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Single Bubble Dynamics Study during Nucleate Boiling

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Abstract -A large number of studies of bubble release frequency and departure diameter are found in the literature. Number of vapor bubbles per unit time depends on liquid, evolving interface, system physical parameters. Wall superheat, size of nucleation site etc. parameters affect bubble departure diameter in nucleate boiling heat transfer. This paper reports experimental study of effect of wall superheat in nucleate pool boiling heat transfer on single bubble dynamics using ammonium chloride. Single bubble is generated using vertical hypodermic needle tip as nucleation site. Here the hypodermic needle is used where inner diameter is 0.514 mm with a constant depth of 25 mm. Single bubble dynamics is studied using PCO high-speed camera operating at 120 frames per second at atmospheric conditions and at a wall superheat of 3 K to 20 K for heat flux 601 kW/m2 and 3 K to 29 K for heat flux 950 kW/m2. Concentration of ammonium chloride is 2200ppm and 2600 ppm which is critical micelle concentration at heat flux both 601 kW/m2 and 950 kW/m2. Second order polynomial for departure diameter and third order polynomial for bubble release frequency is investigated. The results conclude that addition of ammonium chloride enhances formation of vapor nuclei at nucleation site. At critical micelle concentration, the bubble release frequency is maximum and enhances nucleate pool boiling at artificial nucleation site.

Index Terms—Heat flux, nucleate, pool boiling, surfactant, wall superheat, bubble, dynamics

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 developed from isolated bubbles. Nucleate boiling heat transfer achieves high heat transfer rate. 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. Gajghate et al. [5] concluded 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 was not recorded. Enhancement observed is due to the change in the thermo-physical properties of the aqueous solution. It is observed that as ammonium chloride is added in pure water, the surface tension of the mixture considerably reduces.

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2 Experimental Method for Ammonium chloride at 2200 ppm

Table 1
Dimension of Needle.

Needle Gauge	Inner Diameter d_{ni}=(mm)	Depth (mm)
21	0.514	25

Table 1 gives dimensions of needle used for experimentation. The bubble departure diameter in nucleate pool boiling heat transfer using saturated water is 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 ammonium chloride 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 0.514 mm with a constant depth of 25 mm. Single bubble dynamics is studied using PCO high speed camera operating at 120 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 948 kW/m^2. Concentration of ammonium chloride is 2200 ppm at heat flux 601 kW/m^2 and 948 kW/m^2.

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 also shown. Bubble waiting time is measured 0.02 second to 0.11 second.

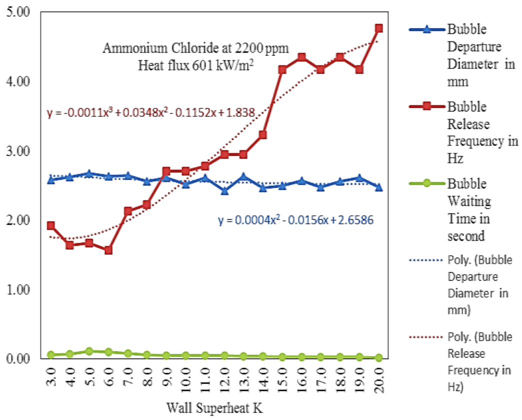


Fig. 1. Bubble dynamics at heat flux 601 kW/m^2

Fig. 1 shows Bubble departure diameter, Bubble Release Frequency and Bubble waiting time variation w.r.t. wall superheat. Bubble release frequency is measured from at different wall superheat. Fig. also shows increase in bubble release frequency due to increase in rate of formation of vapor nuclei with wall superheat. Equation of bubble release frequency with respect to wall superheat in K is found is shown.

Heat flux 948 kW/m²

In nucleate boiling region, at 948 kW/m^2, bubble departure diameter at same heat flux is measured between 2.27 mm to 2.63 mm.

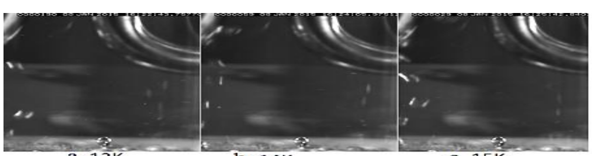


Fig. 2. Bubble Dynamics at wall superheat at heat flux 601 kW/m²

Fig. 2 shows image of bubble formed at tip of needle with different wall superheat. These wall superheat being too close, much difference in bubble diameter is not observed.

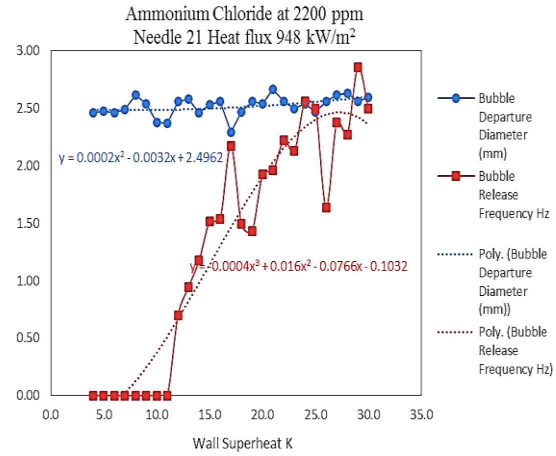
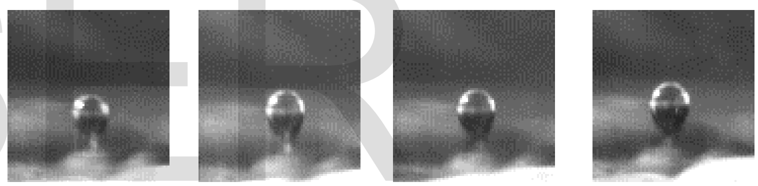


Fig. 3. Bubble dynamics at heat flux 948 kW/m^2

Fig. 3 shows Bubble departure diameter, Bubble Release Frequency and Bubble waiting time variation w.r.t. wall superheat. Bubble release frequency is measured from at different wall superheat. Fig. also shows increase in bubble release frequency due to increase in rate of formation of vapor nuclei with wall superheat. Equation of bubble release frequency with respect to wall superheat in K is shown.



a. 3 K b. 9 K c. 17 K d. 26 K

Fig. 4. Bubble Dynamics at wall superheat at heat flux 948 kW/m^2

Fig. 4 shows image of bubble formed at tip of needle with different wall superheat. This wall superheat now being distinct, difference in bubble diameter is now observed.

Experimental Method for Ammonium chloride at 2600 ppm

Heat flux 601 kW/m²

Fig. 5 shows that in nucleate boiling region, at 601 kW/m^2, bubble departure diameter at same heat flux is measured between 2.42 mm to 2.67 mm. Equation of bubble departure diameter with respect to wall superheat in K is shown. Bubble waiting time is measured 0.02 second to 0.11 second.

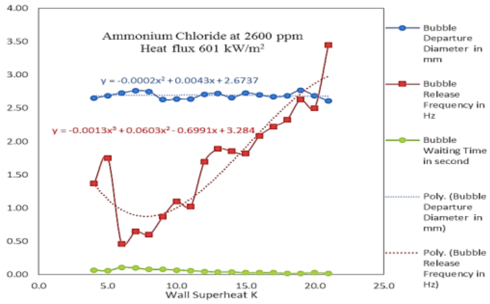


Fig. 5. Bubble dynamics at heat flux 601 kW/m^2

Bubble release frequency is measured from 1.56 Hz to 4.76 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 superheat. Equation of bubble release frequency with respect to wall superheat in K is shown.

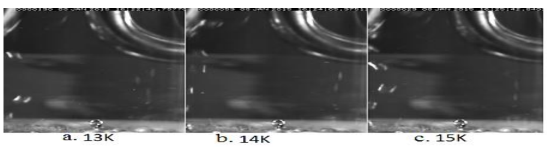


Fig. 6. Bubble Dynamics at wall superheat at heat flux 601 kW/m^2

Fig. 6 shows image of bubble formed at tip of needle with different wall superheat. This wall superheat now being distinct, difference in bubble diameter is now observed.

Heat flux 948 kW/m²

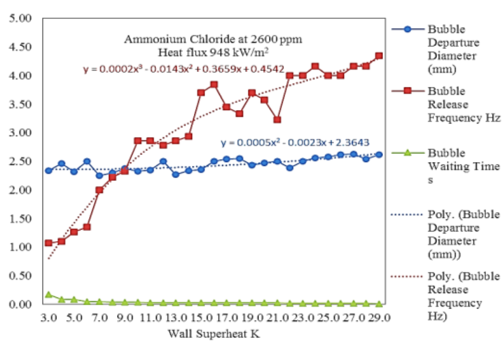


Fig. 7. Bubble dynamics at heat flux 948 kW/m^2

Fig. 7 shows that 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 shown. Bubble waiting time is measured 0.00 second to 0.03 second.

In nucleate boiling region, at 948 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 shown

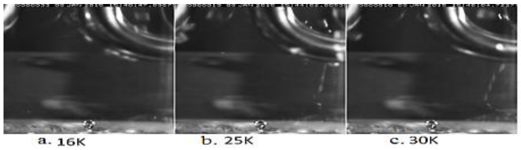


Fig. 7. Bubble Dynamics at wall superheat at heat flux 948 kW/m^2

Fig. 7 shows image of bubble formed at tip of needle with different wall superheat. This wall superheat being too close, much difference in bubble diameter is not observed.

3 Conclusions

The results conclude that addition of ammonium chloride enhances formation of vapor nuclei at nucleation site. At critical micelle concentration the bubble release frequency is maximum and enhances nucleate pool boiling at artificial nucleation site. Results can be summarised as:

i. Bubble departure diameter is independent on wall superheat.
ii. Bubble release frequency increases with increase in wall superheat.
iii. Bubble waiting time decreases with increase in wall superheat.

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