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A review on Augmentation of heat transfer in pool boiling Process

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Abstract- *Surface orientation and roughness of heater surface has a significant impact on boiling process. Roughened surfaces have increased number of nucleation sites and wide variation in size of cavities and thus enhancing boiling heat transfer. The current study is based on the literature review of the experimental investigation showing effect of surface textures on nucleate pool boiling heat transfer for various mixtures with varying concentration. The roughned surface shows higher heat transfer coefficient than smoother one. When test heater surface is sufficiently rough, there is no benefit on adding roughening.*

Keywords- *Pool Boiling, Heat Transfer, Surface Texture, Surface Orientation*

1. INTRODUCTION

Boiling is the liquid to vapor phase change phenomenon occurs at solid-liquid interface when a liquid is brought into contact with a surface maintained at a temperature T_s sufficiently above the saturation temperature T_{Sat} of the liquid. It is the rapid vaporization of a liquid, which occurs when a liquid is heated to its boiling point, the temperature at which the vapor pressure of the liquid is equal to the pressure exerted on the liquid by the surrounding atmosphere. The boiling techniques are used in various industries like thermal, refrigeration and air conditioning, production etc. The interest in enhanced heat transfer is closely tied to energy prices. There are many parameters which affect the boiling phenomenon. Surface roughness and orientation of heater surfaces are among important parameters which affect boiling process. Surface roughness not only affects superheat required for boiling but also the slope of boiling curve. Rougher surfaces resulted in lower superheats for given heat flux, which are attributed to presence of larger unwetted cavities on the rougher surfaces. The aim of present work is to provide insights into role of surface roughness on nucleate pool boiling with an experimental exploration using with two fluids Distilled water and varying concentration of ethanol as additive.

There are some techniques to increase the heat transfer rate in pool boiling like Passive technique, Active technique and compound techniques. Passive technique requires no direct application of external power. For example, treated or rough surfaces on heating element to increase number of nucleation sites. An active technique requires external power. For example, additives or surfactants to reduce surface tension of liquid and hence heat transfer rate increases. Compound techniques involve use of two or more of above techniques simultaneously to enhance heat transfer that is usually larger than the individual techniques. The current study uses compound technique of heat transfer enhancement. It involves use of both rough surfaces and additive for heat transfer enhancement.

Surface orientation has a greater impact on boiling process. Previous investigations indicated that the critical heat flux and minimum heat flux decrease when surface is inclined. The aim of present work is to provide insights into role of surface orientation on nucleate pool boiling with an experimental exploration using various mixtures in upward facing region (0° -60°) and downward facing region (>165°). The current study is based on pool boiling techniques which are used in various industries like processing, thermal, refrigeration and air conditioning, production etc. Due to the energy crisis problem, the aim is to reduce the energy required for phase change during the pool boiling. The current study can be used to save the energy required for boiling by increasing heat transfer rate.

2. LITERATURE REVIEW

.Jones et.al. [1] have experimentally studied the effect of surface roughness on pool boiling heat transfer over a wide range of roughness values in water and Fluorinert FC-77.The test surfaces ranged from the polished surfaces having average roughness value 0.027 µm to 0.038 µm to electrical discharged machined surfaces with roughness ranging from 1.08 µm to 10 µm. A total of six test pieces of varying surface roughness were fabricated. Separate test pieces were manufactured with a polished surface for use in water and FC-77 experiments. In both cases, the polishing was achieved using successively finer grits of sandpaper. The other test pieces were manufactured with surfaces roughened to varying degrees. Different trends were observed in heat transfer coefficient with respect to surface roughness between the two fluids on the same set of surfaces. For FC-77, the heat transfer coefficient was found continuously increase with increasing roughness. For water, EDM surface of intermediate roughness displayed similar heat transfer coefficient that were higher than for the polished surface ,while the roughest surface showed the highest heat transfer coefficients. For FC-77 roughest surface produced 210% higher heat transfer coefficients than polished surface while for water, more modest 100% enhancement was measured between the same set of surfaces.

Harish et al. [2] have proposed that the pool boiling characteristics of nanofluids is affected by the relative magnitudes of average surface roughness and the average particle diameter. An attempt has been made to study the interactions between nanoparticle and heater surface. Experimental methodology accounts for transient nature of boiling phenomena. The boiling curves of electro-stabilized Al_2O_3 water based nanofluids at different concentrations on smooth and rough heaters and burn out heat flux have been obtained experimentally. Experimental results show that different values of surface particle interaction parameter can lead to either splitting or plugging of surface cavities thereby enhancing or deteriorating boiling heat transfer. Fig. 1 shows schematic of heat flux test facility used.

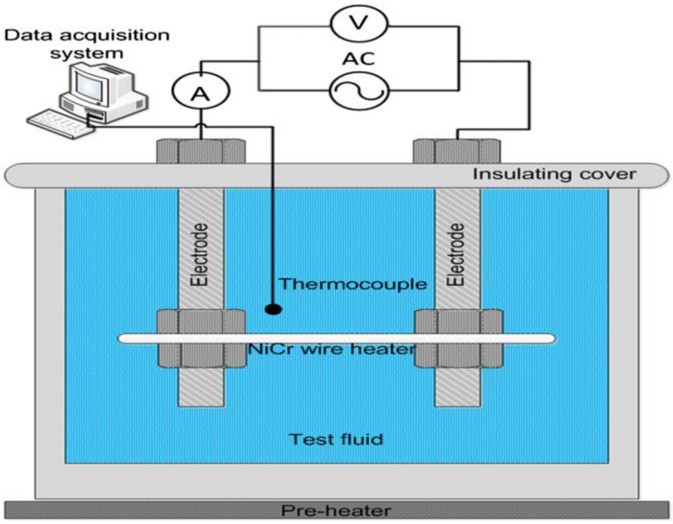

Figure1. Schematic of heat flux test facility

Luke [3] has studied by experiments that roughness of heating surface has significant influence on the heat transfer coefficient. Experiments have been conducted with propane boiling on single horizontal copper and steel tubes with different surface roughness (emery ground, fine or rough sandblasted).The results can be correlate in preliminary manner by no longer separating the influence of surface roughness from the other parameter in empirical prediction method. A detailed description of three surfaces on steel tube examined is given, with surface profiles, quasi three dimensional topography presentation, SEM photographs, and with the statistical analysis of a selected roughness parameter. Results shows that the effect of surface roughness on heat transfer decrease with increasing pressure and with increasing heat flux. The densities of active nuclease calculated from the heat transfer measurements using model assumptions for the heat transfer near growing and detaching bubbles on horizontal evaporator tubes react sensitively on input data of departure diameter (d_A) and frequency (f) of bubbles.

Kang [4] have studied the effect of surface roughness on pool boiling heat transfer, the experiments were carried out for the saturated pool boiling of water at atmospheric pressure. The experimental results show that increased surface roughness enhances heat transfer and its effect is magnified as the orientation of a tube changes from the horizontal to the vertical. In addition, it is identified that the increase in the ratio of a tube length to its diameter magnifies the effect of surface roughness on pool boiling heat transfer.

Hubner and Kunstler [5] have investigated the pool boiling heat transfer from finned tubes with different shapes of fins (Trapezoidal–shaped, T-shaped, Y-shaped) to various hydrocarbons and partly fluorinated hydrocarbons. Compared to corresponding measurements on plain tube, the heat transfer on traditionally finned tubes with trapezoid shaped fins is considerably improved and even better results are achieved with T-shaped and Y-shaped fins. The influences of macrostructure (fin geometry) or microstructure (surface roughness) on the heat transfer coefficient have been studied separately, in order to evaluate the improvement the heat transfer by either influence.

Saiz Jabardo [6] proposed the paper which aims at an overview of heating surface microstructure effects on nucleate boiling heat transfer. A comprehensive chronological literature survey is presented followed by an analysis of the results of an experimental investigation. Boiling data of refrigerants R-134a and R-123 on 19 mm diameter copper and brass tubes of average surface roughness varying from 0.07 μm to 10.5 μm have been gathered under the present investigation. Though most of the data confirm previous literature trends, according to which the heat transfer coefficient increases with surface roughness, very rough surfaces present a peculiar behaviour with respect to that of the smoother surfaces (R_a<3.0 μm). Heat transfer performance of very rough surfaces is superior to the smoother ones at low heat fluxes (q<20 kW/m^2). Finally, an analysis of the active cavities density is performed using some models from the literature in order to evaluate the effect of surface roughness in cavity activation.

Hibiki and Ishii [7] studied the significance of the active nucleation site density as an important parameter for predicting the interfacial area concentration in a two-fluid model formulation, the active nucleation site density has been modelled mechanistically by knowledge of the size and cone angle distributions of cavities that are actually present on the surface. The newly developed model has been validated by various active nucleation site density data taken in pool boiling and convective flow boiling systems. The newly developed model clearly shows that the active nucleation site density is a function of the critical cavity size and the contact angle, and the model can explain the dependence of the active nucleation site density on the wall superheat reported by various investigators.

Ahmad et al. [8] studied compound Effect of EHD and Surface roughness in pool boiling and CHF with R-123. Saturated pool boiling of R-123 at 1 bar is studied. The critical heat flux (CHF) was enhanced by modifying the surface characteristics and applying a high intensity electrostatic field, the latter termed as electro hydrodynamic (and abbreviated as EHD) enhancement. The heat flux was varied from very low values in natural convection regime to CHF. Experiments were performed with increasing and decreasing heat flux to study boiling hysteresis without and with EHD. The data from rough surface were compared with earlier data for smooth surface and indicated a significant increase in heat transfer rates.

Howard and Mudawar [9] have studied the effect of orientation effect on pool boiling critical heat flux (CHF) and modeling of CHF near vertical surfaces. Photographic studies of near saturated pool boiling at various surface orientations were conducted in order to determine critical heat flux trigger mechanism associated with each orientation. Based on vapor behavior observed just prior to CHF, it is shown that surface orientations can be divided in to three regions – upward facing, near vertical, and downward facing. It is found that in upward facing region buoyancy force remove the vapor vertically off the heater surface. Near vertical region is characterized by wavy liquid – vapor interface which sweeps along the heater surface. In downward facing region, the vapor repeatedly stratified on the surface, greatly decreasing CHF.

Kandlikar [10] have studied theoretical model to predict pool boiling CHF incorporating effects of contact angle and orientation .A theoretical model is developed to describe the hydrodynamic behavior of vapor –liquid interface of bubble at heater surface leading to initiaton of critical heat flux (CHF) condition. The momentum flux resulting from evaporation at bubble base is identified to be an important parameter.

Lin et al. [11] have studied relative stability of subcooled flow boiling on non-uniformly heated, inclined flat surface. It described the effect of liquid subcooling on the relative stability between nucleate boiling and film boiling on an inclined surface. At each heaters orientation and liquid subcooling of 0- 20 K, the coexisting heat fluxes were found from which equilibrium heat flux was identified . The experimental results indicate that equilibrium heat flux increases with liquid subcooling with maximum occurs at rotating surface by 90^0 from horizontal position.

Kwark et al. [12] have studied the effects of pressure, orientation, and heater size on pool boiling of water with nano-coated heaters. Tests were experimentally conducted to observe the role of average nano particle size, heater orientation, and heater size during pool boiling of water using Al_2O_3 nanoparticle coated flat heaters. Results indicated that pool boiling performance is dependent on parameters tested.

Brusstar et al. [13] have studied the effects of heater surface orientation on critical heat flux ,an experimental evaluation of models for subcooled pool boiling. Experimental results concluded that growth and motion of large bubbles at heat flux levels approaching the CHF are modeled reasonably well by the balance of buoyancy and virtual mass forces acting on spherical bubble growing with constant volumetric generation rate.

Prakash Narayan et al. [14] investigated that there is a significant effect of surface orientation on pool boiling performance and mechanisms, when a pure liquid is boiled over tubular heating surfaces. However, there is no similar study reported in literature for pool boiling of nanoparticle suspensions. This paper investigates the effect nanoparticle, suspended in pure liquids, can have on nucleate pool boiling heat transfer at various surface orientations. Systematic experiments were conducted on a smooth tube (average surface roughness 48 nm) of diameter 33 mm and length 170 mm at various inclinations (0^0, $45^0$and 90^0). Electro-statically stabilized water-based nanoparticle suspensions containing alumina nanoparticle (primary average sizes 47 nm and 150 nm) of concentrations 0.25%, 1% and 2% percent by weight were used. It has been found that there is a significant effect of surface orientation on the heat transfer performance. Horizontal orientation gave maximum heat transfer and the heating surface, when inclined at $45^{0,}$ gave minimum heat transfer. Further, it was observed that surface-particle interaction and modified bubble motion can explain the behaviour.

Benjamin and Balakrishnan [15] have conducted an experimental investigation on the nucleation density during nucleate pool boiling of saturated pure liquids at low to moderate heat fluxes is described. The surface-liquid interaction during the boiling phenomena and its effect on nucleation site density and thereby heat flux is examined. Stainless steel and Aluminium with different surface finishes obtained by polishing surfaces with different grades of emery paper was used in study. The parameter R_a (The arithmetic average) was used to characterize the surface micro roughness.

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3. EXPERIMENT

1. Nichrome wire is used as test heater. For starting the experiment, experimental set up must be ready with the all accessories required for completing the project. Preliminary things which are carried for doing experiment are as follows.
2. Some liters of distilled water for every test is taken.
3. The solutions of additives of different concentrations are prepared in distilled water.
4. The aqueous solution is heated to saturation temperature by bulk heater. Then the nichrome wire heater is supplied with electrical input.
5. The complete phenomenon is recorded using camera so that bubble behavior can be studied carefully.
6. Procedure is repeated for making the different proportions of additives aquoes solution.
7. Temperature of bulk is measured with thermometer and that of copper tube with thermocouple attached to it.

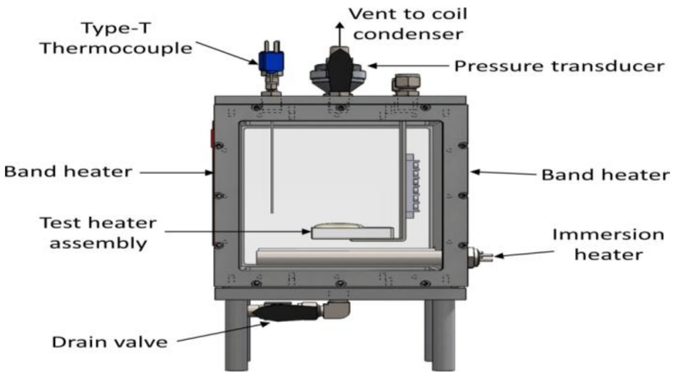
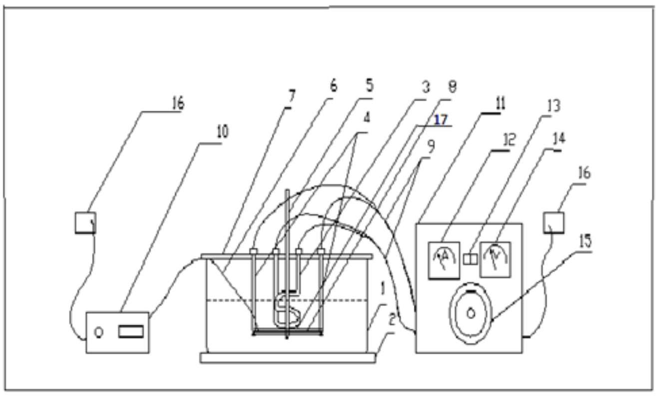


Figure 2: Pool Boilng Apparatus



1.Glass Container **2**.Wooden Platform **3**.Auxilary Heater (R1) **4**.Test Heater (R2) **5**.Thermometer **6**.Thermocouple **7**.Clay Lid **8**.Nichrome Wire **9.**Heater Connecting Cable **10**.Digital Temperature Indicator **11**.Control Panel **12**.Ammeter **13**.Voltage Range Selector Switch **14**.Voltmeter **15**.Dimmerstat **16**.Electric Power Switch **17**.Tube with Different Surface Texture

Figure 3: Experimental setup for pool boiling of water ethanol mixture

8. The project is carried at atmospheric pressure.
   Also, surface orientation readings are taken as follows (Different orientations are given to tube from horizontal to inclined with various inclination angles).
9. Procedure is repeated for different orientations of tube from horizontal to Inclined.
10. Temperature of bulk is measured with thermometers and thermocouple attached to it.
11. The project is carried at atmospheric pressure.

4. CONCLUSIONS

Based on above detailed review on experimental investigations of pool boiling, the following significant conclusions are drawn:

1. For pool boiling of various mixture, rougher tube shows higher heat transfer coefficient than smother one. Intermediate roughness tube shows intermediate enhancement in heat transfer.
2. The improvement in heat transfer coefficient for mixture with some additives is higher than for distilled water.
3. Addition of some additives like Ethanol etc. in water increases heat transfer coefficient to certain concentration, after that the effect is not useful.
4. When surface is sufficiently rough there is no benefit to additional roughening. Intermediate roughness tube shows intermediate enhancement in heat transfer.
5. Surface orientation has significant effect on pool boiling heat transfer enhancement.
6. Two or more pool boiling enhancement techniques may be utilized simultaneously to produce an enhancement that is usually larger than the individual techniques applied simultaneously, called as compound techniques of enhancement.

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