Pool Boiling Enhancement by Using CuO Nanostructured Surfaces

N. A. Doifode[1], R.N. Pote[2], S.P. Chavan[3] C.G. Burande[4], S. P. Borole[5]

[1]*Assistant professor, Mechanical department, SKNCOE, Pune,* ***pnitindoifode@gmail.com***
[2] *Assistant professor, Mechanical department, BSCOER, Pune,* ***poterajesh@gmail.com***
[3] *Assistant professor, Mechanical department, SKNCOE, Pune,* ***Sandip4284@gmail.com***
[4] *Assistant professor, Mechanical department, SKNCOE, Pune,* ***chaitanyaburande5791@gmail.com***
[5] *Assistant professor, Mechanical department, PR Pote COEM,* ***sushil.borole@gmail.com***

ABSTRACT

Nanostructuration of surfaces is considered as a promising track in many micro-thermo-fluidic applications, as it is expected to allow noticeable heat transfer enhancement or hydraulic resistance reduction is due to momentum transfer to the solid walls. In this paper we have studied the nucleate pool boiling heat transfer performance of nanostructured copper surface fabricated by Fluidized Powder Bed Process over glass tube heater with thin layer of epoxy resin. The pool-boiling heat transfer performance of the nanostructured copper surface made from this process is investigated with saturated deionised water. The experimental result implies that the pool boiling heat transfer performance is dramatically enhanced with the nanostructured surface structure.

Keywords***: Pool boiling, Nanopartical, Critical heat flux, Heat transfer coefficient, Thin film coating***

.---

1. INTRODUCTION

Heat transfer systems that operate in the nucleate boiling regime are limited by a critical heat flux (CHF), at which a vapour film envelopes the heated surface and severely deteriorates heat transfer. It is crucial that systems such as nuclear reactors operate below the critical heat flux to prevent a temperature excursion and subsequent failure of the heat transfer surface. Therefore, raising the upper limit of nucleate boiling could allow for higher safety margins, higher rates of heat transfer in existing systems, or a reduction in the size of new systems while maintaining the same heat transfer capability. The nucleate boiling heat transfer coefficient dictates the operational temperature of a boiling surface at a given heat flux. Devices such as power electronics are highly sensitive to temperature rise. It is therefore desirable to increase the nucleate boiling heat transfer coefficient in two-phase cooling systems to optimize the performance and operating lifetime of such devices. An overreaching goal of thermal-fluid design has been to find a cost-effective means of enhancing CHF and boiling heat transfer [1].

The development of special surface geometries/structures is a critical issue for the performance-enhancement of the pool boiling heat transfer. Numerous studies and experiments on nucleate pool boiling, an effective way to remove high heat flux from a heated surface, have focused on enhancing the boiling heat transfer coefficient by fabricating micro-scaled surface geometries / structures[2]. One approach that has success is to create a number of small micro-porous cavities on the boiling surfaces to increase the vapour/gas entrapment and the number of active nucleation sites. These cavities reduce the incipient and nucleate boiling wall superheats and increase the pool boiling heat transfer coefficient. While many of the previous studies on the surface structure focused on improving the heat transfer coefficient of pool boiling in micro-sized dimensions. However, with the evolution of nanotechnology and nanomaterials, current study focused on well-defined nanomaterials suitable for use in pool boiling. Nanotextured surface effects on two-phase heat transfer and boiling are even more in their infancy. Recently, there has been an increased interest in evaluating the pool-boiling performance of nanowire / nanotube surfaces. The expected advantages of nanoscale modifications include finer control over porosity and surface roughness, thinner coating layers to reduce thermal resistance and thermal stress and ultimately higher durability [1].

1.2 RECENT DEVELOPMENTS IN EPOXY COATINGS

Epoxy coatings are the workhorses of the protective coatings industry. They have excellent chemical and corrosion resistance, high mechanical strength, good adhesion to a variety of substrates and a combination of other properties that have made them a material of choice for providing cost effective, long term protection on industrial, marine and offshore structures. The major limitations of epoxy coatings are their relatively slow cure in cold climates and poor exterior color and gloss retention. The issue of color stability and chalking is typically addressed by top coating with aliphatic polyurethane, acrylic-siloxane, epoxy siloxane or other inherently weatherable coating [3]. Slow cure at low temperatures is a continuing problem.

1.3 Review of CuO Nanomaterial

Among the oxides of transition metals, copper oxide nanoparticles are of special interest because of their efficiency as nanofluids in heat transfer application, secondly it is the basis of several high-Tc superconductors. CuO is a semiconducting material with a narrow band gap and used for photoconductive and photo thermal applications. Opposite to n-type semiconducting metal oxides, cupric oxide (CuO) is a p-type semiconductor with a band gap of 1.2–1.9 ev. Its applications also include catalysis, lithium–copper oxide electrochemical cells, solar cells, and gas sensors. The nanoparticles, plates, and nanowires of CuO were also reported to sense NO2, H2S, and CO ,Some methods for the preparation of nanocrystalline CuO have been reported such as the nonchemical method, sol–gel technique ,one-step solid state reaction method at room temperature, electrochemical method, thermal decomposition of precursors[4].

2. Experimental Apparatus and Procedure

The test heater was prepared by using a borosilicate glass tube (outer diameter = 19.80 mm, inner diameter = 12.6 mm, and length L = 100 mm). A cylindrical test heater (nichrome) of diameter 12.5mm was inserted into glass tube. The glass tube was cleaned to remove dust and other impurities. Epoxy resin paste of thickness 0.3mm was coated on the glass surface by general craftsman's technique. Immediately after sticking of epoxy resin, we use the fluidized powder coating method to coat the CuO nanoparticles uniformly (coating all over the surface) on the glass coated epoxy surface. After coating of nanoparticles powder heat the coated surface for 5 to 10minutes, for drying of epoxy resin. For preparing nonuniformly (exposing some surface without nanoparticles) distributed surfaces, apply the CuO nanoparticles powder on the surface randomly or manually spray the powder.

Procedure : Initially, glass container was filled with pure water, and it was heated to saturation temperature at atmospheric pressure using auxiliary heater. The auxiliary heater was switched OFF, and glass tube heater was switched ON as soon as pure water reaches saturation temperature. The electric power supply to the test heater was increased gradually using dimmer. The temperature of water and test heater was recorded at each step. At each value of heat input, Journalwall heat flux, q was calculated from the measured voltage V, current I, and heater surface area A as additional analysis. The experiments were carried out until reproducibility of the boiling curves became satisfactory.The procedure was repeated. Glass vessel was emptied and filled with purewater and glass tube heaterwas replaced nanoparticle coated test heater. Thermocouple was reconnected. As the temperature distribution on boiling surface was nonuniform and transient, the following time space average temperature was used: additional analysis. The experiments were carried out until reproducibility of the boiling curves became satisfactory.The procedure was repeated. Glass vessel was emptied and filled with purewater and glass tube heaterwas replaced nanoparticle coated test heater. Thermocouple was reconnected. As the temperature distribution on boiling surface was nonuniform and transient, the following time space average temperature was used:
Wall heat flux, q was calculated from the measured voltage V, current I, and heater surface area A as

$$q = \frac{V \times I}{A}$$

Boiling behaviour was recorded on high speed camera for additional analysis. The experiments were carried out until reproducibility of the boiling curves became satisfactory. The procedure was repeated. Glass vessel was emptied and filled with pure water and glass tube heater was replaced nanoparticle coated test heater. Thermocouple was reconnected.

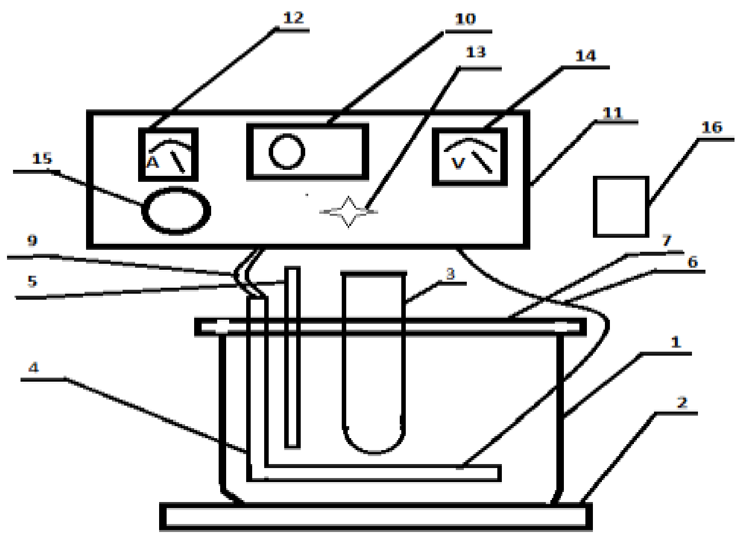

Fig-1: Schematic of experimental apparatus.

(1) Glass container (2) Supporting stand (3) Auxiliary heater (4) Test heater (5) Thermometer (6) Thermocouple (7) Clay lid (8) Test heater (9) Heater connecting cable (10) Digital temperature indicator (11) Control panel (12) Ammeter (13) Selector switch (14) Voltmeter (15) Dimmerstat (16) Electric power switch

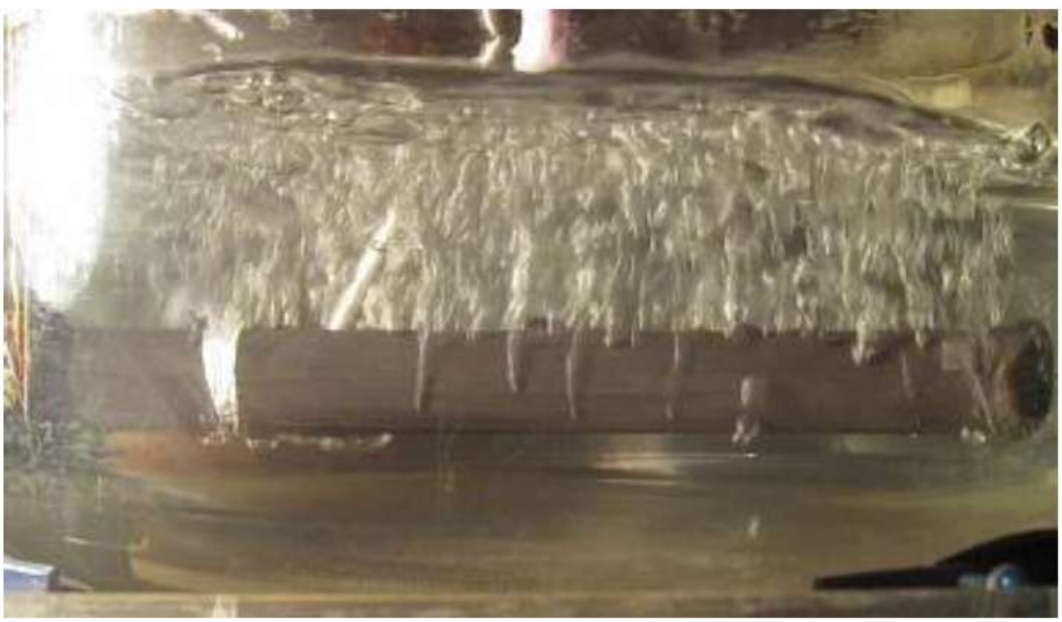

Figure 2: Photo Image showing experimentation and thermocouple

3. Results and Discussion

The experiments are conducted on glass surface and on uniformly distributed CuO nanostructured surfaces, nonuniformly distributed nanostructured surface and on glass coated epoxy surface. Results are compared by plotting the curves. The wall superheat and heat flux are compared for different test heater surfaces having different nanostructured surfaces.

ISSN: 2321-8169
1484 – 1489

Figure 3 shows the boiling curves, i.e. the dependence of dissipated heat flux on wall superheat and compares the performance of various nanostructured surfaces against plain glass surface in the pool boiling tests. The epoxy coated glass surface has the maximum difference in wall superheat as compared to glass and nanostructured surfaces. Because the epoxy have the very low thermal conductivity as compared to glass. As seen in our experiment the maximum wall superheat on epoxy surface is 99.3 ºC. But as compared to the epoxy coated glass surface, the plain glass surface has the 10.1 ºC less superheat. As seen from the graph the curve for glass and epoxy surfaces the wall superheat is going continuously increasing and it is maximum at higher heat fluxes respectively.

Conventional wisdom proposes that nanostructured surfaces will not improve boiling heat transfer because the bubble nucleation process is not expected to be enhanced by very small cavities. But CuO nanostructured surfaces displayed all the characteristics of a typical boiling curve where the initial heat transfer process was natural convection limited and ONB (onset of nucleate boiling) was observed as the wall superheat is reached for bubble nucleation. At higher wall superheat, these nanostructured surfaces activated discrete bubbles on the heater surfaces, PNB (partial nucleate boiling), and transitioned to fully-developed nucleate boiling where the bubbles merge to form vapor columns (see Figure 3) At higher heat flux (CHF), the bubbles are large and merge to form a continuous vapor film between the heater and water. Due to lower thermal conductivity of the vapor compared to liquid water, the thermal resistance increases sharply due to the presence of a vapor film

After deposition of nonmaterials on glass coated epoxy surfaces uniformly and nonuniformly, it's seen that the nucleate boiling curve shifts towards left. It's means that there is decrease in wall superheat of nanostructured surfaces. At first in the region of nucleate boiling the wall superheat is very low for all the surfaces but when the isolated bubble region is reached the wall superheat is going on dramatically changed. The formation of bubbles on the glass and epoxy surface is very less as compared to nanostructured surfaces hence wall superheat is high in these surfaces. The thermal layer by nanostructured surfaces is not considered because the nanoparticles layers can be assumed to behave layer of packed insulating spheres in which the heat is will mostly be conducted through the water in the pores. As compared to the uniformly distributed nanostructured surfaces of CuO the nonuniformly distributed surfaces have the larger wall superheat .The larger decrease in wall superheat is observed on CuO surface. In our experiment it is 67.9 °C which is less than plain glass surface by 21.3 °C.

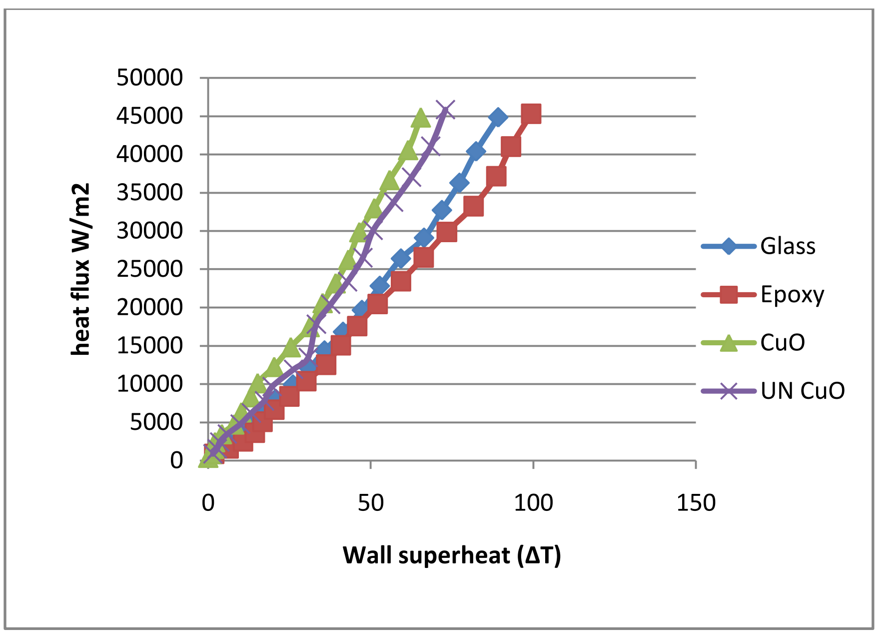

Figure3 Heat Flux vs. Heat Transfer Coefficient

The heat transfer coefficient and heat flux are compared for plain glass, epoxy coated glass and different nanostructured surfaces.

In the figure 4 the results are shown on the data obtained in increasing order of heat flux. The effect of heat flux on the nucleate boiling heat transfer coefficient of nanostructured surfaces in water is more evident if the experimental data are expressed as a plot of heat transfer coefficient versus heat flux, as shown in Fig. 4. The heat transfer coefficient increases as the heat flux is increased. For plain glass surface the heat transfer coefficient is more than epoxy coated surface but less than the nanostructured surfaces. This is because the wall superheat is more on epoxy surface and bubble formation is very less as compared to other surfaces. Here the thermal conductivity plays major role in increasing the heat transfer coefficient. Because as seen from graph the CuO having higher thermal conductivity has the more heat transfer coefficient than the other surfaces.

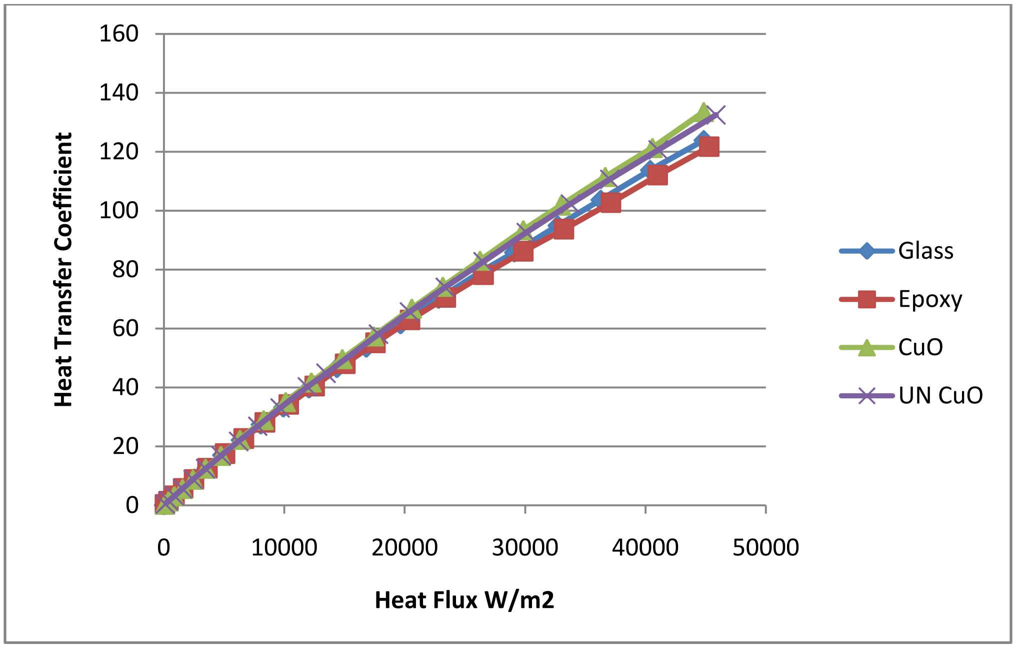

Figure 4: Heat flux vs. Heat transfer coefficient

4. Conclusion

The pool boiling experiment was carried out over a plain glass and glass coated nanomaterials for various heat fluxes. The following conclusions were obtained:

1. It is concluded that the maximum heat transfer coefficient enhancement occurred on CuO coated glass. The nonuniformly coated nanomaterial surfaces have the heat transfer coefficient in between the glass and uniformly distributed nanomaterial surfaces. So for maximum heat transfer the coating of nonmaterial should be uniform.

2. As compared to Glass and CuO nanostructured surfaces, the maximum heat transfer coefficient is occurred on CuO nanostructured surface hence thermal conductivity of nanomaterial plays an important role in the boiling enhancement performance.

3. As compared to the glass the boiling curve shifts towards left this means that wall superheat is minimum on the nanostructured surfaces. Reduction in wall superheat is maximum for high conductivity CuO nanostructured surface than the Al2O3 and glass surface.

REFERENCES

[1] Rezaifard, A.H., Hodd, K.A. and Barton, J.M., „Toughening epoxy resin with poly (methyl methacrylate)-grafted natural rubber‟, Washington D.C., American Chemical Society, 233, 381, 1934.

[2] Qe W. And Mudawar I., „Measurement and correlation of Critical Heat Flux in Two-Phase Micro-channel Heat Sinks‟, International Journal of Heat and Mass Transfer, 47, 2045 ,2004.

[3] Mathiazhagan A. and Jose R., „Nanotechnology-A New Prospective in Organic Coating – Review‟, International Journal of Chemical Engineering and Applications, Vol. 2 , No. 4 , 2011.

[4] Zhang H .and Cui Z., „Solution-phase synthesis of smaller cuprous oxide nanocubes, Materials Research Bulletin‟, 43, 2008, pp. 1583-1589.

[5] Mudawar I., „Assessment of High-Heat-Flux Thermal Management Schemes‟, IEEE Transactions on Components and Packaging Technologies, 24, 122-140 2001.

[6] Kang M., „Effect of surface roughness on pool boiling heat transfer‟, Int. J. Heat Mass Transfer, 43 (22), 4073–4085 2000.

[7] Cengel Y. A. (2003), „Heat Transfer – A Practical Approach‟, Second Edition, Tata Mc-Graw Hill Edition, New Delhi.

[8] Thome J.R., Dupont V. and Jacobi V.A., „Heat transfer model for evaporation in microchannels, Part I: Presentation of the model‟, Int. J. Heat Mass Transfer 47, 3375–3385, 2004.