

Enhancement of Critical Heat Flux of Nichrome Wire By Using Nanofluids

Prof. K.T. Pawale¹, Mr. Kiran Navratne², Mr. Pankaj Moghe³, Mr. Pankaj Kumar⁴, Mr. Ashutosh Nerkar⁵

^{1, 2, 3, 4, 5} Dept of Mechanical Engineering

^{1, 2, 3, 4, 5} DYPIEMR, Maharashtra, India

Abstract- Nanofluids (suspensions of nanometer-sized particles in base fluids) have recently been shown to have nucleated boiling critical heat flux (CHF) far superior to that of the pure base fluid. Over the past decade, numerous experimental and analytical studies on the nucleate boiling CHF of nanofluids have been conducted. The purpose of this article is to provide an exhaustive comparison of enhancement of critical heat flux using various nanofluids. Nanofluids of CuO and Al₂O₃ with 0.3%, 0.6% and 1.2% (by wt.), Nanofluid mixture of CuO and Al₂O₃ with 1.2% of nanoparticles are prepared using probe sonication process with magnetic stirring. And performing experiment to enhance the critical heat flux and interpreting the result.

Keywords- CHF, BHT, Nanofluid, Magneto stirrer, Sonication.

I. INTRODUCTION

When heat is added to a liquid from a submerged solid surface, which is at a temperature higher than the saturation temperature of the liquid, it is usual for a part of the liquid to change phase. This change of phase is called boiling. Boiling is of various types, the type depends upon the temperature difference the surface and the liquid. The different types are indicated in which a typical experimental boiling curve obtained in a saturated pool of liquid is down^[1]

II. DESCRIPTION

The apparatus consists of cylindrical glass container housing and the Nichrome wire test heater. Test heater is connected via a dimmer. An ammeter is connected in series while a voltmeter across it in parallel to read the current and voltage. The glass container is kept on a stand, which is fixed on a metallic platform.

This experimental set up is designed to study the pool-boiling phenomenon up to critical heat flux point. The pool boiling over the heater wire can be visualized in the different regions up to the critical heat flux point at which the wire melts. The heat flux from the wire is slowly increased by gradually increasing the applied voltage across the test wire

and the changeover from natural convection to nucleate boiling can be seen.

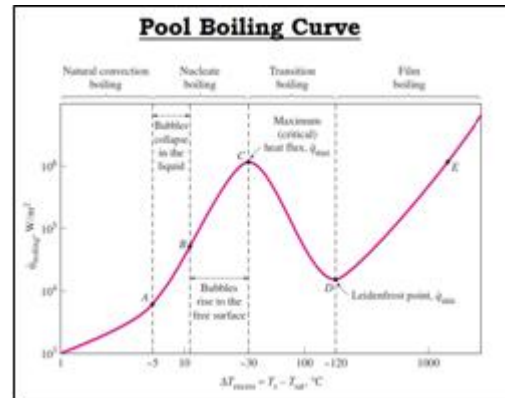


Fig no.1 pool boiling curve

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 this in the braking of wire indicating the occurrence of critical heat flux point^[1]

2.1 THEORY

The heat flux supplied to the surface is plotted against ($T_w - T_s$) the difference between the temperature of the surface and the saturation temperature of the liquid. It is seen that the boiling curve can be divided into three regions:

- Natural Convection Region
- Nucleate Boiling Region
- Film Boiling Region

The region of natural convection occurs at low temperature differences (of the order of 10 oC or less). Heat transfer from the heated surface to a liquid in its vicinity causes the liquid to be superheated. The superheated liquid rises to the free liquid surface by natural convection, where vapour is produced by evaporation. As the temperature difference ($T_w - T_s$) is increased, nucleate boiling starts. In this region, it is observed that bubbles start to form at certain locations on the heated surface.

Region II consists of two parts. In the first part, II – a, the bubbles formed are very few in number. They condense in the liquid and do not reach the free surface. In the second part, II – b, the rate of bubbles formation and the number of locations where they are formed increase. Some of the bubbles now rise all the way to the free surface. With increasing temperature difference, a stage is finally reached when the rate of formation of bubbles is so high, that they start to coalesce and blanket the surface with a vapour film. This is the beginning of the region III viz film boiling.

In the first part of this region III-a, the vapour film is unstable, so that the film boiling may be occurring on a portion of the heated surface area, while nucleate boiling may be occurring on the remaining area. In the second part, III-b, a stable film covers the entire surface. The temperature difference in this region is of the order of 1000°C and consequently radioactive heat transfer across the vapour film is also significant.

It will be observed that the heat flux does not increase in a regular manner with the temperature difference. In region I, the heat flux is proportional to $(T_w - T_s)^n$, where 'n' is slightly greater than unity. When the transition from natural convection to nucleate boiling occurs the heat flux starts to increase more rapidly with temperature difference, the value of n increasing to about 3. At the end of region II, the boiling curve reaches a peak. Beyond this, in the region II-A, in spite of increasing temperature difference, the heat flow increases with the formation of a vapour film.

The heat flux passes through a minimum at the end of region III-a. It starts to increase again With $(T_w - T_s)$ only when stable film boiling begins and radiation becomes increasingly important. It is of interest to note how the temperature of the heating surface changes as the heat flux is steadily increased from zero. Up to point A, natural convection boiling and nucleate boiling occur and the temperature of the heating surface is obtained by reading off the value of $(T_w - T_s)$ from the boiling curve and adding to it the value of T_s . If the heat flux is increased even a little beyond the value of A, the temperature of the surface will shoot up to the value corresponding to the point C. It is apparent from figure that the surface temperature corresponding to point C is high.

For most surfaces, it is high enough to cause the material to melt. Thus in most practical situations, it is undesirable to exceed the value of heat flux corresponding to point A. This value is therefore of considerable engineering significance and is called the critical or peak heat flux. The pool - boiling curve as described above is known as *Nukiyam*

pool Boiling Curve. The discussions so far has been concerned with the various type of boiling which occur in saturated pool boiling. If the liquid is below the saturation temperature we say that sub-cooled pool boiling is taking place. Also in many practical situations, e.g. steam generators; one is interested in boiling in a liquid flowing through tubes. This is called forced convection boiling, may also be saturated or sub-cooled and of the nucleate or film type.^[2]

Thus in order to completely specify boiling occurring in any process, one must state

- Whether it is forced convection boiling or pool boiling,
- Whether the liquid is saturated or sub cooled, and
- Whether it is in the natural convection nucleate or film boiling region

COMPONENTS OF EXPERIMENTAL SETUP

It consists of following components (I) Glass beaker (ii) Acrylic covers (iii) Auxiliary heater (IV) Test wire (Ni-Cr) (v) Stainless steel electrodes (VI) Thermocouples (vii) Schematic diagram is shown in the figure4.1

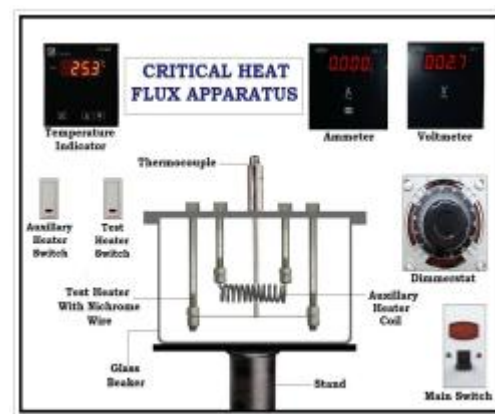


Fig: 2.1 Schematic diagram of pool boiling Apparatus for nanofluid

III. PREPARATION METHODS FOR NANOFLUIDS

The initial key step in experimental studies with nanofluids and the optimization of nanofluid thermal properties requires successful preparation methods for producing stable suspensions of nanoparticles in liquids. Some special requirements are essential (i.e.) negligible agglomeration of particles, uniform, durable and stable suspension and no chemical change of the fluid, etc. There are two main techniques adopted for the preparation of nanofluids: single-step method and two-step method.

3.1 SINGLE STEP METHOD:

Single step method simultaneously produces and disperses the nanoparticles directly into the base fluid medium which is suitable for metallic nanofluids. The aggregation problem can be much reduced with direct evaporation condensation method. This inert-gas technique involves the vaporization of source material in a vacuum. In this process of preparation, the condensation forms nanoparticles through direct contact between the base fluid and vapor.^[12]

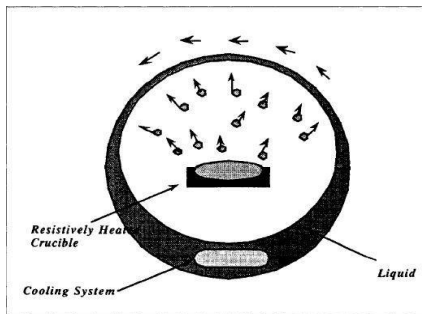


Fig: 3.1 Schematic representation of one-step method of nanofluid preparation

The continuous circulation of base fluids minimizes the agglomeration of nanoparticles. The schematic representation of direct evaporation condensation technique is shown in figure 3.1. The researchers from Argonne National Laboratory reported yet another interesting technique is laser ablation technique, in which the metal nanoparticles in deionized water are synthesized by using multi- beam laser ablation in liquids, where the laser parameters control the size and distribution of nano particles.

IV. TWO-STEP METHOD

Two-step method is the most common method for the preparation of nanofluids and its schematic representation is shown in figure 4.1. Nanosized solid particles such as nanorods, nanotubes, nanofibers, or other functionalized nanomaterials are used in this method. Nanoparticles are initially synthesized in powder form by physical or chemical methods. Then, the Nanosized powder particles are dispersed in base fluid in the successive processing step with the aid of intensive ultra sonication method or by using surfactants. This method is most widely used economic method for large scale production of nanofluids, since nanoparticle synthesis techniques were scaled up to industrial production levels.^[12]

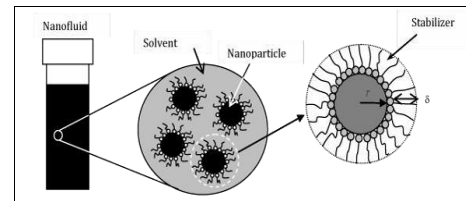


Fig: 4.1 Schematic representation of two-step method of nanofluid preparation

4.1.1 PROBE SONICATOR SPECIFICATION:

1) OBJECTIVE	To describe procedure for the operation and Maintenance of the Ultrasonic wave cell pulverizes
2) SCOPE	To understand the efficient and safe working of Ultrasonic Wave cell pulverize
3) PURPOSE	The Ultrasonic wave cell pulverize produce ultrasonic sound waves to improve solubility of poor water soluble drugs by means of reducing Particle size
4) RESPONSIBILITY	4.1) Operator 4.2) Subject Incharge 4.3) Head of Department
5) Definition	A sonicator is vital laboratory device used to break apart cells so transmitted into the solution with a tiny probe, which has a tip that moves up and down



Fig: 4.2 Photographic view of probe sonicator

V. NANOFLUID PREPARATION SET UP

Weighing balance Model made M/s CONTECH, least count 0.1 mg weighing balance having capacity 300 gm. is used to measure the weight of nanoparticles as shown in the figure 4.17. The Contech weighing machine is used for measure the weight of nanoparticles having following specifications. As shown in the table 4.4 the repeatability of weighing balance is ± 0.2 mg and other specifications are

shown in the table 4.4, is good for laboratory use. As shown in the figure 4.18, a Borosil glass beaker, of 2000ml capacity is used for the preparation of nanofluid. Magnetic stirrer of Model 08849-00 makes M/s Magneto. With 230 V AC supply is used. A magnetic needle of 10×10 mm used to stirrer the solution.

5.1 PROCEDURE FOR PROBE SONICATION:

1. Switch on the main supply.
2. Connect main power cord of instrument to voltage stabilizer
3. Fix the probe on top of ultrasonic wave generator. Don't touch the probe while working.
4. Wash the probe with hydro alcoholic solution.
5. Keep the beakers containing sample solution on platform which are place in sound proof box.
6. Place the temperature sensor plug inside the container having solution which need to cut off the temperature above its required.
7. On the front panel of instrument ON/OFF switch is at the centre while set the ultrasonic wave times/count mode digital time controller appear at the left hand side of panel.
8. **Set the ultrasonic time:** on the left of panel, press "▶" for sonication time setting. Press "▲" once, the time will go higher; press "▼" once, the time will go lower. (Do not set more than ten second)
9. **Set interval (cycle or gap):** on the right of panel, press "▶" for interval time setting .press "▲" once, the cycle time will go higher; press "▼" once, the cycle time will go lower.
10. **Set power (Amplitude):** On the left of panel, press "▶" for power setting. Press "▲" once, the power will go higher; press "▼" once, the power will go lower.
11. **Set the temperature:** on the right of panel, press "▶" for interval time setting .press "▲" once, the cycle time will go higher; press "▼" once, the cycle time will go lower.
12. Press the centre button (●) to run on the instrument.
13. After carry out the sonication for desire temperature, amplitude, cycle and time, press switch OFF and unplug the power cable.
14. After use switch off the instrument. Clean the probe with water and keep it dry.

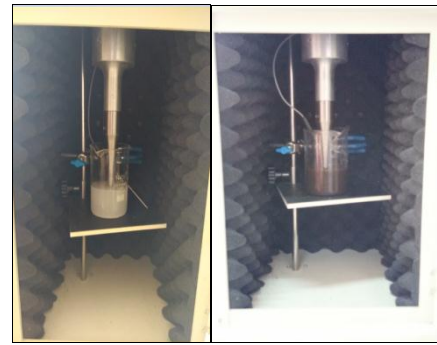


Fig: .5.1 prepared sonicated nanofluid of Al_2O_3 & CuO

5.2 TEST PROCEDURE OF SONICATED NANOFLUID PREPARATION:

In this investigation CuO , Al_2O_3 nanoparticles were chosen because of their well-documented thermal properties, ease of dispersion in de-ionized water and wide spread use in the research community. Copper and Aluminum Oxide nanoparticles were added to de-ionized water on a mass basis with concentrations of 0.3%, 0.6% and 1.2% wt. nanoparticles are added to the deionized water and then stirrer for four hours in magnetic stirrer.

1. The deionized water of 1500 ml is taken in the beaker.
2. The beaker is placed on the magnetic stirrer.
3. The magnetic needle is immersed in the beaker.
4. Put the supply ON of stirrer and it is stirrer with maximum capacity.
5. The nanoparticles are dispersed in the water.
6. It is stirred continuously for four hours.
7. After four hours it is directly used for experimentation.



Fig: 5.2 Photographic view of CuO nanofluid preparation

VI. DISPERSING OF NANOPARTICLES IN THE BASE FLUID

In this method, the nanoparticles are directly mixed in the base liquid and thoroughly stirred. Nanofluids prepared

in this method give poor suspension stability, because the nanoparticles settle down due to gravity, after a few minutes of nanofluid preparation. The time of particle settlement depends on the type of nanoparticles used, density and viscosity properties of the host fluids.

6.2 ADDITION OF SURFACTANTS TO THE BASE FLUID:

In this method a small amount of suitable surfactant, generally one tenth of mass of nanoparticles, is added to the base fluid and stirred continuously for few hours. Nanofluids prepared using surfactants will give a stable suspension with uniform particle dispersion in the host liquid. The nanoparticles remain in suspension state for a long time without settling down at the bottom of the container.

In the present investigation, neither surfactants nor acid are added in the CuO as well as Al₂O₃ nanofluids, because with the addition of surfactants the thermo physical properties of nanofluids are affected Addition of acid may damage the tube material an corrosion takes place after a few days with the prolonged usage of such nanofluids in practical application^[11]

VII. EXPERIMENTAL PROCEDURE FOR DETERMINATION OF CRITICAL HEAT FLUX FOR DEIONIZED WATER

1. Glass container is cleaned by deionised water.
2. Glass Container is cleaned by deionized water.
3. Almost one-half space of glass vessel is left as vapour space; only 1500ml water is taken in to vessel.
4. The test wire of known surface roughness is horizontally submerged in to water. Both the ends of Ni-Cr wire hold sufficient tight with the help of nut and bolt arrangement.
5. Deionized water is heated using Auxiliary heater to different Temperature of water iis noted by using thermocouple.
6. After reaching test fluid temperature to 100 °C the auxiliary heater supply is turned off.
7. A.C. supply is given to the test wire and initially voltage is increased with large steps and then with smaller steps.
8. For each incremental step Voltage and current is recorded during the test.
9. At particular Voltage and current Ni-Cr Wire breaks, corresponding Voltage and current just before burn out point is recorded.
10. A.C. Supply is turned off after burn outpoint.
11. Experiments are repeated for different temperatures.

$$q_{\text{experimental}} = \frac{V_{\text{CHF}} \times I_{\text{CHF}}}{A} \dots\dots\dots (1)$$

A = Surface Area of Heater

$$A = \pi \times d \times l$$

Where,

d = diameter of wire Ni-Cr (SWG 40) = 0.079 mm

l = length of Ni-Cr wire = 110 mm

$$A = \pi \times 0.079\text{E-}03 \times 0.110$$

$$A = 2.419\text{E}05.\text{m}^2$$

VIII. SAMPLE CALCULATIONS OF EXPERIMENTAL CHF FOR EXPERIMENT

V_{CHF} = 84.8 Volts, I_{CHF} = 0.423 Ampere

Putting these values in equation

$$(1) q_{\text{experimental}} = \frac{84.8 \times 0.423}{2.419\text{E-}05}$$

$$q''_{\text{experimental}} = 1482860.686\text{W/m}^2$$

q''_{experimental} is equal to 1.4827E+06W/m²

TABLE: 8.1 DEIONIZE WATER READING

8.1 Pool Boiling Experiment with CuO Nanofluid

Test No	Temp eratur e (°C)	Current Ichf (A)	Voltage Vchf(V)	Surfac e area A (m ²)	CHF q" (W/m ²)	CHF q" (MW/m ²)
01.	55	0.423	84.8	2.419E-05	1.4827E+06	1.4827
02.	65	0.392	75.15	2.419E-05	1.2178E+06	1.2178
03.	75	0.368	63.0	2.419E-05	0.9584E+06	0.9584
04.	85	0.346	50.7	2.419E-05	0.7252E+06	0.7252
05.	95	0.324	30.1	2.419E-05	0.4032E+06	0.4032

The test is performed on 1.2 wt% CuO nanofluids. The test procedure followed is same discussed in Section 8.1. This experiment is performed for 5 times and the results obtained are as follows, the CHF value of experiment Trial 1 to Trial.5 during step wise increase in power supply.

Table: 8.2 for 1.2 wt% CuO nanofluid

Exp. No.	T (°C)	Current(I _{CHF}) Ampere	Voltage (V _{CHF}) Volt	Area (m ²)	q _{exp} = $\frac{V_{\text{CHF}} \times I_{\text{CHF}}}{A}$ (kW/m ²)
Trial 1	55	1.039	52.2	2.419E-5	2242.075
Trial 2	65	1.020	51.9	2.419E-5	2188.424
Trial 3	75	0.789	40.1	2.419E-5	1307.933
Trial 4	85	0.640	37.0	2.419E-5	978.916
Trial 5	95	0.544	27.2	2.419E-5	611.690

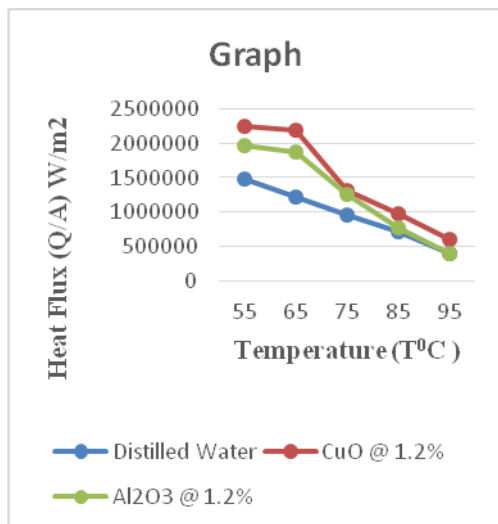
Table: 8.3 for 1.2 wt % of Al₂O₃ nanofluid

Exp. No.	T (°C)	Current(I _{CHF}) Ampere	Voltage (V _{CHF}) Volt	Area (m ²)	$q_{exp} = \frac{V_{CHF} \cdot I_{CHF}}{A}$ (KW/m ²)
Trial 1	55	0.929	51.3	2.419E-5	1970.140
Trial 2	65	0.886	51.0	2.419E-5	1867.961
Trial 3	75	0.744	40.6	2.419E-5	1248.714
Trial 4	85	0.567	32.7	2.419E-5	766.469

8.4.3 EXPERIMENT WITH 1.2 WT % AL₂O₃ NANOFLUIDS:

The test is performed on 1.2 wt% Al₂O₃ nanofluids. The test procedure followed is same discussed in Section 7. This experiment is performed for 5 times and the results obtained are as follows, the CHF value of experiment Trial 1 to 5 during step wise increase in power supply.

8.5 GRAPH:



Graph no.3 Variation of Heat Flux with respect to Temperature (1.2% of CuO & Al₂O₃)

IX. CONCLUSION

It is observed from the structural analysis that the copper oxide and aluminum oxide nanoparticles are monoclinic in nature. The average size of the particle is 30 - 50 nm. Critical heat flux in the nanofluid is investigated with one weight concentrations of CuO and Al₂O₃ in the nanofluid at 1.2 percent weight concentrations nanofluid reading. Ni-Cr wire is used to generate heat flux. It is observed that critical heat flux increases with increase in weight concentration of nanoparticles. The maximum enhancement was found 51.19 percent of CuO & 32.86 percent of Al₂O₃ nanofluid as compared to deionised water fluid at 55°C temperature of fluid. It is found that temperature of nano fluid increases with decreases the critical heat flux (CHF) of Ni-Cr wire.

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