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

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ABSTRACT

Transferring a large amount of energy to/from a system has always been a challenge in cooling/heating systems as well as power cycles and refrigerants. Boiling phenomena is a key method for removing the heat from the high heat flux mediums and surfaces. Thus, specific attention should be dedicated to the enhancement of heat transfer coefficient. Nano-fluid is an engineered colloidal suspension of nano-sized particles in a base fluid, such as water or glycols, which provides special heat transfer features, such as enhancement of thermal conductivity and changing of the heat transfer surface due to scale formation. It literally has best of both worlds cause we can use the heat transfer fluid as a liquid with added benefits of solid dispersed in it. Stable nanofluid was prepared with CuO nanoparticles (30-50 nm in diameter) and deionized water. The microscopic morphology of the nanoparticle deposition layer at the heated surface was characterized by SEM images. It seems that the deposition layers can modify the morphology, but it also delays the detachment of small bubbles from the heated surface. The effect of geometry and bulk temperature was 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 effective surface roughness on CHF by adding different concentrations of copper oxide nanoparticle.

KEYWORDS: CuO Nanoparticle, Surface roughness,CHF.

INTRODUCTION

Heat transfer is a very important problem in many industrial applications. Heat transfer in the nucleate boiling regime, the latent heat of vaporization during the change from liquid to gas phase can be exploited, and is the most effective way of cooling thermal systems running at high temperatures. However, the boiling heat transfer is limited by the critical heat flux (CHF). This is the highest heat flux where boiling heat transfer sustains its high cooling performance. When the surface reaches CHF, it becomes coated with a vapor film which isolates the heating surface and the fluid, and the heat transfer decreases dramatically. In these conditions, the wall temperature rises quickly, and if it exceeds the limits of its constituent materials, system failure occurs. For this reason, every system incorporates a safety margin by running at a heat flux lower than CHF, but this approach reduces system efficiency. This compromise between safety and efficiency is a very serious problem in the industry. For this reason, a vast amount of work has been carried out to understand heat transfer mechanisms in nucleate boiling and CHF conditions, and to increase the CHF point.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). 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 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 housed in a box beneath the test rig. Bulk heater and test heater are firmly attached to top cover by means of electrodes.

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Fig.1 Experimental setup

The apparatus shown in Figure 1 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 . 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 is 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 water temperature. 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 CuO nanoparticles were used without the addition of additives [3]. The CuO nanoparticles were procured from Nano labs having 99% purity with an average size of 30/50 nm. A RADWAG A82/220/2X374215/12 microbalance precision balance 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. Different concentrations of the Cuo nanofluid were (0.1g/l,0.2g/l,0.3g/l and .4g/l) made. The above mentioned different concentrations of nanoparticle solution were then subjected to a half hour long ultrasonic bath using ULTRASONIC HOMOGENIZER (TOSHIBA) ultrasonicator. The mixture is then allowed to vibrate in the sonicator for 15 min duration, then it is stirred thoroughly with the help of a metal rod and then ultimately concluded with further sonication process in the sonicator for the next 15 minutes. The solution was then poured into the test vessel. The vessel was then sealed and the valve above the test section was opened. Now both the heaters are completely submerged in water. The thermocouple is inserted from top of the cover along the arrangement provided for the same. The heater coil R1 is connected to the main supply as mentioned in the set up description and the test heater wire of 36G/38G is tightened across the studs and checked for the necessary electrical connections. Switch on the heater R1. Now keep it on till you get the required bulk temperature of water in the container which is 50ºC/75ºC as per the required case temperature. After reaching required temperature switch off the heater R1. Then switch on test heater with nichrome wire R2. Very gradually increased the voltage across it by slowly changing the variac from its initial position to its ultimate position and while doing so, it is stopped at each position to observe the boiling phenomenon on the wire and to take the requisite data. Temperature, current, voltage etc readings are tabulated down for different voltage. The experiment is carried on by increasing the voltage till the test wire breaks. The point at which the test wire breaks is the critical heat flux point. The process in real time is very swift and it is very much necessary to carefully note down the voltage and current at this point. The experiment is repeated by altering the bulk temperature of water. Same procedure is repeated with only de-ionised in order to show the % increase in the CHF value.

RESULTS AND DISCUSSION

The CHF values obtaines after calculations were then graphically compared to see the amount of increase in the CHF value obtained**.**

3.1CHF comparison of Copper oxide (CuO)-water nanofluids with 38 SWG micro wire.

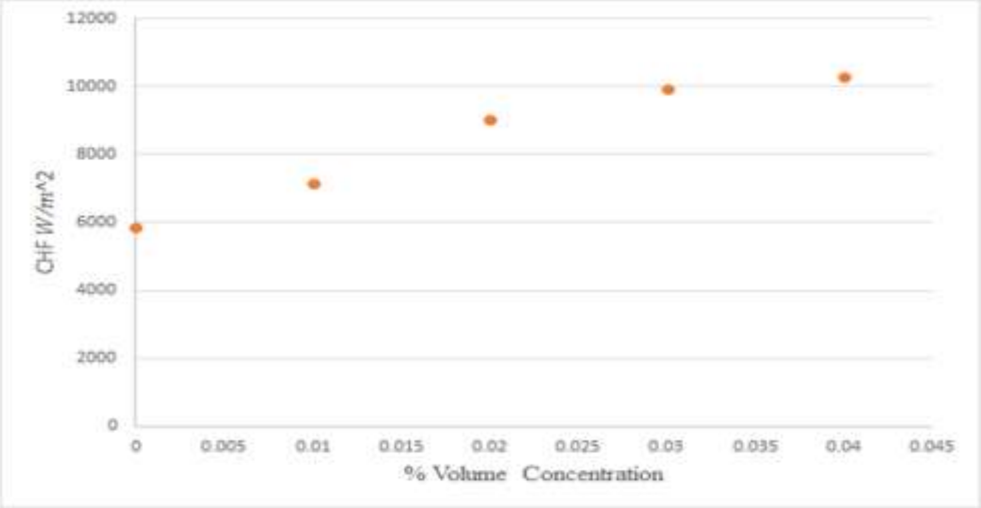

Fig 2 CHF Vs volume concentration (%) for CuO nanofluid 38 SWG

In experimentations for CuO-water nanofluid with a lowest concentration i.e. 0.1 gram/liter, average value of CHF is 7146.59 KW/m². At this concentration CHF enhancement is 21.87 %. Further as the concentration of nanofluid increased to the 0.2gram/liter, average CHF value measured is 9031.41 KW/m² having 54.02 % enhancement.

Similarly, increasing trend of CHF is observed for 0.3 gram/liter and 0.4 gram/liter nanofluid. CHF at 0.3 gram/liter CuO-water nanofluid is 9937.17 KW/m² which indicate 69.46 % CHF enhancement. For 0.4 gram/liter nanofluid CHF increase to 10267.01KW/m² with 75.09 % enhancement. In case 0.4 gram/liter nanofluid highest CHF is obtained. It is clear from data that as the nanoparticle concentration increases CHF also increases.

3.2 CHF comparison of Copper oxide (CuO)-water nanofluids with 36 SWG micro wire.

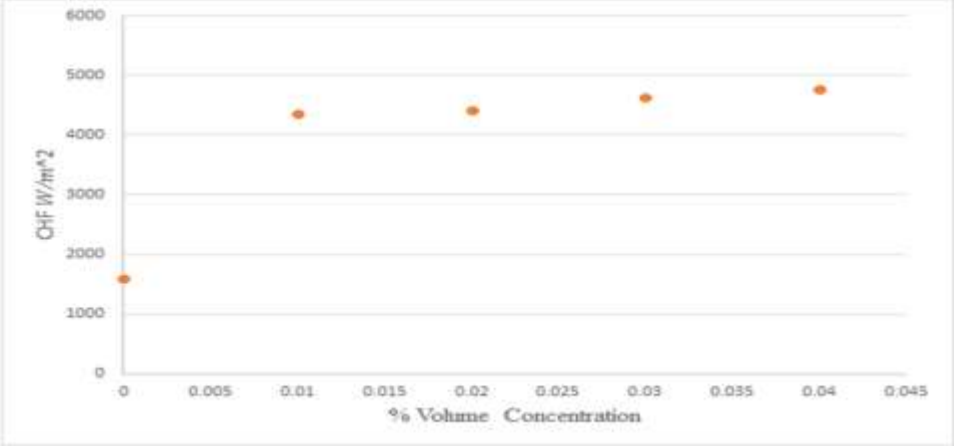

Fig.3 CHF Vs volume concentration (%) for CuO nanofluid 36 SWG

In experimentations for CuO-water nanofluid with a lowest concentration i.e. 0.1 gram/liter, average value of CHF is 4354.64 KW/m². At this concentration CHF enhancement is 170.78%. Further as the concentration of nanofluid increased to the 0.2gram/liter, average CHF value measured is 4420.61 KW/m² having 174.88% enhancement.

Similarly, increasing trend of CHF is observed for 0.3 gram/liter and 0.4 gram/liter nanofluid. CHF at 0.3 gram/liter CuO-water nanofluid is 4626.8 KW/m² which indicate 187.7% CHF enhancement. For 0.4 gram/liter nanofluid CHF increase to 4767.01 KW/m² with 196.42 % 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.

The surface rougness of the nichrome wire was calculated with one of the sample (0.02%CuO) and then was compared with the wire tested solely with de-ionised water. To calculate the Rf number 10 point irregularities method was used.

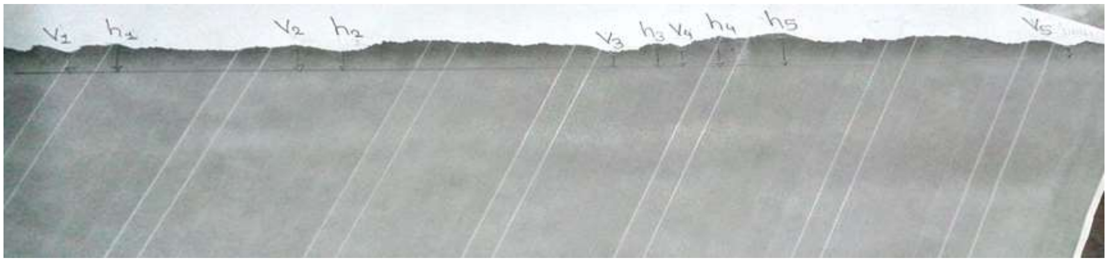

Fig.4. 38 SWG with De-Ionised water (avg roughness)

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.

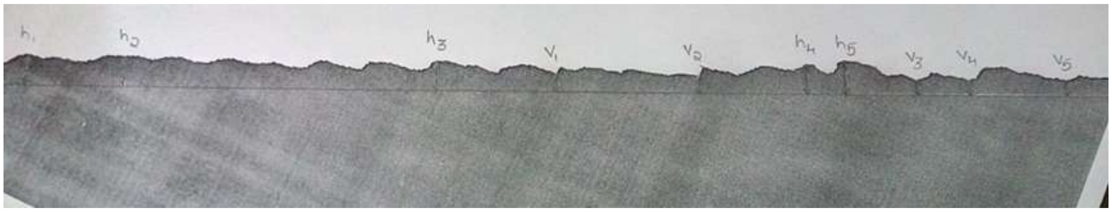

Fig.5. 38 SWG with 0.02 % CuO (avg roughness)

Wire heater surface roughness before pool boiling experiment is 1.93 μm. The wire sample which is used in nanofluid pool boiling of 0.2 gram/liter concentration shows surface roughness 2.028μm. 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.

When 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. Thus, the surface characteristics affecting the bubble departure dynamics needs to be verified carefully.

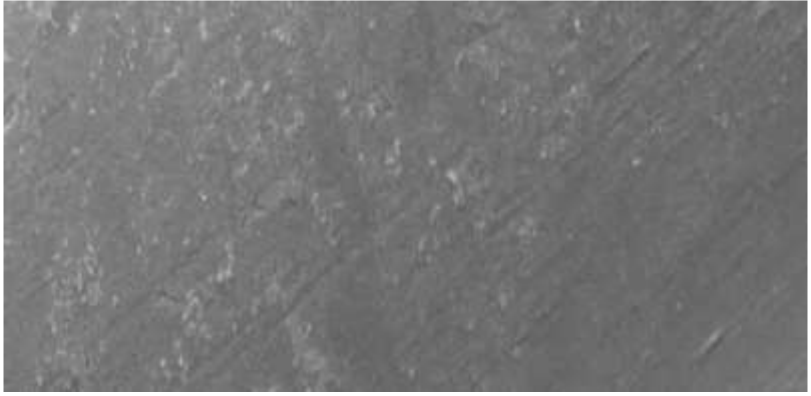

Fig.6. Heater surface with 1500 magnification (deionized water)

Fig 6 show that the inclusion of nanoparticles could somewhat change the wire surface morphology given numerically by the scanning electronic microscope. The uncertainty or the average roughness of micro heater could also be of the same order of magnitude as the diameter change, therefore the diameter change of the micro heater is essentially very small.

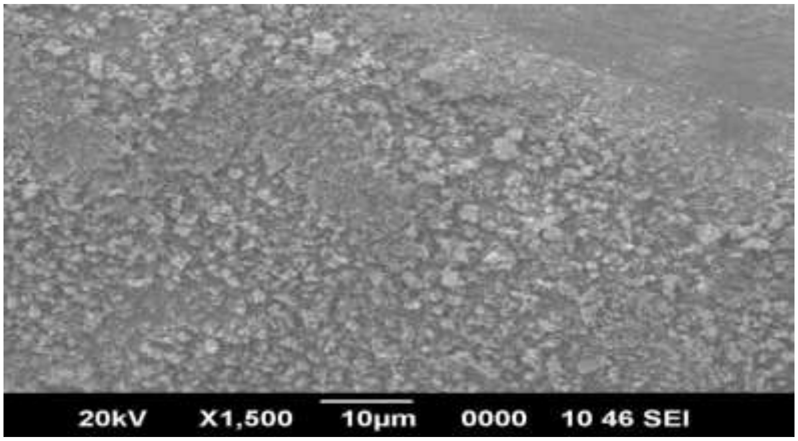

Fig 7 Heater surface with 1500magnification (0.02% CuO)

The deposition profiles could be uniform for the micro heater after boiling with nanofluid, as shown in Fig.7

SEM data for micro wire shows surface changes after nanoparticle inclusion, it can be clearly seen that the surface after having been tested with CuO nanofluid is experiencing more inclusions and surface irregularness. This reduces the bubble size and increases the bubble detachment rate as well as the number of nucleation sites. Thus the heat ransfer rate increases and the CHF also is seen to increase.

CONCLUSION

The Dilute dispersions of copper 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 higher wettability can produce CHF enhancement which is consistent in magnitude with the experimental observations. 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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