Ammonium Chloride as Surfactant for Heat Transfer Enhancement in Pool Boiling

A. R. Acharya, A. T. Pise, and I. I. Momin

Abstract—**The heat transfer in boiling can be enhanced by adding small amount of additive in fluid. Addition of small amount of additive in the fluid changes the physical behavior of the boiling phenomenon. Surfactant changes thermo-physical properties of the fluid. Experiments on pool boiling were carried in presence of the surfactant in pure water with an aim to enhance heat transfer in pool boiling by addition of surfactants. Ammonium Chloride (NH4Cl) is taken as test surfactant and added separately in water with varying concentration. The results of surfactant NH4Cl up to 2800 ppm in pure water showed the heat transfer enhancement and above this range no enhancement was observed. Also the trend of boiling curves in presence of this surfactant in the water, shifted towards the lower excess temperature side. Kinetics of vapor bubble in pool boiling phenomena for pure water with and without surfactant was observed in terms of bubble nucleation, growth and its departure.**

Index Terms—**Surfactant, Boiling, Additive, Surface Tension, Bubble behavior, Flow Visualization.**

I. Introduction

There is a general need to increase the heat transfer rate in pool boiling applications for saving the energy required to phase change. Energy crisis and global warming is forcing to exert more to save the energy from different applications. Hence the main motive here is to reduce the energy i.e. increase the heat transfer rate in pool boiling. Researchers found enhancement techniques in heat transfer for the boiling. The addition of surfactant as additive in the solution is the cost effective technique and simple to handle. Some of the researchers had conducted the experiments on pool boiling enhancement-using additives.

Hetsroni and his group [1,2] in their study of pool boiling on horizontal stainless steel tube inside a transparent glass vessel observed the bubble behaviors. They observed that boiling in surfactant solution when compared with that in pure water was more vigorous and more activation of nucleation sites in clustered mode. For the boiling curve, wall temperature of the heated tube decreased with an increase in the concentration of the alkyl polyglucosides. Bubble form in Habon-G solution was very much smaller than those in water and surface becomes covered with them faster. Kotchaphakdee et al., [3] studied the effects of Poly acryl amide (PA), and Hydroxyl Ethyl Cellulose (HEC), solute concentrations ranged from 62 to 500 ppm liquids in water boiled at atmospheric pressure on a horizontal steam heated chrome-plated surface. They observed that amount of polymers in water increases nucleate boiling heat flux. PA leads to significantly improved heat transfer coefficient over the entire range of excess temperature. The peak heat flux is considerably higher than for water. Klein et al., [4] investigated the effects of APG surfactant solution flows through a micro-channel heat sink in which heat generated due to electronic components were removed. Surfactants mixed solution-boiling phenomena were also found to stabilize the maximum and average surface temperatures for a wide range of applied heat fluxes. Further effort invested on revealing proper surfactant additives and performing experiments of surfactant solutions flowing through a various micro-channel heat-sink configurations. Urquiola, et al., [5] did the boiling experiments with pure water and surfactant solutions of SDS on horizontal heating surface. Surfactant behavior was studied in terms of static contact angle directly related with the surface conditions, rather than the surface tension value. Higher contact angle leads the boiling curve of a specific liquid or solution to show better heat transfer characteristics. Wen and Wang [6] observed the effects of surface wettability on nucleate pool boiling heat transfer for Sodium Dodecyl Sulphate (SDS) and Triton (X-100) surfactant in water. They found that both SDS and Triton X-100 could increase boiling heat transfer coefficient. Also the boiling phenomena is mainly depends on thermo physical properties of fluid that are density, surface tension and kinematic viscosity. The addition of small amount of surfactant does not affect the density of solution but it slightly increases the viscosity and measure reduction in surface tension if surfactant is polymeric [7]. Number of researchers measured the surface tension data with and without surfactants in water, [2,8] which shows with increase in surfactant concentration surface tension decreases.

After the extensive literature reviewed some of the questions are unattempted, like selection of the additive and its optimum quantity, whether surfactant mixes in solution or not, The mechanism of enhancement is not yet properly understood, but it is clearly understood that reduction in surface tension changes the boiling behavior. Better understanding of this process is needed. So in this work, the effect of surfactants in pool boiling for enhancement of heat transfer is experimentally investigated. Ammonium Chloride NH_4Cl served as test surfactant and added in water with varying concentration in search to find optimum quantity[8]. The overall aim of this work is to understand the phenomenon of nucleate pool boiling of water with and without surfactants, as it is very complex in nature.

II. Experimental Method

A. Experimental setup

The apparatus for experimental studies on pool boiling is shown in Figure 1. It consists of cylindrical glass container

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housing, the test heater and the heating coil for the initial heating of the water. The heater coil is directly connected to the mains (Auxiliary Heater R1) and the test heater (Nichrome wire) is connected also to mains via a dimmerstat. An ammeter (range 0-10A) is connected in series while the voltmeter across it to read the current and voltage. Voltage selector switch is used to select the voltage range 50/100V. These controls are placed inside the control panel.

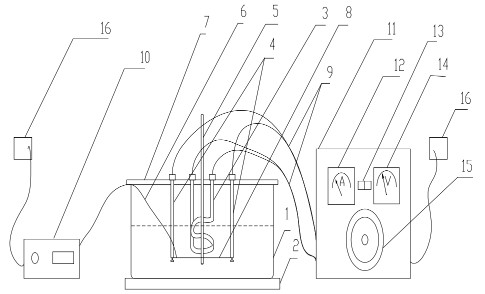

Figure 1. Schematic Figure of Experimental Setup

1.Glass Container 2.Wooden Platform 3.Auxilary Heater (R1) 4.Test Heater (R2) 5.Thermometer 6.Thermocouple 7.Clay Lid 8.Nichrome Wire 9.Heater Connecting Cable 10.Digital Temperature Indicator11.Control Panel 12.Ammeter13.Voltage Range Selector Switch 14.Voltmeter 15.Dimmerstat 16.Electric Power Switch

To study the kinetics of vapor bubble in pool boiling phenomena for pure water with and without surfactant a camera is fixed near to apparatus in such a way that boiling phenomenon can be recorded by camera to make observations in terms of bubble nucleation, growth and its departure. Electronic balance was used for the measurement of the mass of NH_4Cl has least count of 1mg.

B. *Test Procedure*

The glass container was filled with 2.5 liters of pure water and it kept on a stand, which is fixed on a wooden platform. The temperature of bulk water i.e. saturation temperature of water was measured using mercury thermometer with least count of 0.5^{o}C. A Cr-Al k-type thermocouple is connected to nichrome heater wire to measure the temperature of wire using digital temperature scanner having least count 0.1^{0}C. The kinetics of boiling (bubble nucleation, growth and departure) i.e. bubble behavior with and without surfactants in water was recorded by Handy camera (800X) video recording. Experiments were carried with and without surfactant (NH_4Cl) in pure water (i.e. deionised water) by varying heat flux. Concentration of NH_4Cl was varied from 0-3000 ppm in pure water. Each experiment was repeated three times to maintain the repeatability.

III. Results and Discussion

The extensive experimentation of pool boiling was carried for pure water with and without surfactant of varying concentrations of NH_4Cl and heat flux. From the obtained experimental data, results are plotted in terms of boiling curve as a heat flux vs. heater excess temperature. Also the some images of kinetics of boiling (bubble nucleation, growth and departure) i.e. bubble behavior for water and water with surfactants by varying heat flux were recorded by Sony Handy camera (800X). These are discussed in Comparative studies of results of surfactant were broadly discussed into two categorize as boiling behavior and boiling curves.

A. *Boiling Behavior*

The kinetics of vapor bubble in pool boiling phenomena for pure water with and without surfactants was observed in terms of bubble nucleation, growth and departure the evolution of vapor bubble. The growth of bubble is one of the parameters determining the intensity of the heat transfer from a heated surface. All the pool boiling experiments were carried out under atmospheric pressure. The phenomenon of foaming, often observed during boiling in the presence of surfactant in water. The foam formed on the surface of the solution and its height increased with the heat flux. The bubble behavior was recorded at 24 frames per second by the video camera and recording was done for varying the concentration of the surfactants and heat flux. The typical stages of bubble growth analyzed for this study are shown in Figure 2 to Figure 3.

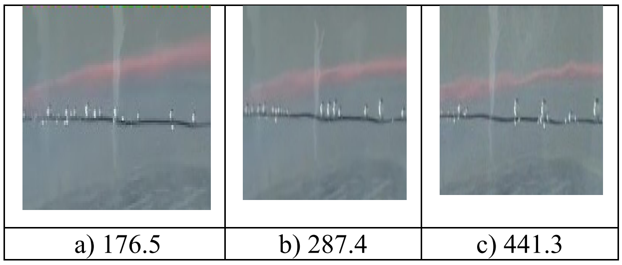

Figure 2. Images of boiling of pure water for heat fluxes (kW/m2): a) 176.5 b) 287.4 c) 441.3

Figure 2 (a-c) show typical images of deionized water boiling on the nichrome wire at heat fluxes 176.5, 287.4 and 441.3 kW/m^2 respectively. Population of bubbles was observed in the vicinity of the heated wire. The bubble dynamics for water were seen to depend on heat flux, similar to well-known boiling visualization data. After the onset of nucleate boiling, the regime of single bubbles occurred close to the heated wall (Figure 2a). As the heat flux increased, bubble coalescence takes place (Figure 2b). This phenomenon was more pronounced at heat flux 441.3 kW/m^2 (Figure 2c). For pure water, the average bubble size was observed to slightly increase with increasing heat flux. The bubbles have an irregular shape at all values of heat flux. Same heat fluxes with NH_4Cl of 1200 ppm in pure water were observed and the images are shown in Fig. 3(a-c).

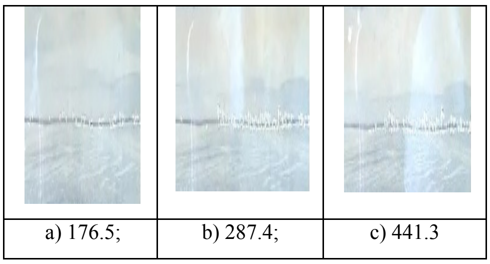

Figure 3. Images boiling of 1200 ppm NH4Cl in water for heat fluxes (kW/m2): a) 176.5; b) 287.4; c) 441.3

The time between detaching bubbles from wire and reaching the bubble up to free surface is measured in Windows Movie Maker and the distance between wire and free surface was measured using Adobe Photoshop 7.0 software. The same procedure was repeated in three times for each concentration as well as heat flux and average velocity was calculated. The results showed that the velocity of bubble slightly increased with varying heat flux and concentrations. This might be due to addition of surfactant, surface tension force decreases and hence resistance to bubble motion also decreased [2,8]. Figure 4. (a-n) show the images of boiling of 200–3000 ppm NH_4Cl in pure water. It is particularly noticeable that diameter of bubble in surfactant solution is smaller as compared to water. Bubbles form a blanket over the wire, which can't be observed in water. This might be due to reduction in surface tension of solution and increase in the number of nucleation sites on the same wire. The phenomena of foaming were observed after 1200-ppm concentration. As discussed earlier the approximate bubble velocity is measured. The results showed that the velocity slightly increases with varying concentrations from 200 to 3000 ppm. Up to 800ppm NH_4Cl in the water the boiling behavior quite similar to that of water.

The shape of bubbles is closer to spherical than for pure water. The bubbles are adjacent to each other and the cluster neck is not observed, hence energy required to create a bubble is less.

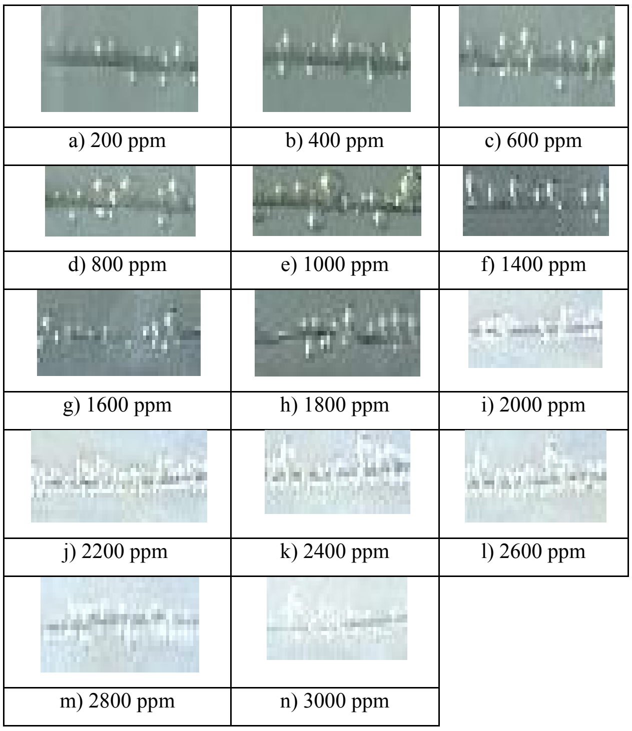

Figure 4. images of 200-3000 ppm NH4Cl in Water for heat flux 300 kW/m2

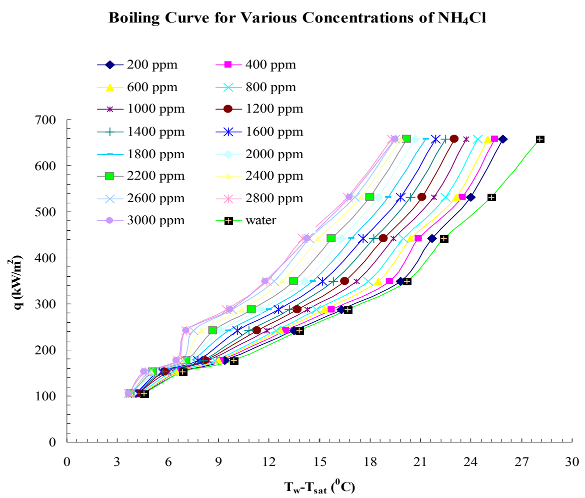

Figure 5. Pool boiling curves of pure water with NH4Cl

B. *Boiling Curves*

The saturated pool boiling curves are plotted with varying concentrations of surfactant in pure water as a function of the heat flux q (kW/m^2) vs. the heater excess temperature (T_w-T_{sat}) ^{0}C (Figure 5). The effects of NH_4Cl as a surfactant in pure water are also checked. The surface temperature of the heated nichrome wire decreased monotonically with an increased in the concentration of the NH_4Cl solution up to 2800 ppm, also noted that the effect of surfactant additives on nucleate boiling heat transfer slightly decreased, when the concentration of NH_4Cl solution is higher than 2800 ppm. Figure 5 shows the boiling curve for various concentrations of NH_4Cl in water.

IV. Conclusions

From the experimental results of this study the following major conclusions are drawn. The bubbles formed in water with surfactant solutions are much smaller than pure water and they covered the surface of wire faster. Presence of the surfactant reduces the boiling excess temperature ΔT. It is observed as the boiling curves shifted to the left side and promotes activation of nucleation sites in a clustered mode. For pure water average bubble size was observed to slightly increase with increasing heat flux. Up to 800-ppm ammonium chloride (NH_4Cl) in the water the boiling behavior quite similar to that of water. Also upto 2800 ppm enhancement was observed. This might be due to slight reduction in surface tension up to 800 ppm and due to its higher solubility limit in the water. The surfactant showed that heat transfer coefficient was increased up to solubility limit of the surfactant in water. The addition of the surfactant beyond the solubility limit was almost constant or slightly decreases the heat transfer coefficient. Presence of surfactant in water increases average bubble velocity.

Experimentation can be extended for searching different surfactants in order to find their optimum quantity in pure water.

References

[1] Hetsroni G., Gurevich M., Mosyak A., Rozenblit R. and Segal Z, "Boiling Enhancement with Environmentally Acceptable Surfactants", *Int. Jou.of Heat and Fluid Flow* 25, 2004, pp. 841-848

[2] Hetsroni G., J.L. Zakin, Z. Lin, A. Mosyak, E.A. Pancallo and R. Rozenblit, "The effect of surfactants on bubble growth, wall thermal patterns and heat transfer in pool boiling", *International Journal of Heat and Mass Transfer* 44, pp. 485-497, 2001.

[3] Kotchaphakdee P., and. Williams M. C., "Enhancement of Nucleate Pool Boiling with Polymeric Additives", *International Journal of Heat and Mass Transfer* 13, pp. 835-848,1970.

[4] Klein D., Hetsroni G., & Mosyak G., "Heat Transfer Characteristics of Water and APG Surfactant Solution in a Micro-Channel Heat Sink", *International Journal of Multiphase Flow* 31, pp. 393-415, 2005.

[5] Urquiola Erwin & Fujita Yasunobu, "Contact Angle Effects in Boiling Heat Transfer" *Memoirs of the Faculty of Engineering, Kyushu University, Japan* 62(1), pp. 55-65,2003.

[6] Wen D.S., & Wang. B.X., "Effects of Surface Wettability on Nucleate Pool Boiling Heat Transfer for Surfactant Solutions", *International Journal of Heat and Mass Transfer* 45, pp.1739-1747,2002.

[7] "Handbook of Pharmaceutical Excipients", A joint publication of the American Pharmaceutical Association and The Pharmaceutical Society of Great Britain, 1989.

[8] A.T.Pise, A.R.Acharya, Momin I.I., "Effect of Surfactants on Boiling Phenomena", *International Conference ExHFT*-7, 28 June -03 July 2009, Krakow, Poland, June 2009.

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