Experimental Investigation and Measurement of Contact Angle of Drop on Surface with Triton X-100 as Surfactant in Pure Water

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Abstract- *Boiling using surfactant is important in many industrial applications such as the petrochemical processing, pharmaceutical, refining, refrigeration, and food processing, among others. Moreover, surfactants in trace amounts are present in boilers of conventional power plants.*

The experimental set up for the present investigation includes electric heating wire (D= 0.3 mm and L= 100 mm) submerged in water and mounted horizontally. Two thermocouples and a digital indicator measured the temperature of the heater surface and solution temperature. The actual heat transfer rate is obtained by multiplying the voltmeter and ammeter readings. The main heater also present which heats the solution at 40⁰C to 50⁰C. The camera was fixed to take photos of water drop on nichrome wire for measurement of contact angle.

Several different surfactants were available, to check boiling behavior with and without surfactant in water. For this test Triton X-100 (Octylphenol Ethoxylate) was used as surfactant in pure water to reduce the contact angle and increase the heat transfer coefficient. Pool boiling experiments were carried out a relatively wide range of surfactant concentrations Triton X-100 (50 - 200) ppm and heat fluxes (61.53 - 152.79) kw/m². The boiling results show that with the addition of small amounts of surfactants, the saturated nucleate pool boiling heat transfer coefficient of water is found to be altered due to reduction in the surface tension and this enhances the heat transfer. The photographic and visual observations indicate boiling behavior is different than pure water with surfactant and shaped bubbles clustering on the heater surface reducing coalescence.

Key Words: Contact angle, wettability, heat transfer, and surface tension

1. INTRODUCTION

Nucleate pool boiling phenomenon has attracted considerable research and practical attention, due to its ability to transfer large amounts of heat with relatively small temperature differences. From last 60 years there has been extensive research to address issues such as bubble growth, bubble dynamics, effects of heater surface characteristics, fluid-surface interaction, and fluid properties, among others [1]. In recent years, due to importance that directed towards the energy conservation and economic imperatives, much effort have been made to advance techniques that lead to enhance nucleate boiling heat transfer.

The extent of enhancement has been found to be dependent on additive concentrations, its type and chemistry, wall heat flux, and the heater geometry. Many studies, have reported the importance of decreasing the surface tension by adding additives to the solution and its impact on the boiling heat transfer coefficient [5].

1.1 Contact angle

It is defined geometrically as the angle formed by a liquid at the three phase boundary where a liquid, gas and solid intersect. The measurement of a single static contact angle to characterize the interaction is no longer thought to be adequate. For any given solid/ liquid interaction there exists a range of contact angles which may be found. The values of static contact angles are found to depend on the recent history of the interaction. When the drop has recently expanded the angle is said to represent the 'advanced' contact angle. When the drop has recently contracted the angle is said to represent the 'receded' contact angle. These angles fall within a range with advanced angles approaching a maximum value and receded angles approaching a minimum value. If the three phase (liquid/solid/vapors) boundary is in actual motion the angles produced are called Dynamic Contact Angles and are referred to as 'advancing' and 'receding' angles. The difference between 'advanced' and 'advancing', 'receded' and 'receding' is that in the static case motion is incipient and in the dynamic case motion is actual. Dynamic contact angles may be assayed at various rates of speed. Dynamic contact angles measured at low velocities should be equal to properly measured static angles. In this test static advanced contact angle is measured. The fig. 1 shows the hoe contact angle is formed on surface at three boundary layer.

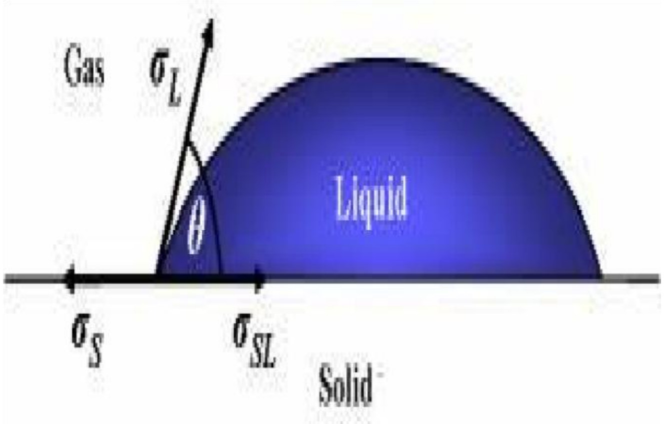


Fig -1: Single drop contact angle balance

Where σ_L, σ_{SL} and σ_S are liquid, solid- liquid and solid forces to balance the drop on surface. Wetting of a surface with liquids is an important parameter in the chemical engineering process such as heat transfer boiling & condensation distillation, absorption and desorption. It also has a significant impact on the tubes where a higher wetted area leads to an increase of the interfacial area and enhances heat and mass transfer rates. Reducing the contact angle increases the wettability and increases the heat transfer coefficient which is aim of experiment [3].

1.2 Surfactants

Surfactants are essentially low molecular weight chemical compound, with molecules consisting of a combination of a water-soluble means hydrophilic and water insoluble means hydrophobic part.

For this test Triton X-100 (Octylphenol Ethoxylate) is used as surfactant. Addition of surfactants to water reduces the surface tension of their solutions in water considerably. This reduction in surface tension is dependent upon several factors such as surfactant bulk concentration, surfactant type and molecular weight, solution temperature, and interfacial conditions, among others. Higher molecular weight surfactants affect a higher surface-tension depression compared to the lower molecular weight surfactants. Surface tension reduction of an aqueous solution decreases continually with increasing concentrations till the critical micelle concentration CMC is reached, at which point the surfactant molecules cluster together to form micelles [5].

2. Experimental Set up

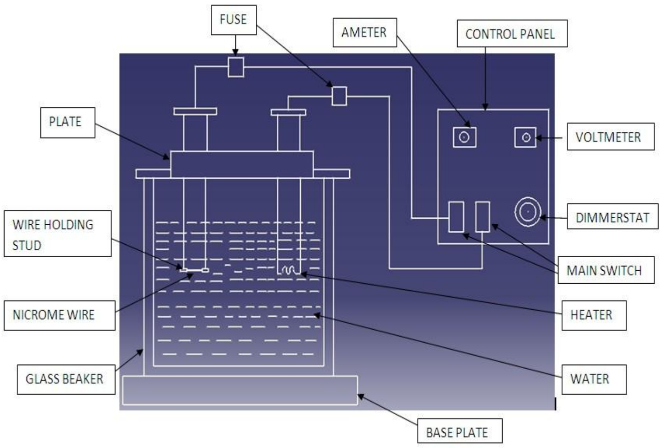


Fig -2: Block Diagram of Experimental Set up

This apparatus is useful to study the boiling behavior and measurement of contact angle of drop on nichrome wire at horizontal. It consists of cylindrical glass container filled with water. In which, the main test heater to heat the solution around 40^{0}C to 50^{0}C and nichrome wire heater on which bubbles will appear is submerged in water. Two thermocouples which is used to measure the temperature of nichrome wire and solution temperature. Dimmer stat is provided to adjust the voltage and current at required. By multiplying voltage and current heat transfer rate (q) is determined and dividing by excess temperature ΔT to q, heat transfer coefficient (h) is determined. Where ΔT is difference between nichrome wire and solution temperature.

For measurement of contact angle. a camera was fixed near the set up in such a way that boiling phenomenon can be recorded using Canon EOS 6D camera to make observations in terms of bubble nucleation, growth and its departure. Using adobe photo shop software measured the contact angle. The Triton X-100 is measured in ml and conversion was made from ml to ppm (part per million). Addition was to be done at different ppm to observe the boiling phenomenon.

3. Result and Discussion

Boiling with surfactant solutions when compared with that in pure water was observed to be more vigorous. The photographic views of boiling behavior are shown in fig.3 and fig.4 with and without surfactant in water. The surfactant reduces significantly the tendency of coalescence between vapor bubbles. The bubble grows continuously and collapse on the surface heater. The bubbles are smaller in size but much larger in number than in the case of pure water as shown in fig.4.

A decrease in the bubble size at boiling in the surfactant solution may be attributed to a decrease in the surface tension compared to the pure water.

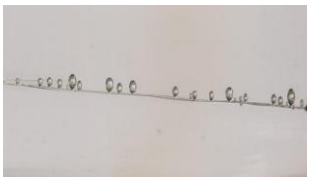
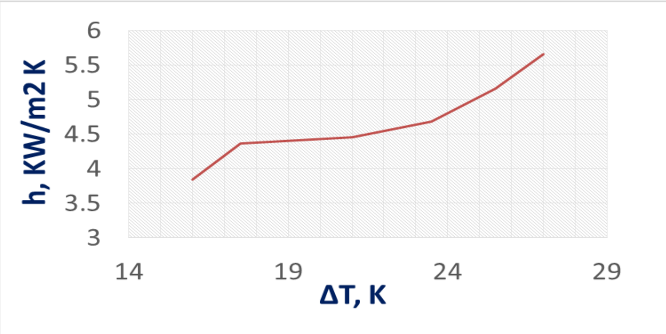


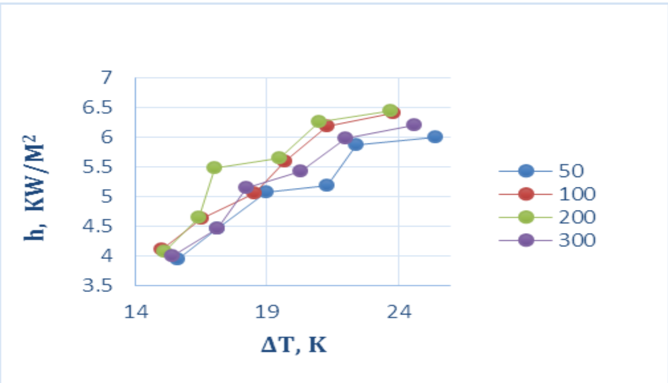
Fig -3: Pure water at Heat flux = 61.53 Kw/m^2

Fig -4: Pure water with 100 ppm Triton X-100 at Heat flux = 61.53 Kw/m^2

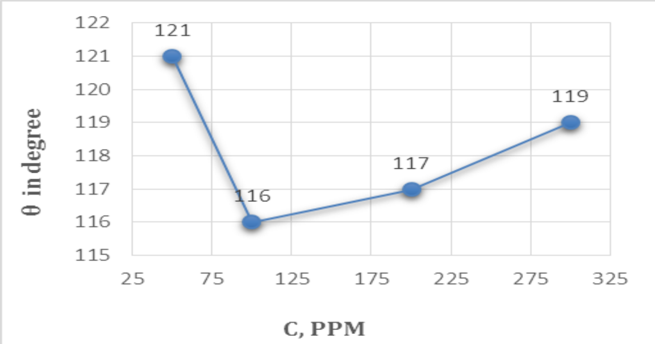
From obtained experimental data, results are plotted in terms of boiling curves. The graph 1 shows that increase in excess temperature ΔT, increases the heat transfer coefficient h for pure water. Also from graph 2 it is seen that as excess temperature increases, there is increase in heat transfer coefficient. The heat transfer coefficient h for different concentration that is from 50 ppm to 300 ppm is plotted.



Graph-1: Effect of excess temp. ΔT on heat transfer coeff. H for pure water



Graph-2: Effect of excess temp. ΔT on heat transfer coeff. H for Triton X-100 in pure water at 50 ppm to 300 ppm



Graph-3: Effect of concentration (C) on contact angle (θ) for Triton X-100 in pure water at 50 ppm to 300 ppm

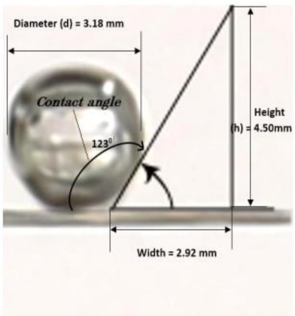


Fig- 5: Contact angle for pure water

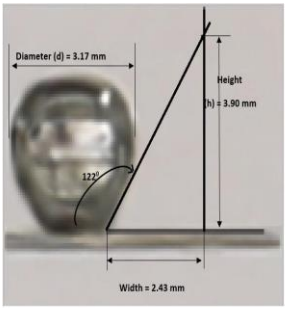


Fig- 6: Contact angle for Triton X-100 at 50 ppm

Table-1: Behavior of Triton X-100 at different parameters

Sr. No.	Concentration C (ppm)	Contact Angle (θ^0)	Surface Tension σ (N/M)	Heat Transfer Coeff. h (%)
1	50	121	0.067	2.30
2	100	116	0.063	5.96
3	200	119	0.059	6.66
4	300	119	0.059	2.30

The measurement of contact angle is done on Adobe Photo shop software. Drawn tangent to bubble and using tanθ formula angle is measured. For getting required contact angle, obtained angle is deducted from 180^0. For water and Trito X-100 at 50 ppm in water the measured contact angle is 123^0 and 121^0 respectively. The effect of concentration on solution is tabulated in table no.1.

4. CONCLUSIONS

1) The maximum enhancement in nucleate pool boiling is found to be dependent upon wall heat flux (or temperature difference), surfactant concentration and molecular weight.
2) Photographic visualization was carried out to quantify the nucleate pool boiling heat transfer enhancement of anionic surfactant solutions. This enhancement is characterized by a rapid departure of smaller-sized, regularly shaped bubbles from the heater surface, and an increase in the number of bubbles.
3) As heat flux increases, the heat transfer coefficient increases from 50 ppm to 200 ppm and after that it is decreases.
4) As heat flux increases, the surface tension decreases up to 200 ppm and contact angle decreases only up to 100 ppm and after that it is increases.
5) Presence of the surfactant reduces the boiling excess temperature ΔT. It is observed as the boiling curves shifted to the left due to decrease in ΔT excess temperature.

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