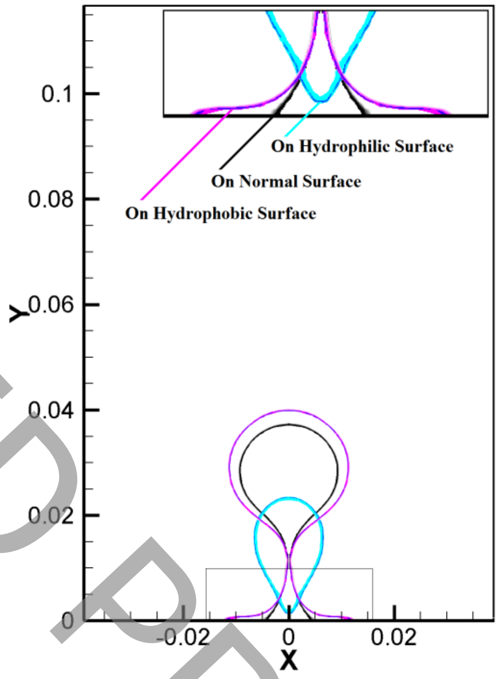

Fig. 2. . The root of separating bubble in the Lee model

The bubble formation dynamics of the boiling phenomenon while planting three nucleation sites are presented in Fig.3. This type of simulation was applied in order to study the effects of 1) bubbles on each other, 2) interference and bubble merging on different types of surfaces, and 3) two-phase change models of Lee and Tanasawa.

4. Conclusion

The results obtained from the boiling simulation on the three surfaces indicated that the surface type, in terms of the contact angle, directly affects the amount of vapor generation, and consequently the rate of heat transfer, the

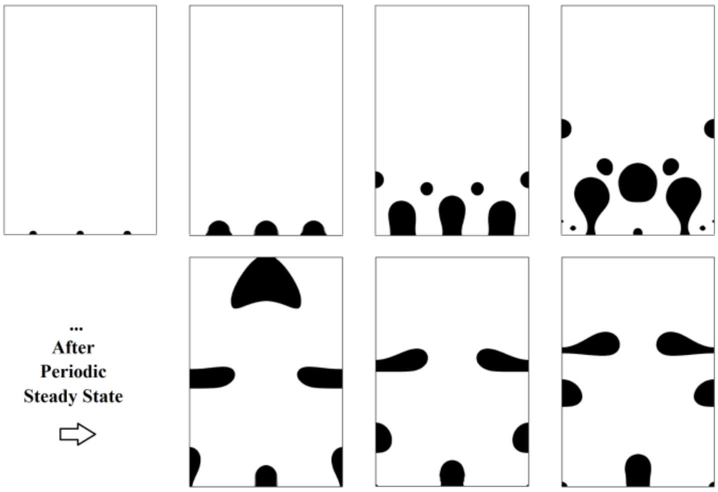

Fig. 3. Contour of the volume fraction of the triple bubble in nucleate boiling on the normal surface in Tanasawa model

bubble formation dynamics, and the bubble detachment radius and frequency. Thus, a change from the hydrophilic to the hydrophobic surface would increase the bubble radius and decrease its frequency at the time of the detachment from the surface. Findings suggest that the merging bubbles which were formed in closely-spaced nucleation sites on the hydrophobic surface lead to the formation of a vapor layer on the surface and a change of boiling toward a film boiling. The results also proposed that the Lee model, while generating larger bubbles, was a more appropriate model in the boiling simulation. Since in addition to a continuous boiling simulation, this model also doesn't generate small bubbles in regions far from the heater, where the temperature gradient is lower than the heater surface. However, the Tanasawa model, while generating extra unnecessary bubbles, stops the boiling process on the hydrophilic surface.

References

[1] C. Kunkelmann, Numerical Modeling and Investigation of Boiling Phenomena, Technische Universität Darmstadt, 2011.

[2] I. Tanasawa, in: Advances in Heat Transfer, Academic Press, San Diego, 1991, pp. 55-139.

[3] W.H. Lee, in: Multiphase Transport Fundamentals, Hemisphere Publishing, Washington, DC, 1980.

[4] S.A. Hosseini, R. KouhiKamali, Simulation of film boiling heat transfer on flat plate and the impact of various phase change models on it, Modares Mechanical Engineering, 16(5) (2016) 169-177 (in Persian).