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A Comparative Study on Various Boiling Heat Transfer Enhancement Techniques

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Abstract-In this paper a brief review on the various boiling heat transfer enhancement techniques is presented. A comparison of all techniques was made based on their application in the industrial level application and the methodology adopted. Boiling heat transfer coefficient and critical heat flux were identified as the parameters that have to be analyzed in each technique. The experimental results obtained in various techniques were analyzed and summarized.

Index Terms: boiling heat transfer, critical heat flux, heat transfer coefficient, nano/micro porous structure.

1. INTRODUCTION

Removal of heat has become a critical issue in various fields like steel industry, nuclear industry, micro devices, and thermal control process of power equipments. The thermal systems are now a day is being working at higher efficiency compared to the ancient days. Hence the necessarily to remove the heat has also become a issue. Here arises the question, efficiency of heat removal systems? Various researches methods are now a days passing based on the effective heat removal. Which includes, surface machining, chemical process on heating materials, surface coating. All the above mentioned processes aim to make the heating surface porous. So that the surface area will get increased and it can leads to increase the number of nucleation sites.

Most of the research outcomes is found with various techniques that makes the boiling surfaces porous also various fluids are taken boiling medium. The effect of nano structured surfaces on oiling characteristics has been the subject of much research. Nanoparticles deposition on boiling surface enhances the critical heat flux [1]. Research found out that introduction of free particles on to the boiling surface will enhances the critical heat flux and the pool boiling heat transfer rate [2]. Variations of output with respect to the different particle size are also studied and result shows that the particle diameter of 3 and 6 millimeter have the greater enhancement. Critical heat flux enhancement is achieved using modulated porous coating, is done by [3] scott g and massoud kaviany. Here critical heat flux has been increased by three times. It explained in terms of liquid vapor counter flow. A modulated porous coating can separate liquid and vapor thus it reduces the liquid vapor counter flow resistance at the boiling surface.[4] Liang z et al made a study on influence of heater thermal capacity on bubble dynamics and heat transfer in boiling heat transfer. The effect of material parameters of wall, and wall thickness on growth time and departure diameter of bubble was analyzed. He concluded that there is some growth diameter and departure diameter varies with respect to the increase in the wall thickness.Investigation on effect of pool boiling heat transfer enhancement on the micro poros structure was done by yong t et al [5]. In his experiment the heating range was fixed from 15 kw/m^2 to 90 kw/m^2 .according ti him the maximum enhancement in heat transfer coefficient was achieved for the heat flux of 20 kw/m^2(63.3%). Li and Peterson [6] investigated sintered copper wire screens of varying thickness volumetric porosity, and mesh size to determine the dependence of boiling performance on these geometric parameters.Sujith et al[7] made an experimental investigation on flow boiling heat transfer enhancement using spray pyrolysed alumina porous coatings. Enhancement of 28.3% in the heat flux was observed for the 300 C spray pyrolysed alumina coated sample compared to the bare Cu sample, for a lower mass flux of 88 kg/m^2s.

All the research out comes related to the enhancement of BHT arrives at a common conclusion that, the micro porous surface can increase the surface wettability, departure bubble diameter and thus increases the nucleation sites density also the departure frequency(1,2, 3,4)

2. BOLING HEAT TRANSFER

During boiling heat transfer there occur various stages among which the nucleate boiling is the area where most of the researches are concentrating why because this is the stage where there occur large amount of heat transfer with less economy. Nucleate boiling heat transfer coefficient (NBHTC) is the parameter that gives the rate of heat transferring to a medium. Some of the research outcomes gives various correlations on this. Jakob[8], who first studied the effect of surface roughness on the boiling of water, found that a surface with a square grid of machined grooves improved boiling heat transfer by approximately 300% compared to a smooth surface. So thus the boiling heat transfer enhancement on a rough surface was first established by him. All the researches on the same helped to relate the BHT as a function of morphology of the heating surface.

Critical heat flux is the highest heat value which is considered during the nucleate boiling heat transfer. Critical heat flux is the parameter that is to taken into consideration while experimenting the higher heat input also it includes much more complication while experimenting. Saeidi et al[9] reported the enhancement in critical heat flux on a nano structured aluminum substrate. According to him critical heat flux has increased by 8% when compared to that of unstructured aluminum.

3. EXPERIMENTATION

Experimenting a technique to find the boiling enhancement is usually done by, setting up an experimental setup and doing the boiling experiment on a bare surface and modified surface. The boiling heat transfer coefficients achieved in both substrates are then compared. Before starting the experiment one has to fix the size of the substrate, fluid, heating range and power of the heating element. Somehow the above factors are having some relations between each other. Maximum heat fluxes that can be supplied have to be calculated by analyzing the substrate area and the power of heat source. Two methods of doing boiling experiments are as follows:

a. Experimenting up to the critical heat flux, heating source should have the capacity to reach the heat flux up to the critical heat flux of the fluid in the boiling chamber. To accomplish this, the following have to be satisfied

$$w/a \geq f_{CHF} \quad (1)$$

So that it is preferred to use the fluids which is having less critical heat flux for low power heat source. Saeidi et al [9] carried out an experimental investigation of pool boiling heat transfer on nano structured surfaces and measured the critical heat flux.

b. If Experimentation does not have regulation to heat up to critical heat flux then the heat input range has to be fixed. While fixing the heating heat range, the lower input heat flux should be able to achieve the surface temperature greater that the saturation temperature of the fluid. Lower limit of heat input can be fixed using the following equation.

$$\frac{V \times I \times X}{K \times A} + T_{X=0} = T_{SAT} + 1 \quad (2)$$

Equation (2) is a modified form of Fourier law. Finally readings are taken at the steady state, for each heat input. yong et al[5] investigated on pool boiling heat transfer enhancement by novel metallic nano porous surface. According to the experimentation the heating range was initially fixed the lower heat input was 15 kw/m^2.

3.1 Fabrication of Substrate

In boiling heat transfer experiments, the substrates can be fabricated using the following methods:

3.1.1. Fabrication of substrates by machining

Maching of substrate is usually done by sand blasting ,emery papers with different grain size cutting groves of different shape and size. Depending on the size of the grains roughness on the surface will be varied, which varies the boiling heat transfer rate.

Benjamin and balakrishna[10] made an experimental investigation on surface with various roughness on stainless steel and aluminum as the substrate. Roughness was varied using emery papers of different grains. They reported that roughness ranges from 0.2-1.17mm have the maximum enhancement.

3.1.2. Fabrication of substrate using coating techniques

It is observed that researchers adopting the coating process to modify the substrate to ensure that the is free from the deformation other than at its surface. There are many coating techniques on which the surface can be coated listed out, spray pyrolysis, calcinations, boiling of coating solution, vapour deposition are some common techniques. Also the metal oxides, varbon nanotubes, nano particles are the coating substance.

Sujith et al [6]made an experimental investigation on flow boiling heat transfer enhancement using spray pyrolysed alumina porous coatings. enhancement of 28.3% in the heat flux was observed for the 300^{o}C spray pyrolysed alumina coated sample compared to the bare Cu sample, for a lower mass flux of 88 kg/m^{2}s

3.1.3. Fabrication of substrate by chemical processes

Anodisation and etching are the commonly adopted chemical processes for the fabrication of substrate. It is well known that both processes can improve the wettability of the substrate thus the boiling heat transfer rate

A brusly et al[16] made a thermal performance analysis of an anodized two phase closed thermosyphon. According to him nucleation sites present on the anodized surface are 2-3 times higher than the ordinary surface.

4. RESULTS

It is observed that the nucleation site density, bubble departure diameter, surface wettability, have a great impact on the boiling heat transfer. Hence it is encouraged to increase the above factors to improve the boiling heat transfer. Also a surface with porosity will can improve the above mentioned factors and thus increase the boiling heat transfer rate. So the research outcomes are with different methods to improve the surface roughness and the wettability.

The boiling curve of experiment done by kim et al [2] is shown in the fig 3. This is a kind of experimentation in which there the input heat is regulated upto the critical heat flux . Figure 1and 2 shows the visualization of FC-72 on polished surface and free particle surface. In this BHT is enhanced using the free particle technique and maximum enhancement is obtained for particle of 10 micro meter. To enhance the NBHT changing the shape of the cavities can improve the, the formation of reentrant cavities can increase the nucleation sites and thus increase the NBHT. [11,12,13]

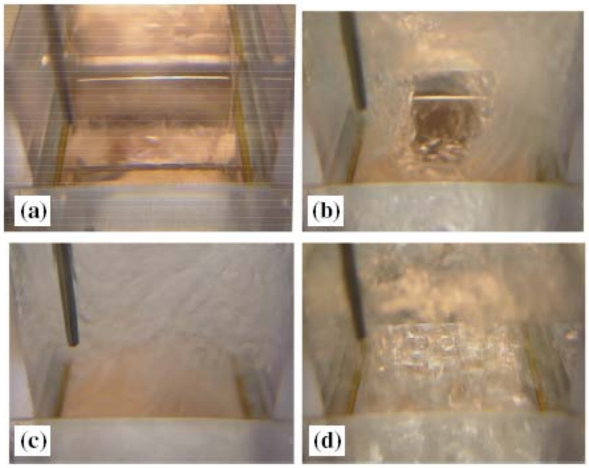

Fig 1 Visualization of boiling ofFC-72 on polished surface at a)22 kw/m^2 b)33 kw/m^2 c)71kw/m^2 d)146 kw/m^2

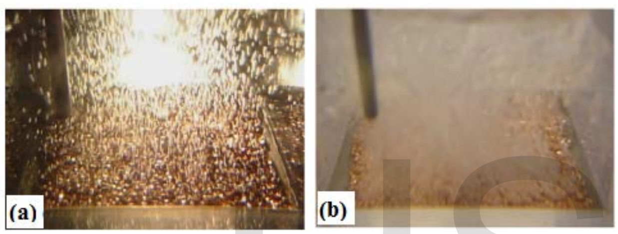

Fig 2 Visualization of boiling ofFC-72 with free particle size 3g of 0.6-0.8 mm at a) 5.7 kw/m^2 b) 24 kw/m^2.

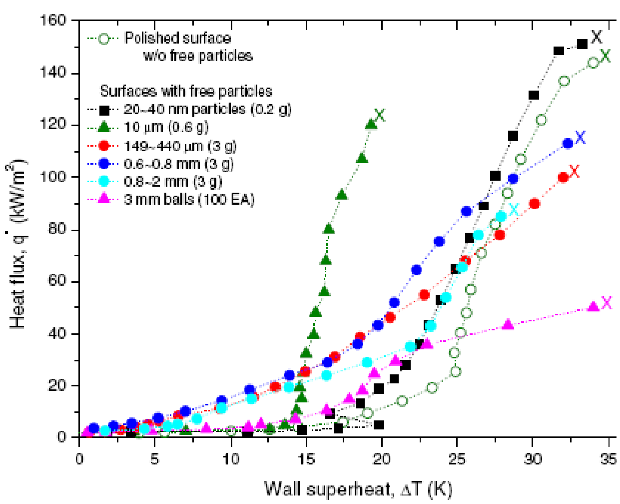

Fig 3

Suraj at al [14] made a quantitative measurement of bubble diameter at departure, nucleation sites density and departure frequency on micro porous copper surface. It is now then compared with that of plane surface. According to him micro porous surface with coating thickness in the range 100-700µm, porosity of 55-60% and cavity size in the range of 0.5-5µm have significant enhancement of critical heat flux of 33-60% and heat transfer coefficient enhancement of 50-270%.

Yong et al[5] made an investigation by dealloying copper substrate to achieve the microporous surface. In his experiment the heat flux range was 15 kw/m^2 to 90kw/m^2, maximum heat reduction achieved was 63.3% at a heat flux near 20kw/m^2 . pool boiling experiments done by yao et al[15,16] on silicone wafers with micro/nano structures gives a higher NBHT than the plane surface. It is explained with the fluid surface contact area at different structured heater surface fig(4).

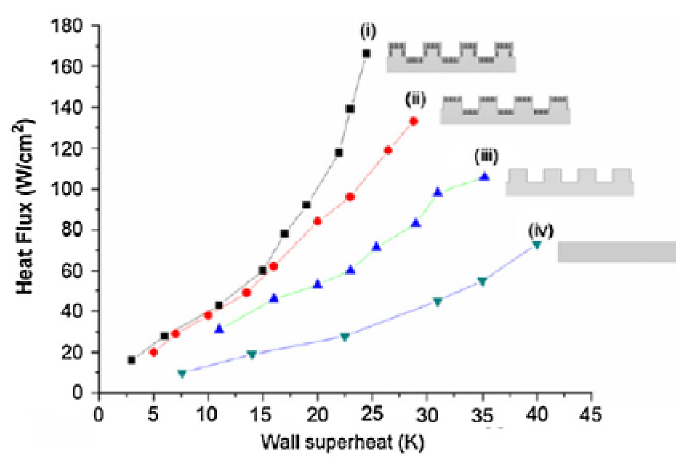

Fig 4

It is observed that the techniques which provide micro/nano structured surface can provide an enhancement in the boilng heat transfer rate. Sol gel dip coating techniuqe is yet another coating techniuque which has the characteristic of yielding aporous surface. However, the application of this technique in enhancing the boiling heat transfer have not been studied so far and offer a scope for indepth study.

5. CONCLUSIONS

In this paper, a systematic review on the various boiling heat transfer enhancement techniques were carried out and the following conclusions were drawn:

a, A nano/micro porous surface leads to an increase in the nucleation site density.

b, Wettablity of the surface increases in nano/micro porous or roughsurfaceswhich reduces the liquid solid contact angle.

c, The parameters like nucleation site density, bubble departure frequency and surface wettability which favor the heat transfer enhancement will get increased with increase in nano/micro porosity or roughness.

d, Apart from the above mentioned enhancing techniques, a method which provide nano/micro porous or roughness can enhance the boiling heat transfer rate.

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