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Enhancement of Critical Heat Flux in Pool Boiling Using Nanofluids

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Abstract: **One of the effective methods for transferring thermal energy with large heat flux is liquid-vapour phase change process is called boiling. The aim of this research is to enhance nucleate pool boiling heat transfer by delaying critical heat flux (CHF). For this we have used Al_2O_3 and C_uO (average size less than 100nm) nanofluid to study the effect on pool boiling heat transfer and its effect on critical heat flux enhancement using horizontal test wires of Ni-Cr immersed in nanofluid with different volume concentration. The result shows the evidence of enhancement of critical heat flux to a significant level.**

Keywords: **Pool boiling, Nucleate pool boiling, Nanofluids, Critical Heat flux, Heat transfer enhancement.**

I. INTRODUCTION

Now a days major challenge faced by many industries are about lack of efficient method to reduce the losses in heat transfer so as to make the process efficient as well as economic. Nucleate boiling is highly efficient heat transfer mode for removing large amount of heat at a low temperature difference. However, a maximum value of heat flux, known as a critical heat flux (CHF), exist at which nucleate transition to film boiling, which is a very poor boiling heat-transfer regime. As a result of the CHF phenomenon, the temperature of the heated surface increases tremendously, thus causing serious damage to the thermal systems. Obviously, a higher CHF is desirable. Several techniques to enhance the CHF have been explored.

According to Rohsenow et al. they can be classified into active (requiring external changes to the heater) or passive (requiring no external changes to the heater) methods. Typical active approaches include vibration of the heated surface or the cooling fluid (to increase the bubble departure frequency), heater rotation (to promote bubble departure from and liquid deposition onto the heater surface) and applying an external electric field (to facilitate the bubble departure from the surface by dielectrophoretic force), and passive approaches include coating the surface with porous coatings (to increase the number of active nucleation sites) and oxidation or selective fouling of heater surface (to increase surface hydrophilicity) [3]. In this research work we are using one of the emerging methods to increase heat transfer rate and to increase critical heat flux is that of nanofluid as fluid in pool boiling.

Nanofluid is a new kind of heat transfer medium, containing nanoparticles (1–100 nm) which are uniformly and stably distributed in a base fluid. These distributed nanoparticles, generally a metal or metal oxide greatly enhance the thermal conductivity of the nanofluid, increases conduction and convection coefficients, allowing for more heat transfer rate. For this reason in this study analysis of critical heat flux in pool boiling is investigated so as to get comparison of critical heat flux of nickel-chromium wires using water and Al_2O_3 aluminium oxide (Al_2O_3)/ water nanofluid and copper oxide (CuO)/water nanofluid as it has wide applications.

II. METHODOLOGY

A. *Nanoparticles :*

Aluminium oxide (Al_2O_3) and copper oxide (C_uO) nanoparticles were brought from Nano Labs, Jamshedpur, Jharkhand.

The properties of Al_2O_3 and C_uO nanoparticles are as shown in table no.1.

TABLE I: PROPERTIES OF Al_2O_3 AND C_uO NANOPARTICLES

Properties	Aluminum Oxide	Copper Oxide
Chemical Formula	Al_2O_3	C_uO
Color	White	Black
Morphology	Spherical	Spherical
Density	3.950 g/cm3	6.4g/cm^3
Phase	Alpha phase	Alpha
Average particle Size	Less than 100 nm	30-50nm
Surface area	15-20 m^2/gm	>10m^2/g

B. Nanofluid preparation:

In this work, nanofluids were prepared by using two-step method, dispersing dry nanoparticles into the base liquid followed by magnetic stirring and then by process of ultrasonication. Distilled water was used as the base liquid, and Al_2O_3 and C_uO nanoparticles were used without the addition of additives. The Al_2O_3 and CuO nanoparticles were procured from Nano lab having 99% purity. Magnetic stirring was performed for 8 hours followed by ultrasonication just before pool boiling experiments.

Fig. 1: Stirring of nanofluid

Concentrations of nanofluids used in this research are:

1. Concentration of 0.01, 0.02 and 0.03% of Al_2O_3 –water nanofluid by weight.
2. Concentration of 0.01, 0.02 and 0.03% of C_uO –water nanofluid by weight.

In beaker of 1500ml capacity, 1400ml distilled water was taken. Required mass of Al_2O_3 and C_uO nanoparticles was taken by weighing on a digital electronic balance. Magnetic Needle was kept in the beaker. This beaker was placed on Magnetic stirrer. Magnetic stirrer supply was turned on and the stirring was kept on maximum speed. Al_2O_3 and C_uO nanoparticles were added into the distilled water very slowly. This solution was stirred for 8 hours continuously. Then ultrasonication was done to nanofluid. Then this solution was poured into beaker of capacity 2.5 litre having 500 ml of distilled water and was stirred for 1 hour. This prepared nanofluid was used in pool boiling experiment.

Al_2O_3 nanoparticles were white in colour; hence nanofluids formed were white in colour. Whereas C_uO nanoparticles were black in colour and hence nanofluids formed were black in colour. It is observed as the nanoparticles concentration was increased nanofluid colour becomes darker for both the nanofluids.

Since the characteristics of nanofluids are governed by not only the kind and size of the nanoparticles but also their dispersion status in the base fluid i.e. stability of nanofluids in other words can be said that uniform distribution of nanoparticles in nanofluids. Therefore it is essential to have the test fluid sample without any agglomeration. To ensure no agglomeration, after preparation of nanofluid, the nanofluid sample were left for 1 hour to verify any agglomeration of the particle and subsequent settling in the vessel bottom. It was found that negligible or almost no agglomeration in the first 60 minutes. No agglomeration for the first 60 minutes was more than enough to get reliable results from the experimentation.

C. Experimental setup and procedure:

The apparatus used in analysis consists of cylindrical glass housing, the test heater and heater coil for heating of the water. This heater coil is direct connected to the mains (Heater R1) and the test wire is also connected to mains via. variac. An ammeter is connected in series while a voltmeter across it to read the current and voltage respectively. The glass container is kept on a stand. There is provision of observing the test heater wire with the help of a lamp light from back and the heater wire can be view a lens. Specifications of apparatus used are: Glass container – Diameter – 250 mm Height – 100 cm, Heater for initial heating, Nichrome Heater (R–1) – 1 kW, Test Heater (R-2), Nichrome wire size - Φ mm (To be calculated according to wire used say 36 SWG to 40 SWG.) and Length of test Heater (R-2) = 100 mm, Thermometer – 0 to 100^{o}C. The schematic experimental setup used for analysis of critical heat flux in pool boiling is as shown below:

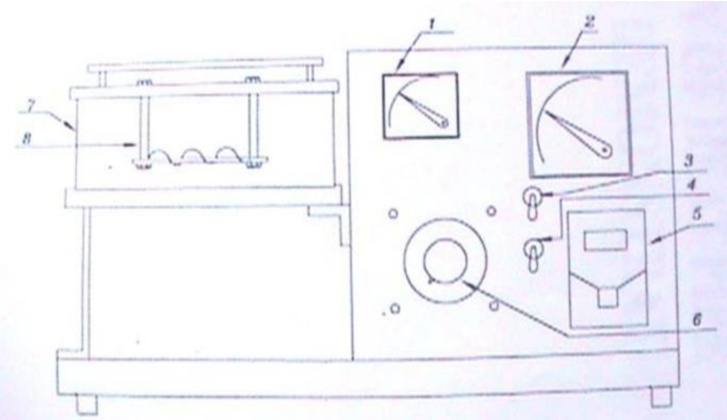

Fig. 2: Layout of Experimental setup

The fig. 2 shows that 1.Voltmeter, 2.Ammeter, 3.Heater switch, 4.Lamp switch, 5.Main switch, 6.Heater control, 7.glass container and 8.Heater fitting. The procedure used for experimentation is first keep dimmerstat knob at zero position and switch on the equipment. Then on the heater and let the temperatures rise to reach a steady temperature. Now switch off the heater and rotate the dimmerstat knob, so that voltage is applied to test heater. Wait until steady state is reached. Note down all the temperatures and input of heater in terms of volts and current.

III. RESULT AND DISCUSSION

Experimental Investigation is carried out by using hard water (9-10 Times) and Aluminium oxide (Al_2O_3)/ water nanofluid and Copper oxide (C_uO) / water nanofluid with different concentration (five to six Times) in pool boiling for critical heat flux analysis. Results obtained are plotted as shown below.

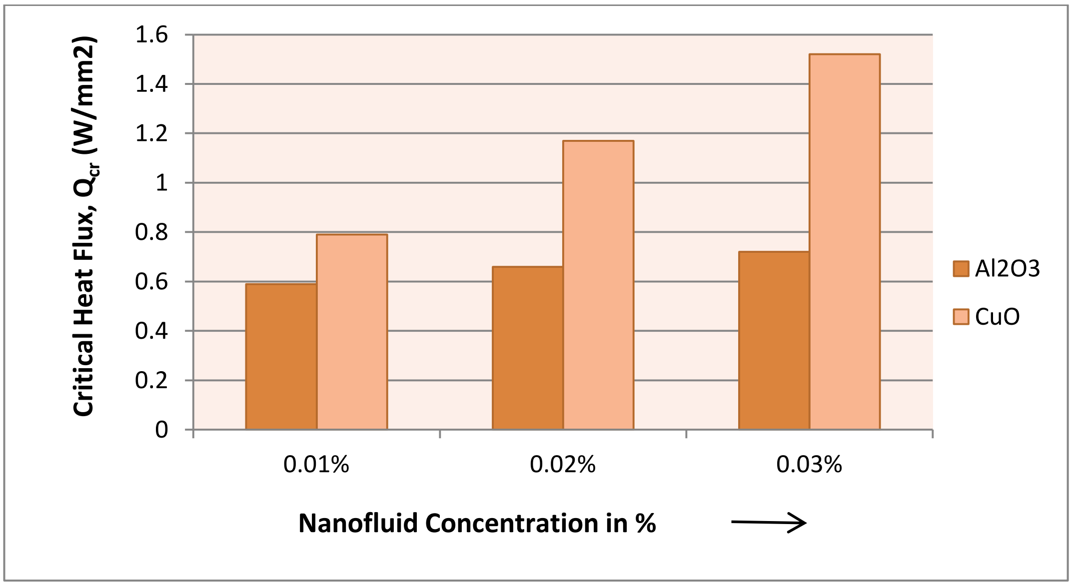

Fig. 3: Comparison of Critical heat flux of Al_2O_3/water and C_uO/water nanofluid

Above fig. 3 shows comparison of critical heat flux of copper wire using Al_2O_3/water nanofluid and C_uO/water nanofluid with 0.01%, 0.02%, and 0.03% concentration of nanoparticles in base fluid. It is found that critical heat flux has increases with each increase in concentration.

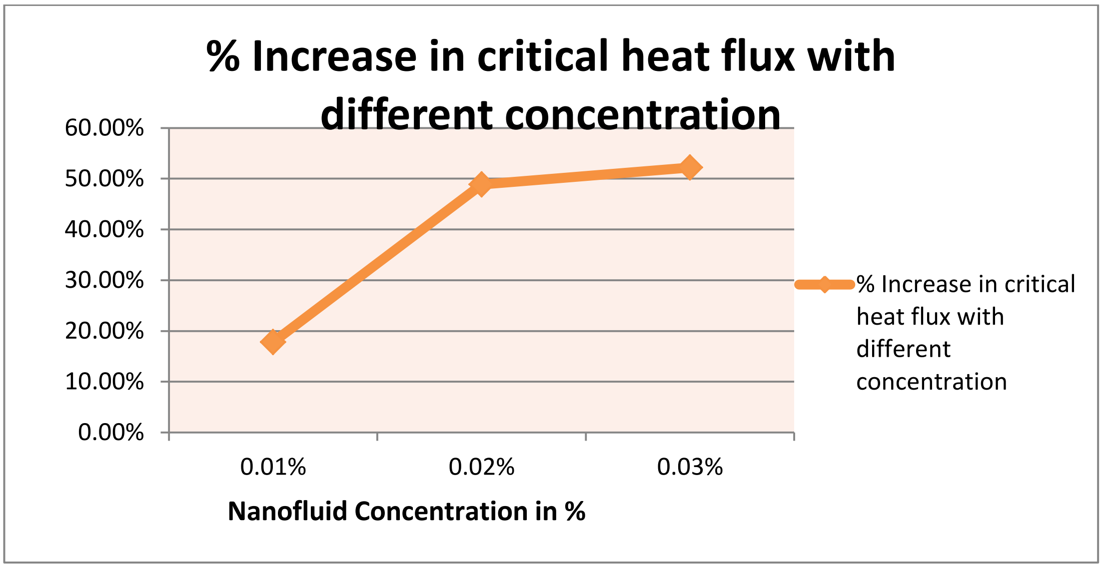

Fig. 4: Comparison of percentage increase in critical heat flux of Aluminium oxide (Al_2O_3)/ water nanofluid and Copper oxide (C_uO) / water nanofluid with increase in concentration

Above fig. 4 shows Comparison of percentage increase in critical heat flux of Aluminium oxide (Al_2O_3)/ water nanofluid and Copper oxide (C_uO) / water nanofluid with increase in concentration. It is found that critical heat flux percentage has increases with increase in concentration along with rate of percentage also increases. This also shows that nanofluid has significant effect on enhancement of critical heat flux.

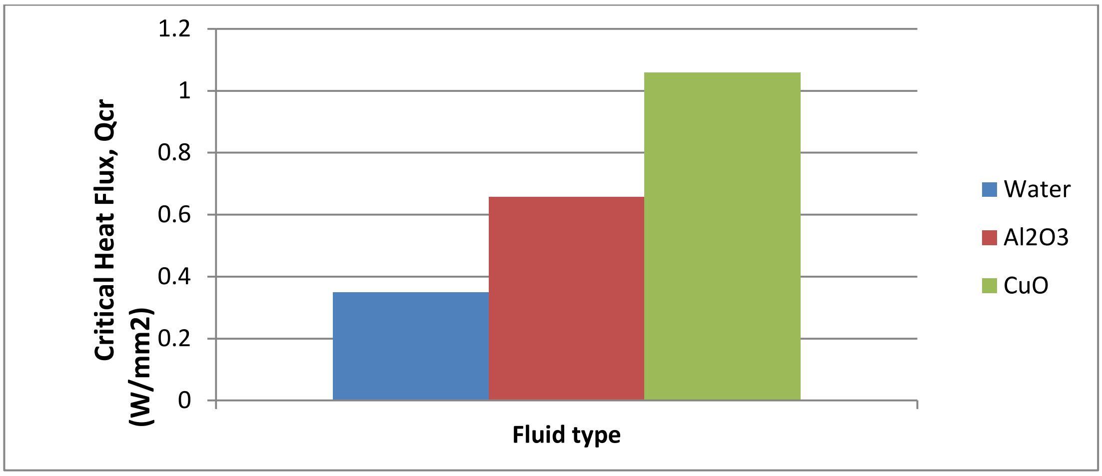

Fig. 5: Comparison of Critical heat flux of water, Aluminium oxide (Al_2O_3)/ water nanofluid and Copper oxide (C_uO) / water nanofluid.

The above fig. 5 shows that critical heat flux of Nickel chromium wire with water, Aluminium oxide (Al_2O_3)/ water nanofluid and Copper oxide (C_uO) / water nanofluid which shows that critical heat flux of aluminium (Al_2O_3)/water nanofluid is more than water and critical heat flux of copper (C_uO)/water nanofluid is more than Al_2O_3/water nanofluid.

From above analysis of experimentation and results we can conclude following observations:

- Percentage difference in critical heat flux for 0.01% concentration of aluminium oxide (Al_2O_3)/water and copper oxide (C_uO)/water nanofluid is 17.8%.

- Percentage difference in critical heat flux for 0.02% concentration of Aluminium oxide (Al_2O_3)/ water nanofluid and Copper oxide (C_uO) / water nanofluid is 48.89%.

- Percentage difference in critical heat flux for 0.03% concentration of Al_2O_3/water and C_uO/water nanofluid is 52.21%.
- Percentage difference in critical heat flux for water and aluminium oxide (Al_2O_3)/water nanofluid is 47%.
- Percentage difference in critical heat flux for water and copper oxide (C_uO)/water nanofluid is 70.13%.

VI. CONCLUSION

The conclusions we can derive is as follows:

- Critical heat flux of nickel chromium can be increased by using nanofluid instead of water.
- Critical heat flux of nickel chromium can be increased by using nanofluid of copper oxide (C_uO)/water nanofluid than of aluminium oxide (Al_2O_3)/water nanofluid.
- Critical heat flux increases to due deposition nanoparticles on heater surface.
- For aluminium oxide (Al_2O_3)/water nanofluid dispersion of nanoparticles is more uniform and homogeneous than copper oxide (C_uO)/water nanofluid.
- Stability of nanofluid is of major concern. After few days (for almost 20-25 days) nanoparticles tends to settle.
- Ultrasonication has positive impact on stability of nanofluid.
- Critical heat flux of plain water at first was comparatively less as compare to same plain water when experimentation was done after taking readings of nanofluid. This is because of deposition of nanoparticles on heater surface.
- After a certain level of concentration, critical heat flux enhancement does not occur to significant level and thus is not economical.

Thus nanoparticles has important role in enhancement of CHF of base fluid. CHF enhancement increases with increases in concentration up to certain concentration above which CHF decreases even with increase in concentration.

It is also concluded that deposition of nanoparticles increases nucleation density due to which diameter of bubble departure decreases. This in turn decreases vapour blanket forming on heater surface. This also helps in faster departure of bubbles. This increases critical heat flux.

Nanoparticles in nanofluid form a layer on heater surface. This increases roughness of heater surface which increases wettability of surface. This leads to delay of critical heat flux (CHF) and enhancement of heat transfer. This higher critical heat flux got by using nanofluid helps to design a system for higher heat transfer. Thus system can be designed with higher safety limits.

Nanoparticles 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. This gives an opportunity for engineers to develop highly compact and effective heat transfer equipment for higher transfer rate requirement systems such as boilers, nuclear power plants, thermal power plants, etc.

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