

# Experimental Study of Single Bubble Dynamics during Nucleate Pool Boiling Using Saturated Water for Heat Transfer Enhancement

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**Abstract**— The bubble departure diameter in nucleate pool boiling heat transfer using saturated water affected by wall superheat, size of nucleation site etc. In this paper, effect of wall superheat in nucleate pool boiling heat transfer on single bubble dynamics using saturated water has been studied experimentally. Single bubble is generated using vertical hypodermic needle tip as a nucleation site. The hypodermic needles were used of inner diameters 0.603 mm with a constant depth of 25 mm. Single bubble dynamics was studied using PCO high speed camera operating at 100 frames per second at atmospheric pressure and at a wall superheat of 9 K to 30 K. Bubble growth in saturated water is studied at heat flux 430 kW/m<sup>2</sup>, 900 kW/m<sup>2</sup>, the results show that, bubble departure diameter increases with increase in wall superheat at 430 kW/m<sup>2</sup>. The bubble release frequency increases with increase in wall superheat at 900 kW/m<sup>2</sup>.

**Index Terms**— Heat flux, nucleate pool boiling, Single Bubble dynamics.

## I. INTRODUCTION

Nucleate boiling heat transfer is utilized in many applications where large amount of heat has to be transferred in comparatively small areas such as nuclear reactor, rocket engines. Generation of isolated bubble is crucial for the process of boiling because slugs and columns are ultimately developed from isolated bubbles. High heat transfer rate achieved by boiling heat transfer can be induced by liquid jets flowing in between rising bubble column, impinging on the heated surface. Therefore it is necessary to understand single bubble dynamics in order to gain an understanding of nucleate boiling heat transfer and for developing mechanistic models of boiling heat transfer. The evolution of a bubble from its incipience to departure is termed as bubble dynamics, which is characterized by three parameters: bubble growth period, bubble departure diameter and bubble release frequency. It is necessary to understand bubble dynamics in order to gain an understanding of nucleate boiling heat transfer, developing mechanistic models of boiling heat transfer.

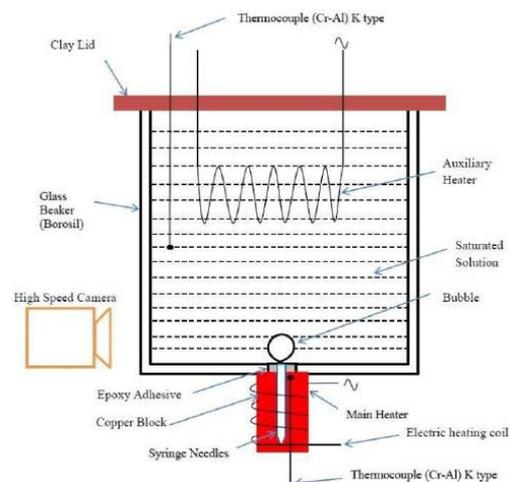
Shoji & Takagi [1] studied bubbling features from a single artificial cavity. Conical, cylindrical and re-entrant cavities were tested. Qiu and Dhir [2] studied experimentally and numerically, the growth and detachment of a single bubble on a heated surface during parabolic flights of the KC-135 aircraft. Lee et al. [3] concluded in their experiment that the bubbles, practically two-dimensional, assume a balloon-like

shape elongated in the stream wise direction. The bubble departure size, independent of the input power, decreases exponentially with increasing Reynolds number (flow rate). Siedel et al. [4] investigated experimentally the bubble growth, departure and interactions during pool boiling on artificial nucleation sites. Bubble growth is studied under various wall superheat conditions. The result shows that, bubble growth appears very reproducible, the volume at detachment being independent of the wall superheat, whereas the growth time is dependent on the surface with artificial nucleation sites experimentally. A. Najim [5], P. B. Pawar [6][7] studied experimentally bubble dynamics in pool boiling heat transfer using saturated water and aqueous Ammonium Chloride (anionic surfactant) solution.

## II. EXPERIMENTAL METHOD

### A. Experimental Set-up

Experimental set-up consists of borosilicate glass container of 2 liters capacity. DISPO VAN® hypodermic needle which is normally used in medical application was used as a heating surface. A schematic diagram of the experimental setup is shown in Figure 1.



**Figure 1** Experimental set-up

### B. Final Stage

The needle is placed right angle at the centre of each glass container. One end of the needle is precision cut

while the other is pinched preventing any flow through the needle. The needle sizes are given in Table 1.

Needle Gauge	Outer Diameter [mm]	Inner Diameter [mm]	Depth [mm]
20	0.908	0.603	25

### C. Working

The needle was heated by means of electric current and the heat flux released from the heating element to the liquid is controlled by adjusting the supplied current. A cylindrical calibrated heater was used to heat the needle. In order to ensure that the electrical connections do not interfere with the bubble growth apart from heating element, a layer of insulation is set over the connections. The heat is used to vaporize the liquid near the needle tip where in is not wrapped with insulation. The gap between the needle wall and borosil glass at its base was sealed with transparent epoxy adhesive. An auxiliary heater 1000 watt is installed to maintain the temperature of the liquid at saturation temperature. The pool temperature and temperature at tip of needle is measured by K-type thermocouples. The bubble growth was recorded by PCO high speed camera operating at 100 frames per second.

### III. UNCERTAINTY ANALYSIS

The voltmeter and ammeter used for the experimentation were within  $\pm 1$  and  $\pm 0.001$  accuracy respectively. The temperature of heated surface and working fluid was measured by 0.3mm K-type thermocouple having accuracy of within  $\pm 0.2K$ . The dimensions of a bubble were measured by counting the number of pixels in a symmetric bubble image. The bubble dimensions could be measured with the error of  $\pm 2$  pixels with ImageJ open source software.

### IV. RESULT AND DISCUSSION

When the energy input from the heater reached a value for onset of bubble generation, single bubble could be observed clearly, stably and repeatedly at the right angle tip of needle. The bubble dynamics was studied from wall superheat of 9 K up to 30 K.

A constant heat flux is applied to heating surface. Heat Fluxes applied to needle surface by means of main heater are  $430 \text{ kW/m}^2$ ,  $900 \text{ kW/m}^2$ . Two curves represent dependence of bubble departure diameter on wall superheat. Figure 3 and figure 5 compares the magnitude of bubble departure diameter for Heat Fluxes applied  $430 \text{ kW/m}^2$ ,  $900 \text{ kW/m}^2$  respectively.

#### A. Bubble Dynamics at $430 \text{ kW/m}^2$

Figure 2 shows magnitude of bubble departure diameter as a function of wall superheat under condition of saturated pool boiling of water in the present work. In nucleate boiling region, at  $430 \text{ kW/m}^2$ , bubble departure diameter from single artificial nucleation site increases with wall superheat. This is due to increasing rate of

formation of vapor inside needle heating surface. Bubble release frequency at same heat flux is cannot completely measured due to very slow nucleation rate of bubble formation.

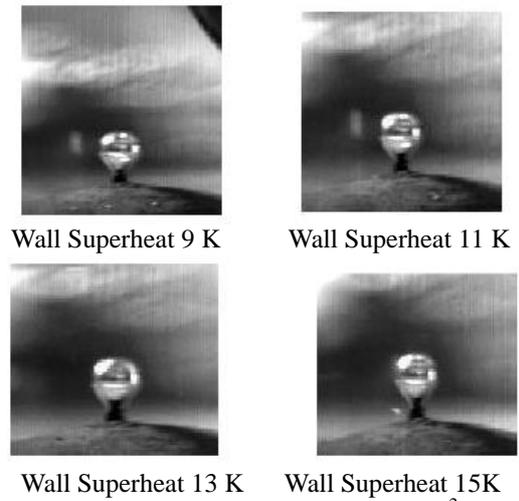


Figure 2 Bubble sizes at  $430 \text{ kW/m}^2$

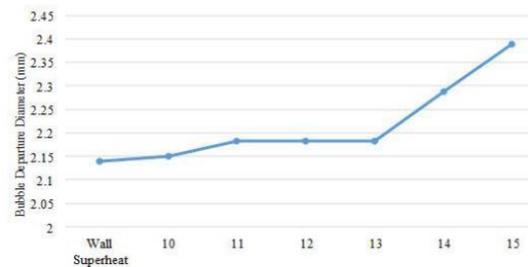


Figure 3 Bubble departure diameter at  $430 \text{ kW/m}^2$

Bubble departure diameter is measured from 2.14 mm at 9K up to 2.39 mm at 15K wall superheat. Bubble release frequency is measured from 0.62 Hz up to 4.8 Hz at these set of wall superheat. Bubble waiting time is measured 0.03 second at each wall superheat temperature.

#### B. Bubble Dynamics at $900 \text{ kW/m}^2$

In nucleate boiling region, at  $900 \text{ kW/m}^2$ , bubble release frequency from single artificial nucleation site increases with wall superheat. This is due to increasing rate of formation of vapor inside needle heating surface. Bubble departure diameter at same heat flux is measured almost same from 1.82 mm up to 2.1 mm. Bubble release frequency is measured in between 1 to 3 Hz at these set of wall superheat. Bubble waiting time is measured 0.03 second at each wall superheat temperature.

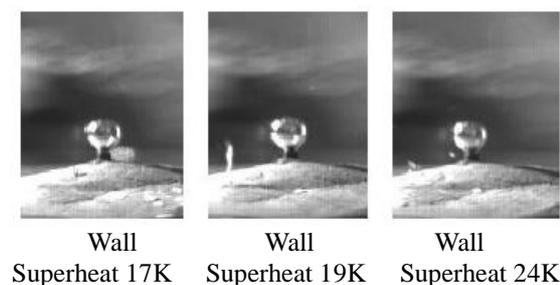
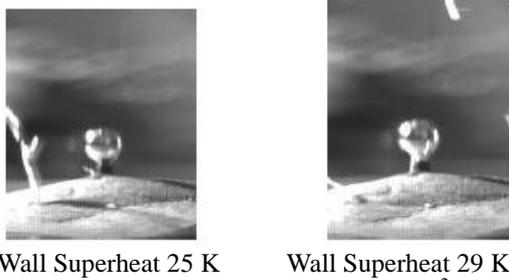
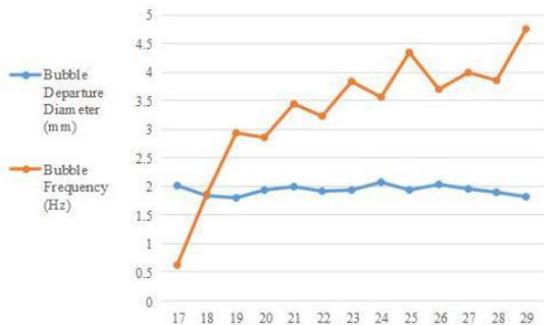


Figure 4 Bubble sizes at  $900 \text{ kW/m}^2$



**Figure 4** Bubble Sizes at  $900\text{kW/m}^2$



**Figure 5** Bubble departure diameter at  $900\text{kW/m}^2$

## V. CONCLUSION

The effect of heat flux and wall superheat on bubble dynamics during nucleate pool boiling heat transfer in saturated water was studied experimentally. The bubble dynamics was studied using PCO high speed camera operating at 100 frames per second at atmospheric pressure and at heat flux  $430\text{ kW/m}^2$  and  $9000\text{ kW/m}^2$ . Single bubble was generated using right angle tip of a hypodermic needle as a nucleation site. The hypodermic needles were used of inner diameters  $0.603\text{ mm}$  with a constant depth of  $25\text{ mm}$ .

The captured images shows that single bubble grew rapidly initially in spherical shape and then in balloon like shape axi-symmetrically until reaching its maximum size, and then departed from the right angle tip of needle. The bubble departure diameter increases with increasing wall superheat at at heat flux  $430\text{ kW/m}^2$ . At heat flux  $900\text{ kW/m}^2$ , bubble release frequency from single artificial nucleation site increases with wall superheat, bubble departure diameter at same heat flux is measured from  $1.82\text{ mm}$  up to  $2.1\text{ mm}$ .



## REFERENCES

- [1] M. Shoji, Y. Takagi, "Bubbling Features from a Single Artificial Cavity", *International Journal of Heat and Mass Transfer*, vol. 44, pp. 2763-2776, 2001.
- [2] D. M. Qiu, V. K. Dhir, "Single Bubble Dynamics during Pool Boiling Under Low Gravity Condition", *Journal of Thermophysics and Heat and Heat Transfer*, vol. 16, pp. 336-345, 2002
- [3] M. Lee, L. S. Cheung, Y. Lee, Y. Zoha, "Height Effect on Nucleation-Site Activity and Size-Dependent Bubble Dynamics in Micro-Channel Convective Boiling", *Journal of Micromechanics and Microengineering*, vol. 15, pp. 2121-2129, 2005.
- [4] S. Siedel, S. Cioulachtjian, J. Bonjour, "Experimental Analysis of Bubble Growth, Departure and Interactions during Pool Boiling on Artificial Nucleation Sites", *Experimental Thermal and Fluid Science*, vol. 32, pp. 1504-1511, 2008.
- [5] A. Najim, A. R. Acharya, A. T. Pise, S. S. Gajghate, "Experimental Study of Bubble Dynamics in Pool Boiling Heat Transfer using Saturated Water and Surfactant solution", *IEEE - International Conference on Advances in Engineering and Technology ICAET-2014*, ISBN No.: 978-1-4799-4949-6, 2014.
- [6] P. B. Pawar, A. R. Acharya, A. Najim, A. T. Pise, "Experimental study of wall superheat effect during nucleate pool boiling heat transfer on single bubble dynamics using ammonium chloride", *International Journal of Engineering and Management Research*, special issue, ISSN Online 2250-0758, ISSN Print 2394-6962, 253-258, 2015.
- [7] P. B. Pawar, A. R. Acharya, A. T. Pise, "Experimental study of single bubble dynamics during nucleate pool boiling using ammonium chloride for heat transfer enhancement", *Journal of Material Science and Mechanical Engineering*, vol 1, ISSN Online 2393-9109, ISSN Print 2393-9095, 95-99, 2015.