

## **EXPERIMENTAL STUDY OF EFFECT OF WALL SUPERHEAT ON SINGLE BUBBLE DYNAMICS DURING NUCLEATE POOL BOILING HEAT TRANSFER**

[PAPER ID: ICITER-D164]

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### **ABSTRACT:**

**In nucleate pool boiling heat transfer of saturated water the wall superheat, orientation of nucleation site etc. affects bubble departure diameter. In this paper, effect of wall superheat in nucleate pool boiling heat transfer on single bubble dynamics using saturated water as a base fluid has been studied experimentally. Single bubble generated using vertical hypodermic tip of needle as a nucleation site. The hypodermic needles were used of inner diameters 0.514 mm with a constant depth of 25 mm having different cross section varying from 30° to 90° with respect to tip. Single bubble dynamics was studied with the help of PCO high speed camera operating at more than 100 frames per second at atmospheric pressure and at different wall superheat of 4 K to 30 K for constant heat flux.**

### **INTRODUCTION:**

There are a number of applications in which pool boiling is used as mode of heat transfer. For many years nuclear reactors have utilized boiling heat transfer for cooling. Refrigeration systems have also used refrigerant boiling to provide the necessary heat transfer fluxes. As a result, a large amount of research has focused on boiling heat transfer in such applications. All researchers stated that boiling is a liquid to vapour phase change process occurs at the solid-liquid interface when a liquid is brought into contact with a surface maintained at temperature  $T_s$  which is sufficiently above the saturation temperature  $T_{sat}$  of the liquid. The boiling process is characterized by the rapid formation of vapour bubbles at the solid-liquid interface that detach from the surface when they reach a certain size and attempt to rise to the free surface of the liquid. It is a

complicated phenomenon because of the large number of variables involved in the process and complex fluid motion patterns.

The development of a bubble from its emerging to departure is termed as bubble dynamics, which is characterized by parameters such as bubble departure diameter and bubble release frequency. Many experimental and numerical studies have been discovered on the bubble trajectory and shape oscillations. Shoji & Takagi [1] studied features of bubbles from a single artificial cavity. Like conical, cylindrical and re-entrant cavities were tested. Qiu and Dhir [2] experimentally and numerically studied the growth rate and detachment of a single bubble on a heated surface during parabolic shape flights of the aircraft KC-135 to see the effect of gravity variation. Lee et al. [3] concluded in their experiment that, the bubbles, practically 2D formed 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. Nam et al. studied [5] studied experimentally, the single bubble dynamics on a superhydrophilic surface of with CuO nanostructures on a silicon substrate artificial nucleation sites. The bubble departure diameter in water is recorded to be 2.5 times smaller and the growth period 4 times shorter on the superhydrophilic surface than on a silicon substrate. Fazel et al. [6] presented extensive new experimental data for the bubble departure diameter for different electrolyte aqueous solutions over a wide range of heat fluxes and concentrations.

The objective of the study is to compare the bubble growth with variation of orientation nucleation site from 30° to 90° angle. The base liquid was pure water.

## EXPERIMENTAL:

### A. EXPERIMENTAL SET-UP:

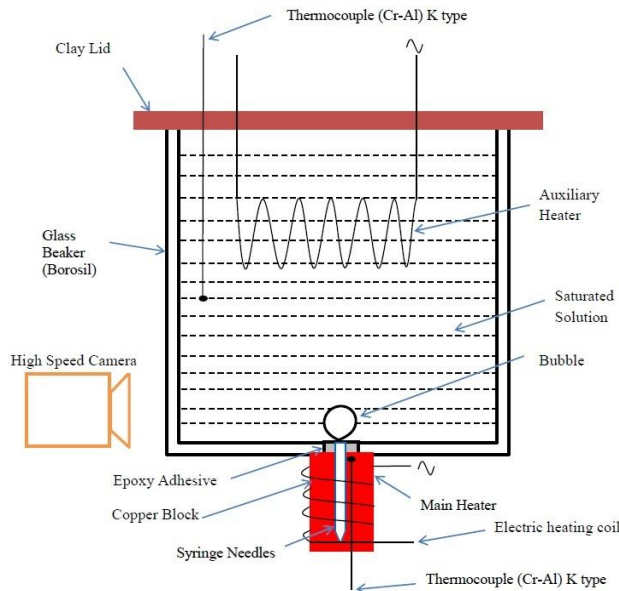


Fig. No.1. Experimental set-up

The experimental set-up consists of borosilicate glass container of 2 liters capacity, a DISPO VAN® hypodermic needle which is normally used in medical application attached at the bottom which used as a heating surface. A needle is placed right angle at the center of the glass container. One end of the needle is precision cut while the other is pinched preventing any flow through the needle. Single bubble was generated using needle tip with different cross section as a nucleation site. A schematic diagram of the experimental setup is shown in Fig no. 1.

### WORKING:

The needle was heated with help of electric current and the heat flux given from the heating element to the liquid is modulated by controlling the current. A cylindrical calibrated heater was used to heat the needle. In order to ensure that the electrical connections do not obstruct the bubble growth apart from heating element, a layer of insulation is set over the connections. The heat is consumed to evaporate the liquid closer to the needle tip where in is not wrapped with insulation. The aperture between the needle wall and glass at its base was sealed with transparent epoxy adhesive. An

additional heater of 1000 watt is installed to maintain the temperature of the liquid at saturation temperature. The pool temperature and needle tip temperature is measured by K-type thermocouples. The bubble growth was recorded by PCO high speed camera operating at more than 100 frames per second and then studied using ImageJ open source software.

Table 1: Needle size

| Needle |       | Nominal outer Diameter | Nominal Inner Diameter |                  | Depth |
|--------|-------|------------------------|------------------------|------------------|-------|
| Gauge  | mm    | Uncertainty (mm)       | mm                     | Uncertainty (mm) | mm    |
| 21     | 0.819 | ±0.0064                | .514                   | ±0.019           | 27    |

### B: UNCERTAINTY ANALYSIS

The voltmeter and ammeter used for the measurement were within ±1 and ± 0.001 accuracy respectively. The temperature of heated surface and pool fluid was measured by 0.3mm K-type thermocouple having accuracy of within ± 0.2K. The parameters of a bubble were noted by measuring the number of pixels in a symmetric bubble image. The bubble dimensions could be measured with the error of ± 4 pixels with ImageJ open source software.

### RESULTS AND DISCUSSION:

Single bubble dynamics was studied using PCO high speed camera operating at more than 100 frames per second at atmospheric pressure and at a wall superheat of 4 K to 30 K for constant heat flux.

Bubble dynamics of needle tip with 90° cut:

In nucleate boiling region, needle with 90° cut tip as a nucleation, average bubble departure diameter at same heat flux is measured between 1.94 mm to 2.19 mm. Equation of average bubble departure diameter with respect to wall superheat in K is found to be

$$y = 3E-05x^3 - 0.0106x^2 + 1.3068x - 51.081 \dots (1)$$

The minimum bubble diameter varies from 1.69 mm to 2.00 mm. Also the maximum bubble diameter varies from 2.20 mm to 2.48 mm.

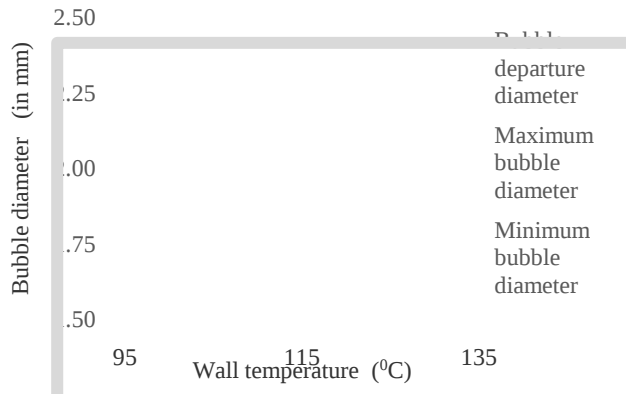


Fig. No.2. Variation of Bubble Diameter Vs wall temperature for 90° cut needle

From Fig no. 2 we observed as the wall temperature increases the bubble diameter first increases then decreases. The frequency of formation of bubble found to be increasing as the wall temperature increase.

Bubble dynamics of needle tip with 60° cut:

When needle with 60° cut tip used for nucleation, average bubble departure diameter at same heat flux is measured between 1.98 mm to 1.79 mm. Equation of average bubble departure diameter with respect to wall superheat in K is found to be

$$y = -8E-05x^3 + 0.0273x^2 - 3.1975x + 124.3 \dots (2)$$

The minimum bubble diameter varies from 0.84 mm to 1.49 mm. Also the maximum bubble diameter varies from 1.13 mm to 1.97 mm.

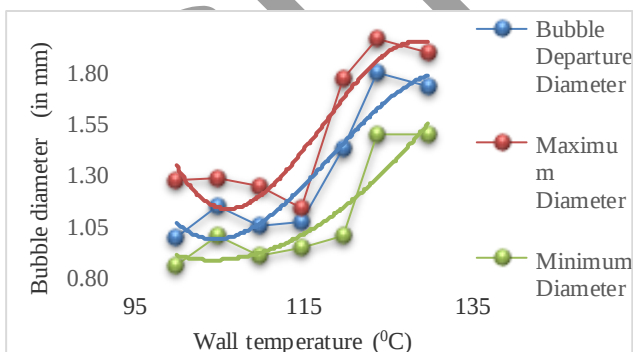


Fig. No.3. Variation of Bubble Diameter Vs wall temperature for 60° cut needle

From Fig no. 3. we observed as the wall temperature increases the bubble diameter first decreases up to some extent then goes on increasing. Here though the frequency of formation of bubble

increases but rate of increase is much higher than 90° cut needle as the wall temperature increase.

Bubble dynamics of needle tip with 45° cut:

When needle with 45° cut tip used for nucleation, average bubble departure diameter at same heat flux is measured between 1.39 mm to 2.05 mm. Equation of average bubble departure diameter with respect to wall superheat in K is found to be

$$y = 0.0002x^3 - 0.0621x^2 + 7.1092x - 267.6 \dots (3)$$

The minimum bubble diameter varies from 0.84 mm to 1.49 mm. Also the maximum bubble diameter varies from 1.13 mm to 1.97 mm.

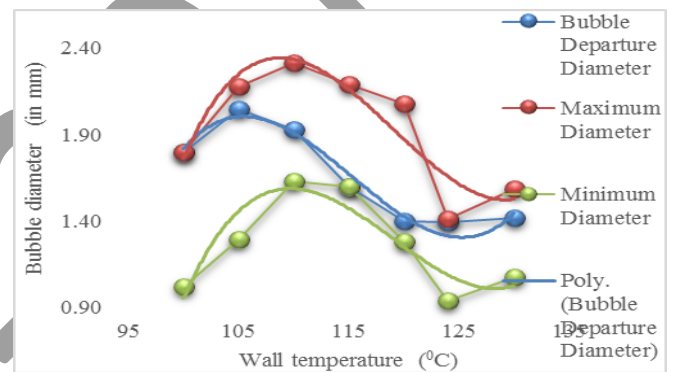


Fig. No.4. Variation of Bubble Diameter Vs wall temperature for 45° cut needle

From Fig no. 4. we observed as the wall temperature increases the bubble diameter first increases up to some extent then decreases again starts increasing. Here though the frequency of formation of bubble increasing but rate of increase is much lower than 90° cut needle as the wall temperature increase.

Bubble dynamics of needle tip with 30° cut

When needle with 30° cut tip used for nucleation, average bubble departure diameter at same heat flux is measured between 0.93 mm to 1.58 mm. Equation of average bubble departure diameter with respect to wall superheat in K is found to be

$$y = 9E-06x^3 - 0.0043x^2 + 0.6298x - 28.786 \dots (4)$$

The minimum bubble diameter varies from 0.79 mm to 1.40 mm. Also the maximum bubble diameter varies from 1.02 mm to 1.81 mm.

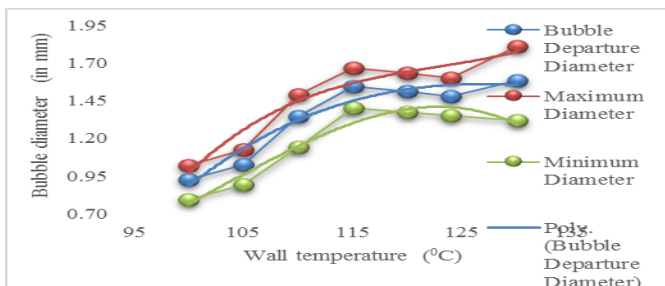


Fig. No.5. Variation of Bubble Diameter Vs wall temperature for 30° cut needle

From Fig no. 5. we observed as the wall temperature increases the bubble diameter goes on increasing. Here though the frequency of formation of bubble increasing but rate of increase is similar to that of 90° cut needle as the wall temperature increase.

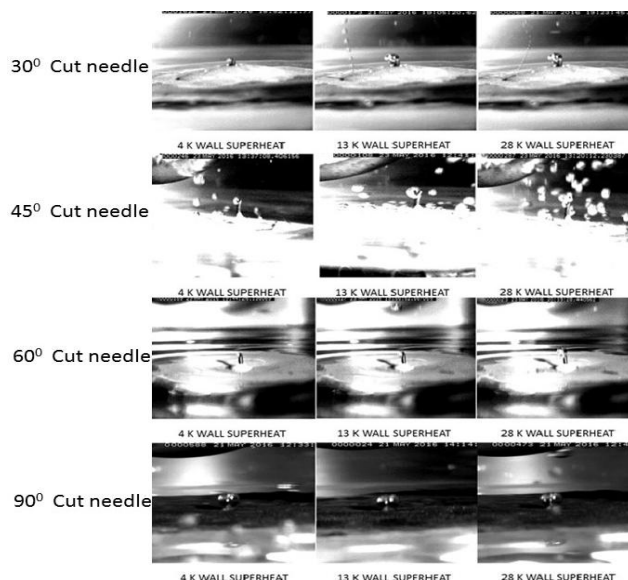


Fig. No.6. Bubble dynamics of nucleation sites (photographic travel)

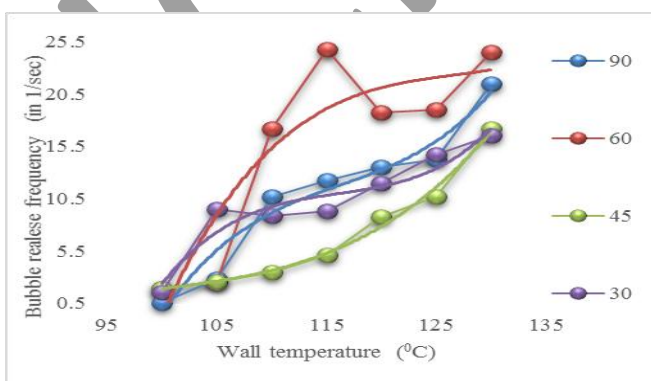


Fig. No.7: Bubble release frequency Vs Wall temperature

## CONCLUSIONS:

The effect of wall superheat on bubble dynamics during nucleate pool boiling heat transfer using saturated water was studied experimentally. The study of bubble dynamics done using PCO high speed camera operating at more than 100 frames per second at atmospheric pressure Single bubble was generated using needle tip with different cross section as a nucleation site.

The captured images show that single bubble grew rapidly initially in spherical shape and then convert to shape like balloon axi-symmetrically until reaching its maximum size, and then departed from the tip of needle. The average bubble departure diameter of 90° cut needle is almost constant as compared with other nucleation sites, whereas other nucleation site as 60° and 30° have less diameter of bubble diameter but it goes on increasing as increase in wall superheat. Also the frequency of bubble formation is increases in each nucleation site as increase in wall temperature, it happens due to higher rate formation of vapour as increase in wall superheat but the rate of increase is found more in 60° cut needle.

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ICITER-2016