Effect of Al_2O_3 Nanofluid and Breaking of Vapour Bubble Using Different Baffle Materials in Pool Boiling for Heat Transfer Enhancement

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Abstract- *A simple pool boiling setup is fabricated to study the effect Al_2O_3 nanofluid on heat transfer enhancement characteristics. The distilled water is used as the base fluid. In the present investigation, effect of breaking of vapour bubble on bubble dynamics during nucleate pool boiling heat transfer in saturated water is studied experimentally. In this investigation breaking of vapour bubble is done by mechanistic approach i.e. baffles are used. There are three different concentrations of nanofluid used namely 0.05%, 0.1% and 0.15% by volume. There are two materials used for baffle namely iron and ceramic each made in three quantities. Also effect of breaking of vapour bubble is studied on the nanofluid solution at different concentrations. Results shows that maximum of 25% decrease in time achieved using Al_2O_3 at 0.15% as compared with distilled water. Maximum 54.23% decrease in time achieved for combined Al_2O_3 nanofluid at 0.15 and ceramic baffle.*

Keywords- Bubble, Al_2O_3, nanofluid, breaking, vapour, iron, ceramic, baffle.

I. INTRODUCTION

Nucleate pool boiling is a very efficient and important mode of heat transfer. It has been found in a wide range of applications in both traditional industries such as various energy conversion system, heat exchange system, 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, nuclear power plants etc. Generally, boiling is classified as pool boiling and flow boiling. Pool boiling refers to boiling under natural convection conditions, whereas in flow boiling, liquid flow over the heater surface is imposed by external means. 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. Boiling is a complex and elusive process. As such, we often rely on dimensionless groups and empirical constants when correlating data. Concurrent with development of correlations useful for engineering applications, progress continues to be made in understanding the physics of the boiling process. Because the process is so complex and because so many heating elements and fluid variables interact, completely theoretical models have not been developed to predict the boiling heat fluxes as a function of heater surface superheat temperature. In many cases, a consensus is lacking in the technical community with respect to the dominant mechanisms of the heat transfer (in nucleate and transition boiling) and the degree to which the contribution of various mechanisms to total heat flux changes with wall superheat temperature and heater geometry.

Han and Griffith [1] 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. Kenning et al. [2] studied experimentally and numerically the Confined growth of a vapour bubble in a capillary tube at initially uniform superheat. The diameter of capillary tube is 800 µm and depth is 120mm. Bubble growth was triggered in a capillary tube closed at one end and vented to the atmosphere at the other and initially filled with uniformly superheated water. Siedel et al. [3] investigated experimentally the bubble growth, departure and interactions during pool boiling on artificial nucleation sites. They used conical shaped cavities as artificial nucleation sites to study interactions between cavities. Bubble growth is studied under various wall superheat conditions. The diameter of cavity is 180 µm and depth is 500 µm. Bubble growth appears very reproducible, the volumes at detachment being independent of the wall superheat, whereas the growth time is dependent on the superheat. Wu and Dhir [4] investigated dynamics and heat transfer associated with a single bubble in sub cooled Pool boiling. The applied numerical procedure coupling level set function with moving mesh method has been validated by comparing the results of bubble growth history including bubbled departure diameter with data from experiment. Lesage [5] analysed quasi-static bubble size and shape characteristics at detachment, experimentally and numerically. He uses four needles of diameter 0.394mm, 0.543mm, 0.838mm and 1.185 mm with depths 77.96mm, 42mm, 64.24mm & 62mm respectively. It shows that bubble detachment shape and normalize size characteristics are dependent on the Bond number with characteristics length equal to cavity radius. Lee et al. [6] studied experimentally Height effect on nucleation-site activity and size-dependent bubble dynamics in micro-channel convective boiling. Nucleation sites were shaped as an inverted pyramid with a square base. Bubble nucleation activity is found to depend on the channel height. The variation height is 5 µm - 500 µm. The critical size, above which nucleation sites are active, increases with the channel height. Hence, smaller nucleation sites are active in smaller height micro-channels. The bubbles, practically two-dimensional, assume a balloon-like shape elongated in the stream wise direction. Nam et al. [7] studied experimentally, the single bubble dynamics on a superhydrophillic surface with artificial nucleation sites. The superhydrophillic surfaces are prepared by forming CuO nanostructures on a silicon substrate with an isolated micro-cavity. The bubble departure diameter in water is observed to be 2.5 times smaller and the growth period 4 times shorter on the superhydrophillic surface than on a silicon substrate. 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.

II. LITERATURE REVIEW

In the present study, Al_2O_3 nanoparticles of size 20–30 nm were mixed with distilled water and stabilizers and then sonicated continuously by ultrasonic vibrator to break down agglomeration of the nanoparticles, prior to being used as the working fluid. The desired volume concentrations used in this study were 0.05, 0.1 and 0.15%. For each test a new nanofluid was prepared and used immediately. Surfactants can be defined as chemical compounds added to nanoparticles in order to lower surface tension of liquids and increase immersion of particles. Correct quantity of surfactant should be added to the base fluid to achieve long term stability. For this dissertation work SDS surfactant is added one tenth of mass of nanoparticles for every concentration of Al_2O_3 nanofluid. Magnetic Stirring process is carried out on the each concentration of Al_2O_3 Nanofluid for preparing the stable Al_2O_3 nanofluid. This is done with the help of stirrer which is kept in the beaker containing Al_2O_3 nanofluid. The stirring is carried out at the speed of 1500 rpm for 1 hour for each beaker containing 1 litre of nanofluid.

Figure 1. Photographic Image of Powdered form of Al_2O_3 3Nano particles

In the ultra-sonication process the ultrasonic sound waves of 20 kHz are produced from the bottom of the container for about 1 hour for 1 litre of Al_2O_3 nanofluid. This will help to prepare a homogeneous mixture of Al_2O_3 nanofluid. The ultra-sonication process is done at the atmospheric condition.

III. 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.

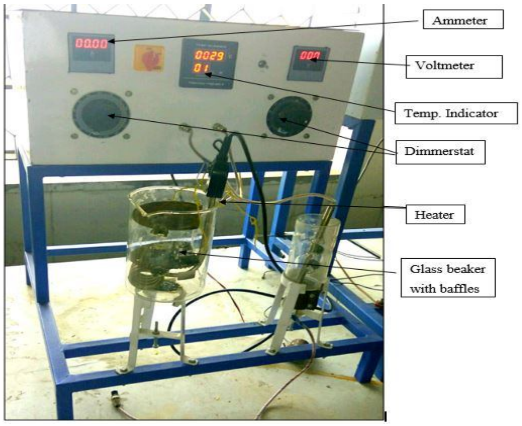

Figure 2. Photographic Image of Experimental Setup

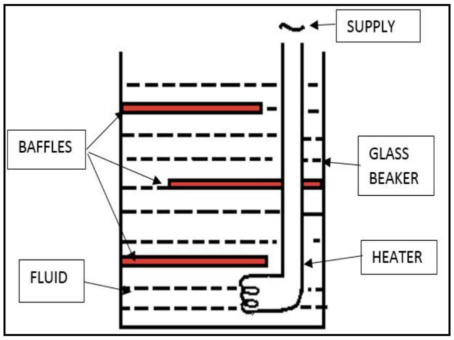

Figure 3. Schematic Diagram of Experimental Setup

2. Baffles

Figure 3.3 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.

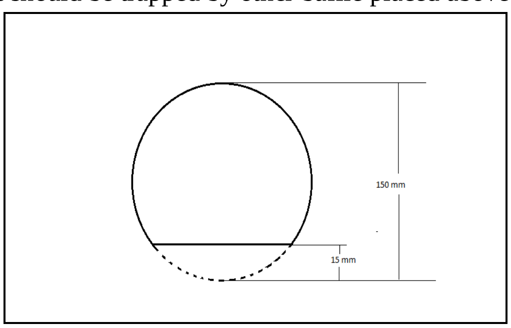

Figure 4. Schematic diagram of baffles

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. 3.1. 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 3.4 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^{0}C	Melting Point ^{0}C	Boiling Point ^{0}C	C_p kJ/kg.K
7.8	80.3 at	1536	2861	0.45

Figure 5. 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 3.2 shows properties of ceramic material.

Table 2. Properties of Ceramic Material

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

Figure 6. Photographic Image of Ceramic Baffle

Figure 3.5 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.

IV. RESULTS AND DISCUSSIONS

1. Effect 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.

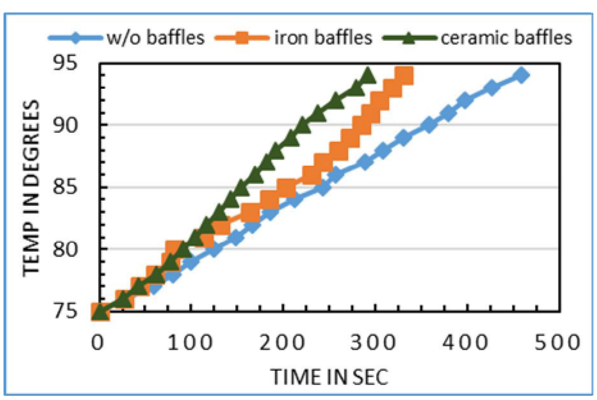

Figure 7. Effect of Baffles for Distilled Water

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

2. Effect of Al2O3 nanofluid of 0.05% concentration

After experimentation on distilled water, different concentration of SDS surfactant solution next part of study is on α- Al_2O_3 nanofluid with 0.05% concentration by volume. So that after addition of nanoparticles thermal conductivity of the liquid increases highly. In this study α- Al_2O_3 nanofluid with 0.05% concentration by volume is used for experimentation without baffles, iron baffles and ceramic baffles.

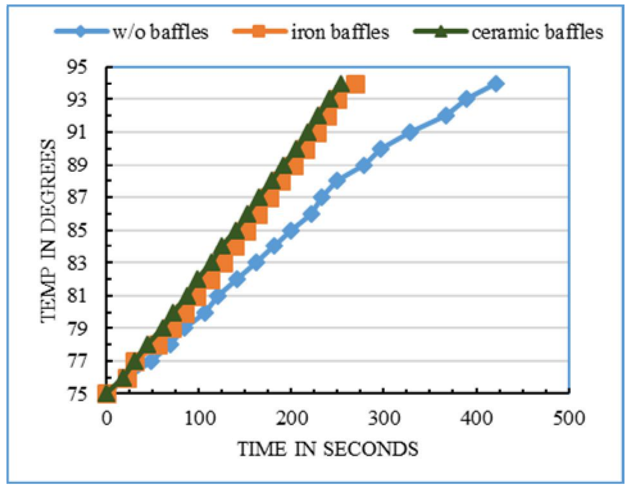

Figure 8. Effect of Baffles on α- Al_2O_3 Nanofluid with 0.05% Concentration by Volume

The graph clears that α- Al_2O_3 nanofluid with 0.05% concentration by volume takes less time to reach a particular temperature with ceramic baffles i.e. to reach 940 C it takes 254 seconds and moderate time for setup with iron baffles i.e. 269 seconds and takes maximum time for setup without baffles i.e. 422 seconds.

3. Effect of Al2O3 nanofluid of 0.1% concentration

Figure 4.3 clears that setup with ceramic baffles gives more heat transfer rate than setup with iron baffles and setup without baffles. Setup with ceramic baffles requires minimum time to reach particular temperature i.e. to reach 940C it takes 243 seconds and it takes moderate time to reach same temperature i.e. 253 seconds and maximum time for setup without baffles i.e. 403 seconds. So we can conclude ceramic baffles are beneficial for enhancement of heat transfer rate than setup with iron baffles and setup without baffles.

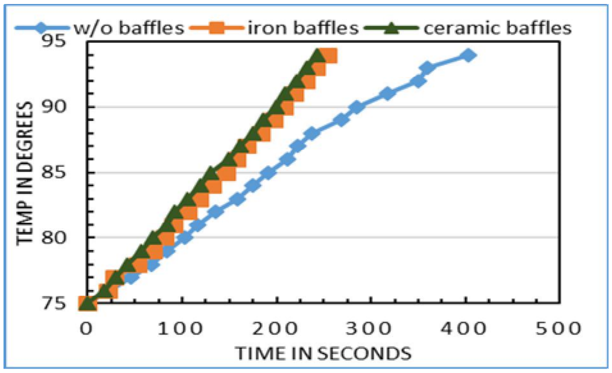

Figure 9. Effect of Baffles on α- Al_2O_3 Nanofluid With 0.10% Concentration by Volume

4. Effect of Al2O3 nanofluid of 0.15% concentration

Figure 4.4 clears that setup with ceramic baffles gives more heat transfer rate than setup with iron baffles and setup without baffles. Setup with ceramic baffles requires minimum time to reach particular temperature i.e. to reach 940C it takes 235 seconds and it takes moderate time to reach same temperature i.e. 245 seconds and maximum time for setup without baffles i.e. 391 seconds. So we can conclude ceramic baffles are beneficial for enhancement of heat transfer rate than setup with iron baffles and setup without baffles. Also we can conclude that addition of nanofluid of optimum concentration with setup of ceramic baffles giver higher heat transfer rates in minimum time.

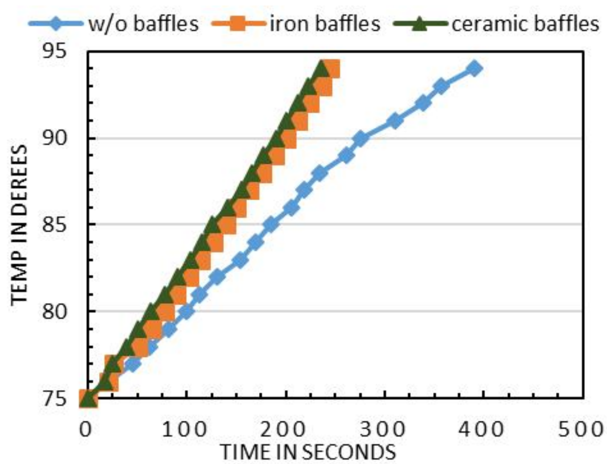

Figure 10. Effects of Baffles on α- Al_2O_3 Nanofluid With 0.15% Concentration by Volume

V. CONCLUSION

Following are the conclusions made from the experimental results:

1. For α- Al_2O_3 nanofluid with 0.05% concentration by volume percentage decrease in time by using iron baffles as compared without baffles is (8.33%-37.5%).
2. For α- Al_2O_3 nanofluid with 0.05% concentration by volume percentage decrease in time by using ceramic baffles as compared iron baffles is (3.62%-19.64%).
3. For α- Al_2O_3 nanofluid with 0.05% concentration by volume percentage decrease in time by using ceramic baffles as compared without baffles is (25.0%-39.81%).
4. For α- Al_2O_3 nanofluid with 0.10% concentration by volume percentage decrease in time by using iron baffles as compared without baffles is (3.54%-39.13%).
5. For α- Al_2O_3 nanofluid with 0.10% concentration by volume percentage decrease in time by using ceramic baffles as compared iron baffles is (3.73%-22.64%).
6. For α- Al_2O_3 nanofluid with 0.10% concentration by volume percentage decrease in time by using ceramic baffles as compared without baffles is (22.72%-39.70%).
7. Maximum of 25% decrease in time achieved using Al_2O_3 at 0.15% as compared with distilled water.
8. For α- Al_2O_3 nanofluid with 0.15% concentration by volume percentage decrease in time by using iron baffles as compared without baffles is (0.0%-25%).
9. For α- Al_2O_3 nanofluid with 0.15% concentration by volume percentage decrease in time by using ceramic baffles as compared iron baffles is (3.84%-23.52%).
10. For α- Al_2O_3 nanofluid with 0.15% concentration by volume percentage decrease in time by using ceramic baffles as compared without baffles is (19.04%-54.23%).

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