Heat Transfer Enhancement in Pool Boiling Using Sodium Dodecyl Sulphate and by Breaking of Vapour Bubble Using Different Baffle Materials

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Abstract- *A simple experimental setup is fabricated to study the effect of Sodium Dodecyl sulphate (SDS) and breaking of vapour bubble using different baffle materials on heat transfer characteristics. The aim of this paper is to decrease the time required for heating of fluid by adding surfactant and by providing baffles to break the bubble inside the test section so that the heat inside the bubble is completely absorbed by the fluid. Here 1.8 and 2.2 g/ltr concentrations of SDS and two materials namely iron and ceramic baffles are used each made in three quantities. The distilled water is used as the base fluid. Results shows that maximum of 18.18% decrease in time achieved using SDS at 2.2 g/ltr as compared with distilled water. And maximum of 38.27% decrease in time achieved using ceramic baffle as compared with distilled water. Maximum 42.26% decrease in time achieved for combined SDS of 2.2 g/ltr and ceramic baffle.*

Keywords- Bubble, breaking, vapour, ceramic, iron, baffle, Sodium Dodecyl sulphate.

I. INTRODUCTION

Boiling is broadly classified as pool boiling or flow boiling depending on the presence of bulk fluid motion. In the pool boiling, there is absence of bulk fluid flow. . Boiling is a liquid to vapour phase change occurring at the solid–liquid interface when a liquid is brought into contact with a surface maintained at temperature which is sufficiently above the saturation temperature of liquid. The boiling process is characterized by the rapid formation of vapour bubbles at the solid–liquid interface that detach from the surface when they reach a certain size and attempt to rise to the free surface of the liquid. Heat transfer enhancement is the process of improving the heat transfer rate from a heater surface for which boiling fluids involving vapor bubbles is identified as the best mechanism. The dynamics of vapor bubbles formed on a heated surface placed in a pool of liquid or subjected to forced flow has been studied extensively in the past. Motivating factors for these studies include the influence of bubble dynamics on the wall heat transfer, the partitioning of energy into vapor and liquid phases, and the development of void profile during flow boiling. So in present work, effect of breaking of vapour bubble on heat transfer rate in nucleate pool boiling is studied experimentally for distilled water, surfactant solution and different baffle materials. The overall objective of the proposed work is to study the effect on breaking of vapour bubble to avoid evaporation losses. This study will be beneficial for commercial as well as pharmaceutical application of pool boiling heating surface.

Pioro et al. [1] assessed the state-of-the-art of heat transfer in nucleate pool-boiling. They reviewed and examined the effects of major boiling surface parameters affecting nucleate-boiling heat transfer and examine the existing prediction methods to calculate the nucleate pool-boiling heat transfer coefficient (HTC). They pointed out that the major parameters affecting the HTC under nucleate pool-boiling conditions are heat flux, saturation pressure, and thermo-physical properties of a working fluid. Han and Griffith [2] developed a criterion for bubble initiation from a gas filled cavity on a surface in contact with a superheated layer of liquid (Water). A constant heat flux was applied at heating surface. It is found that the temperature of bubble initiation on a given surface is a function of the temperature conditions in the liquid surrounding the cavity as well as the surface properties themselves. It is also found that the delay time between bubbles is a function of the bulk liquid temperature and the wall superheat, and is not constant for a given surface. Mimik et al. [3] derived simple general relation for bubble growth rates in a uniformly superheated liquid under non-uniform temperature field around the bubble. The relation is valid in both regions: inertia controlled and heat diffusion controlled growth, respectively. Shoji & Takagi [4] studied bubbling features from a single artificial cavity. A single artificial cavity was manufactured on a thin Cu plate and was heated by a laser in a saturated water pool. Conical, cylindrical and re-entrant cavities were tested. Range of cavity depth is 30µm- 50µm. Range of cavity diameter is 50µm-100 µm. conical cavities shows highly intermittent bubbling with large temperature fluctuations, requiring high superheat. Cylindrical cavities show continuous bubbling from low superheat with small temperature fluctuations. Hetsroni et al. [5] studied experimentally, the bubble growth in saturated pool boiling in water and surfactant solution. The study was conducted at two values of heat fluxes to clarify the effect of the heat flux on the dynamics of bubble nucleation. The bubble generation was studied on a horizontal flat surface; and the natural roughness of the surface was used to produce the bubbles. Manglik et al. [6] studied dynamics and equilibrium surface tension of aqueous surfactant and polymeric solutions. The additives employed are SDS, SLES, Triton X-100, Triton X-305, HEC QP-300, and carbopol 934. The result indicate significant differences between dynamics and equilibrium surface tension values as well as those measured at room and elevated temperature. Yang and Maa [7] concluded in their study of nucleate pool boiling enhancement by surfactant additives that for a highly soluble surfactant, boiling heat transfer enhancement by its addition is enhanced by the depression of equilibrium surface tension but suppressed by the depression of equilibrium contact angle. These two effects counterbalance each other and result in different degrees of boiling enhancement. Inoue et al. [8] observed in their experiment that the coefficients were enhanced in a lower ethanol fraction and in low heat flux which is slightly higher than heat flux at the onset of boiling. It is also found that the enhancement due to the surfactant disappears over 1000 ppm. A. Najim et al. [9] studied experimentally bubble dynamics in pool boiling heat transfer using saturated water and aqueous Ammonium Chloride (anionic surfactant) solution. The concentration of surfactant was taken 2600 ppm (Parts per Million). Single bubble is generated using right angle needle tip of a hypodermic needle as a nucleation site. Bubble growth in saturated water is compared with surfactant solution. Fazel et al. [10] presented extensive new experimental data for the bubble departure diameter for various electrolyte aqueous solutions over a wide range of heat fluxes and concentrations. It is showed that the bubble detachment diameter increases with increasing either boiling heat flux or electrolyte concentration. Experimental results also present a close relation between the dimensionless capillary and bond numbers. A new model for the prediction of vapour bubble departure diameter in nucleate boiling for the electrolyte solutions is proposed, which predicts the experimental data with a satisfactory accuracy. From above it is clear that there are three types of artificial nucleation sites viz. cylindrical, conical and re-entrant used to study bubble dynamics. The condition of liquid i.e. sub-cooled, saturated or superheated and wall superheat affects the bubble dynamics. The size of artificial nucleation sites studied so far ranges from diameter 2µm to 1.185mm and depth 10 µm to 120mm. The effect of variation of depth of cylindrical cavity on bubble dynamics has been studied experimentally. Addition of very small amount surfactants additives in water can enhance the nucleate boiling heat transfer remarkably.

II. EXPERIMENTAL METHOD

1. Experimental Setup for Breaking of Vapour Bubbles

This setup is slight modification of single bubble dynamics setup. It contains calibrated glass beaker of same specifications, baffles of iron and ceramics material, heater for formation of bubbles, Thermocouples, Temperature indicators, Dimmerstat, voltmeter and ammeter, measuring flasks. Some provisions are made for positioning the baffles so that baffles can obstruct the movement of bubbles towards the surface of the liquid. In this setup three baffles are used of each material i.e. iron and ceramic. A notch is made in middle baffle for adjusting the heater. Some roughness is provided to the lower surface of the baffles so that easily breaking of bubbles should takes place. A coil heater is used for heating the liquid and forming of bubbles through multiple nucleation sites.

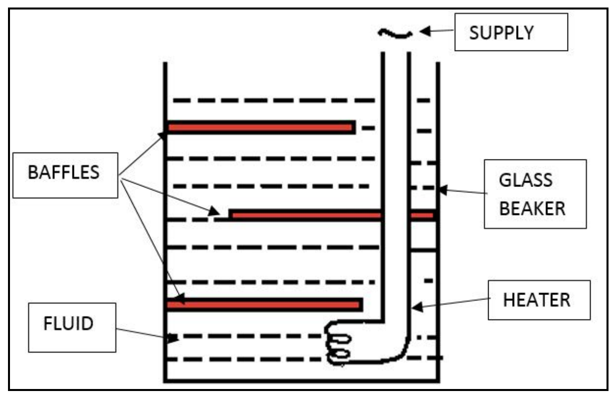

Figure 1. Schematic Diagram of Experimental Setup

2. Baffles

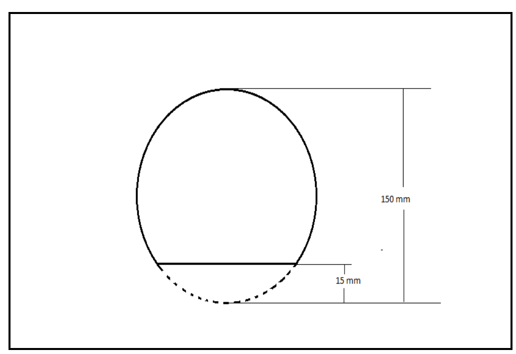

Figure 2. Schematic diagram of baffles

Figure 2.2 shows the dimension of baffles. The baffles are having cut portion of 15 mm for adjusting heater. Roughness is provided to the surfaces of baffles for ease of breaking of vapour bubbles. These baffles are placed on the some provisions bonded to the glass beaker by epoxy. The arrangement of baffles so made as if bubble escapes from a baffle it should be trapped by other baffle placed above it.

Iron Baffle

In this investigation two types of baffles are used. One of them is iron baffles which is having good thermal conductivity. The properties of iron material are given in table No. 2.1. Three baffles are manufactured having same diameter as inner diameter of glass beaker. Baffles are so arranged that maximum number of bubbles should trapped in liquid only. Figure 2.3 shows iron baffles having diameter 150 mm with tolerance of 1mm so that it can be placed easily in the glass beaker. And baffles are having thickness of 2mm. a cut of 15mm is done to adjust the heater and allow escaped bubbles to move toward upper baffle. The surface roughness is provided for ease of breaking of vapour bubble.

Table 1. Properties of Iron Material

Density in g/ cm^3	**Thermal conductivity in W/mK at 20^0C**	**Melting Point ^{0}C**	**Boiling Point ^{0}C**	**C_p kJ/kg.K**
7.8	80.3 at	1536	2861	0.45

Figure 3. Photographic Image of Iron Baffle

Ceramic Baffles

These baffles are made of same internal diameter of glass beaker with tolerance of 1mm so that it can be easily placed in the beaker horizontally. Table 2.2 shows properties of ceramic material.

Table 2. Properties of Ceramic Material

Density in g/ cm^3	**Thermal conductivity in W/mK at 20^0C**	**Melting Point ^{0}C**	**Cp in kJ/kg.K**
3.12	5.223 at 20^0C	1650	0.80

Figure 4. Photographic Image of Ceramic Baffle

Figure 2.4 shows ceramic baffles having diameter 150 mm. a cut is done to adjust the heater and allow escaped bubbles to move toward upper baffle. The surface roughness is provided for ease of breaking of vapour bubble.

3. Surfactant

Table 3. Concentration of Surfactants

Sr. No	**Base Liquid**	**Surfactant Additive**	**Concentration**
1.	Pure Water	Sodium Dodecyl Sulphate	1.8 g/litre
			2.2 g/litre

Table 4. Properties of Surfactants

Surfactant	**Chemical formula**	**Ionic Nature**	**Form**
Sodium Dodecyl Sulphate	$NaC_{12}H_{25}SO_4$	Anionic	Crystalline

III. RESULTS AND DISCUSSIONS

1. Effects of Baffles for Distilled Water

The graph is plotted for distilled water without baffles, iron baffles and ceramic baffles. Baffles works as obstructing elements for bubbles. Due to the baffles maximum number of bubbles are trapped below the baffles. And there is heat transfer enhancement of liquid takes place due to trapping and braking of vapour bubbles beneath of the baffles. Graph declares time required to reach a particular temperature. Time required to reach a particular temperature is minimum for setup having ceramic baffles i.e. to reach 940C temperature time is 292 seconds and maximum for setup without baffles i.e. to reach 940C it requires 459 seconds. The setup with iron baffles will take moderate time to reach a particular temperature i.e. to reach 940C temperature time is 330 seconds. This means that ceramic are good thermal insulators so that it absorbs less as compared to iron baffles. Therefore setup with ceramic baffles requires less time than iron baffles.

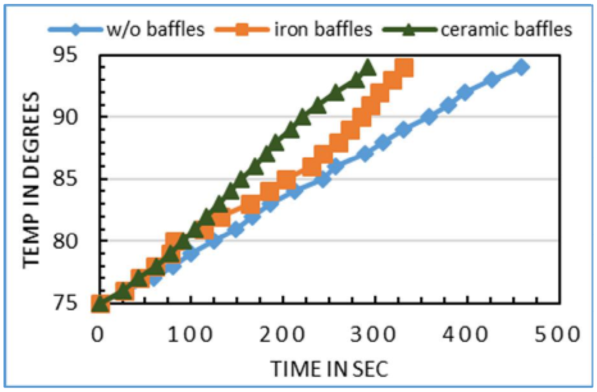

Figure 5. Effect of Baffles for Distilled Water

For distilled water percentage decrease in time by using iron baffles as compared without baffles is (3.57%-34.4%).

2. Effect of SDS (Sodium Dodecyl Sulphate) Solution at 1.8 g/liter Concentration

SDS is the surfactant added into the distilled water for reducing the surface tension of the water. Due to decrease in surface tension bubble release frequency increases resulting in enhancement of heat transfer. Figure 3.2 shows comparison between SDS solution with setup of no baffles, iron baffles and ceramic baffles. The time required to reach temperature 940C. By results obtained we can say that due to addition of surfactant in the water heat transfer rate increases.

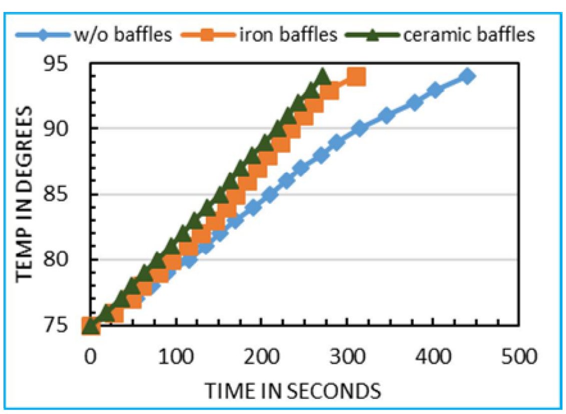

Figure 6. Effect of Baffles on SDS Solution as Surfactant solution at 1.8 g/litre Concentration

Figure 3.2 shows that distance between curve without baffles and with baffles goes on increasing. And also slope of curve without baffles is more than the curves with baffles. So that we can conclude due to the baffles time required to reach particular temperature reduces. Among these baffles ceramic baffles gives better results of enhancement of heat transfer. For surfactant solution with 1.8 g/liter concentration percentage decrease in time by using iron baffles as compared without baffles is (3.51%-31.2%).

3. Effect of SDS (Sodium Dodecyl Sulphate) Solution at 2.2 g/litter Concentration

Surfactants are used to reduce the surface tension of the liquid. So that bubble releasing frequency increases which is resulting in enhancement in heat transfer. As concentration of surfactant increases bubble release frequency increases due to further decrease in surface tension. To study effect of baffles on the solution of increased concentration of surfactant. Figure 3.3 shows results for surfactant solution (SDS) having concentration 2.2 g/liter. It gives better results for increased concentration. With this concentration again time required to reach a particular temperature decreases. So that energy as well as time also saved.

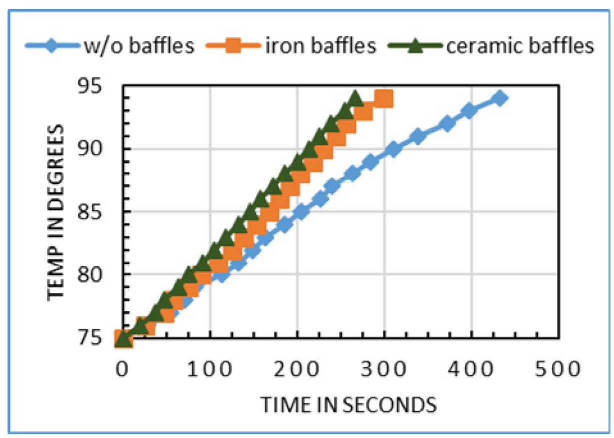

Figure 7. Effect of SDS (Sodium Dodecyl Sulphate) Solution at 2.2 g/liter Concentration

For this concentration maximum heat transfer rate can be obtained for ceramic baffles. And minimum heat transfer rate is obtained for setup without baffles. Form this we can conclude that use of surfactant with optimum concentration gives better heat transfer rate with use of ceramic baffles. For surfactant solution with 2.2 g/litre concentration percentage decrease in time by using iron baffles as compared without baffles is (7.4%-31.2%).

IV. CONCLUSION

Following are the conclusions made from the experimental results:

1. For distilled water percentage decrease in time by using iron baffles as compared without baffles is (3.57%-34.4%).
2. For distilled water percentage decrease in time by using ceramic baffles as compared with iron baffles is (4.54%-26.52%).
3. For distilled water percentage decrease in time by using ceramic baffles as compared without baffles is (10.71%-38.27%).
4. For surfactant solution with 1.8 g/litre concentration percentage decrease in time by using iron baffles as compared without baffles is (3.51%-31.2%).
5. For surfactant solution with 1.8 g/litre concentration percentage decrease in time by using ceramic baffles as compared with iron baffles is (6.83%-29.82%).
6. For surfactant solution with 1.8 g/litre concentration percentage decrease in time by using ceramic baffles as compared without baffles is (27.81%-38.26%).
7. Maximum of 18.18% decrease in time achieved using SDS at 2.2 g/ltr as compared with distilled water.
8. For surfactant solution with 2.2 g /litre concentration, percentage decrease in time by using iron baffles as compared without baffles is (7.4%-31.2%).
9. For surfactant solution with 2.2 g/litre concentration percentage decrease in time by using ceramic baffles as compared with iron baffles is (7.03%-24.0%).
10. For surfactant solution with 2.2 g/litre concentration percentage decrease in time by using ceramic baffles as compared without baffles is (23.45%-42.26%).

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