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EXPERIMENTAL INVESTIGATION OF POOL BOILING HEAT TRANSFER

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ABSTRACT

The addition of small concentration surfactant additive in pure water decreases the surface tension of aqueous solution at the liquid vapor interface considerably, and, critical micelle concentration (cmc) decides the asymptotic limit of reduction in surface tension with increasing additive concentration. The objective of the present investigation is to study bubble growth in aqueous De-Ionized Water solution, and compared it with pure water experimentally. All experiments were carried out in saturated solutions at atmospheric pressure. The bubble growth was studied at 100 ppm concentration of Carrageenan which is critical (cmc) of aqueous solution. Single bubble was generated using the right-angle tip of a hypodermic needle as a nucleation site. Bubble growth was studied using high speed camera operating at 1000 frames per second. The investigation was conducted at two values of heat fluxes to check the effect of heat flux on bubble growth. At low heat flux (q=149.04 w/mm^2), the bubble departure diameter was found to be almost equal for both water and aqueous surfactant solution. At high heat flux (q=275.15 w/mm^2), bubble departure diameter increases in water, but, decreases significantly in aqueous surfactant solution. The bubble release frequency was nearly equivalent for both solutions at low heat flux, but, increases for aqueous surfactant solution at high heat flux, which indicates augmentation in boiling heat transfer. This augmentation was observed due to decrease surface tension of the aqueous surfactant solution.

1. INTRODUCTION

Boiling has been found in a wide range of applications such as power generation, refrigeration, and air-conditioning, chemical, and thermal process, cooling of electronic components, micro-fluidic system, thermal control of aerospace station, material processing etc. Most of the industrial applications are operate in nucleate boiling regime. It is very difficult to analyse the boiling regimes, and hence till date boiling is dependent on large number of empirical relations. Over the past decades, a great amount of research on pool boiling and flow boiling has been carried out to understand the fundamental aspect of boiling phenomena, and to provide practical knowledge for the engineering design requirements in various industries.

An active nucleation site features a periodic process of bubble formation, growth and departure. The generation of a bubble from its inception to departure is termed as Bubble Dynamics, which is featured by three parameters: growth period, departure size and release frequency. It is necessary to

understand bubble dynamics in order to gain an understanding of the nucleate boiling heat transfer, developing mechanistic models of boiling heat transfer, and designing bubble driven micro-devices.

Several Researchers have studied the bubble growth rate during pool boiling heat transfer theoretically. Jakob studied pool boiling theoretically, and derived a relation between frequency of bubble formation at favor point on the heated surface and bubble departure diameter. This relation can be approximated by the equation without serious errors.

$$f. Dd = \text{Constant} \quad \ldots\ldots\ldots\ldots..(1)$$

Fritz derived co-relation for bubble departure diameter at low pressure by balancing buoyancy with surface tension force which is given as

$$Dd = 0.02008\ \phi\ \sqrt{\sigma} \div g\ (\rho I - \rho V) \quad \ldots\ldots\ldots(2)$$

where,

ϕ = Contact Angle measured in degree

σ = Surface Tension measured in N/m

The relation between heat transfers to the bubbles while attached to the heated surface can be written with good approximation by Rohsenow as

$$q \div A \propto F \quad \ldots\ldots(3)$$

Researchers have extensively investigated bubble growth dynamics in nucleate pool boiling experimentally. Han and Griffith, Van Stralen, Cole and Shulman, Mimik et al. presented a criterion for bubble growth rate from a gas filled cavity from a surface in contact with a superheated layer of pure liquid. The time dependence of bubble radius was R t0.5. Shoji & Takagi carried out experimentation on bubbling features from a single artificial cavity. Siedel et al. investigated the bubble growth, departure, and interactions during pool boiling on artificial nucleation sites experimentally. Bubble departure diameter, and departure volume being independent of wall superheat, whereas the growth time is dependent on the superheat.

The addition of very small amounts of surfactant additive in pure water can enhance nucleate boiling heat transfer remarkably. The forces acting on bubble growing on a heated wall are buoyancy force, surface tension force, liquid inertia force, viscous drag etc. When a bubble grows on a heated surface, buoyancy force acts as the main upward force, and surface tension force as a main countering force. The surface tension force generally tries to keep bubble attached to the heated surface. Other forces (lift, drag, and inertia etc.) try to push bubble away from the heated surface. Generally, when bubble is small capillary forces are strong. When the bubble is larger, other forces will strong or large. So, when bubble grows, other forces start dominating, and the bubble departs. After this, repetition of a cycle takes place.

Amid the different enhancement techniques probed, the use of surfactant additives in water has been found to be very effective. Surfactant additive change the boiling phenomenon significantly. The addition of small concentration surfactant additive in pure water decreases the surface tension of aqueous solution at the liquid vapor interface considerably, and, critical micelle concentration (cmc) decides the asymptotic limit of reduction in surface tension with increasing additive concentration. The critical micelle concentration (cmc) indicates effectiveness of a surfactant to reduce surface tension of the solution. After critical micelle concentration (cmc), the surface tension will not reduce. Anionic and non-ionic surfactants fulfil most of industrial surfactant requirements. Because of their low concentration, presence of surfactants in water causes no significant change in the solvent physical properties except for surface tension, and, in some cases, the viscosity. Boiling with surfactant additive is generally an exceedingly complex process, and it is influenced by the large number of variables like the phase change process of pure water, surface tension of aqueous solution, the concentration of surfactant additive, kinematic and dynamic viscosity of aqueous solution, surface roughness of heated surface, the presence of electric field etc.

The effect of surfactant additives on pool boiling heat transfer were reported as a means of heat transfer enhancement. Wu et al. listed the literature of researchers who carried out work using different surfactants, and under different conditions.

2.METHODS OF HEAT TRANSFER IS USED WHEN BOILING WATER

Conduction

The process of transmission of energy from one particle to another is called the conduction, but here each particle of the medium remains in its position.

In physics or chemistry, conduction is primarily understood as the transfer of heat energy through a material. Conduction can occur in solids, liquids and gases.

Convection

Convection is the process of heat transfer by the bulk movement of molecules within liquids such as gases and liquids.

The initial heat transfer between the object and the fluid occurs through conduction..

Boiling of water is the process of convection.

- When a water is heated from below, thermal expansion occurs due to which the lower layers of the water become less dense due to overheating.
- Buoyancy causes the less dense and hotter part of the water to rise and the cooler and denser water takes its place.
- This process is repeated until the water becomes uniformly heated. In this way heat is transferred by convection.

3. Boiling and Condensation Boiling

- Boiling is a liquid to vapor change process just like evaporation.
- Evaporation occurs at the *liquid–vapor interface* when the vapor pressure is less than the saturation pressure of the liquid at a given temperature. Boiling occurs at the *solid–liquid interface* when a liquid is brought into contact with a surface maintained at a temperature sufficiently above the saturation temperature of the liquid.
- Evaporation involves no bubble formation or bubble motion.

Eco-friendly Additive

Red Areca Nut Powder is extracted from red Areca Palm (see Fig. 1a). Powdered areca nut is used as a constituent in some dentifrices. other traditional usage include the removal of other tapeworms intestinal parasites by

swallowing a few teaspoons of powdered areca nut, drunk as a decoction, or by taking tablets containing the extracted alkaloids. Their main application is Fine powder of areca nuts is used as dusting powder to treat wounds and control bleeding. The decoction of areca nuts is given in a dose of 10 ml to treat intestinal worms and diarrhea. The decoction of Areca catechu is pushed through the vaginal route as a type of enema to treat the condition of leucorrhea. They are widely used for removal of tapeworms and other intestinal parasites by swallowing a few teaspoons of powder areca nut. The add-in from areca nut powder in to the working fluid can alter the surface tension and viscosity of the fluid, thus

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affecting the dynamics of bubbles when the pool boils. This study aims to study the effect of the areca nut additive on bubble growth during pool boiling.

Red areca nut powder Properties

Areca Nut has a unique ability to produce psychostimulant effects such as euphoria, well-being, and increased capacity to work at room temperature:

1) rigid or elastic

2) clear or turbid

3) tough or tender

4) heat stable or thermally reversible

5)low or high melting/gelling temperatures.

It may also be used as a Powdered areca nut is used as a constituent in some dentifrices. Other traditional uses include the removal of tapeworms and other intestinal parasites by swallowing a few teaspoons of powdered areca nut, drunk as a decoction, or by taking tablets containing the extracted alkaloids in other industrial applications.

As linear, water-soluble, polymers, typically form highly viscous aqueous solutions.

Fig: ARECA NUT POWDER

Components: parts can easily be dismantled for replacement, maintenance, and repair.

Fig4.1 Diagram representation of the model

4.CALCULATION

Calculation of De - Ionized Water (pure water)

Voltage = 10 v

Ampere = 0.01Ω

Area = 3.14× $(0.5)^2$

= 0.785 mm²

1) Heat Flux, q = $\frac{VI}{A}$

= $\frac{90\times1.3}{0.785}$

= 149.04 w/m^2

2) Temperature Difference,

$\Delta T = Temp.\ of\ saturation\ - Temp.\ of\ water$

= 60-55

= 5

3) Heat Transfer Coefficient = $\frac{q}{\Delta T}$

= $\frac{149.04}{5} = 29.80\ w/m^2$℃

Calculation of Additive mixing de-ionised water

Given:

Votage= 90v

Ampere=2.6Ω

Area =3.14× $(0.5)^2$

=0.785mm²

1) Heat Flux, q = $\frac{VI}{A}$

= $\frac{90\times2.6}{0.785}$

= 298.089 w/mm^2

2) Temperature Difference,

$\Delta T = Temp.\ of\ saturation\ - Temp.\ of\ water$

= 51-45

=6℃

3) HTC = $\frac{q}{\Delta T}$

= $\frac{298.089}{6} = 49.683\ w/m^2$℃

Expected Outcomes

Methodology used to determine bubble dimensions

The methodology used to determine bubble dimensions was taken from literature (Hetsroni, 2006). The dimensions of the bubble were measured by counting the no. of pixels on symmetrical bubble image. A physical dimension of 1mm resembles to 30 pixels, i.e., 1 pixel in the image corresponds to 0.033 mm. To calculate the radius, and diameter of actual bubble, the coordinates of vapor-liquid interface were measured.

5.RESULT AND DISCUSSION

The experiment was conducted under atmospheric temperature with and without additives in DI water for a variable range of heat flux. To check the consistency of the experimental outcomes, a repeatability test was conducted with DI water, as shown in Figure, and observed the results were found to the consistency, with little deviation observed due to the vibration of the bubble phenomenon.

6. CONCLUSION & FUTURE SCOPE

It was found that mixing Areca Nut additive with deionized water improved boiling heat transfer performance due to changes in the thermal properties of the liquid, such as surface tension. The Areca Nut additive promotes nucleation and increases the bubble starting point. The results showed that adding these additives significantly increases the heat transfer coefficient of the smooth needle surface. Additionally, using environmentally friendly additives can provide a sustainable solution for improving heat transfer without harming the environment. Overall, 54% rise in heat transfer coefficient compared to DI water.

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