STUDY OF NUCLEATE POOL BOILING USING SURFACTANT ADDITIVES

Shekhar P.Dadgal[1], Dr. S. M. Lawankar[2]
[1]*P.G. Student, Department of Mechanical Engineering Govt Engineering College, Amravati, Maharashtra, India*
[2] *Assit. Professor, Department of Mechanical Engineering Govt Engineering College, Amravati, Maharashtra, India*

Abstract- **Pool boiling is phase change heat transfer process in which liquid is converted into vapor bubbles when exposed to the temperature greater than saturation temperature of the liquid. The vapor bubbles act as heat transfer carrier, and Surface tension is one of the physical property which affect bubble dynamics (bubble growth, departure rate), nucleation site. Addition of small amount of additives in base fluid decreases surface tension considerably without affecting other properties of base fluid, which further increases the growth of bubble and increases number of nucleation site. In earlier literature most of the study discusses the impact of nanofluid on dynamics of bubble and nucleate pool boiling. The nanofluid are ionic in nature, which may further affect the environment, and therefore this paper aim to review the impact of non-ionic surfactant on nucleate pool boiling heat transfer. It also discusses the effect of different concentration of surfactant on critical heat flux (CHF) and heat transfer coefficient.**

Index Terms- **pool boiling heat transfer; surfactant; enhancement; nicotine; ammonium chloride; betel nut**

I. INTRODUCTION

Nucleate boiling heat transfer is utilized in many applications where large amount heat has to be transferred in comparatively small temperature range such as nuclear reactor, rocket engines, heat exchanger, air-conditioning, refrigeration and heat pump system, chemical thermal process and in highly specialized fields such as cooling of high energy-density electronic components, micro-fabricated fluidic system, the thermal control of aerospace station, bioengineering reactors etc. Hence it is important to increase heat transfer rate in nucleate pool boiling application to save the energy required during phase change. Heat transfer technique found to be available in literature. Most of the researchers conducted experiment on nucleate pool boiling enhancement using surfactant (nano fluid and additives).

II. BOILING HEAT TRANSFER

Boiling is a liquid-to-vapor phase change process same as evaporation, but occur at different conditions. Evaporation start at the liquid–vapor interface when the vapor pressure is less than the saturation pressure of the liquid at a given temperature.

Boiling is a complex to understand because it involved large number of unknown variables and the complex fluid motion patterns caused by the bubble formation and growth at the liquid–vapor interface due to the attraction force on molecules at the interface toward the liquid phase. Therefore it is necessary to classify boiling heat transfer and its variation with different parameter before discussing the different enhancement technique.

III. CLASSIFICATION OF POOL BOILING

Depending on the presence of bulk fluid motion boiling is classified as pool boiling or flow boiling. In pool boiling, the fluid is at rest, and any motion of the fluid is due to natural convection currents and the motion of the bubbles under the influence of buoyancy. While in flow boiling, the fluid is move by some external means such as a pump as it undergoes a phase-change process. The boiling in this case exhibits the combined effects of convection and pool boiling.

The emerging work on boiling was done in S.

Nukiyama, who experimentally conducted experiment on electrically heated nichrome and platinum wires immersed in liquids. Nukiyama observed that depending on the value of the excess temperature ΔT_{excess}, boiling takes different forms, four different boiling regimes are observed: natural convection boiling, nucleate boiling, transition boiling, and film boiling as shown in figure 1.

(a) Natural Convection Boiling (up to point A), according to thermodynamics for pure substance at specified pressure start boiling when reaches saturation temperature. But in practice first bubble form few degree above saturation temperature. The fluid motion in this mode of boiling is governed by natural convection currents, and heat transfer from the heating surface to the fluid is by natural convection.

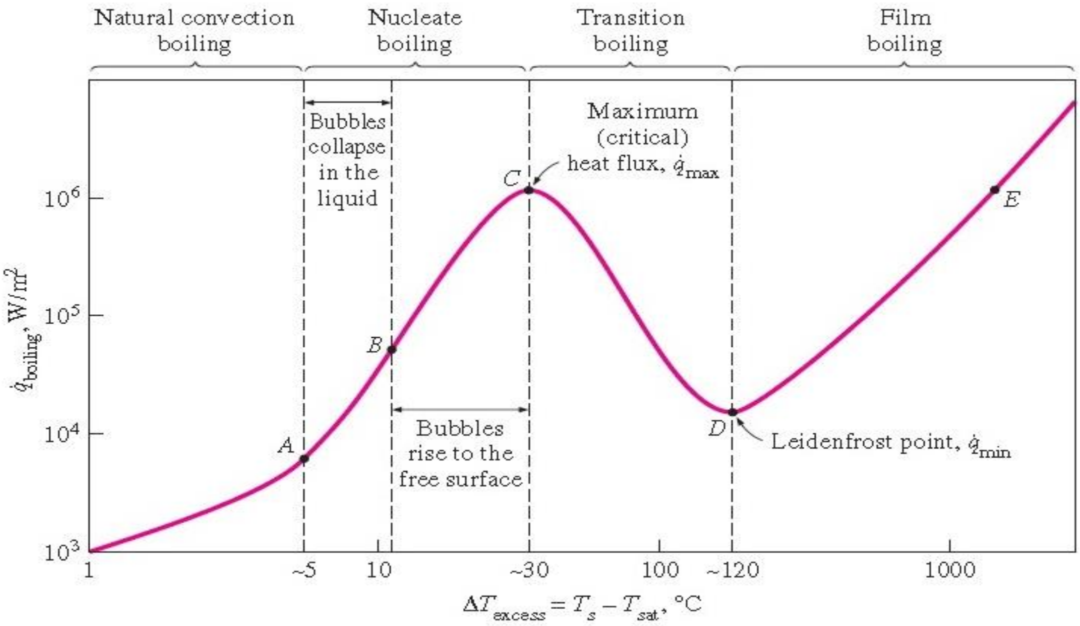

Figure 1: Typical boiling curve for water at 1 atm pressure (adapted from S. Nukiyama)

(b) Nucleate Boiling regime (between Points A and C), The first bubbles start forming at point A of the boiling curve at various preferential sites on the heating surface. It is divided into two sub region

Isolated bubbles are formed in region A-B. But these bubbles are disappear in the liquid as it is separate from the heating surface. As bubble disappear, liquid in immediate vicinity filled the space vacated, and the process is repeated. The stirring and agitation caused by the entrainment of the liquid to the heater surface is primarily responsible for the increased heat transfer coefficient and heat flux in this region of nucleate boiling.

As the heater temperature is further increased as shown in region B-C and bubbles start forming at such great rates on a large number of nucleation sites that they form numerous continuous columns of vapor in the liquid. These bubbles travel to the free surface, where they break up and release it heat content. The large heat fluxes obtainable in this region are caused by the combined effect of liquid entrainment and evaporation. As values of ΔT_{excess}, increases, the bubbles form at higher rate, and a large fraction of the heater surface is covered by bubbles, making it difficult for the liquid to reach the heater surface and wet it. Consequently, the heat flux increases at a lower rate with increasing ΔT_{excess}, and reaches a maximum at point C, which is critical heat flux (CHF). As high heat transfer rates can be achieved in this regime with relatively small values of ΔT_{excess}, this most desirable regime in pool boiling.

(c) Transition Boiling (between Points C and D), as temperature of heating element is increased further, large area of heating surface is covered with vapor bubble and vapor bubble has lower thermal conductivity than that of liquid, which in lead decreases heat flux. Transition boiling is regime where both nucleate and film boiling occur partially. At point D nucleate boiling is completely replaced by film boiling. A point of minimum heat flux is known as Leidenfrost point.

(d) Film Boiling (beyond Point D), in this region the heater surface is completely covered by a continuous stable vapor film. The heat transfer rate increases with increasing excess temperature as a result of heat transfer from the heated surface to the liquid through the vapor film by radiation, which becomes significant at high temperatures.

These four regimes are distinguish by three important point (i) beginning of boiling corresponding to formation of first bubble on the heating surface, (ii) critical heat flux (CHF), where heat flux is maximum and heater surface is fully covered by bubble layer, and (iii) minimum heat flux corresponding to beginning of breakup of the continuous vapor blanket in film boiling when decreasing the wall superheat.

IV. ENHANCEMENT TECHNIQUE

As nucleate boiling is the most desirable boiling regime, the methods to enhance nucleate pool boiling should include following points.

(1) Increase number of active nucleation sites, bubble departure frequency, which will lead to decreasing heating surface temperature.

(2) Initiating nucleate boiling at lower heat flux and lower wall superheat.

(3) Increase point of critical heat flux (CHF) to higher heat flux values.

Methods that have been suggested to enhance nucleate boiling are active and passive [1]. The active techniques involve use of external power to achieve mechanical mixing, surface and/or liquid rotation, vibration, suction or injection, or inducing an electrostatic or magnetic field, but these found to be unreliable and costlier for small area and high heat flux demanding application. While, passive technique does not require mechanical power as above, but it is found to be strongly dependent on modification to heating surface (such as surface roughening and surface texturing) and fluid properties (by adding surfactant in base fluid) or both.

V. REVIEW OF PREVIOUS STUDY

Surfactant is chemical agent which when added in small proportion to base fluid leads to considerable decrement in surface tension without affecting other properties of the liquid. Surface tension decreases with increasing surfactant concentration asymptotically [2].

A. Nazim et. al. [3], experimentally studied bubble dynamics for single bubble. The result show that as surface tension decrease by increasing surfactant concentration, the departure diameter of bubble decreases and bble release frequency increases.

Yang et. al. [4] experimentally reported the effect of surfactant and as surfactant concentration increases, boiling curve shifted to lower wall temperature, which leads to early formation of bubbles and increase in nucleate heat transfer coefficient (h). Increment in heat transfer coefficient and depression in surface tension up to critical micelle concentration (CMC) is related as $h \propto \sigma^n$

Where value of n ranges from 0 to -3.3 [5].

Hetrosoni et. al. [6], Zhang et. al. [7], A. Nazim et. al. [8], Gajghate et. al. [9], and Tzan et. al. [10] shown that as surface tension reduces, bubble grow in smaller sizes, increase in bubble departure rate. Due to this bubble start forming earlier, and cover heater surface faster. There is no effect of surfactant after critical micelle concentration (CMC).

Wasekar et. al. [11], established correlation between heat transfer coefficient (h) and molecular weight (M), and found that h is proportional to M^n with n = -0.5 for two anionic surfactants, sodium dodecyl sulphate (SDS) and sodium lauryl ether sulfate (SLES) and n = 0 for two nonionic surfactants, Triton X-100 and Triton X-305.

Hao Peng et. al. [12] experimentally investigated Effect of surfactant additives on nucleate pool boiling heat transfer of refrigerant-based Nano fluid. Three types of surfactants including Sodium Dodecyl Sulfate (SDS), Cetyltrimethyl Ammonium Bromide (CTAB) and Sorbitan Monooleate (Span-80) were used in the experiments. The study shows that presence of surfactant enhances the nucleate pool boiling heat transfer of refrigerant-based nanofluid on most conditions, but deteriorates the nucleate pool boiling heat transfer at high surfactant concentrations.

VI. CONCLUSIONS

A review of the effect of surfactants on pool is presented in literature. The study shows that nucleate pool boiling heat transfer behavior depends surface tension.

(1) Addition of small amount of surfactant in base fluid decreases surface tension considerably without affecting other properties of fluid.

(2) With the addition of surfactant in liquid, boiling curve shift towards lower surface superheats, and maximum enhancement was found at critical micelle concentration (CMC).

(3) There is further scope for use cheap and environment friendly surfactant such as Betel nut as it has characteristic to lower the surface tension as compared to surfactant used.

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