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EXPERIMENTAL INVESTIGATION OF CHF ENHANCEMENT USING NANOFLUIDS (Al2O3) IN SUBCOOLED POOL BOILING

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ABSTRACT

Phase-change heat transfer is an important process used in many engineering thermal designs. Boiling is an important phase change phenomena as it is a common heat transfer process in many thermal systems. There are many applications/processes in which engineers employ the advantages of boiling heat transfer, as they seek to improve heat transfer performance. Recent research efforts have experimentally shown that nanofluids can have significantly better heat transfer properties than those of the pure base fluids, such as water. Stable nanofluid was prepared with alumina nanoparticles (30-50 nm in diameter) and deionized water. The nanoparticle behaviors near the liquid wedge of bubbles were observed by high-speed camera. The microscopic morphology of the nanoparticle deposition layer at the heated surface was characterized by SEM images. It seems that the deposition layers could modify the morphology, but it also delays the detachment of small bubbles from the heated surface. The effect of geometry and bulk temperature also studied. A comparative experiment indicates that critical heat flux improved with increase in nanoparticles concentration. In the same fashion, the secondary objective is to give effect surface roughness on CHF by adding different concentrations of aluminium oxide nanoparticles.

KEYWORDS:Critical heat flux, Nanoparticle, Nanofluid, Concentration, Surface roughness.

INTRODUCTION

As the technological trend of increasing speed and size reduction of components continues the ability to remove high heat fluxes is becoming an ever more critical area of research. In an attempt to resolve these issues several methods are being investigated. One area that has drawn considerable attention in recent years has been the use of nanofluids as a heat transfer fluid .With regard to the energy crisis, the intensification of heat transfer processes and the reduction of energy losses are the important tasks to be investigated. Boiling heat transfer is used in various industrial processes and applications, such as power generation and electronics components. Enhancements in boiling heat transfer processes could make these previously industrial applications more efficient. Changing thermo-physical properties of the boiling liquids and morphology of boiling surface are the two important methods to improve the boiling heat transfer performance.

Heat dissipation is rapidly becoming the limiting factor in the production of next generation electronic components, and is motivating a search for more efficient cooling mechanisms. Two-phase (boiling) heat transfer has been recognized as an effective method to dissipate high heat loads and extensive research has been conducted to further enhance boiling heat transfer. These efforts are, for the most part, aimed at finding techniques to obtain the earlier onset of boiling incipience, enhance nucleate boiling heat transfer rates, and/or increase the critical heat flux (CHF).

One of the first boiling heat transfer investigations of nanofluids was reported by Das et al. [1]. Aluminum oxide -water nanofluids were tested at volume concentrations ranging from 0.1% to 4%. Nanofluid pool boiling tests were carried out at atmospheric pressure and conducted using a 20 mm diameter cartridge heater as the heating source. Das et al. [1] demonstrated a decrease in boiling heat transfer rate with increasing nanoparticle concentrations. Further, Das et al. [2] conducted similar nanofluid pool boiling tests, under the same conditions as their previous study, using smaller diameter size heaters. As was the case for the 20-mm-diameter cylindrical heater, the smaller heaters also show heat transfer degradation with increasing nanoparticle concentration. Das et al. [1] attributed the heat transfer degradation to the "Smoothening" of the heater surface by the nanoparticles. It is reported that individual nanoparticles are settling within the surface cavities and, in effect, smoothing out the heater surface. Critical heat flux (CHF) data, for these studies was not given. Recently, a dramatic 200% enhancement of CHF using Al2O3-water nanofluids at a 0.025 g/L concentration (0.0007% vol. concentration) has been reported by You et al. [4]. In contrast to the studies performed by Das et al. [1,2] at higher concentration (0.1 to 4% vol.), no heat transfer degradation was observed for Al2O3 concentrations up to 0.05 g/L (0.001% vol.). Similar results as [4] were obtained by Vassallo et al. [3] who measured significant nanofluid CHF enhancement using silica-water nanofluids. A subsequent study by Kim et al. [5] compared boiling characteristics such as departing bubble size and frequency for water and Al2O3-water nanofluids at 0.025 g/L concentration. Their findings show that the departing bubble size increases (25%) while bubble departure frequency decreases for the nanofluid tested as compared to water.

1.1 Objectives

The main objective of this study is to further understand nanofluids and their performance in pool boiling heat transfer. Nanofluid performance will be evaluated by varying different nanofluid parameters and evaluating the effect of each on pool boiling heat transfer. The nanofluids parameters which will be studied include nanoparticle type, nanoparticles size and base fluid. This study aims to determine whether this nanofluid CHF enhancement phenomenon can be replicated using nanofluids composed of nanoparticles which have never before been tested under pool boiling conditions. Additionally, the effect of nanoparticle size on nanofluid CHF enhancement will be investigated through the use of gravimetrically separated Al2O3 nanoparticles. These nanofluid pool boiling tests were carried out to increase our understanding of nanofluids and their ability to enhance boiling heat transfer.

EXPERIMENTAL APPARATUS AND PROCEDURES

Experimental setup shown in figure 2.1 consist of test vessel, test heater, dimmerstat, Voltmeter and Ammeter. All equipments are housed into one test rig on a table. Thermocouple is attached at top of test vessel.Dimmerstat coil is hosed in box beneath the test rig. Bulk heater and test heater are firmly attached to top cover by means of electrodes

. **Figure 2.1**

Experimental setup

The apparatus consists of a cylindrical glass container of diameter 200 mm and height 150 mm having thickness 3 mm housing the test heater and a heater coil for the initial heating of the water. This bulk heater is made up of Nichrome coil wounded around heater in between electrode. It is directly connected to the mains (Heater R1) .The test heater (Nichrome wire of different diameter) is connected also to mains via a dimmerstat. An ammeter (0-30A, AC) is connected in series with test heater while a voltmeter (0-100V, AC) is connected across test heater to read the current and voltage, respectively. The glass container is kept on an iron stand which could be fixed on a platform. There is provision of illuminating the test heater wire with the help of a lamp projecting light from behind the container and the heater wire can be viewed through lens. The top of container is cover by cover with provision of two opening, one for thermocouple and other to maintain atmospheric pressure condition in test facility. K-Type Thermocouple (-99 to 999°C) use to measure instantaneous bulk temperature. Camera facility is provided which use to collect pictorial data of boiling process.

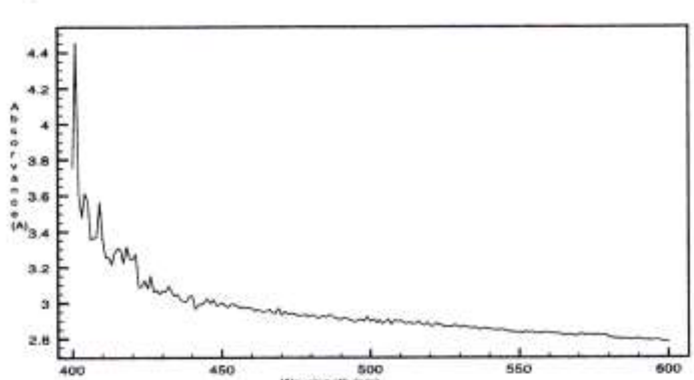
2.1 Nanofluid preparation procedures
In this work, nanofluids were prepared by the two-step method, dispersing dry nanoparticles into the base liquid followed by Ultrasonic stirring. Distilled water was used as the base liquid, and Al2O3 nanoparticles were used without the addition of additives. The Al2O3 nanoparticles were procured from Nano lab having 99% purity with an average size of 30-50nm. RANWAG A82 microbalance was used to measure the appropriate quantity of nanoparticles. Which were then dispersed in a beaker containing 250 ml of base fluid (distilled-deionized water) and stirred with a metal rod.
Concentrations of Al2O3 water nanofluids were as follows.
1. 0.15 gram of Al2O3 nanoparticles in 1.5 liter of distilled water (i.e. 0.1gram/liter)
2. 0.3 gram of Al2O3nanoparticles in 1.5 liter of distilled water (i.e. 0.2 gram/liter)
3. 0.45 gram of Al2O3 nanoparticles in 1.5 liter of distilled water (i.e.0.3 gram/liter)
4. 0.6 gram of Al2O3 nanoparticles in 1.5 liter of distilled water (i.e. 0.4gram/liter)

This nanoparticle solution was then subjected to a half hour long ultrasonic bath using Toshiba ultrasonic homogenizer. The mixture is allowed to vibrate in sonicator for 15 min then it is stirred with metal rod and followed by next 15 min sonication. Following this, the 250ml of nanoparticle solution was then combined with an additional 1,250ml of base fluid to make a total nanofluid volume of 1.5 liters. These 1.5 liters of nanofluid made up the sample which was then tested under pool boiling conditions.

2.2 Nanofluid characterization
Nanofluid characterization consists of evaluating the particle size distribution for a given nanofluid. This work was completed at the NANOLABS Gopalpur, Jharkhand and was performed using a wide range of techniques and equipment including UV-Vis spectrophotometer, X-ray powder diffraction (XRD) and Transmission Electron Microscope (TEM) equipment.

2.2.1 UV-Vis Spectrophotometer
Figure.2.8 shows UV-Vis spectrophotometer reading of Aluminium oxide nanoparticle. Ultraviolet/Visible/Infrared (UV/Vis/IR) spectroscopy is a technique used to quantify the light that is absorbed and scattered by a sample (a quantity known as the extinction, which is defined as the sum of absorbed and scattered light).

Figure 2.2



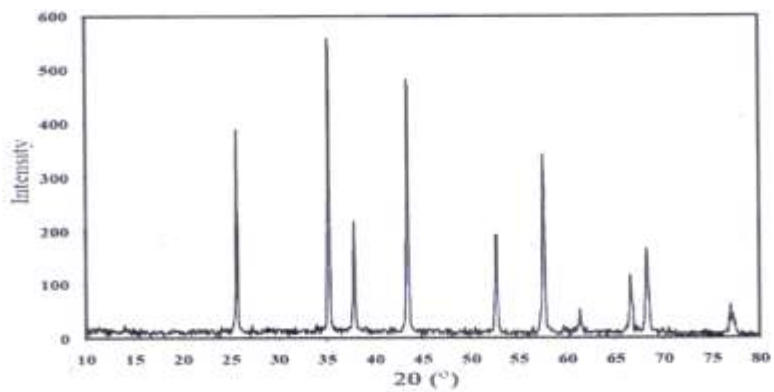
UV-Vis spectrophotometer reading of Aluminium oxide nanoparticles

In its simplest form, a sample is placed between a light source and a photodetector, and the intensity of a beam of light is measured before and after passing through the sample. These measurements are compared at each wavelength to quantify the sample's wavelength dependent extinction spectrum. The data is typically plotted as extinction as a function of wavelength. Nanoparticles have optical properties that are sensitive to size, shape, concentration, agglomeration state, and refractive index near the nanoparticle surface, which makes UV/Vis/IR spectroscopy a valuable tool for identifying, characterizing, and studying these materials.

2.2.2 X-ray powder diffraction (XRD) of Al2O3 Nanoparticles

X-ray powder diffraction (**XRD**) is a rapid analytical technique primarily used for phase identification of a crystalline material and can provide information on unit cell dimensions. The high-intensity peaks result when the Bragg diffraction condition is satisfied. Figure 2.3 depicts the X-ray diffraction spectra of Al2O3 nanoparticles taking intensity on vertical axis and ‘2θ’ on horizontal axis.

Figure 2.3



Diffraction pattern for Al2O3 nanoparticles

The average size of the nanoparticle was determined by the following Scherrer’s formula given as

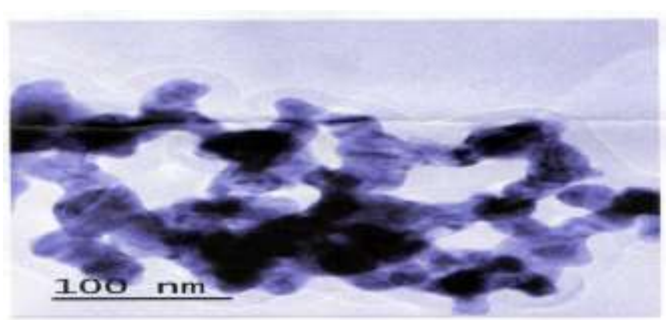
$$d = \frac{0.9 \times \lambda}{\beta \times \cos \Theta}$$

The average size of the nanoparticles measured by using Scherrer’s formula was ranges from 30nm to 50nm.

2.2.3 Transmission Electron Microscope (TEM)

Figure 2.4 shows TEM Analysis of Al_2O_3. Transmission electron microscopy (TEM) is a microscopy technique in which a beam of electrons is transmitted through an ultra-thin specimen, interacting with the specimen as it passes through it.

Figure 2.4



TEM Analysis of Al_2O_3

An image is formed from the interaction of the electrons transmitted through the specimen; the image is magnified and focused onto an imaging device, such as a fluorescent screen, on a layer of photographic film, or to be detected by a sensor such as a charge-coupled device. The TEM image of Al2O3 nanoparticles at 100 nm magnifications is shown in figure. TEM micrographs show the spherical morphology of Al_2O_3 nanoparticles.

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Analysis result
Aluminum Oxide Nanoparticles (Al_2O_3, Alpha, Purity 99.5%),
Average Particle size: 30-50nm
Specific surface area: 120-140 m^2/g
Bulk Density: 1.5 g/cm^3
True Density: 3.97 g/cm^3
Colour: White
Morphology: Spherical
Crystallographic Structure: rhombohedral
Atomic Weight: 101.96 g mol^{-1}
Melting Point: 2055 °C

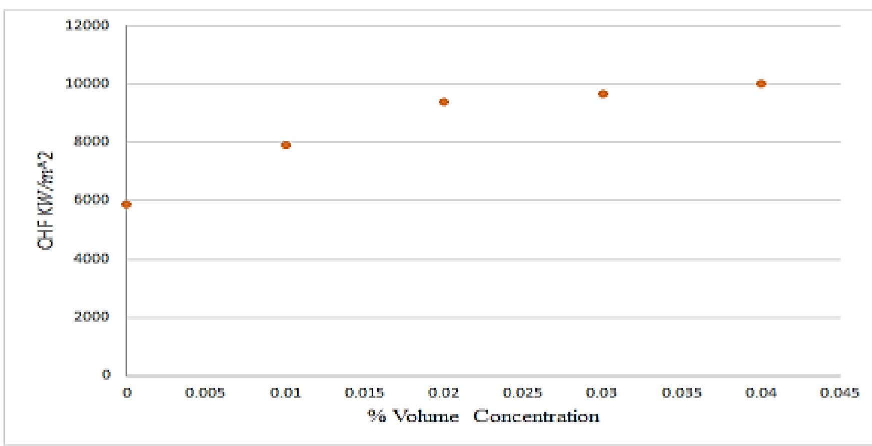
RESULTS AND DISCUSSION

Pool boiling tests were performed with four different concentration of Al_2O_3 nanofluid, 0.1 gram/liter, 0.2 gram/liter, 0.3 gram/liter and 0.4 gm/liter. In the present experimentations, diameter of Nichrome (80) wire was varied from 36 gauge to 38 gauge. The main objectives are to investigate and compare the influence of each nanofluid concentration on nucleate boiling heat transfer and CHF. All nanofluid pool boiling tests were conducted at a temperature of T_b = 50 °C and 75°C. In order to understand the mechanism for the extremely large CHF of nanofluids, correlations must be made between the nanoparticle properties and the resulting CHF enhancement.

3.1 CHF comparison of Aluminum oxide (Al_2O_3)-water nanofluids with 38 SWG micro wire

In experimentations for Al_2O_3-water nanofluid with a lowest concentration i.e. 0.1 gram/liter, average value of CHF is 7879.58 KW/m². At this concentration CHF enhancement is 34.37 %. Further as the concentration of nanofluid increased to the 0.2gram/liter, average CHF value measured is 9392.67 KW/m² having 60.17 % enhancement.

Figure 3.1



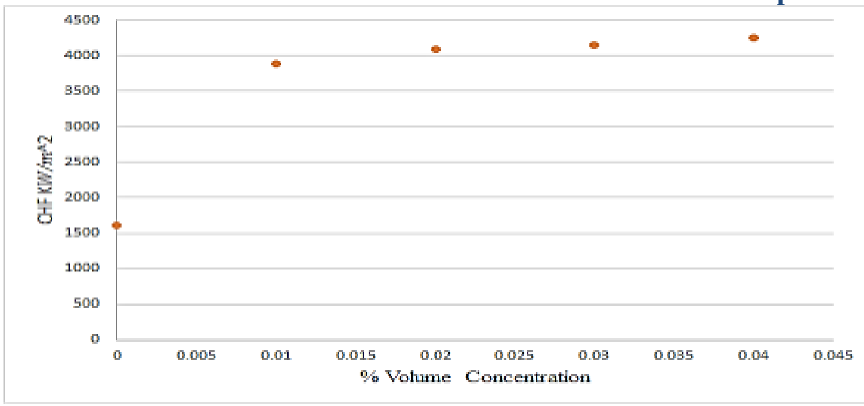
CHF Vs volume concentration (%) for Al_2O_3 nanofluid 38 SWG

Similarly, increasing trend of CHF is observed for 0.3 gram/liter and 0.4 gram/liter nanofluid. CHF at 0.3 gram/liter Al2O3-water nanofluid is 9675.39 KW/m² which indicate 65.00 % CHF enhancement. For 0.4 gram/liter nanofluid CHF increase to 10013.08KW/m² with 70.75 % enhancement. In case 0.4 gram/liter nanofluid highest CHF is obtained. It is clear from data that as nanoparticle concentration increases CHF also increases.

3.2 CHF comparison of Aluminum oxide (Al_2O_3)-water nanofluids with 36 SWG micro wire

In experimentations for Al_2O_3-water nanofluid with a lowest concentration i.e. 0.1 gram/liter, average value of CHF is 3886.59 KW/m². At this concentration CHF enhancement is 141.97%. Further as the concentration of nanofluid increased to the 0.2gram/liter, average CHF value measured is 4090.72 KW/m² having 154.68% enhancement.

Figure 3.2



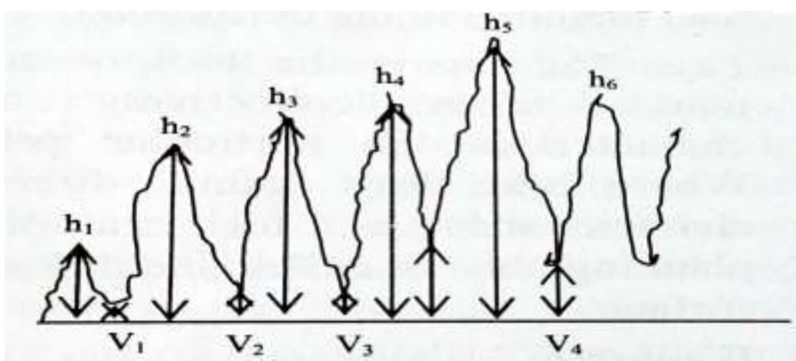
CHF Vs volume concentration (%) for Al_2O_3 nanofluid 36 SWG

Similarly, increasing trend of CHF is observed for 0.3 gram/liter and 0.4 gram/liter nanofluid. CHF at 0.3 gram/liter Al2O3-water nanofluid is 4144.32 KW/m² which indicate 158.02 % CHF enhancement. For 0.4 gram/liter nanofluid CHF increase to 4249.48KW/m² with 164.57 % enhancement. In case 0.4 gram/liter nanofluid highest CHF is obtained. It is clear from data that as nanoparticle concentration increases CHF also increases.

3.3 Surface roughness

Figure 5.13 shows Ten point height of irregularities. The parameter, which is used in this investigation, is the Rz value. The Rz value is defined as the 10 point average of the vertical deviation from the mean line established in a surface roughness measurement and has unit usually µm. In this method max peaks and max valleys are measured with respect to base line.

Figure 3.2



Ten point height of irregularities

$$Rz = \frac{[(h1 + h2 + h3 + h4 + h5) - (v1 + v2 + v3 + v4 + v5)]}{5} \times \frac{1000}{V.M.}\ \mu m$$

V.M. =Vertical magnification
h1, h2, h3……are max peaks (in mm)
v1, v2, v3……are valleys (in mm)

For micro wire of diameter below 1mm general methods to measure surface roughness are not useful. Hence it is very difficult to measure surface roughness for micro wires. But it is essential to have data related to surface roughness of micro wire in order to know the effect of nanofluid deposition on surface and to find out the causes of increase in CHF. In order to find out surface roughness of micro wire, we used new approach in which micro wire is first scan under SEM.

Figure 3.3

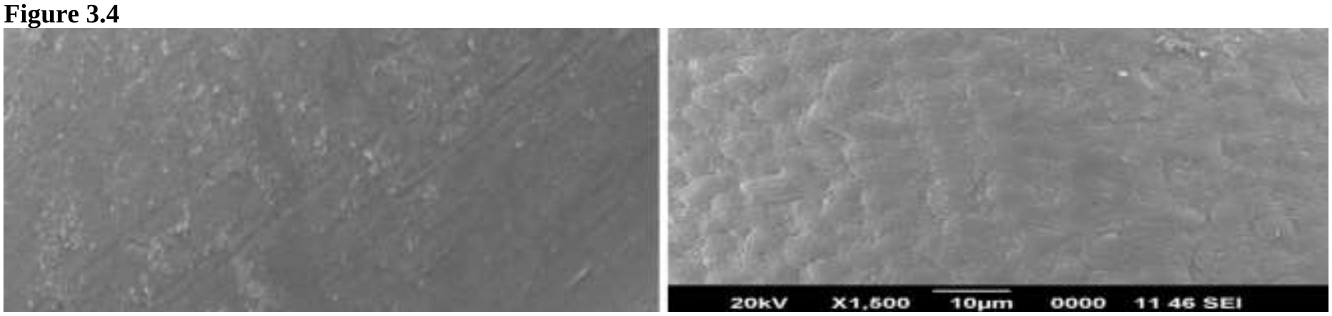
Avg. roughness: (a) 38 SWG with De-Ionised water (b) 38 SWG with 0.02 % Al_2O_3

The edge of micro wire is focused by keeping SEM perpendicular to wire surface. Micro wire magnified SEM images are captured with vertical magnification of about 2070.From data and images obtain from SEM, we can clearly see the peaks and valleys on the edge surface of micro wire. These peaks and valleys height from centre line is measured. First from the SEM images only micro wire profile is extracted by removing background with image editing software. Now clearly we can distinguish between valleys and peak. Then from image each peak and valleys height is measured in mm.
Wire heater shown in Figure 3.3 (a), surface roughness before pool boiling experiment is 1.93 µm. The wire shown in Figure 3.3 (b) sample which is used in nanofluid pool boiling of 0.2 gram/liter concentration shows surface roughness 3.18µm.
Thus, surface roughness value of bare wire changes when it is used in pool boiling of nanofluid. These results clearly indicates that in pool boiling of nanofluid, nanoparticle deposits on heater surface forms a porous layer and causes surface roughness change of heater surface. Due to this porous layer trapping of liquid near heater surface takes place which leads to delay in occurrence of CHF.Also, these porous layer causes breaking of voids near heater surface and prevent the formation of vapor blanket on the heater surface, thus CHF enhancement occurs. Nanoparticle deposition increases nucleation site density. Due to increase in nucleation site density bubble departure diameter decreases. Due to this, coalescence of bubble decreases and vapor blanketing on the heater surface decreases. Also, reduced bubble departure diameter causes increased bubble departure frequency as small size bubble forms. Irregularity due to roughness allows bubble to leave heater surface more easily.

3.4 Nanoparticle deposition

While nanoparticles deposit on the smooth heating wire, it will extend the heat transfer area of the heated surface and provide more potential nucleation sites for bubble growth. Therefore, the heat transfer rates would be potentially enhanced. However, it is not definitive that the heat transfer rates are enhanced intensively, since the heat transfer rate is proportional to bubble departure diameter and frequency and nucleation sites.

Figure 3.4



Heater surface at 1500 magnification (a) De-Ionosed water (b)0.02% Al_2O_3

Thus, the surface characteristics affecting the bubble departure dynamics needs to be verified carefully. The deposition morphologies on heating wires are characterized by scanning electronic microscopy (SEM) images after the boiling experiment. The SEM images for the heating wire are presented in Figure 3.4. Nanoparticle depositions increase nucleation site density. Due to increase in nucleation site density bubble departure diameter decreases. Due to this, coalescence of bubble decreases and vapor blanketing heater surface decreases. Also, reduced bubble departure diameter causes increased bubble departure frequency as small size bubble forms. Irregularity due to roughness allows bubble to leave heater surface more easily hence ability to wet the heater surface increases which leads to delaying CHF.

CONCLUSION

It was observed that at CHF a localized hot spot develops and subsequently spreads over the entire thin-film heater which either damages the heater or increase temperature at heater liquid surface. Above investigation predicts CHF to increase monotonically with an areal surface roughness parameter Rz, defined as the average roughness. The logic behind their argument is that surface roughness increases the effective length of the three-phase contact line, thereby increasing the capillary forces that help to prevent the boiling crisis by keeping the surface wetted with liquid. It is known that at heat fluxes close to CHF dry spots are continuously forming on the boiling surface and getting rewetted by the surrounding liquid. The boiling crisis is characterized by one or more of these localized dry spots spreading irreversibly and enveloping the entire heated surface in a continuous vapour layer. In Nucleate boiling liquid evaporation results in the motion of the liquid vapour interface away from the dry spot because of mass and momentum conservation. Under normal circumstances, the surrounding liquid moves in to rewet the surface under the influence of gravitational and capillary forces, and the dry spot disappears. However, at high heat fluxes the temperature in the interior of the dry spot may rise rapidly due to the incoming heat flux and the absence of evaporative/liquid convective cooling. Therefore, we hypothesize that the boiling crisis is triggered by the inability of the surrounding liquid to rewet a localized dry spot on the boiling surface because of a competition with high rates of evaporation precipitated by elevated temperatures in the interior of the dry spot.

The main findings of this study are as follows:

– Dilute dispersions of alumina nanoparticles in water exhibit significant CHF enhancement in boiling experiments with wire heaters.

_CHF enhancement increases with nanoparticle concentration from 0.1 gram/liter to from 0.4 gram/liter

– During nucleate boiling some nanoparticles deposit on the heater surface to form a porous layer. This layer improves the wettability of the surface considerably

_ The surface roughness value of bare wire changes when it is used in pool boiling of nanofluid increases significantly. Due to this porous layer trapping of liquid near heater surface takes place which leads to delay in occurrence of CHF.

To elucidate CHF enhancement mechanism more definitively, additional work is however needed, including a thorough characterization of the layer growth and morphology during boiling, which will clarify the effect of the porous layer on the nucleation site density.

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REFERENCES

[1] Das, S. K., Putra, N. and Roetzel, W. (2003). "Pool Boiling Characteristics of Nanofluids." International Journal of Heat and Mass Transfer, 46, 851-862.

[2] Das, S. K., Putra, N. and Roetzel., W. (2003). "Pool Boiling of Nano-Fluids on Horizontal Narrow Tubes." International Journal of Multiphase Flow, 29, 1237-1247.

[3] Vassallo, P., Kumar, R. and D'Amico, S. (2003). "Pool Boiling Heat Transfer Experiments in Silica-Water Nano-Fluids." International Journal of Heat and MassTransfer, 47, 407- 411.

[4] You, S. M., Kim, J. H. and Kim & K H. (2003). "Effect of Nanoparticles on Critical Heat Flux of Water in Pool Boiling Heat Transfer." Applied Physics Letters, 83, 3374.

[5] Kim, J. H., Kim, K. H. and You, S. M. (2004). "Pool Boiling Heat Transfer in Saturated Nanofluids." Proceedings of ASME Int. Mech. Engineering Congress,Anaheim, California.
[6] Hyungdae Kim and Moohwan Kim.(2007). "Experimental study of the characteristics and mechanism of pool boiling CHF enhancement using nanofluids." Heat Mass Transfer (Springer-Velar), 45:991–998
[7] Youngping Yang and Xiaoze Du (2014)."Effects of nanoparticle behaviors and interfacial characteristics on subcooled nucleate pool boiling over microwire." Experimental thermal and fluid science- Researchgate 310-316
[8] Xiang-Qi Wang and Arun S. Mujumdar (2008). "A review on nanofluids - part ii:experiments and applications. Brazilian Journal of Chemical Engineering." ISSN 0104-6632
[9] Lee, S., Choi, S. U. S., Li, S. and Eastman, J. A. (1999). "Measuring Thermal Conductivity of Fluids Containing Oxide Nanoparticles." Transactions of ASME, 121,280-288.
[10] H.U. Kang, S.H. Kim and J.M. Oh, "Estimation of Thermal Conductivity of Nanofluid using Experimental Effective Particle Volume," Experimental Heat Transfer 19 (2006) 181-191.