NUMERICAL STUDY OF SINGLE BUBBLE DYNAMICS BY VARYING CONTACT ANGLES DURING NUCLEATE POOL BOILING

Pradip Gunavant[1,a)], Ashok Pise[2,b)], Vahid Jamadar[3,c)], Ranjit Chavan[4,d)], Ganesh Jadhav[5,e)]

[1,3,4]*Department of Mechanical Engineering, AGTI's, Dr. Daulatrao Aher College of Engineering,*
Karad 415124, Maharashtra, India
[2]*Department of Mechanical Engineering, Government College of Engineering,*
Karad 415124, Maharashtra, India
[5]*School of Design, Dr. Vishwanath Karad MIT World Peace University,*
Pune -411038, Maharashtra, India

[a)]*Corresponding author*

Abstract: *The contact angle has a major impact on nucleation pool boiling and heat transfer. The purpose of this study is to determine the impact of contact angle on single bubble behavior during the water pool boiling nucleation. Numerical simulations are done using Ansys-13.0, a commercial Computational Fluid Dynamics (CFD) tool Fluent. For two-dimensional fluid flow, the numerical setup is chosen The Navier-Stokes equations, as well as the continuity and energy equations, are all solved by using the SIMPLE method. The liquid-vapor interface is captured using the multiphase model's finite volume technique. The only half domain is modeled to take advantage of symmetry boundary conditions and simulations are initialized from the saturated condition of water for reducing computational time. To understand the associated convective mechanisms, the bubble growth and its departure from a horizontal heated surface have been numerically simulated by varying excess temperature ($T_{excess}=T_S- T_{sat}$). Also, the contact angles are altered from 0° to 180° to analyze its effect on bubble dynamics. The result emphasizes the impact of contact angle on bubble diameter before to leaving as well as the time necessary to leave. A research of grid independence and temporal independence is carried out to see if they have any effect on the outcomes.*

Keywords - *Nucleate pool boiling, bubble dynamics, CFD, contact angle*

1. INTRODUCTION

The heat transfer rate in nucleation boiling is heavily influenced by its types such as the number of surface active nucleation sites and the bubble formation rate at each site are difficult to estimate. The heat transfer have highly influenced by the quality of the heated surface. On this surface, bubble formation, growth, and detachment are taking place. Theoretical heat transfer relations are difficult to build because of these problems.We must rely on relationships based on experimental and numerical data in the nucleate boiling regime. An attempt is made in this paper to numerically capture bubble behavior using the Computation Fluid Dynamics (CFD) code Ansys-Fluent-13 for 2D configurations.

The numerical analysis of single bubble have performed by many investigators by mentioning initial release bubble size and behavior of bubble is simulated but in this study bubble created automatically by using Volume of Fluid (VOF) multiphase model.

2. STATE OF ART

The phenomenon of nucleate boiling is fundamentally complicated. Nonetheless, researchers have attempted to explore such complexity under certain assumptions, and we have had some success.

The studies were carried out by Hai Trieu Phan et al. [1][2] in order to know the effect of the wettability of surface on nucleate boiling. To alter the contact angles, the author used nano-coating techniques. To explain the observed behavior, they also develop the concept of micro and macro contact angles. Igor Pioro et al. [3] in Parametric Effects of Boiling focuses on surface material thermophysical properties. John McHale et al. [4] use high-speed visualization techniques to capture nucleate boiling on smooth and rough surfaces. Sphurti Sweta [5] numerically analyses nucleate boiling using the CFD tool Fluent. To determine the influence of contact angle, Eduardo Aktinol & Vijay Dhir [6] employ a numerical model. Damien Serret et al. [7] carried out experimentation and observed remarkable behavior of contact angle in the fundamental study of growth bubble. Gihun Son et al. [8] explored numerically high heat flux nucleation boiling and the influence of wall super-heat, nucleation site frequency, and waiting duration of bubble and heat transfer rate in nucleation boiling.J. F. Zhao et al. [9] performed numerically single bubble behavior study by changing gravity conditions. Nitin Korde et al. [10] have done CFD study to analyze flow on the tube surface. Sameer Gajghate et al. [11, 12] have done experimentation for improvement and enhancement to transfer heat.

3. PROBLEM MODELING

A small heating element is fixed on the base wall of the domain and away from the heater; two vertical walls are fixed on the base wall such that they will not affect the bubble behavior. This becomes like a small tank is filled with water. The surface of the water is described as a free surface. The free surface of the water is in contact with air. The problem is modeled by considering the bulk of the water is saturated. So, we can see the bubble throughout the bulk of water. A saturated boundary condition is also helpful to reduce the computational time. For numerical study of nucleate boiling, assumptions are applied, which aids in a better understanding of the true situation. The thermo physical properties are assumed as constant in this model. This numerical study uses mass, momentum, and energy equations. The boundary conditions for the heating element and the sidewall of the domain are both wall. The pressure outlet condition is used for the free water surface. At the symmetry plane, there is zero normal velocity, pressure, and temperature gradient of all variables.

4. METHOD OF SOLUTION

For the solution of this problem, the numerical method is applied. ANSYS-ICEM-CFD tool is used for the generation of the 2D model. Also, mesh generation is done as well as the boundary conditions applied to the model in the same tool. Domain has symmetry condition, due to which only ½ domain is modeled. This is helpful to reduce the model cell count results in decrease in computational time.

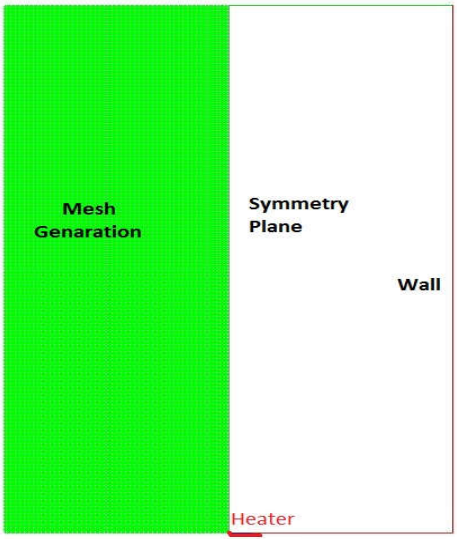


Figure 1. Mesh generation and the computational domain

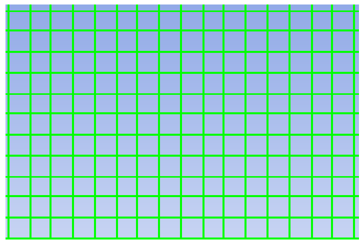


Figure 2. Close view of mesh generation

Rectangular grid elements have been generated with maximum aspect ratio 1.46 and quality 1 by using the blocking method in the ICEM-CFD tool. To capture the complex phenomenon in the nucleate boiling very fine mesh has been produced. Grid independence study is carried out for 99678, 66452 and 49839 cell count and temporal independence study for 0.00001, 0.0005 and 0.0001 time steps. Both studies observe nearly same results. Figure1. Describe the computational domain and mesh generation used for CFD analysis and Figure 2. Represents close view of grid generation. Changing the contact angle of water vapor with saturated water from 0^o to 180^o is used in the numerical analysis. For varying contact angles, the temperature is kept constant. Table1. Show the thermo physical characteristics used in this numerical analysis, which are obtained from the standard.

Table 1. Thermo-Physical properties of a Fluid

Fluid	Thermo-Physical properties				
	Density, ρ (Kg/m^3)	**Dynamic Viscosity, µ (Kg/m-s)**	**Specific Heat, Cp (J/KgK)**	**Temperature, T (K)**	**Thermal Conductivity,K (w/m-k)**
Water Vapor	0.5542	1.34×10^{-5}	2014	373.15	0.0261
Water Liquid	957.9	0.000282	4217	373	0.679

By changing the contact angles of water vapor with water liquid, such as 0^o, 30^o, 60^o, 90^o, 120^o, 135^o, 150^o, and 180^o, the single bubble dynamics in nucleate boiling can be observed. The parameters are configured to run for 0.00001 second time steps. For the analysis a Volume-of-fluid (VOF) model with 2D double-precision transient pressure-based solver is used. The multiphase model includes wall adhesion. With the Geo-Reconstruct formulation, an explicit volume fraction technique is applied. Pressure, momentum, and energy discretization are set to Body force weighted, QUICK, and First-order upwind using the first-order implicit transient formulation, respectively. The SIMPLE algorithm for pressure-velocity coupling is employed, and the first-order technique is used for all discretization schemes. To achieve the requisite accuracy, relaxation factors of 0.1, 0.8, 0.3, 1, and 1 are utilized for pressure, density, body forces, momentum, vaporization mass, and energy. The grid used for solution settings is examined for grid and time step, both of which have the same profile. In FLUENT, video clips of volume fraction contour plots are made for the single bubble dynamic investigation. In the study of bubble dynamics, these clips proved to be quite useful in detecting nucleation, bubble growth, and bubble detachment. These videos are again turned to pictures for further analysis.

5. RESULTS AND DISCUSSION

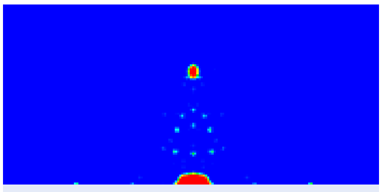
Numerical analysis of single bubble dynamics in nucleate boiling is carried out by varying contact angles of water vapor with saturated water.

The bubble dynamics behavior captured numerically for various contact angles is shown in Figure 2. In numerical analysis, it is observed that when the contact angle is 30^0 the bubbles are strongly restricted to detach from the surface and the size of the bubble is increases. After a certain amount of time has passed, the bubble adhering to the surface begins to detach in the form of little bubbles from the bubble surface's top. When the contact angle is 60^0, the size of the attached bubble is smaller than when it is 30^0, and the frequency of small bubbles detaching from attached bubbles increases.

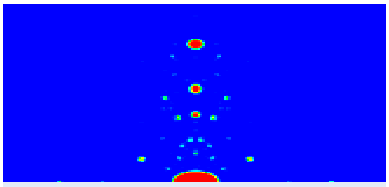
The unstable bubble behavior and irregular shape of the bubble can be seen at the contact angle of 90^0. In comparison to 30^0 and 60^0 contact angles, the diameter of the detached bubble from the attached bubble is larger.

The process of detachment of a bubble begins from the surface of heater when the value of contact angle exceeds 90^0. At 120^0 contact angle the bubble takes place more time to form and grow and also detachment frequency is less. But the bubble size is more, also more nucleation sites on the heated surface are observed.

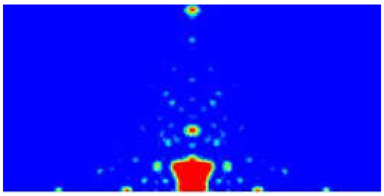
At 135^0 contact angle the continued bubble formation and detachment of bubble process is observed with bubble size greater than the 150^0 contact angle. For 150^0 contact angle, bubble formation and detachment takes place with bubble size less than 130^0 and with the increase in detachment frequency with an increase in departure sites



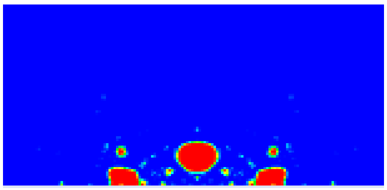
a. Contact angle: 30°



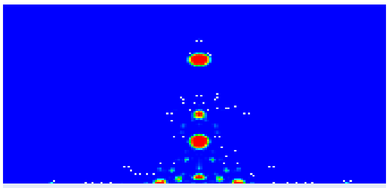
b. Contact angle: 60°



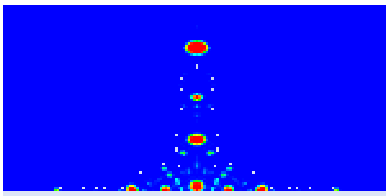
c. Contact angle: 90°



d. Contact angle: 120°



e. Contact angle: 135°

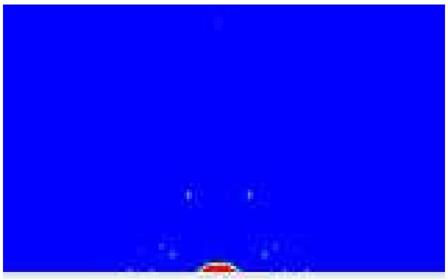


f. Contact angle: 150^0

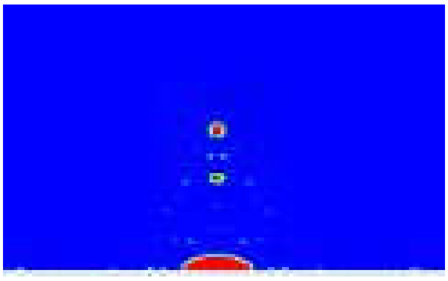
Figure 2. Single bubble dynamics behavior for different contact angles in nucleation pool boiling

.

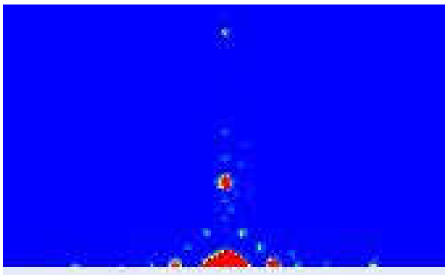
For analyzing the excess temperature (T_{excess}=T_s- T_{sat}), it is observed that if we increase the value of excess temperature the bubble detachment frequency get increases and the bubble size get decreases.



a. $T_{excess}=T_s- T_{sat}= 327$ k



b. $T_{excess}=T_s- T_{sat} =527$k



c. $T_{excess}=T_s- T_{sat} = 727$k

Figure 3. Effect of excess temperature variation on single bubble dynamics in nucleation pool boiling when contact angle 30º

To describe the effect of excess temperature, numerical simulation is performed using contact angle: 30º for the three different values 327 K, 527 K and 727 K for the same time interval of 0.12 sec. This effect of excess temperature is shown in Figure. 3. The excess temperature is raised further higher, resulting in an increase of nucleation sites. The bubbles created on the heater surface are dissipated in the liquid water after separation. The nature of bubble formation, growth and detachment are validated by previous available experimental and numerical results which show close agreement [13][14].

6. CONCLUSIONS

The nucleate boiling phenomenon was anticipated using a numerical model in 2D configuration; the study's precise conclusions are as follows:

1. A successful numerical simulation of single bubble dynamics for changing contact angles has been completed.
2. The effective nucleate boiling occurs at a contact angle of 130º to 150º, according to numerical simulations.

3. The contact angle has an impact on the size and leaving frequency of the bubbles.
4. Excess temperature variation has an effect on bubble size and frequency of departure.

Further study is needed to predict the actual change in diameters of bubbles and to know the actual departure time.

Acknowledgements

The support of Government College of Engineering (GCE), Karad is appreciatively acknowledged.

REFERENCES

1. *Hai Trieu Phan, Nadia Caney, Philippe Marty, Stéphane Colasson, and Jérôme Gavillet Int. J. of Heat and Mass Transfer **52** (2009) 5459–5471*
2. *Hai Trieu Phan, Nadia Caney, Philippe Marty, Stéphane Colasson, and Jérôme Gavillet, C. R. Mecanique **337** (2009) 251–259*
3. *Igor Pioro, Rohseno WM and S Doerffer, Int. J. of Heat and Mass Transfer **47** 5033–5044(2004)*
4. *John McHale, Suresh Garimella, International Journal of Multiphase Flow **36**(4),249-260(2010)*
5. *Sphurti Sweta, Suresh Badholiya and Santosh Dixit, Int. J. Engg. Res. & Sci. & Tech. **4**(1), 168-178(2015)*
6. *Eduardo Aktinol & Vijay Dhir, Interfacial Phenomena And Heat Transfer, **2** (4),301–324 (2014)*
7. *Damien Serret, Stephan Guignard and Lounès Tadrist Microgravity Sci. Technol **21**,101–105 (2009)*
8. *Gihon Son and Vijay K. Dhir, Int. J. of Heat and Mass Transfer **51**(9-10),2566-2582(2008)*
9. *J. F. Zhao, Z. D. Li, L. Zhang, AIP Conference Proceedings **1376**, 565 (2011)*
10. *Nitin Korde, Ashok Pise, Pradip Gunavant, Int. J. of Fluid Mechanics Res., **41**(6),526-535 (2014)*
11. *Jadhav Ganesh, Vahid Jamadar, Pradip Gunavant, Sameer Gajghate, Applied Mechanics and Materials **592**, 2689-2693(2014)*
12. *Sameer Gajghate, Anil Aacharya, Ashok Pise, Ganesh Jadhav, Applied Mechanics and Materials, **592**, 1601-1606(2014)*
13. *Cengel, Y.A. Heat and Mass Transfer (a Practical Approach). 3rd Edition, McGraw-Hill. (2007)*
14. *Youngsuk Nam Jinfeng Wu Gopinath Warrier Y. Sungtaek Ju, Journal of Heat Transfer,131,121004-1 : 121004-7(2009)*