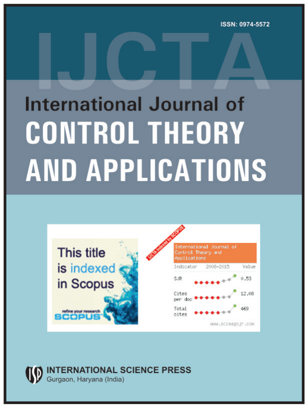

International Journal of Control Theory and Applications

ISSN : 0974-5572

Volume 10 • Number 12 • 2017

Pool Boiling Heat Transfer to Cu-Water Nano-Fluid

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Abstract: This state of art review presents that study of boiling heat transfer. Generally Boiling are two types they are pool boiling and flow boiling. Here we are considering pool boiling. A set of experiments have been performed to quantify the pool boiling heat transfer coefficient of Copper nanofluids at different 80 ppm, 400 ppm, 800 ppm. For investigating the influence of Copper nanoparticle in the boiling heat transfer coefficient of nanofluids, and other parameters like viscosity, thermal conductivity and Heat capacity were experimentally investigated. Results demonstrated a significant deterioration of heat transfer coefficient of nanofluids comparing with the base fluid, in the absence of surfactant, pool boiling heat transfer coefficient was reported. Compare these experiments by using pure water, and adding pure copper Nano particles after doing these experiments at different voltages and at different ppm's results that Cu-water nanoparticle has high heat capacity and high thermal conductivity than the pure water.

Keyword: Thermal conductivity, specific heat, density, Young's theory.

1. INTRODUCTION

Enhancement of heat transfer to copper water nanofluid is important aspect of heat transfer systems used in many applications. Heat exchanger system, Refrigeration system, Heat pump system, Thermal systems, Electronic systems, Bio engineering systems. Generally boiling classified as pool boiling and flow boiling. Pool boiling refers as under natural convection process and flow boiling liquid flow over heated surface. Generally pool boiling is a mode of boiling where the fluid is stationary in the beginning with respect to the heating surface.

There are four stages of boiling they are free convection boiling, nucleate boiling, transition boiling, and film boiling. A schematic diagram of pool boiling curve is shown in Figure 1.

Here in the above figure shows that O-A it shows free convection zone, in this case heat transfer takes place between the vessel and water due to natural convection. Change in temperature and heat flux increases and temperature of water increases to saturation temperature i.e., it attains a positive value. This stage of boiling is known as free convection zone. A-B shows nucleate boiling Second stage is divided in to two regions Liquid

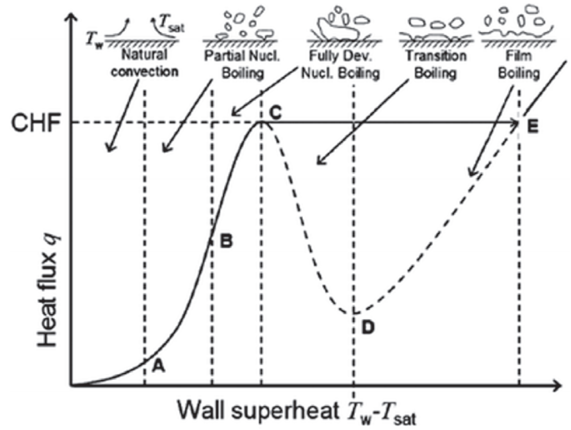


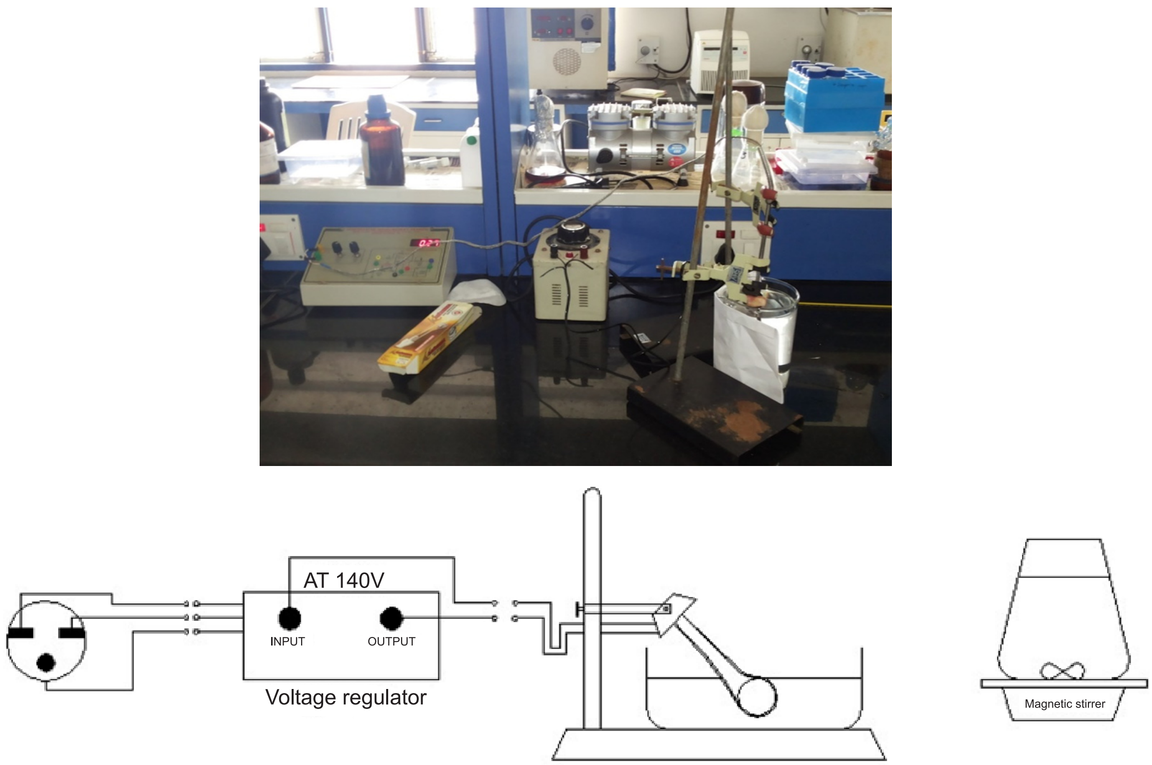
Figure 1: A Schematic Diagram of Pool Boiling Curve

entrainment in this stage due to the continues heating bubbles will form on the surface and these bubbles will move some distance collapse in the middle because these bubbles carry liquid inside the bubble this is known as liquid entrainment disturbance caused by the liquid entrainment in the water increase the heat transfer coefficient. In further B-C stage due to the continues heating bubbles will travel to the end of the water level because these bubbles carry gas inside of that these gas bubbles will travel to the water surface and will collapse and release the gas to the atmosphere. Due to this heat flux reaches to its maximum value known as critical heat flux (CHF). C-D shows transition boiling if temperature increases beyond the critical point vapor film will formon the surface of vessel acts as insulator then thermal conductivity will be decrease than the water then the heat flux will attains its minimum value then the point 4 is called as Leiden-frost point. D-E shows film boiling in this change in temperature increases due to which the vessel surface is completely covered with the vapor film because of the high temperature the radiation heat transfer takes place between the surface and liquid through the vapor film.

Metals like pure copper and aluminum nanoparticles having with high heat transfer coefficient. The first investigation of nucleate pool boiling was undertaken by Jakob, Fritz and Linke. The high heat transfer rates and heat capacities in nucleate pool boiling were attributed to bubbles which induce locally a strong agitation of the liquid near the heating surface. Using surfactant in solution has high surface tension because thermal properties of water and surfactant are different and physical properties are same. Generally Surfactant means Surface-Active-Agent. Surfactant can be classified in to nonionic and ionic surfactant which may be anionic, cationic, and amphoteric or zwitterrionic nature. Nonionic surfactants have no charge. Anionic surfactants have a negative molecular charge. Cationic surfactant has a positive charge. Amphoteric or zwitterrionic surfactants have both positive and negative charges. Anionic and nonionic provide most of industrial surfactant requirements and are the most common. These surfactants are nonionic class polymer (PVP), anionic (SDS), cationic (CTAB), and nonionic (Tween 20). Here in this experiment anionic (SDS) is considered.

2. EXPERIMENTAL SETUP

Apparatus used to do this experiment are, beakers has a capacity of 1 liter, heating coil it produces 250 Watts at 220 V and at different voltages the experiment was conducted by using voltage regulator, two supporting stands one is used for handling the thermocouple and another one is for handling the heating coil, voltage regulator is used for varying the voltage, thermocouple which is used to measure the temperature of the surface and thermometer is used to measure the temperature of fluid, another beaker is used to stir the solution and magnetic stirrer is used to mix the solution for 30 minutes and high precision weighing machines to measure the weight of nanoparticles, and stop watch is used to measure the temperature at every 3 minutes and this experiment is fixed for 21 minutes at different voltages experiment is conducted at different ppm time is fixed for 21 minutes. Prior to commencing the experiments, test section, test vessel, were cleaned by methanol or water solution and dried to remove any scale from previous experiments. Once the system was cleaned, the test fluid was introduced to the test vessel and de-aeration process was performed. And the experiment was performed at three different voltages 7 reading will take at each voltage and at different ppm's at each ppm different voltages, experiments conducted including pure distilled water and pure copper nanoparticle added in water with different ppm all these 12 experiments were conducted. Figure 2 shows the experimental set up of boiling process.



A Schematic Diagram of Experimental setup

Figure 2: Experimental Setup of boiling process to Copper Nanofluid

3. PREPARATION OF COPPER NANOPARTICLE

In the present study, the copper nanopowder is prepared by an MM process. This is one of the most widely used physical treatment techniques for preparation of nanosized particles. The copper powder having an average particle size of less than 450 μm has been procured from Sigma-Aldrich (Bangalore, India), and it has been used as starting material for preparation of nanopowder. It has a purity of greater than 99.5%. The copper nanoparticles have been prepared by ball-milling for 30 hr and characterized by means of X-ray diffraction studies of samples at different milling times. For preparation of copper nanoparticles,the MM of elemental Cu has been carried out by using planetary ball mill. The equipment which has been used is Fritsch Pulverisette 5/4 planetary ball mill; it contains four grinding bowls fastened to a rotating base disk.

The working principle of planetary ball mill has been found in the literature [1]. The considered working parameters for current Pulverisette 5/4 planetary ball mill, such as ratio between the rotational speed of the grinding bowl and the disk (taken as 1.25) and the rotational speed of 300 rpm, have been optimized earlier on the basis of the effective size reduction of the product [1]. The process milling has been carried out using tungsten carbide balls with diameter of 10 mm each placed inside the tungsten carbide container. The milling has been performed for 30 hours by maintaining the ball to powder weight ratio of 10:1. The controlling agent which is used to decrease the product contamination due to erosion of containers and balls is toluene. Also, milling in solid form increases risk of reweld of the particles. After milling for 30 hours most of the Cu crystallite size in the milled powder is about 45 nm

4. PREPARATION OF COPPER NANO FLUID

In the current study, the mechanically milled copper nanopowder has been used to prepare the water based nanofluid. In the method of preparation, initially the copper nano particles are slowly dispersed in to the pure water under constant vigorous stirring to produce a stable nano fluid. The copper nanoparticle content in this study is 80 ppm. After 30 min of stirring, the solution is being subjected to boiling where the fluid is stationary in the beginning with respect to the heating surface. And at the same time we will measure the temperature of nanofluid at every 3 minutes and the surface temperature is measured by the thermocouple.

5. THERMOPHYSICAL PROPERTIES OF NANOFLUID

To calculate thermophysical properties of nanofluid, i.e., density, specific heat, viscosity and thermal conductivity are presented.

A. Density

The density of a nanofluid can be calculated from the following relation:

$$\rho_{nf} = \left(\frac{m}{v}\right)_{nf} = \frac{m_f - m_p}{v_f + v_p} = \frac{\rho_f v_f - \rho_p v_p}{v_f + v_p}$$

where, $\varnothing_p = \dfrac{v_p}{v_f + v_p}$

$$= \frac{\rho_f v_f}{v_f + v_p} - \rho_p \varnothing$$

$$\rho_{nf} = \rho_{nf} = \rho_f (1 - \phi) - \rho_p \varnothing \tag{1}$$

where, ρ_f is the density of base fluid, ρ_p is the density of nano particle, and $\varnothing$ is the volume fraction of nano particle.

To examine the validity of Eq. (1), Pak and Cho [2] and Ho et. al., [3] conducted experimental studies to measure the density of Al_2O_3–water nanofluids at room temperature

B. Specific Heat

There are two expressions to calculate the specific heat (C_{nf}) of nanofluid. The first relation is.

$$= \rho_{nf}\left(\frac{Q}{m, \Delta T}\right)$$

$$= \rho_{nf}\left(\frac{Q_f - Q_p}{\left(m_f + m_p\right)\Delta T}\right)$$

$$= \rho_{nf}\left(\frac{(mc)._f \Delta T - (mc)._p \Delta T}{(m_f + m_p)\Delta T}\right)$$

$$= \rho_{nf}\left(\frac{(\rho c)._f v_f - (\rho c)._p v_p}{(\rho_f v_p + \rho_p v_p)}\right)$$

$$C_{nf} = \frac{\rho_f C_f (1-\varnothing) - \rho_p C_p \varnothing}{\rho_{nf}} \tag{2}$$

where, C_f and C_p are the specific heats of base fluid and nano particles, respectively.

Some authors [4, 5, 6-8] they prefer to use simple equations.

Alternatively,

$$C_{nf} = (1 - \varnothing)\, C_f - \varnothing C_p \tag{3}$$

C. Viscosity

To find out the viscosity of nanofluid Einstein model [9] on kinetic theory he developed the following correlation.

$$\mu_{nf} = \mu_f (1 - 2.5\varnothing) \tag{4}$$

And another correlation is developed by the Brinkman model [10].

$$\mu_{nf} = \frac{\mu_{nf}}{(1-\varnothing)^{2.5}}$$

And Corcione [11] represented the following correlation for the viscosity ratio

$$\frac{\mu_{nf}}{\mu_f} = \frac{1}{1 - 34.87(d_{p/d_f})^{-0.3} \varnothing^{1.03}}$$

where, d_p is nanoparticle size, d_f is the molecule diameter of base fluid, It can be calculated as:

$$d_f = \left[\frac{6M}{N\pi\rho_{f,0}}\right]^{1/3}$$

where, M is the Molecular weight of the base fluid, and N is the Avogadro number which is dimensionless number it is 6.022×10^{23}, and $\rho_{f,0}$ is the density of base fluid at the temperature of 293K.

D. Thermal Conductivity

To calculate the thermal conductivity using Maxwell model [12] of solid-liquid mixtures, Where,

$$k_{nf} = \frac{k_p + 2k_f + 2\varnothing(k_p - k_f)}{k_p + 2k_f - \varnothing(k_p - k_f)} k_f$$

where, k_f, k_p, k_{nf} are thermal conductivity of basefluid, nanoparticle, and nanofluid and the above equation is applicable only for $\varnothing \ll 1$.

6. RESULTS AND DISCUSSION

These are the results obtained by doing experiment analysis. These experiment are done at different voltages what are physical properties of the nano fluid is obtained. At 140 V the following shows the graph between the temperature and physical properties of nano fluid

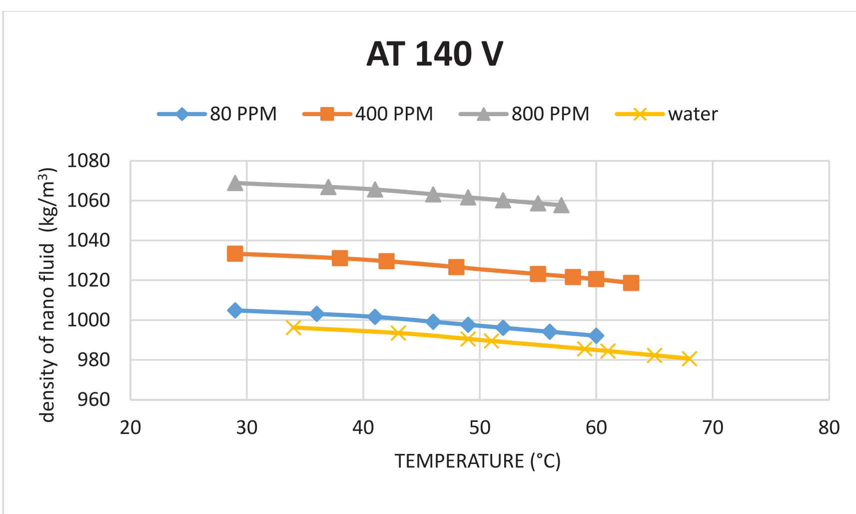
The following shows the images of experiment and graphs at 140 Volts.

These images taken at every 3 minutes and time is fixed as 21 minutes for every experiment and within 21 minutes 7 images have taken. The following images are pure water, 80 ppm, 400 ppm, 800 ppm of copper nanofluid in pure distilled water at 140,180,220 Volts.

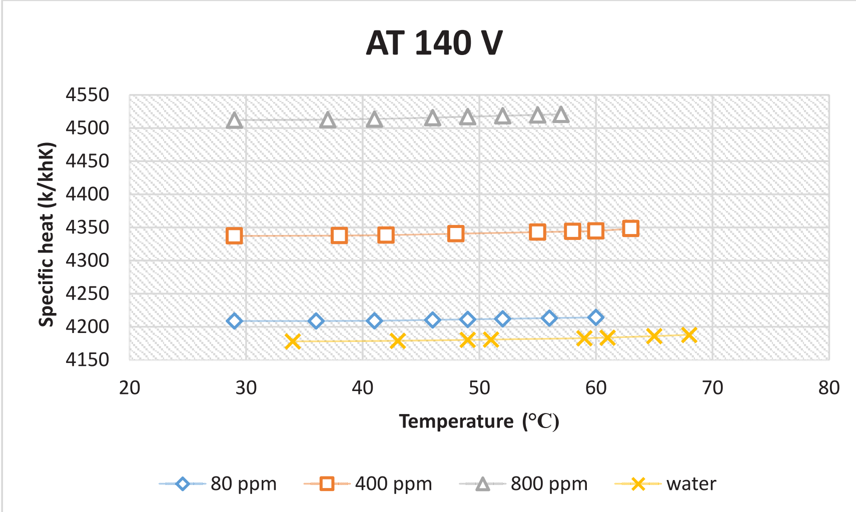
Pure water, 80 ppm, 400 ppm, 800 ppm of Copper nano particle in Pure Distilled Water

Figure 3: These images at 140 Volts at 70°C of Pure water, 80 ppm of copper, 400 ppm of copper & 800 ppm of copper

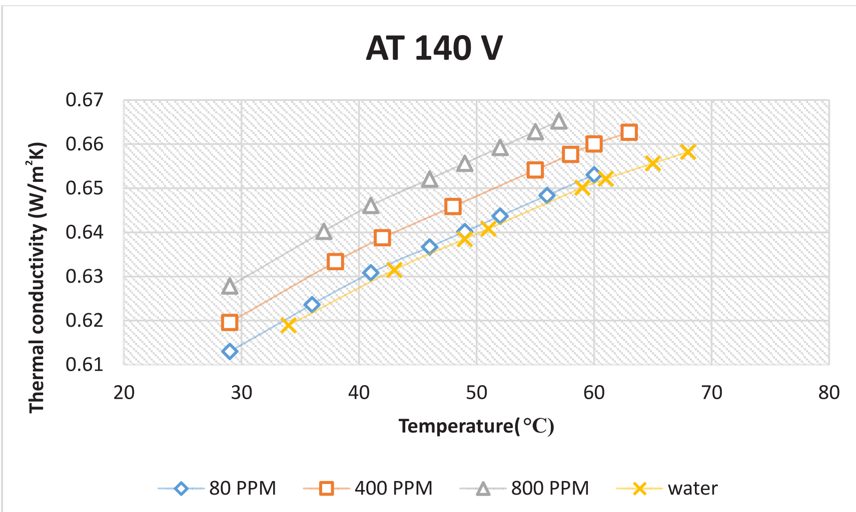
At this stage by using above correlations for Density, Specific heat and Thermal conductivity graphs are plotted at 140 Volts



At 140 Volts Density of nanofluid and the Specific heat of nanofluid.



At 140 Volts Thermal Conductivity of nanofluid is



Know at 180 Volts the following are the experimental results. The following are the experimental Images at 180 Volts.

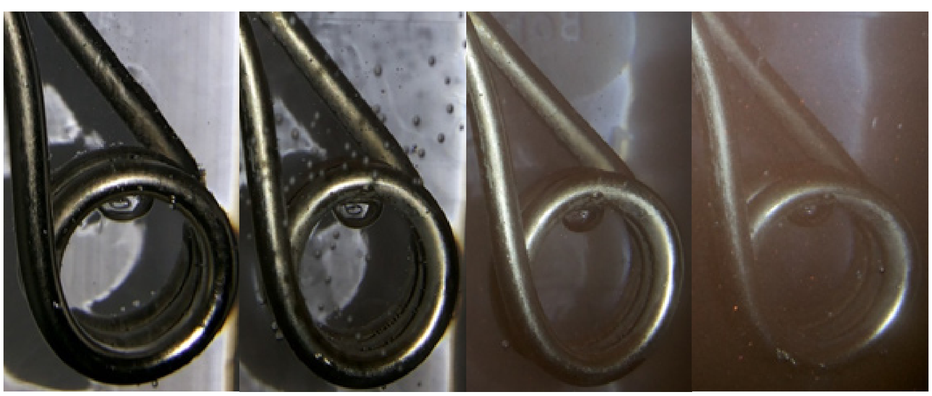
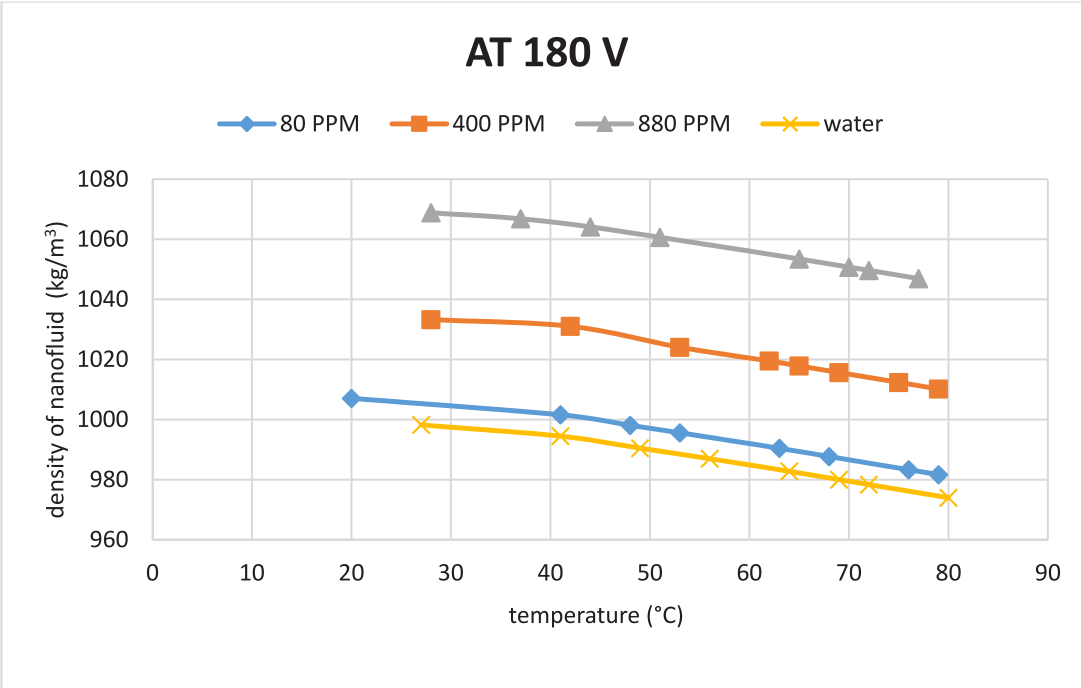


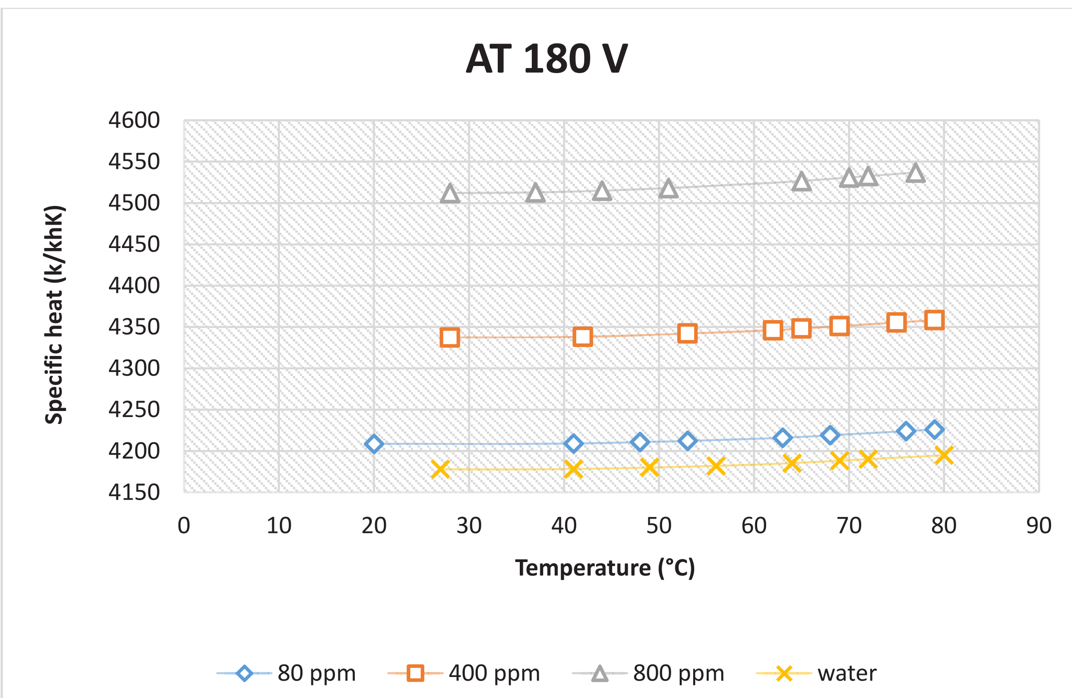
Figure 4: These images at 180 Volts at 80°C of Pure water, 80 ppm of copper, 400 ppm of copper & 800 ppm of copper

At 180 Volts Density, Specific heat, Thermal conductivity is plotted.

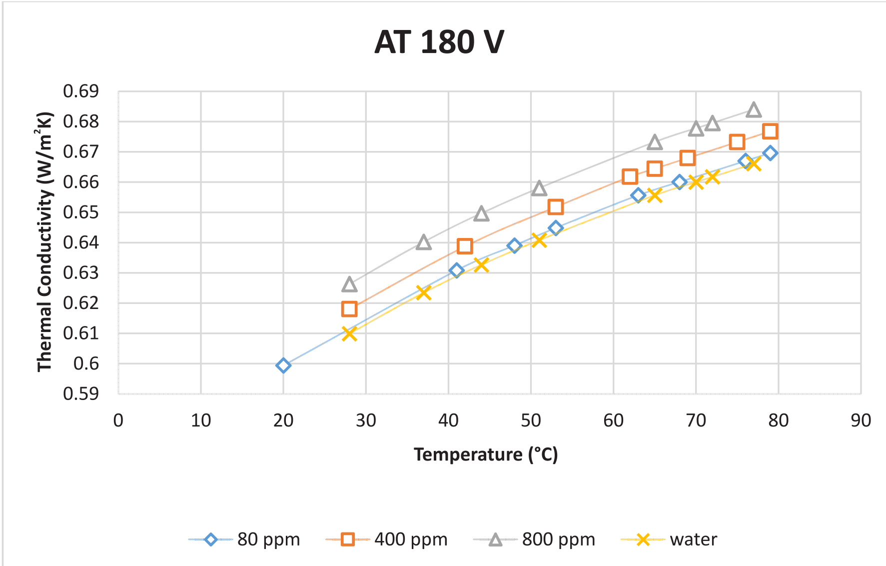
At 180 Volts Density of Nanofluid



At 180 Volts Specific Heat of Nanofluid.



At 180 Volts Thermal Conductivity of Nanofluid



Know at 220 Volts the following experimental images are shown in below figures.

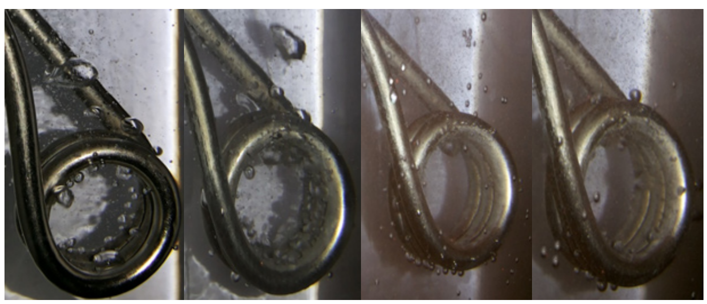
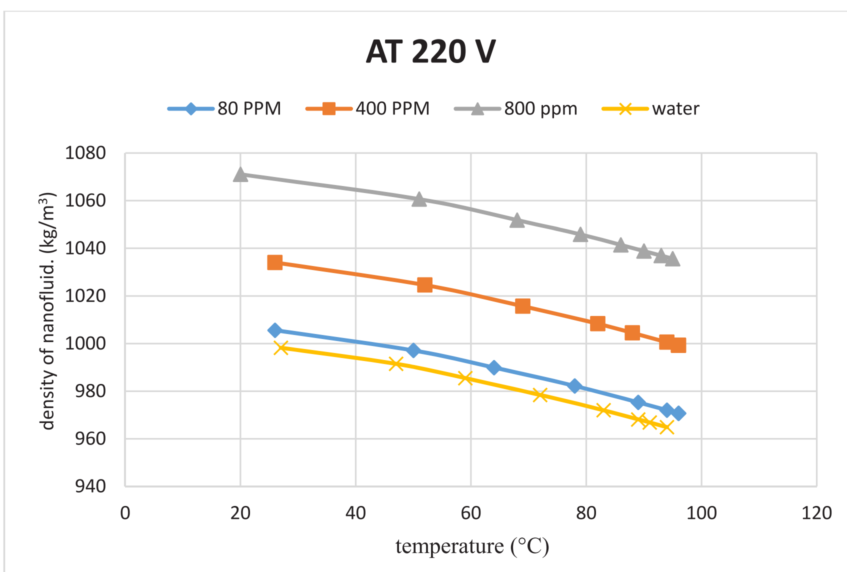
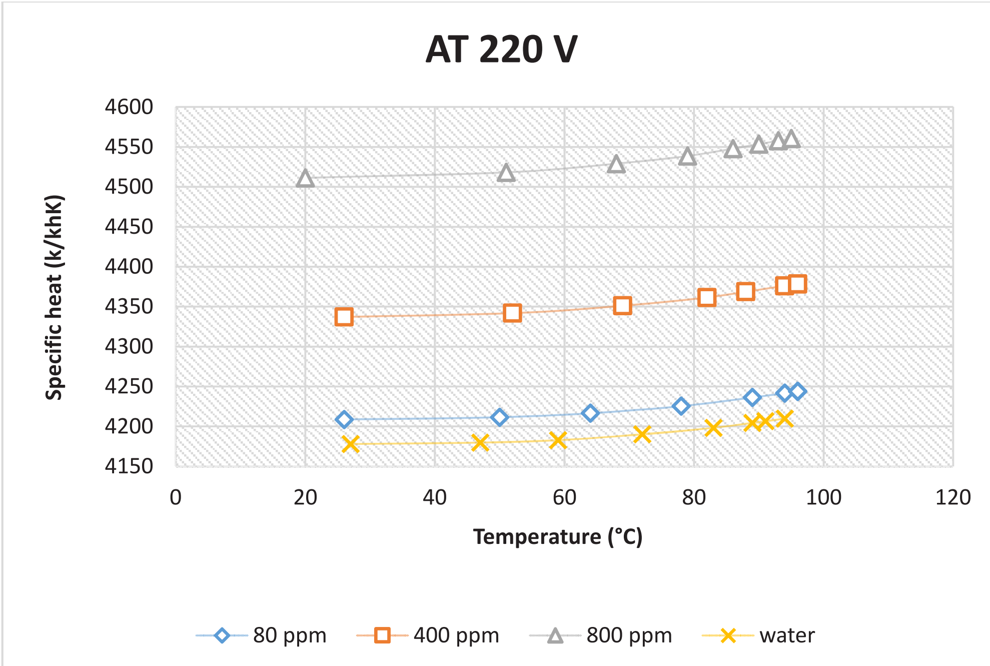


Figure 5: These images at 220 Volts at 96°C of Pure water, 80 ppm of copper, 400 ppm of copper & 800 ppm of copper

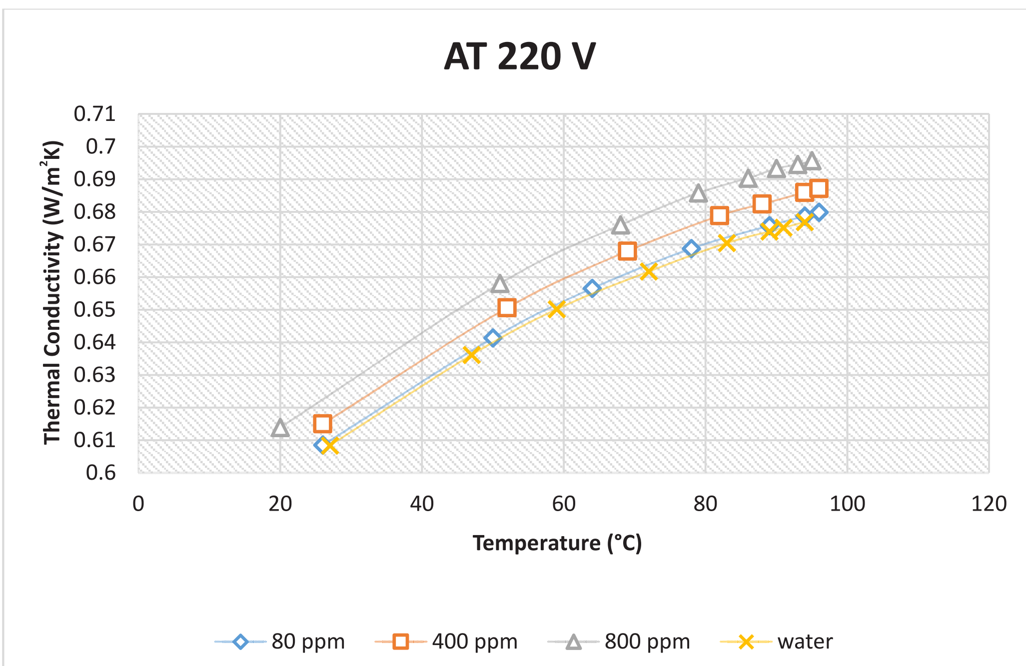
At 220 Volts density of Nanofluid is



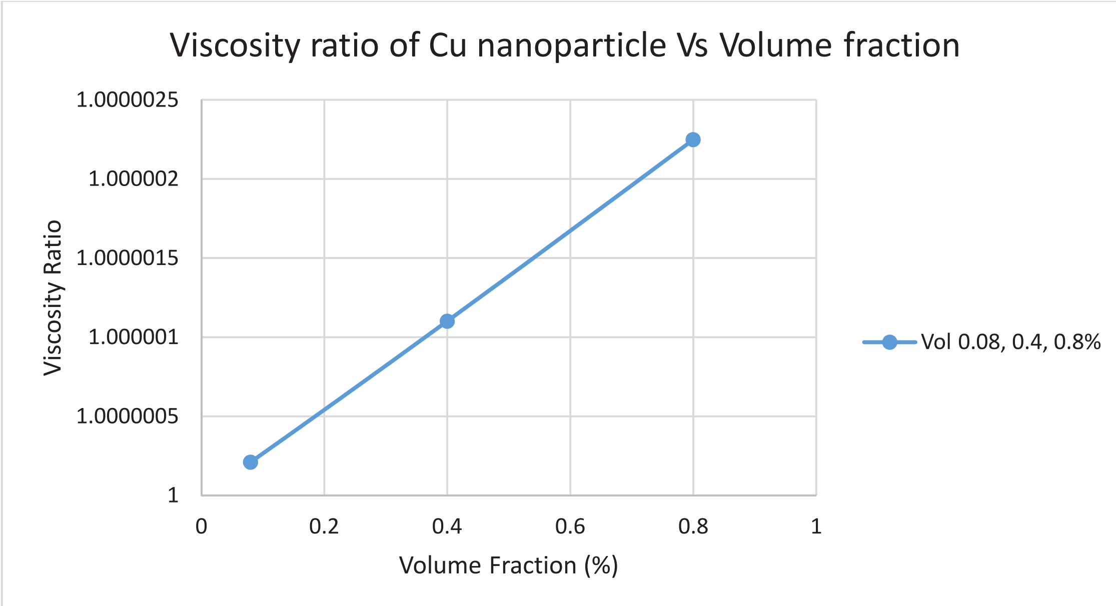
At 220 Volts Specific heat of Nanofluid is



At 220 Volts Thermal Conductivity of Nanofluid is



Viscosity ratio of copper nanofluid to volume fraction is shown that viscosity in copper nanofluis is increasing when the volume fraction is increased the below graph shown between viscosity ratio of copper nanofluid and volume fraction.



These are the experiments are conducted and from these experiments it is observed that Specific heat and Thermal conductivity of Copper nanofluid is increasing and density of nanofluid is decreasing. And the properties of nanofluid are increasing with respect to the voltage.

7. BOILING CONTACT ANGLE CONCEPT ACCORDING TO THE YOUNG'S THEORY

It is well known that pressure is critical parameters in the study of boiling phenomena because it has a great effect on nucleate process, bubble diameter and saturation temperature.

In addition surface tension varies with temperature for liquids. Surface tension decreases with increase in pressure and tends to be zero at critical pressure.

Contact angle is very important parameter in exploring the mechanism of boiling phenomena [14]. As shown in figure contact angle 'θ' is the angle between the liquid and solid interfaceit characterizes the wettability of the solid surface by the liquid.

The liquid-solid system can be either completely wetting ($\theta = 0°$) or having different degrees of wetting ($0 < \theta < 180°$), or completely be non-wetting ($\theta = 180°$). Knowledge of the intermolecular interactions both with in liquids, and across the liquid-vapor or (liquid-gas) and liquid – solid interfaces, is an important part of characterizing surface wettability or contact angle. The degree of the liquid spreading on the solid surface is governed by the surface tension of the liquid and vapor σ_{LV} and the surface tension of solid and vapor σ_{SV}, and the interfacial tension of the solid and liquid σ_{SL}. These forces essentially represents the liquid-vapor, solid-vapor, and solid-liquid interfacial tension and their interactions is shown in Figure 6.

According to young's theory [13]he derives equation finding the surface tension, and contact angle by using his correlation.

Which is still used a fundamental understanding concept for phenomena involving the surface wettability and contact angle (θ).

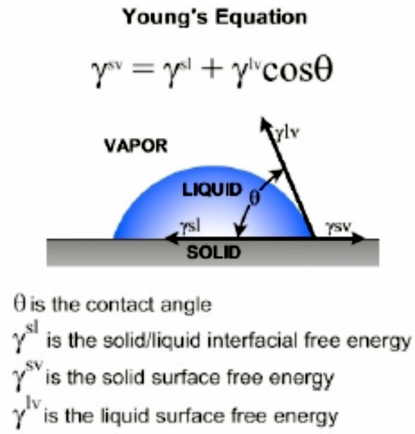


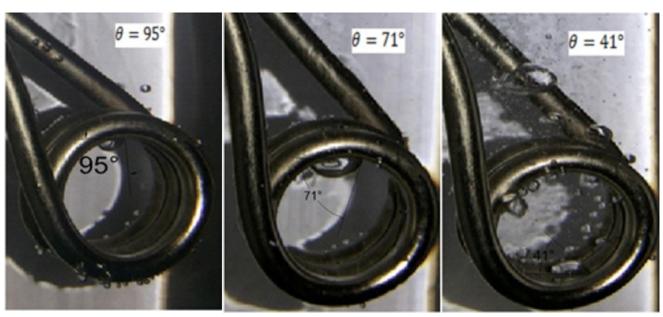
Figure 6: Boiling contact angle concept according to young's theory

$$\theta = \arccos\left(\frac{\sigma_{SV} - \sigma_{SL}}{\sigma_{LV}}\right)$$

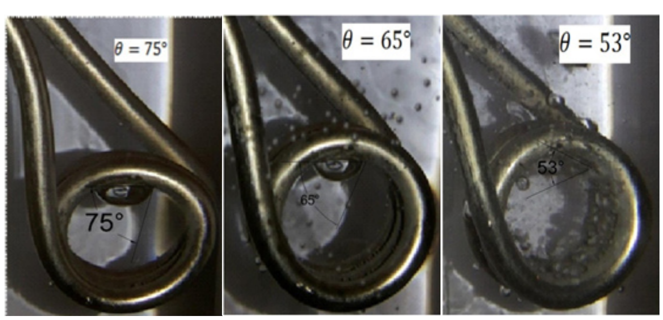
So, here in these present work results of contact angle based on visual observation and young's equation was not employed. As shown in Figure 5. Visual contact angle of bubbles formed on the surface decreases with increasing the concentration of nanofluids. The boiling contact angle decreases, wettability of surface increases. To explain these phenomena by the macroscopic view, it can be said that when the concentration of the nanofluid increases the rate of sedimentation of the particles on the surface increases and coating is formed on the surface which tends to increase the wettability of the surface. However, this coating and particle may not be seen to the naked eye.

Here I have shown the boiling contact angle for water at different voltages and copper nanofluid at different ppm and voltages.

Boiling contact angle of water



At 80 and 400 ppmCopper nanoparticles are



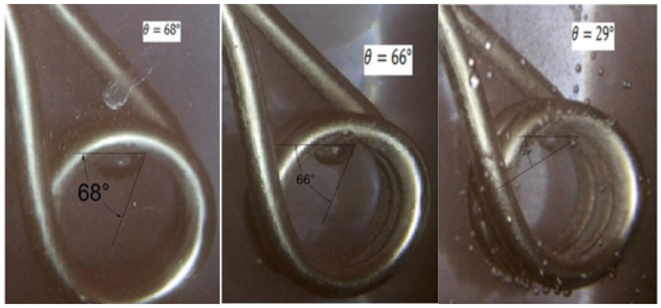


Figure 7: Shows the contact angle of bubble on the heating surface at different volume fraction

8. CONCLUSION

An experimental study of pool boiling heat transfer to cu – water nanoparticle is studied and a thermal property of the nanofluid is observed experimentally. The following conclusion points were observed.

1. Density of nanofluid is measured it is being observed that the density of nanofluid is increasing when the ppm is increased. And when the temperature is increasing the density of particle is decreasing.
2. Specific heat of the nanofluid is increased by increasing the concentration specific heat of copper nanoparticle is morethan the pure distilled water.
3. Thermal conductivity of nanoparticles is measured it is observed that the thermal conductivity of copper nanoparticles is more than that of pure distilled water.
4. Surface wettability is measured using young's theory and it is observed that finding the contact angle of bubble in pure distilled water is more compared to water. Because of thin film form on surface of heating coil the contact angle gradually reducing tends to decrease in heat transfer.

Nomenclature

C	heat capacity, J/kg °C
g	gravitational acceleration, m^2/s
A	Area m^2
k	thermal conductivity W/m^2 °C
q	Heat W
T	Temperature °C

Subscripts

CHF	Critical heat flux
f	Fluid
nf	Nanofluid
p	particle
LV	Liquid-Vapor interface
SV	Solid-Vapor interface
SL	Solid-Liquid interface

Greek Symbols

Δ	Difference
θ	Contact angle
∅	Volume fraction
ρ	Density kg/m^3
µ	fluid dynamic Viscosity

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