Nucleate Pool Boiling Heat Transfer of Saturated Liquid on TiO_2 Nano Wire Red Brass Surfaces

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Abstract - *Pool boiling heat transfer enhancement of untreated, treated and TiO_2 nano wire surfaces were investigated experimentally with water at atmospheric pressure. The red brass untreated, treated surface and the surfaces having nano wire of 250 nm and 500 nm were used for investigation. The nano wire was done by physical vapour deposition method and the emery grate 1000 was used for treating the surface. The above surfaces were characterized with respect to contact angle, roughness. The surface roughness values were obtained by the optical profiler. The experimental data was collected with the heat flux ranges from 57.89 W/Cm² to 151.57 W/ Cm². The results indicate that all TiO_2 nano wire surfaces in nano meter scale influence the boiling heat transfer coefficient significantly. A maximum 48.61%, 37.26%, and 10.58% enhancement was observed for TiO_2 nano wire (500 nm), TiO_2 nano wire (250 nm), and plain surfaces respectively. The enhancement of boiling heat transfer coefficient in nano wire surfaces was due to Capillary effect, better liquid spreading; enhanced wettability and high density active nucleate site and high rate of bubble emission frequency.*

***Key Words*: Nano-wire, Heat transfer coefficient, Surface roughness, contact angle, Red brass surface.**

1. INTRODUCTION

The process of changing the phase from liquid to vapour by transferring the heat to liquid is boiling process and transferring the heat from one place to other by change of phase is Boiling Heat Transfer. We are interested to study in two phase flow as because of high heat transfer rate in boiling. Because of this, the researchers are interested in this area to improve the heat transfer performance by nucleation. Therefore, it is desirable to operate thermal-fluid systems in the nucleate boiling regime. In many engineering applications that require super-high heat transfer rates, nucleate boiling heat transfer is the mode of choice. Boiling heat transfer holds the potential advantage of facilitating the transfer of a large amount of energy over a relatively narrow temperature range with a small weight to power ratio. All types of advanced power devices and high-tech electronic systems ranging from heavy-vehicle engines, computer chips and advanced nuclear reactors depend on efficient thermal energy transport mechanisms to acquire heat input and to reject waste heat for the purpose of achieving higher power density and higher system efficiency. Higher cooling rates can increase energy conversion system efficiency, enable higher power density and also elevate system functionality. The fundamental research on nucleate boiling would unveil the controlling boiling mechanisms such that the next breakthrough in cooling technology, for example using nano fluids and nano surface textures, can be realized. So, fundamental boiling research will directly benefit the high heat flux power and cooling industry, especially for the cooling of electronics and nuclear reactors, by providing new dimensions in modeling and simulation capabilities for engineering design and development. The proper design of thermal fluid system leads to the enhancement of boiling heat transfer coefficient and critical heat flux. Among all enhancement techniques, surface coating is one on which most of the researchers concentrating due to significant enhancement was observed. Some published literatures related to the pool boiling heat transfer from surfaces with nano coating are given here.

Renkun Chen et al. [1] reported that the high surface tension forces offered by liquids in nanowire arrays made of Si and Cu can be exploited to increase both the CHF and the HTC by more than 100%. They reported their experimental work on pool boiling of saturated water on surfaces covered with dense arrays of nanowires made by either Si or Cu. For both Si and Cu nanowires, the CHF and HTC were observed to increase significantly, compared to the boiling on plain surface. H.G. Na et al. [2] fabricated TiO_2/SiO_x core shell nanowires by heating Au/TiN/Si substrates. They demonstrated that the thickness of the Au layer needs to be optimized to obtain nanowires. To investigate the effect of the Au coated surface with respect to its thickness, they varied the Au layer thickness in a range of 0-27 nm. They observed that nanowire formation is favoured with a thicker Au layer in the range of 3-9 nm. XU Jia et al. [3] studied the pool boiling of saturated water on a plain Ti surface and surfaces covered with vertically oriented nanotubes arrays. They observed that the wall super heat on the TiO_2 NTAs was decreased by 11k and both the CHF and HTC of pool boiling on the TiO_2 NTAs were higher than those from boiling on a bare Ti surface. They measured the maximum critical heat flux and heat transfer coefficient as 186.7 w/cm² and 6.22 w/cm²k. Liu et al. [4] studied the effect of oxidant (H_2O_2)

concentration on the fabricated nano structures. They carried out their experiment by taking concentration of 10%, 20% and 30%. They have obtained different morphologies of high density nanowire arrays, low density nanowire arrays, chaotic porous nano structures by changing the oxidant concentration. SiNWs prepared by 30% H_2O_2 exhibit enhanced photo catalytic activity than 10% and 20% H_2O_2.Y Wu et al. [5] reported a simple process to synthesize single crystalline Ge nanowires with diameters less than 30 nm. The nanowires were grown using a vapour transport process mediated by vapour-liquid-solid crystal growth mechanism. In the process of obtaining even smaller and more uniform nanowires, they discovered a simple approach to further reduces the sizes of as-made ones. The obtained nanowires were subjected to a brief vacuum thermal treatment. Z. Yao et al. [6] were successfully fabricated uniform silicon nanowires on the top, bottom and side wall surfaces of silicon microchannels by using a two step electroless etching process. They studied the effects of the microchannel geometry, micro/nano-hierarchical structures on pool boiling. And also compared the bubble dynamics on different sample surfaces. Wu et al. [7] in a recent paper reported the results of their pool boiling experiments on 1-μm-thick titanium oxide (TiO_2) and silicon oxide (SiO_2) nanoparticle-coated surfaces. Their results also indicate that the hydro philicity of titanium oxide surface provides higher heat transfer coefficient and CHF values. Tang et al. [8] performed experiment of nucleate pool boiling heat transfer on nano porous copper zinc alloy on copper subtract by HDGD process. Improvement of heat transfer coefficient was observed .Vemuri and Kim [9] carried out a brief experimental study on the pool boiling heat transfer of a nano porous surface (NPS) using commercially aluminium oxide with a thickness of 70μm in a saturated FC-72 dielectric fluid. Their study revealed that the incipient wall superheat was reduced by 30% in the input power for the NPS versus the plain surface. Hedge et al. [10] studied the heat transfer characteristics using low concentrations (0.1-0.5 g/l) of Alumina-nanofluid at atmospheric pressure in distilled water, the effect of nanoparticle coating on vertical test surface exposed to multiple heating cycles, heat transfer characteristics of nanoparticle coated surface in distilled water and pool boiling behaviour of Alumina nanofluid subjected to transient characteristics. There is deterioration in boiling HTC with increased nano-particle concentration. The nanoparticle coated heater, when tested in pure water showed significant enhancement in CHF. Das et al. [11] investigated nucleate pool boiling characteristics of Al_2O_3-H_2O nanofluids on a cylindrical stainless steel cartridge heaters of 20mm diameter and 420 volt, 2.5 KW rating. The result shows the higher the concentration the more was the sedimentation and hence the boiling performance worsened. The reason is the nanoparticles were found to sediment on the heater, thus making it smoother deteriorating the boiler performance. Later on Das et al. [12] showed that pool boiling of nanofluids on narrow horizontal tubes (4 and 6.5 mm diameter) is qualitatively different from the large diameter tubes. Due to difference in bubble sliding mechanism it was found that at this range of narrow tubes the deterioration in performance in boiling of nano fluids is less compared to large industrial tubes. Bang and Chang [13] conducted an experiment to study the boiling heat transfer characteristics of Al_2O_3-H_2O nanofluids at different volume concentrations of 0.5, 1.0, 2.0, and 4.0 vol. % respectively. The results demonstrated that the nanofluids reduced the heat transfer performance compared with pure water for both natural convection and nucleate boiling heat transfer. You et al. [14] investigated the pool boiling curve and CHF of a square flat copper heating surface immersed in Al_2O_3-H_2O nanofluids. Nanofluids with volume concentrations ranging from 0.001g/l to 0.05g/l were used. The result showed that the CHF increased dramatically when compared with the case of pure water. Zhou et al. [15] experimentally investigated the effects of acoustical parameters, nanofluid concentration and fluid sub-cooling on boiling heat transfer characteristics of a copper- acetone nanofluid. The pool boiling of nanofluids depends on many factors, among those the particle dispersion and its concentrations is one of the most important parameter for the heat transfer enhancement. Vassallo et al [16] experimentally studied the pool boiling heat transfer of Si- water nanofluids and the results were compared with those of water. A Ni-Cr wire heater having a 0.4mm diameter and length of about 120mm were used as the test section. The results showed that both nano and micro solutions dramatically increased the CHF when compared with pure water. Golubovic et al. [17] investigated CHF enhancement of nanofluids experimentally. The BiO_2 and Al_2O_3 nanoparticles dispersed in water were used as working fluids. The test section was made from a Ni-Cr wire heater of 0.64mm diameter and 50mm of length. The results showed that the CHF increased with increases in the volume concentrations. Ding et al. [18] studied the heat transfer intensification using nanofluids. The paper summarizes work on the heat transfer of nanofluids. It covers heat conduction, convective heat transfer under both natural and forced flow conditions, and boiling heat transfer in the nucleate regime. The results showed that the presence of nano particles enhances thermal conduction under macroscopically static conditions mainly due to nano particle structuring. Liu and Liao [19] presented the nucleate pool boiling heat transfer of nanofluids experimentally. In this study, CuO and SiO_2 nano particles were dispersed in water and alcohol based fluids. A plain copper surface was used as the test section. The boiling heat transfer characteristics of the nanofluids were slightly poor compared with those of water and alcohol. Wen and Ding [20] gave a completely different picture of boiling of nanofluids. They observed an enhancement of boiling in the presence of nanoparticles. The particles used by them were same as those used by Das et al. [11] with particle sizes 10-50nm. They stabilized the suspension by adjusting the pH value near 7, which is away from the iso-electrical point of alumina. They used 2.4kw ring heater below stainless steel boiling surface.

2. METHODOLOGY

2.1 Pool boiling experimental setup and procedure

The key objective of this investigation is to obtain experimental data of heat transfer from a horizontal section (i.e. heating specimens) with plain, polished and nano wire red brass surfaces. Fig.1 illustrates the details of the experimental set up for the pool boiling test. The test apparatus is designed to carry out pool boiling experiments under atmospheric pressure.

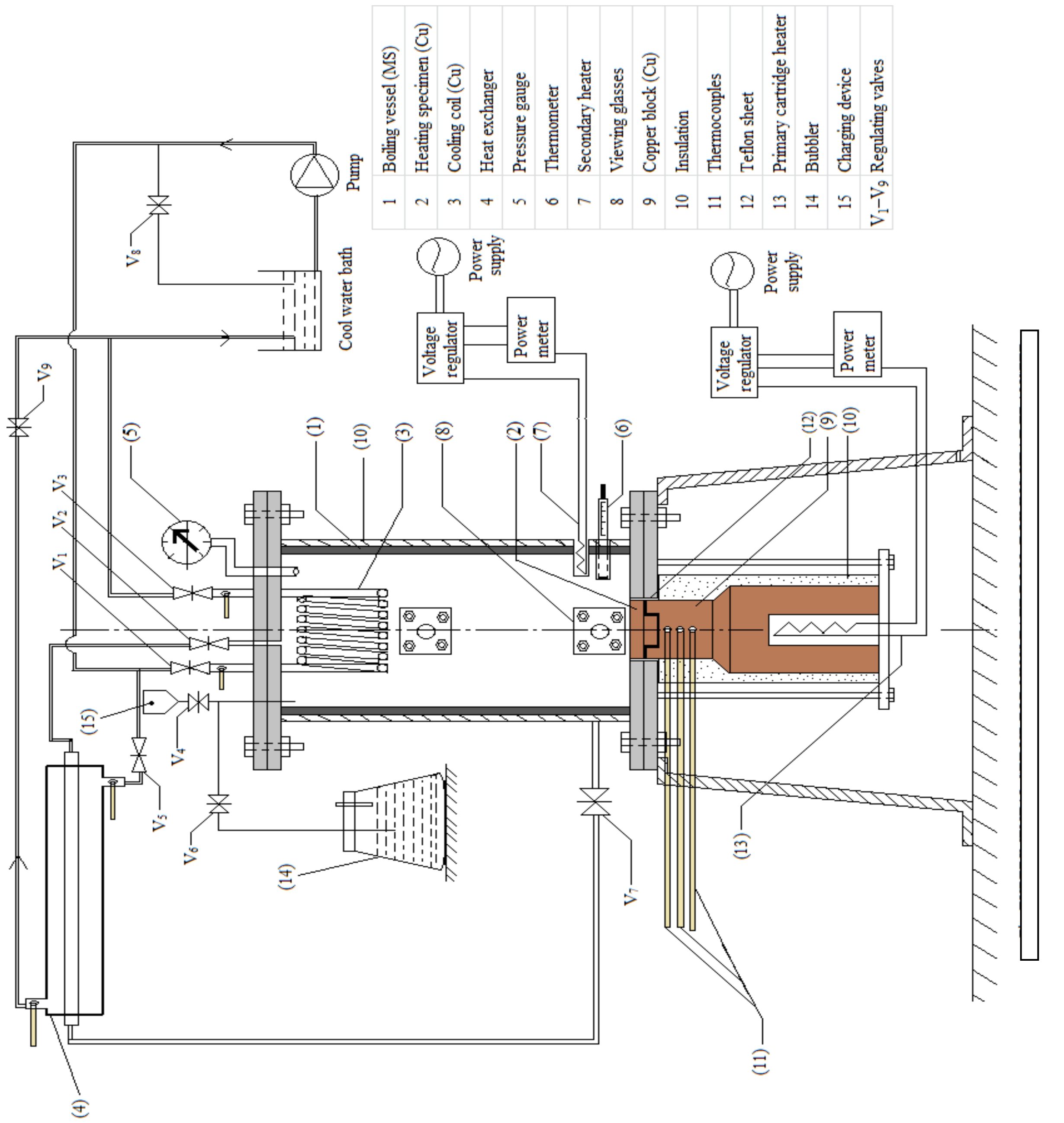

Fig.1 Schematic view of pool boiling experimental set-up

Fig.2 Photographic view of experimental set-up.

The present experimental setup mainly consists of a vertical cylindrical vessel (1) of 305 mm high and 150 mm in diameter holds the pool of (1.5×10^9) mm^3 deep water at atmospheric pressure. The pool boiling heat transfer performance of different heating surfaces is observed by placing four types of test samples (2) inside the vessel. A cooling coil (3) and a heat exchanger (4) are installed to condense the vapor generated from the boiling chamber. A pressure gauge (5), thermometer (6) and secondary heater (7) are attached to the top and side wall of the boiling vessel. To watch the pool boiling phenomena on different heat transfer surfaces three numbers of glass windows (8) are located at different positions of the boiling vessel. At the bottom flange a copper block (9) is provided, which is well insulated to ensure minimum heat loss to the surroundings. The test vessel is totally closed from all sides. The right and left sides of the vessel are bonded with insulating material (10) and top and bottom sides with two circular flanges. Temperature data from the test heater is obtained from the inserted T-type thermocouples (11). The separator (12) is fitted after the heat exchanger to separate the vapours from the condensate and to collect the sample for case study. The Teflon sheet (13) is provided between the heating specimen and the flange walls to avoid the radial heat transfer from the heating surface. For heating the test specimens a primary cartridge heater (14) is inserted into the copper block. During boiling test it should remove the atmosphere air inside the vessel as well as in the pipe lines through vacuum pump (15) connected to the separator, driven by a DC motor (16).To release the non-condensable gases contained inside the boiling vessel and dissolved in the working fluids a bubbler (17) is provided. A charging device (18) is fitted at the top of the vessel for charging the liquid. For proper circulation of test liquid ten numbers of regulating valves (V_1-V_9) are required during boiling experiments.

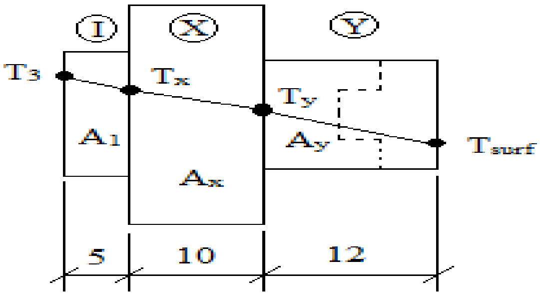

Fig.3 Temperature drop in copper block (all dimensions are in 'mm')

The rate of heat transfer (Q) in section I is calculated using Fourier law of heat conduction

$$Q = (k \times A_I \times \Delta T_I)/t_I; [\Delta T_I = T_3 - Tx]$$

The rate of heat transfer (Q) in section X is calculated using Fourier law of heat conduction

$$Q = (k \times A_X \times \Delta T_X)/t_X; [\Delta T_X = T_X - T_Y]$$

The rate of heat transfer (Q) in section Y is calculated using Fourier law of heat conduction

$$Q = (k \times A_Y \times \Delta T_Y)/t_Y; [\Delta T_Y = T_Y - T_{Surf}]$$

Ohm's Law was used for estimating the input power supplied to cartridge heater.

Q (Power) = V (Voltage) I (Current)

The heat flux q = Q/A; Where A is the cross sectional area.

The heat transfer coefficient $h = q/\Delta T_w$; [$\Delta T_w = T_{surf} - T_{liq}$], from Newton Law of cooling.

3. MODELING AND ANALYSIS

This section illustrates the fabrication process of red brass - based surfaces in order to analyze the heat transfer performance.

3.1 Preparation of surfaces

In this study, four different kinds of surface structures are fabricated: A plain red brass sample prepared by machining process, a polished red brass sample with emery paper of different grit, two red brass samples with TiO_2 nano wire material in nano meter scale by PVD method over their top surfaces. Fig.4 and Fig.5 shows the schematic diagram and a photo of the boiling test specimen.

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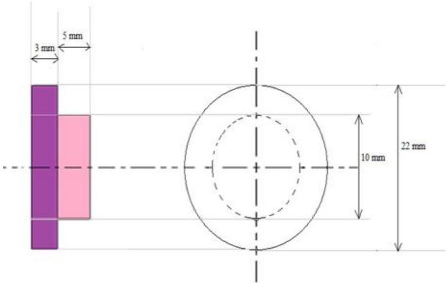

Fig.4: Heating specimen

Fig 5: Photographic view of test specimen

In the present work an experimental pool boiling study was conducted using plain, polished and nano wire surfaces using water as a working fluid. A photographic view of the heating surface (untreated test sample) used for pool boiling test is shown in Fig.5

The uncoated (i.e. polished) surface is made from same plain surface only with some surface modifications. For polished surface the red brass surfaces are initially finishing by using emery wheel. Emery grits of Nos. 150, 400, 600 and1000 were used in polishing wheel to have an almost mirror finish, as shown in Fig.6

Fig.6: Top view of polished specimen TiO_2 nano wire with different nano meter scale was prepared by applying electron beam evaporation method. The schematic of an EBPVD system is shown in Fig.7.Electronbeam physical vapor deposition, yields a high deposition rate from 0.1 µm / min to 100 µm / min at relatively low substrate temperatures, with very high material utilization efficiency.

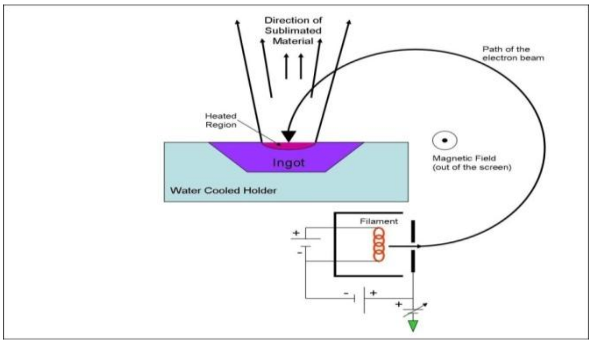

Fig.7: Nanowire by evaporation method Vacuum coating unit model No: 15F6 Producer: Hind High vacuum Co. (p) Ltd)

The growth rate for TiO_2 depositions: 1.2 Å/s.In this work, three red brass-based surfaces, diameter of 22 mm and thickness of 3mm with mirror image 3.2 Contact angle measurement

The change in the surface energy of the boiling surface is characterized by the contact angle of the liquid and vapour phase interface at the heating surface. . A geometric method (Sessile drop method) is employed to determine the contact angles.

Table 1 Contact angles for different surfaces

Sl. No.	Surface type	Contact angle
1	Untreated	82°
2	Treated	93°
3	TiO_2nano wire(250nm)	86°
4	TiO_2nano wire(500nm)	70°

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Fig.a. θ= 82° Fig.b. θ= 93°

Fig.c. θ= 86° Fig.d. θ= 70°

Fig 8: Photographs for water droplet on surface for determining the contact angles.

4. RESULTS AND DISCUSSION The heat transfer characteristics of horizontal red brass surfaces submerged in water were experimentally investigated at atmospheric pressure. In this study boiling experiments were performed to highlight the influence of different types of red brass (Plain, Treated, Titanium oxide nano wire) surfaces and to observe the boiling phenomenon in nucleate pool boiling regime. The experimental data were plotted in pool boiling curves at heat flux varied from 57.89 W/Cm^2 to 151.57 W/cm^2.The experiment was first carried out at different heat inputs (220w, 260w, 300w 340w, 380w, 420w, 460w and 500w) keeping pressure constant at atmospheric pressure. For every run, load was changed and the corresponding temperatures were noted.

4.1 The variation of heat transfer coefficient vs. wall superheat

The heat transfer coefficient appeared to be higher in case of TiO_2 nano wire surface than the other surfaces. The shifting of boiling curve of TiO_2 nano wire surface (250 nm and 500nm) can be observed in fig 9 i.e., the vertical slope of boiling curve of TiO_2 nano wire surface is comparatively higher than the other boiling curves. The surfaces, which are treated and modified showing significant enhancement as compare to the untreated surface. It was observed that, the wall superheat for the plane surface was much higher than the nano wire surface.

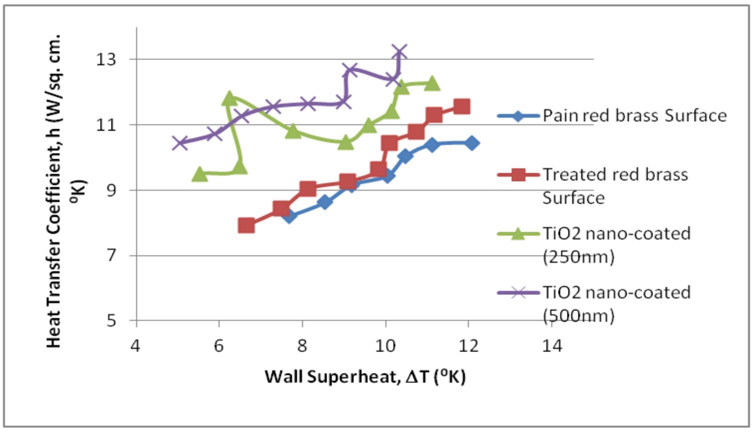

Fig. 9: Boiling curve for Plain, Treated and Nanowire Surfaces

4.2 Boiling curves of tested surfaces: The experiments were carried out for red brass surface (plain, treated and Titanium oxide nano wire) with water, in nucleate pool boiling regime. The curves were drawn for the heat flux versus the wall superheat (ΔTw) for different types of surface (plain, treated and nano wire) and water combination. The heat flux and wall superheat values were follows the ordinate and abscissa axes respectively. The wall superheat was increasing with the increased values of the heat flux for all the surfaces. This increment was significantly higher in case of plain surface and lower for nano wire surface (500 nm) as shown in fig 10.

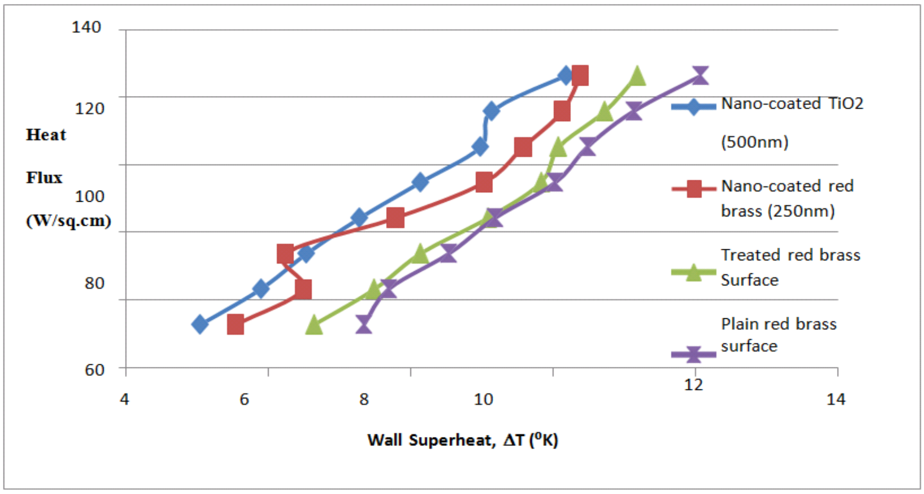

Fig 10: Cumulative Curves showing relation between Heat Flux and Wall Superheat for plain, treated, and nano wire red brass.

4.3 Variation of contact angles with respect to surface roughness:

The magnitudes of contact angles and surface roughness's were tabulated in table 2

Table 2: Change of contact angle

Contact angle	Surface roughness (m)
82^{o}	0.114
93^{o}	0.0501
86^{o}	0.0440
70^{o}	0.168

Surface roughness (m)
0.114
0.0501
0.0440
0.168

The roughness was measured to be 0.112, 0.0493, 0.0450and 0.173 m (after boiling) for plain, treated, 250nm nano wire surface and 500nm nano wire surfaces respectively to fit the boiling curve. The nano wire surface (500 nm) was showing lower contact angles than the other tested surfaces.

4.4 Effect of nucleate pool boiling on surface characteristics:

The surface roughness is appeared to be increased in case of nano wire surfaces after boiling. A dissimilar observation was made in case of plain and treated surfaces i.e., the surface roughness was decreased initially and increasing gradually with the increasing coating thickness, after boiling process due to the heat treatment occurred.

5. CONCLUSIONS

The nucleate pool boiling experiments were carried out within the heat flux range of 57.89 W/Cm^2 - 151.57 W/Cm^2, at atmospheric pressure. The heat transfer coefficient was significantly influenced by the surface modifications and they are characterized by the contact angles. The experimental results and their influences were described in results and discussion. The following conclusions were derived from the results and discussion chapter;

i) The experimental results disclosed that the heat transfer coefficient is higher at TiO_2 nano wire surface of 500nm. Among all four types of red brass surfaces the wall superheat temperature is highest in case of plain red brass surface at same heat flux.

ii) For TiO_2 nano wire (500nm) surface maximum of 48.61% enhancement was observed from the plain red brass surface at reduced heat fluxes about 57.89W/Cm^2.

iii) For TiO_2 nano wire (250nm) surface maximum of 37.26% enhancement was observed from the plain red brass surface at medium heat fluxes about 74.53W/Cm^2.

iv) For plain surfaces maximum of 10.58% enhancement was observed.

v) Also it has been seen that the surface irregularities influences the boiling heat transfer significantly like, for higher surface roughness a reduced heat transfer coefficient was observed. The data of the surface roughness on various test surfaces were observed by Taylor Habson (CCI). The BHT can enhance on nano wire considerably, though the roughness is higher than the treated red brass surface.

vi) Through the measurements of contact angle of liquid on different red brass surfaces it is concluded that enhancement of wettability is an effect of test surface condition which plays an role in boiling heat transfer mechanism. From the present results it can be observed that the treated surface deteriorates the surface wettability because of high values of contact angle as compared to the all other surfaces. Therefore the treated surface can be considered as a hydrophobic surface.

6. REFERENCES

[1] Renkun Chen, Ming-Chang Lu, Vinod Srinivasan, Zhijie Wang, Hyung Hee Cho, and Arun Majumdar. "Nanowires for enhanced boiling heat transfer." *Nano Lett.*, Article ASAP • DOI: 10.1021/nl8026857

[2] Han Gil Na, Dong Sub Kwak, Yong Jung Kwon, Hong Yeon Cho, and Chongmu Lee, Hyoun Woo Kim. "TiO_2/SiO_x Core-Shell nanowires generated by heating the multilayered substrates." Met. Mater.Int. Vol. 19. 4 (2013). pp. 861-867.

[3] XU Jia, YANG Mingjie, XU JinLiang & JI XianBing. "Vertically Oriented Nanotube arrays with different anodization times for enhanced boiling heat transfer". Sci China Tech Sci, 2012, 55: 2184-2190.

[4] Liu Y, Ji G, Wang J, Liang X, Zuo Z and Shi Y (2012) Nanoscale Res.Lett. 7, 663.

[5] Yiying Wu and Peidong Yang "Zermanium nanowire growth via simple vapour transport." *Chem. Mater.* 2000, *12,* 605-607

[6] Z. Yao, Y.-W. Lu, S. G. Kandlikar. "Pool Boiling Heat Transfer Enhancement Through Nanostructures on Silicon Microchannels." Journal of Nanotechnology in Engineering and Medicine AUGUST 2012, Vol. 3 / 031002.

[7] Wu, W., Bostanci, H., Chow, L. C., Hong, Y., Su, M., and Kizito, J. P., Nucleate Boiling Heat Transfer Enhancement for Water and FC-72 on Titanium Oxide and Silicon Oxide Surfaces, International Journal of Heat and Mass Transfer,vol. 53, pp. 1773–1777, 2010.

[8] Y. Tang, B. Tang, Q. Li, J. Qing, L. Lu and K. Chen, Pool boiling enhancement by novel metallic nanoporous surface, Exp. Thermal fluid science, Vol.44, pp.194-198, 2013.

[9] S. Vemuri and K.J. Kim, Pool boiling of saturated FC-72 on nano-porous surface, Int. Comm. Heat mass transfer, Vol.32, PP.27-31, 2005.

[10] R.N. Hedge, S.S. Rao and R.P. Reddy, Studies on nanoparticle coating due to boiling induced precipitation and its effect on heat transfer enhancement on a vertical cylindrical surface, Exp. Thermal fluid science, Vol.38, PP.229- 236, 2012.

[11] Das, S.K; Putra, N; Roetzel, W. pool boiling characteristics of nano- fluids, Int. J Heat and Mass Transfer, Vol.46, PP.851-862 2003.

[12] Das, S.K; Putra, N; Roetzel, W. pool boiling of nanofluids on horizontal narrow tubes, Int J Multiphase Flow, Vol.29, PP.1237-1247, 2003.

[13] Bang, I.C; Chang, S.H. Boiling heat transfer performance and phenomena of Al_2O_3-Water nano-fluids from a plain surface in a pool, Int J Heat Mass Transfer, Vol.48, PP.2407-2419, 2005.

[14] You, S.M; Kim, J.H; Kim, K.M. Effect of nanoparticles on critical heat flux of water in pool boiling of heat transfer, Appl PhysLett, Vol.83(16), PP.3374-3376, 2003.

[15] Zhou, D.W. Heat transfer enhancement of copper nanofluid with acoustic cavitations, International Journal of Heat and Mass Transfer, Vol.47, PP.3109- 3117, 2004.

[16] Vassallo P; Kumar R; D'Amico, S. Pool boiling heat transfer experiments in silica-water nano-fluids, Int J Heat Mass Transfer, Vol.47(2), PP.407-411, 2004.

[17] M.N. Golubovic, H.D. M.Hettiarachchi, W.M. Worek, W.J. Minkowycz. Nanofluids and critical heat flux, experimental and analytical study, Applied Thermal Engineering, Vol.29, PP. 1281-1288, 2009.

[18] Ding, Y; Chen, H; Wang, Liang; and Yang, C.Y.Yurong, W.Yang, W.P. Lee, L.Zhang and R.Huo, Heat Transfer Intensification using Nanofluids. KONA, Vol.25, 2007.

[19] Z. Liu, L. Liao, Sorption and agglutination phenomenon of Nanofluids on a plain heating surface during pool boiling, International Journal Heat and Mass Transfer, Vol.51,PP.2593-2602, 2008.

[20] Wen, D and Ding, Y. Experimental investigation into the pool boiling heat transfer of aqueous based alumina nanofluids, J Nanopart Res, Vol.7, PP.265-274, 2005.