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**ABSTRACT**

The flow and heat transfer characteristics of nanofluid were attracting many researchers during the last two decades. Convection heat transfer in it is especially important for its potential applications. In this investigation, stable self-rewetting fluid was prepared with Copper oxide nanoparticles, deionized water and n-butanol surfactant. The nanoparticle behaviors near the liquid wedge of bubbles were observed by SEM methodology. The effects of nanoparticle behaviors in this region and the interfacial characteristics. While n-butanol was included as surfactant which will change the liquid/ vapor interfacial property, it intensifies the nanoparticle deposition for low heat flux conditions. The analysis shows that the critical heat flux of nanofluid can be obviously improved when n-butanol was included in the nanofluid. The effects at the liquid-vapor interface on convection of nanofluid were experimentally investigated.

**KEYWORDS:** Surfactant, Critical heat flux, Surface morphology.

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**INTRODUCTION**

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. Although there have already been significant researches into the critical heat flux (CHF) enhancements in nucleate boiling of nanofluids, further research on CHF enhancements of nanofluids with self-rewetting fluids as surfactant was investigated to a lesser extent. The self-rewetting fluids were investigated as new heat transfer fluids that have unique surface tension property in the high temperature region that increases with increasing temperature. The self-rewettability of dilute aqueous solutions of high carbon alcohols, e.g., butanol, pentanol, etc., was expected to prevent the development of local dry patch and to improve the CHF to some extent.

**EXPERIMENTAL APPARATUS AND PROCEDURES**

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. The bulk heater is made up of Nichrome coil wound 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 covered 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) used to measure instantaneous bulk temperature. Camera facility is provided which use to collect pictorial data of boiling process.



*Figure 1. Experimental setup*

This experimental set up is designed to study the pool boiling phenomenon up to critical heat flux point. The heat from the wire is slowly increased by gradually increasing applied voltage across the test wire and the change over from natural convection to nucleate boiling can be seen. The formation of bubbles and their growth in size and number can be visualized, followed by the vigorous bubble formation and their immediate carrying over to surface and ending thus in the breaking of the wire indicating the occurrence of critical heat flux point

### **2.1. Self re-wetting fluid preparation**

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 CuO nanoparticles were used without the addition of additives. The CuO nanoparticles were procured from Nano lab having 99% purity with an average size of 30-50 nm.

RANWAG A82/220/2×374215/2 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. 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 15min sonication.

After sonication, 0.5 ml/litre of n-butanol surfactant is added to the nanofluid. Then again by using the metal rod, the mixture is stirred. Following this, the 250ml of nanoparticle solution was then combined with an additional 1,250 ml of base fluid and 0.75ml of n-butanol to make a total test fluid volume of 1.5 liters.

### **2.2. Pool boiling test procedures**

The 1.5 liters of water were poured into the approximately 3 liter capacity test vessel. The vessel was then sealed and the valve above the test section was opened. Both the heaters are completely submerged in water. The thermocouple is inserted from top of the cover with arrangement provided. The heater coil R1 connected to the supply and test heater wire across the studs and checked the necessary electrical connections. Switch on the heater R1. Keep it on till you get the required bulk temperature of water in the container 50°C, 75°C as per required temperature. After reaching required temperature switch off the heater R1. Then switch on test heater with Nichrome wire heater R2. Gradually increased the voltage across it by slowly changing the variac from one position to the other and it is stopped at each position to observe the boiling phenomenon on wire and to take requisite data. Temperature, current readings are note down at different voltage. Then increased the voltage till wire breaks and carefully noted the voltage and current at that point. Repeated this experiment by changing the bulk temperature of water. Same procedure is repeated with bulk liquid as test fluid which is under suspended condition in base fluid due to sonication.

In this investigation, each test fluid mixture and de-ionized water pool boiling experiment was conducted twice. Before applying any voltage to the heater, the fluid level was marked on the glass container. Once the experiment started,

vapor began to escape slowly. When the test fluid level dropped 2 mm below the initial fluid level de-ionized water was added through the rubber tubing in an effort to keep the test fluid concentration consistent.

## RESULTS AND DISCUSSION

Pool boiling tests were performed with four different concentrations of CuO nanofluid, 0.1 gram/liter, 0.2 gram/liter, 0.3 gram/liter and 0.4 gram/liter with 0.5 ml/litre of n-butanol. In the present experimentations, two different diameters of Nichrome (80) wire were used, i.e. 36 gauge and 38 gauge. The main objectives are to investigate and compare the influence of surfactant on nucleate boiling heat transfer and CHF. All test fluid pool boiling tests were conducted at a temperature of  $T_b=50^\circ\text{C}$  and  $T_b=75^\circ\text{C}$ .

### 3.1.CHF comparison

The figure represents comparison of CHF with different concentration of nanoparticle test fluid. It is clear from data that as test fluid concentration increases CHF also increases. The variation of CHF ( $q_{cr}$ ) with respect to the mass fraction of surfactant can also be obtained, as shown in Figure.

#### 3.1.1 CHF comparison of Copper oxide (CuO) – n-butanol test fluid with 38 SWG micro wire

In the third case i.e. 0.03% CuO test fluid gives the highest CHF value, and it shows that up to 88.04% CHF can be increased by addition of nanofluid in boiling application. These results are compared with De-Ionised water (0% CuO test fluid).

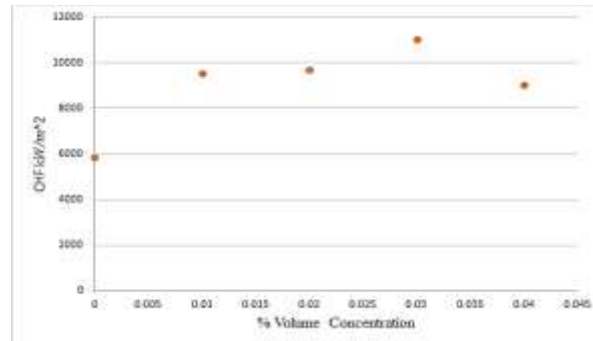


Figure 2. Comparison of CHF for different test fluids with 38 SWG microwire

#### 3.1.2. CHF comparison of Copper oxide (CuO) – n-butanol test fluid with 36 SWG micro wire

Figure shows that CHF increased by 475.28% compared with De-Ionised water CHF. The CHF increased by 80.70% compared with 0.01% CuO test fluid. Also 9.04% for 0.02% CuO test fluid and 5.64% for 0.03% CuO test fluid.

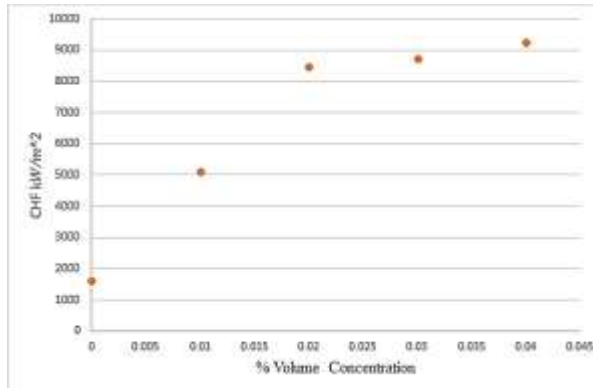


Figure 3. Comparison of CHF for different test fluids with 36 SWG microwire

### 3.2.Surface roughness

Wire heater surface roughness before pool boiling experiment is  $1.93\ \mu\text{m}$ . The wire sample which is used in test fluid pool boiling of 0.2 gram/liter concentration shows surface roughness  $4.64\ \mu\text{m}$ . Thus, surface roughness value of bare wire changes when it is used in pool boiling of nanofluid with surfactant. These results clearly indicate that in pool boiling of test fluids, 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.

Surface roughness could be significantly influenced by inclusion of n-butanol, which can be seen from comparison of values of surface roughness, because the low concentration of self-rewetting fluid produces higher surface tension and thus attracts the nanoparticles onto the surface of heating wire. Because of this the surface gets more nanoparticle deposition which may leads to higher surface roughness value.

### 3.2. 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.

The deposition morphologies on heating wires are characterized by scanning electronic microscopy (SEM) images after the boiling experiment.

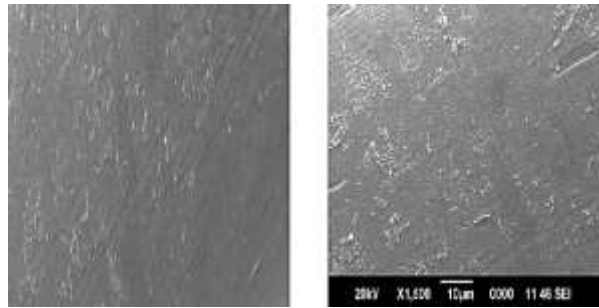


Figure 4. Heater surface with 1500 magnification with de-ionized water & 0.02% CuO test fluid

SEM data for micro wire shows surface changes after surfactant inclusion. Addition of surfactant increases the nucleation site density. 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 point.

## 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 aerial surface roughness parameter  $R_z$ , 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. 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.

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