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EFFECT OF AL_2O_3 - WATER NANO FLUID ON BUBBLE SPACING IN SUBCOOLED FLOW BOILING IN A HORIZONTAL ANNULUS

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ABSTRACT

In this research work, an experiment has been performed in subcooled flow boiling of Al_2O_3 - Water nano fluid at different heat fluxes with the intention of investigating the effect of nano particles on bubble spacing in a horizontal, annular test section with an inner heating surface. High speed photography is used to capture bubble images and subsequently processed by National Instruments Labview IMAQ Vision building image processing software. Bubble spacing with respect to variation in heat flux and concentration of nano particles has been evaluated by automated image processing and analysis algorithms. It is observed that bubble spacing decreases with increase in heat flux and concentration of nano particles which is a clear indication of increase in heat transfer coefficients.

INTRODUCTION

Subcooled flow boiling of water is characterized by the presence of small bubbles, which grow and collapse rapidly near the heated surface. These bubbles are responsible for extremely high heat transfer augmentation. However, conventional heat transfer fluids, including oil, water and ethylene glycol mixture are poor heat transfer fluids, since the thermal conductivity of these fluids play important role on the heat transfer coefficient between the heat transfer medium and the heat transfer surface. Therefore numerous measures have been taken to improve the thermal conductivity of these fluids by suspending nano/micro or larger-sized particle materials in liquids. A nanofluid is a fluid with a colloidal dispersion of nanosized particles of another substance in water, or other base fluids. Nanofluids can conduct heat much faster than scientists had predicted possible. This leads to increase in heat transfer coefficients which influences bubble behavior. It is therefore very important to understand the mechanism of bubble dynamics and parametric effect of heat flux and concentration of nano particles on bubble behavior for proper investigation of heat transfer phenomenon in subcooled flow boiling. The use of high speed visualization and image processing is imperative in understanding and analyzing bubble behavior due to its natural consequence of non- intrusiveness and advent of rapid advancement in use of computerized image processing. The analysis of subcooled flow boiling is also not an exception for using this technique and also highly recommended to study complex phenomena of bubble behavior and parametric effects which play a vital role in augmentation of heat transfer.

The use of high speed visualization and image processing for analyzing subcooled flow boiling had been done previously [1-5]. However, their work was restricted to pure water at atmospheric pressures only.

Experiments were conducted on flow boiling of water in a vertical (internally heated) tube [6]. Through photographic studies they identified three separate regions between ONB (Onset of Nucleate Boiling) and OSV (Onset of Significant Void) with respect to heat flux. They were low heat flux region, isolated bubble region and region of significant coalescence. Bubble behavior varies from one region to another. They also varied the pressure from 1 to 3 bar and found that pressure is a potential parameter which affects bubble behavior significantly. However, they conducted experiments in vertical test section.

Investigation of bubble behavior in subcooled flow boiling of water in a horizontal annulus using high speed visualization had been done [7 & 8]. This discussion revealed that while bubble behavior of pure water has been studied broadly, data for nanofluid flow boiling which is the situation of interest for nuclear and other engineering applications are very scarce. Hence there is a need for investigating bubble behavior of nano fluids.

This work is aimed at investigation of bubble spacing which is one of the important characteristics of bubble behavior in subcooled flow boiling of nano fluids in a horizontal annulus and also to study the parametric effect of concentration of nano particles and heat flux on bubble spacing by using high speed visualization techniques and automated image processing analysis algorithms.

EXPERIMENTAL SETUP

Ultrasonic Vibration Mixer (UVM) was used to prepare the nanofluid. Dry aluminium oxide nanoparticles and distilled water were used to prepare nanofluid. However, the dry nanoparticles are in the form of large agglomerates. In order to break down the large agglomerates, ultrasonication was applied for 8–12 hours to mix a preset amount of nanoparticles with water to give certain nanoparticle concentration. The power available in the ultrasonic bath is 300 W and the ultrasonic frequency is 27±3 kHz. The prepared Nanofluid concentrations were very low (≤ 0.01 volume %) in this study. Therefore, agglomeration of nanoparticles is expected to be less.

The schematic diagram of the experimental test setup is shown in Figure 1. The closed loop test facility of 10 litre capacity mainly consists of ultrasonic vibration mixer, storage reservoir, circulating pump, flow meter, electrically heated horizontal annular test section, condenser and heat exchanger.

The working fluid is pumped from the reservoir to the test section via flow meter. The mixture of working fluid and steam from the exit of the test section passes through a horizontal condenser and counter flow heat exchanger before returning to the reservoir. Condenser condenses the steam into water and heat exchanger reduces the excess temperature and controls the temperature of working fluid before recirculation. The loop allows for varying the heat supply, flow, pressure, inlet temperature of the liquid and degree of subcooling.

The test section as shown in Fig.2 is 780 mm long and consists of an electrically heated rod and an outer borosilicate glass tube of 21.8 mm inner diameter. The heater is 12.7 mm diameter hollow stainless steel rod welded to solid copper rods at both ends. The test section is easily dismountable. In the glass tube, fluid flows over the surface of heater rod. The heated length of 500 mm is located 230 mm downstream of the inlet plenum and thus allowing for the flow to fully develop.

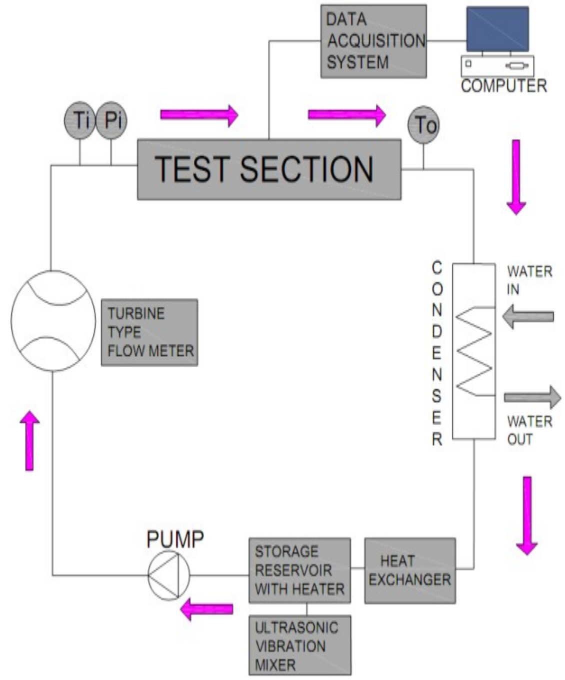

Figure 1 Schematic of Experimental Setup

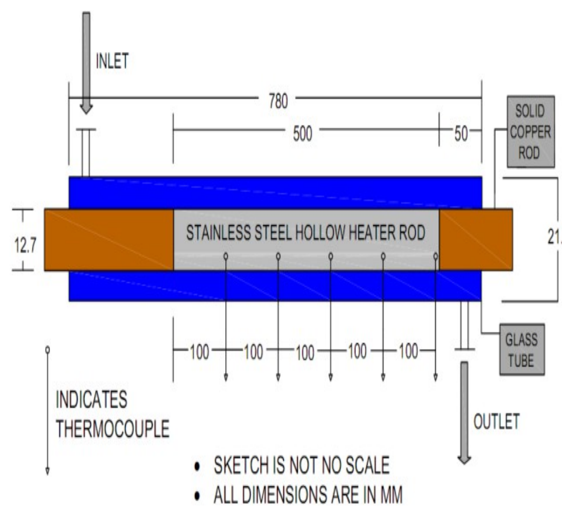

Figure 2 Test section and position of thermocouples

An input 415 V, 3 phase AC power is stepped down to 0–32 V DC power by using 64 kVA DC regulated power supply by which a large range of heat fluxes are applied to the test section. The applied heat flux in the test section, q ″ is given as

Where V and I are the measured voltage and current, respectively, and D and L are the test section diameter and length, respectively. The losses from the projected portion of the copper rod outside the glass tube were calculated and subtracted from applied heat flux q″ to get the actual heat transfer to the fluid.Temperatures at the wall (heater surface), fluid temperature at inlet and outlet of test section were measured with miniature J-type ungrounded thermocouples. The bulk temperature of the fluid was measured by averaging the inlet and outlet temperatures of the fluid at the test section. Surface temperature of heater rod at various locations was measured by five miniature thermocouples which were embedded on it. All these thermocouples are of Omega make, (JMQSS-IM050U-300) 1 mm wire diameter, J-type, ungrounded and covered with stainless steel sheath. Location of all these thermocouples is shown in Figure 2. All thermocouples are connected to Omega make Data Acquisition System, OMB-DAQ-55 which is further connected to computer. Data from the thermocouples can be recorded and stored in the computer at any point of experiment. Static pressure at the inlet of the test section was measured by using a Keller make pressure sensor which has a range of 1–10 bar with an accuracy of ±0.1%. Electronet make, FL-204 4-wire turbine type flow meter with flow range of 0.02–0.4 lps was used for measuring the flow rate. It has less than 100 ms response time with an accuracy of ±1%. The experimental test loop with test section was cleaned with dilute H2SO4 solution to remove oxides and fouling residue after every test. Before the test on another concentration of nanofluid, heater rod of test section was dismounted from the glass tube and cleaned with very fine (Grade P-320) sand paper and assembled again. The boundary conditions are shown in Table 1 and result of uncertainty analysis is shown in Table 2

Table- 1 Boundary conditions

S. No.	Parameter	Range
1	Pressure (bar)	1
2	Flow rate (l/s)	0.1–0.3
3	Heat flux (kW/m^2)	60-600
4	Degree of subcooling (ºC)	20
5	Concentration of nano fluid	0.001 to 0.01 vol %

Table- 2 Result of Uncertainty Analysis

S. No.	Parameter	Uncertainty (%)
1	Pressure (bar)	± 1.23
2	Flow rate (l/s)	± 1.4
3	Heat flux (kW/m^2)	± 1.2
4	Temperature (ºC)	± 0.4
5	Bubble Spacing (mm)	± 1.25

IMAGE CAPTURING

Images are captured with a high speed video camera (XCAP SV-642 of EPIX Company). It is provided with PIXCI imaging board and it can capture at the rate of 19,600 fps at reduced resolution and its shutter speed is 20 microseconds. The camera was located at a distance of 400 mm from the start of the heated section and could capture a region of about 35 mm along the heater surface. A single film could capture about 4.7 ms of boiling process. Uniform illumination over the whole test section was achieved by two CFL lamps equipped with electronic ballast to avoid light scintillation problems. A square box is installed on the test section to minimize the image distortion since the front side of the box (close to the camera) is filled with water. The side surface of the image box is covered by black paper to avoid any sidelight.

IMAGE PROCESSING

Each set of hundred images was batch processed using script implemented with National Instruments IMAQ Vision Builder 6.1 software. The complete script consists of 15 steps like loading, conversion, contrast enhancement, image filtering, convolution, edge detection, cropping of ROI, thresholding, morphological operations, particle filter and analysis were performed on images which are shown in Figure 3. Certain pre-processing operations like averaging of images and subtracting of image from it was performed before loading of image. Bubble spacing was evaluated at the end of image processing operations by using automated algorithms in the software. Previous study [7, 8] describes all the details of image processing operations.

RESULTS AND DISCUSSION

Bubble spacing refers to the distance between centroids of a bubble and its nearest bubble. The variation of bubble spacing with heat flux and concentration of nano particles is observed in the present study. The bubble spacing decreases with the increase of heat flux for all flow rates. The reason is, with the increase in heat flux, the driving force of the bubble growth process, wall super heat increases which leads to increase in heat transfer coefficients. Hence increase in number of bubbles in the same area that leads to reduction in bubble spacing. This trend can be Figure 4.

The results of this experimental work with respect to bubble spacing and its dependence on concentration of nano particles show that with the increase in concentration of nano particles, bubble spacing increases at all heat fluxes and flow rates which is evident from Figure 5. The reason for this behavior is the enhancement in heat transfer coefficients of nanofluids due to the enhanced effective thermal conductivity and the acceleration of the energy exchange process in the fluid due to the random movements of the nanoparticles. This leads to increase in number of bubbles in the same area and hence reduction in bubble spacing.

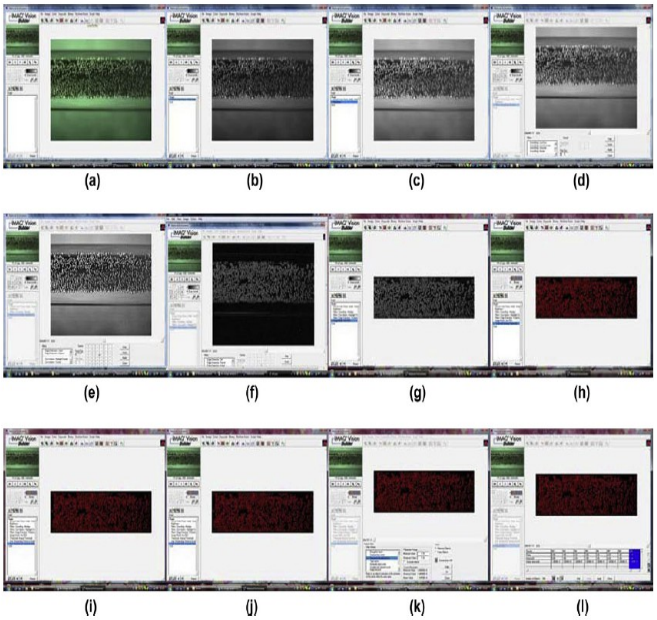

Figure 3. Image processing and analyzing. (a) Loading of image. (b) Conversion of RGB to gray. (c) Contrast enhancement. (d) Image filtering. (e) Convolution – highlight details. (f) Edge detection. (g) Image cropped to show ROI. (h) Manual threshold. (i and j) Basic & advanced morphological operations. (k) Particle filters by using Heywood circularity factor. (l) Particle analysis.

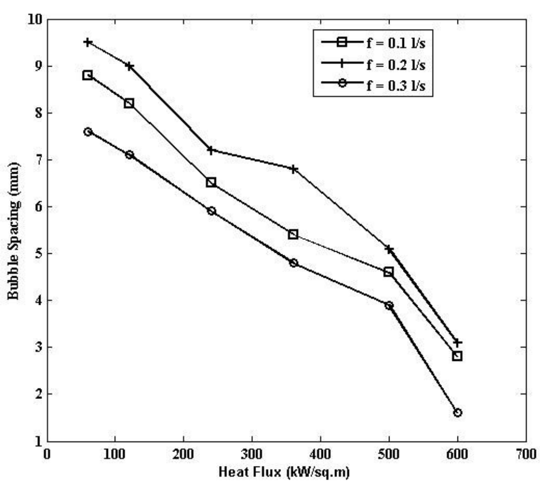

Figure 4 Effect of heat flux on bubble spacing

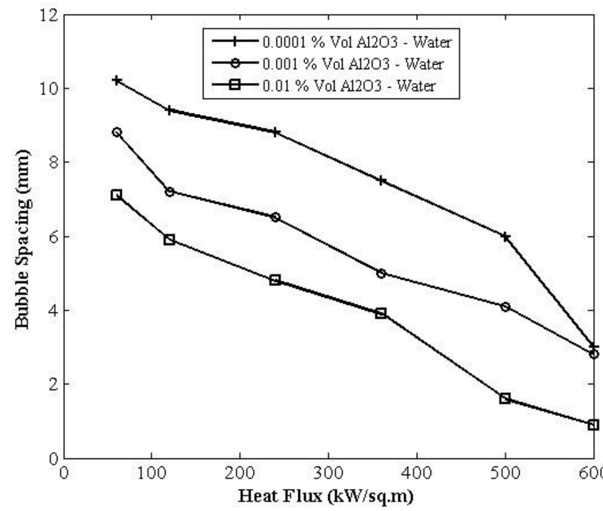

Figure 5 Effect of concentration of nano particles on bubble spacing

CONCLUSIONS

The effect of influencing parameters on bubble spacing during subcooled flow boiling in horizontal annulus has been investigated using high speed visualization technique followed by appropriate image processing. In particular the effects of heat and concentration of nano particles which essentially brings out the contribution of nucleate and convective mechanism of boiling has been brought out through experiments. It is concluded from the experiments that

1. Bubble spacing decreases with increase in heat flux
2. Bubble spacing decreases with increase in concentration of nano particles.

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