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Experimental Study of Single Bubble Dynamics during Nucleate Pool Boiling Using Ammonium Chloride 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, heat flux etc. In this paper, effect of wall superheat in nucleate pool boiling heat transfer on single bubble dynamics using ammonium chloride studied experimentally. Single bubble is generated using hypodermic needle tip as a nucleation site. The hypodermic needles were used of inner diameters 0.514 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 3 K to 20 K for heat flux 601 kW/m*^{2} *and 3 K to 30 K for heat flux 950 kW/m*^{2}*. Concentration of ammonium chloride is critical micelle concentration 2600 ppm at heat flux 601 kW/m*^{2} *and 950 kW/m*^{2}*.*

1. INTRODUCTION

Nucleate boiling heat transfer is utilized in many applications where large amount heat has to be transferred such as nuclear reactor, rocket engines. Generation of isolated bubble is crucial for the process of boiling because slugs and columns are develops from isolated bubbles. High heat transfer rate achieved by nucleate boiling heat transfer. 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. Shoji & Takagi [1] studied bubbling features from a single artificial cavity. Conical, cylindrical and re-entrant cavities also tested. Qiu and Dhir [2] studied experimentally and numerically, the growth and detachment of a single bubble on a heated surface during parabola 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. Siedel et al. [4] investigated experimentally the bubble growth, bubble 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.

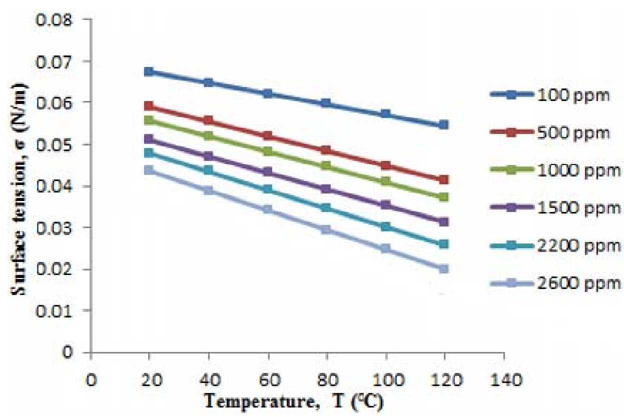

Fig. 1: Surface tension as function of temperature

Gajghate et al. [5] concludes in their experimental study as the maximum level of enhancement is observed up to 2,600 ppm concentration of aqueous ammonium chloride as a surfactant additive in nucleate pool boiling heat transfer. For concentrations more than 2600 ppm, significant enhancement not recorded. A. Najim [6] studied experimentally bubble dynamics in pool boiling heat transfer using saturated water and aqueous Ammonium Chloride solution. Fig. 1 shows the magnitude of surface tension as a function of temperature for various concentrations ammonium chloride.

Enhancement observed is due to the change in the thermo-physical properties of the aqueous solution. It is observed that as ammonium chloride in pure water, the surface tension of the mixture considerably reduces [6].

Table 1: Physiochemical Properties of Ammonium Chloride

Chemical formula	Ionic Nature	Form	Molecular Weight (g/mol)
NH4Cl	Anionic	Crystalline	53.49

The objective of the study is to compare the bubble growth in pure water to that of surfactant additive solution. The surfactant used was ammonium chloride, and base liquid was pure water.

2. EXPERIMENTAL METHOD

2.1 Experimental Set-up

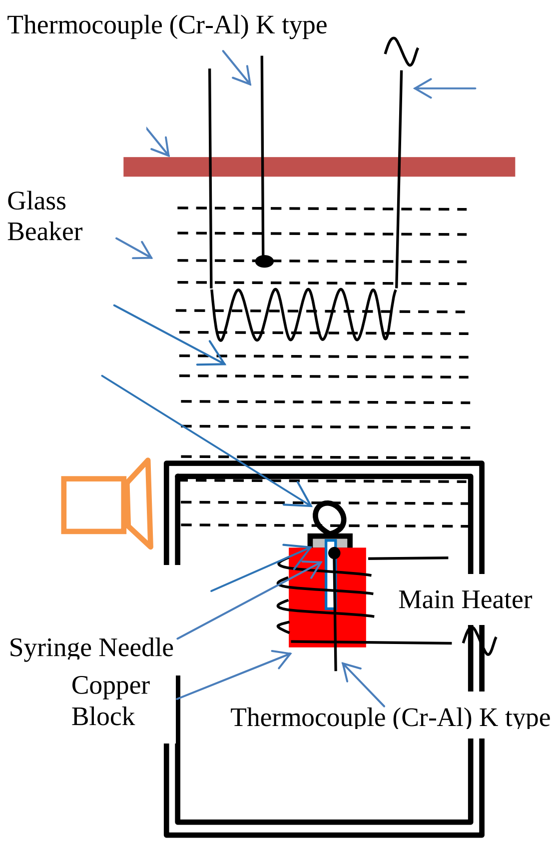

Fig. 2: Experimental set-up

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 Fig. 2.

2.2 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 dimmer stat. An auxiliary 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 gap between the needle wall and borosilicate glass at its base was sealed with epoxy adhesive. An auxiliary heater 1000 watt is installed to maintain temperature of the liquid at saturation temperature. The pool temperature and temperature at tip of needle is measured by K-type thermocouple. The bubble growth recorded by PCO high speed camera operating at 100 frames per second.

2.3 Needle Size

Table 2: Needle Size Gauge 21

	Nominal outer Diameter mm	Nominal Inner Diameter mm	Depth mm
Value	0.819	.514	25
Uncertainty	±0.0064	±0.019	0.01

2.4 Uncertainty Analysis

The voltmeter and ammeter used for the experimentation were within ±1 and ± 0.01 accuracy respectively. The temperature of heated surface and working fluid was measured by 0.3mm K-type thermocouple having accuracy of within ±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 ± 1 pixels with ImageJ open source software which is equal to ±0.125mm.

3. RESULT AND DISCUSSION

3.1 Ammonium Chloride as surfactant in saturated water at 2200 ppm

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 3 K to 20 K for heat flux 601 kW/m^2 and 3 K to 30 K for heat flux 950 kW/m^2. Concentration of ammonium chloride is, 2600 ppm at heat flux 601 kW/m^2 and 950 kW/m^2.

3.1 1 Heat flux 601 kW/m^2

In nucleate boiling region, at 601 kW/m2, bubble departure diameter at same heat flux is measured between 2.61 mm to 2.77 mm. Equation of bubble departure diameter with respect to wall superheat in K is found to be

$$y = -0.0002x^2 + 0.0043x + 2.6737 \quad (1)$$

Bubble waiting time is measured 0.02 second to 0.11 second.

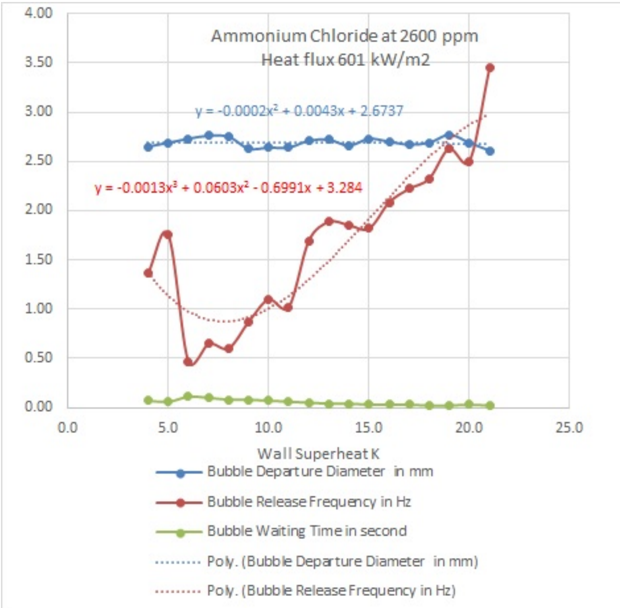

Fig. 3: Bubble dynamics at heat flux 601 kW/m²

Bubble release frequency is measured from 0.47 Hz to 3.45 Hz at these set of wall superheat. This increase in bubble release frequency due to increase in rate of formation of vapour nuclei with wall temperature. Equation of bubble release frequency with respect to wall superheat in K is found to be

$$y = -0.0013x^3 + 0.0603x^2 - 0.6991x + 3.284 \qquad (2)$$

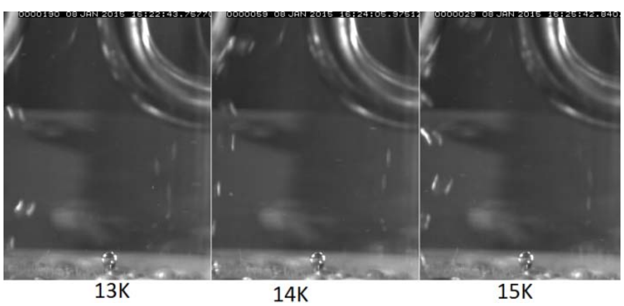

Fig. 4: Bubble Dynamics at wall temperature at heat flux 601 kW/m²

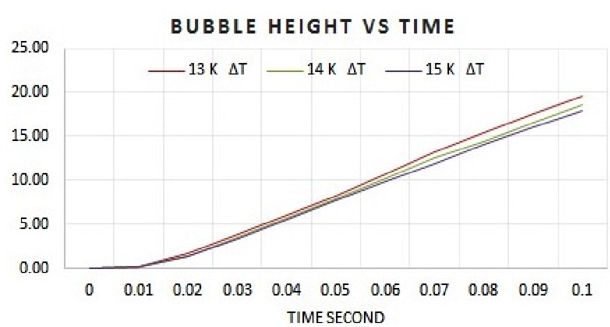

Fig. 5: Bubble height vs time at heat flux 601 kW/m²

Bubble height for these set of wall superheat is plotted in figure. Bubble height at 13 K wall superheat increases with more rate than that of 14 K, 15 K wall superheat.

3.1 2 Heat flux 950 kW/m²

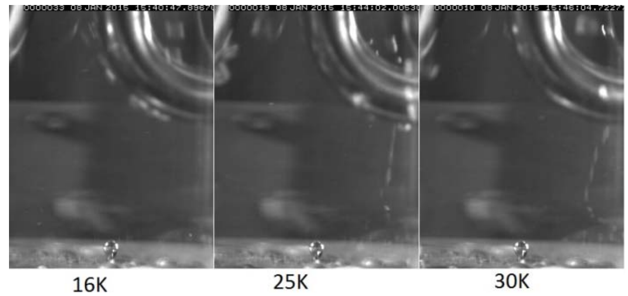

Fig. 6: Bubble Dynamics at wall temperature at heat flux 950 kW/m²

In nucleate boiling region, at 950 kW/m2, bubble departure diameter at same heat flux is measured between 2.29 mm to 2.67 mm. Equation of bubble departure diameter with respect to wall superheat in K is found to be

$$y = 0.0002x^2 - 0.0032x + 2.4962 \qquad (3)$$

Bubble waiting time is measured 0.00 second to 0.03 second.

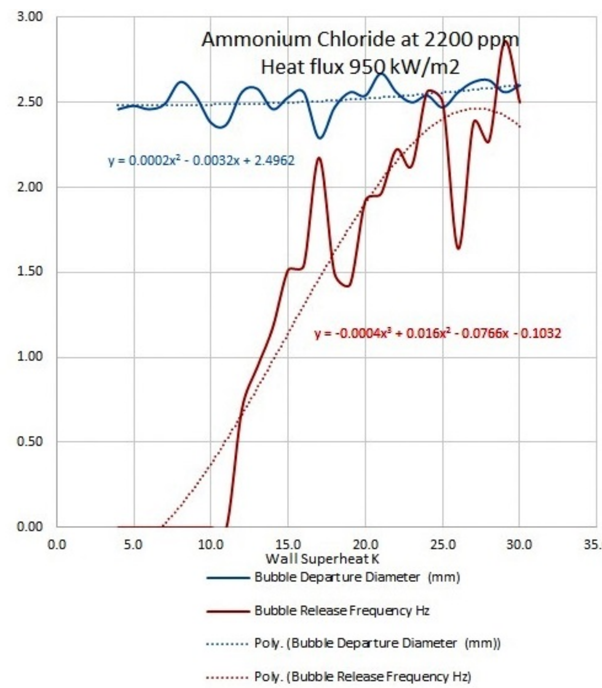

Fig. 7: Bubble dynamics at heat flux 950 kW/m²

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 release frequency is measured from 0.69 Hz to 2.86 Hz at these set of wall superheat. Equation of bubble release frequency with respect to wall superheat in K is found to be

$$y = -0.0004x^3 + 0.016x^2 - 0.0766x - 0.1032 \quad (4)$$

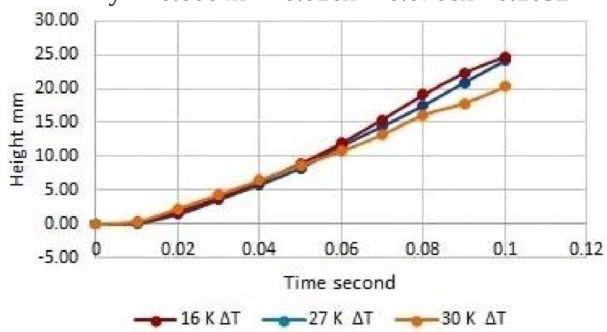

Fig. 8: Bubble height vs time at heat flux 950 kW/m^2

Bubble height for these set of wall superheat is plotted in figure. Bubble height at 16 K wall superheat increases with more rate than that of 27K, 30 K wall superheat.

3.2 Comparison Bubble Dynamics parameters

Four bubble dynamics parameters at both heat flux 601 kW/m^2 and 950 kW/m^2 are studied experimentally. Numerical results tabulated below from table 3 to 6.

3.2 1 Bubble departure diameter

Average Bubble departure diameter at heat flux 601 kW/m^2 is measured 2.69 mm which is greater than 2.52 mm, average bubble departure diameter at heat flux 950 kW/m^2.

Table 3: Comparison of Bubble Departure Diameter

Heat flux 601 kW/m2			Heat flux 950 kW/m2		
Minimum Bubble Departure Diameter mm	Maximum Bubble Departure Diameter mm	Average Bubble Departure Diameter mm	Minimum Bubble Departure Diameter mm	Maximum Bubble Departure Diameter mm	Average Bubble Departure Diameter mm
2.61	2.77	2.69	2.29	2.67	2.52

3.2 2 Bubble departure frequency

Average Bubble release frequency at heat flux 950 kW/m^2 is measured 1.89 Hz which is greater than 1.68 Hz, average bubble release frequency at heat flux 601 kW/m^2.

Table 4: Comparison of Bubble Release Frequency

Heat flux 601 kW/m2			Heat flux 950 kW/m2		
Minimum Bubble release frequency Hz	Maximum Bubble release frequency Hz	Average Bubble release frequency Hz	Minimum Bubble release frequency Hz	Maximum Bubble release frequency Hz	Average Bubble release frequency Hz
0.47	3.45	1.68	0.69	2.86	1.89

3.2.3 Bubble waiting time

Average Bubble waiting time at heat flux 601 kW/m^2 is measured 0.05 second which is greater than 0.04 second, average bubble waiting time at heat flux 950 kW/m^2.

Table 5: Comparison of Bubble Waiting Time

Heat flux 601 kW/m2			Heat flux 950 kW/m2		
Minimum Bubble waiting time second	Maximum Bubble waiting time second	Average Bubble waiting time second	Minimum Bubble waiting time second	Maximum Bubble waiting time second	Average Bubble waiting time second
0.02	0.11	0.05	0.00	0.03	0.02

3.2.4 Bubble Height as function of time

At heat flux 601 kW/m2, bubble height after specific time reduces according to wall superheat as shown in table 6.

Table 6: Comparison of Bubble Height after Specific Time

Heat flux 601 kW/m2			Heat flux 950 kW/m2		
Wall Superheat K	Bubble Height after 0.03 second mm	Bubble Height after 0.07 second mm	Wall Superheat	Bubble Height after 0.09 second mm	Bubble Height after 0.01 second mm
13 K	3.82	13.15	16 K	22.31	24.69
14 K	3.49	12.57	25 K	19.00	21.88
15 K	3.32	11.82	30 K	17.83	20.26

At heat flux 950 kW/m^2, bubble reaches more rapidly to the surface due to decrease in surface tension with wall superheat. This described by table 6, also bubble height after specific time reduces according to wall superheat as shown in table 6.

4. CONCLUSIONS

The effect of heat flux and wall superheat on bubble dynamics during nucleate pool boiling heat transfer using ammonium chloride 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 601 kW/m^2 and 950 kW/m^2. Single bubble was generated using right angle tip of a vertical hypodermic needle as a nucleation site. The vertical hypodermic needles were used of inner diameters 0.514 mm with a constant depth of 25 mm

The captured images conclude 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. At heat flux 601 kW/m^2, bubble departure diameter at same heat flux measured between 2.61 mm to 2.77 mm. Bubble release frequency increases from 0.47 Hz to 3.45 Hz at wall superheat from 3 K to 20 K.

At heat flux 950 kW/m^2, bubble departure diameter at same heat flux measured between 2.29 mm to 2.67 mm. Bubble release frequency increases 0.69 Hz to 2.86 Hz at wall superheat from 3 K to 30 K. Increase in bubble release frequency due to higher rate of vapour formation at increasing wall superheat at both heat flux 601 kW/m^2 and 950 kW/m^2.

Above results conclude that for heat transfer enhancement addition of ammonium chloride at critical micelle concentration enhances formation of vapor nuclei.

REFERENCES

[1] M. Shoji, Y. Takagi, "Bubbling Features from a Single Artificial Cavity," *International Journal of Heat and Mass Transfer*, vol. 44, 2001, pp. 2763-2776.

[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, 2002, pp. 336-345.

[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, 2005, pp. 2121-2129.

[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, 2008, pp. 1504-1511.

[5] S. Gajghate, A. R. Acharya, A.T. Pise, "Experimental study of aqueous ammonium chloride in pool boiling heat transfer", *A Journal of Thermal Energy Generation, Transport, storage, and conversion, Taylor And Francis*, vol. 27:2, Nov. 2013, pp. 113-123.

[6] 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.