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Experimental Investigation of Pool Boiling: Effect of Microscale Roughness

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ABSTRACT

This research paper tells about the how the surface characterization can affect the boiling heat transfer. Enhancement of pool boiling performance have been recognized as a critical thing to increase the performance of the boiling heat transfer by the ideal surface geometries. Instead of that this experiment was performed on the different roughness such as 1000 and 1200 grades of emery paper. Majorly, Copper polished surfaces are used to enhance the heat transfer coefficient in the two-phase heat transfer method. X-ray diffraction, scanning electron microscopic (SEM) are used to study the surface engineering. Increasing the thermal conductivity is one of the major problems in the field of thermal science and energy engineering. So, finally we can get the enhancement in boiling performance and also the increase of the critical heat flux and the heat transfer coefficient when the surface roughness is decreased.

KEYWORDS

Critical Heat Flux, Thermal Conductivity, Heat Transfer Rate, Pool Boiling, Surface Roughness.

Introduction

Pool boiling is one of the most widely using method of heat transfer for giving the cooling purpose in nuclear power plant and electronics component cooling. Pool boiling is one of the heat transfer method ability to transfer heat from the heating surface and can cool the surface. There are many types of process to make the heat transfer efficient. In this paper, we are introduced that the nanostructure surface as a interface of liquid and solid.

Hangjin et al. [1] reported that the hydrophobic surfaces better than hydrophilic surfaces. [2] The temperature fluctuation can appear only in the hydrophilic surfaces. Chin et al [3] says that increase the CHF values whenever the surface is wetted.

In world-wide researchers have studied about the two-phase heat transfer in the horizontal surface. In the earlier stage that they are giving the solution by the nanofluids in pool boiling heat transfer. In this method the deposition of nano particles on the surface is the main reason for the increase CHF. Now we are moving to the nanostructured surface to get an enhancement in the heat transfer rate.

Seongchul Jun et al. [4] reported that nanocoated surfaces gives 6-8 times more heat transfer rate than bare surfaces. Sang M. Kwark et al. [5] says that CHFenhancement is also depending on the surface wettability.

Critical heat flux is an outstanding index in boiling heat transfer. Surface topography is also an affecting factor in boiling heat transfer. CHF is an important standard for the safe performance of the two-phase thermal systems, CHF occurs means the surface temperature gets sudden increases and also it makes the melting of the heated surface. Surface roughness is directly proportional to the heat transfer.

The wettability, surface finish and material are inter-dependent variables. These makes the theoretical descriptions of the pool boiling. Enhancement in pool boiling includes different methods as rough surfaces, treated surfaces, extended surface and different additives for the fluid. It is not feasible to change the working fluid due to different constrains. The high-speed wetting conditions is also based on [5] hydrophilic nature of the coating.

By using the different emery surface, treated surface and different surface characterization method for the augmentation of boiling heat transfer. There are three different types of structures are used that is micro, macro and Nano structured surfaces. Surface coating is also makes some kind of enhancement in the pool boiling heat transfer rate.

Terry J. Hendricks et al. [6] reported that the 10 times improvement was observed when the surface as a nanostructured surface on a bare Al substrate.The heat transfer co-efficient can increase by using the developed materials and surface structure that are used structure has been recognized to play a critical role in the enhancement of nucleate boiling heat transfer. Normally, the heat transfer co-efficient can increase only by the micro cavities on the surface in order to reduce the active nucleation site. Though creating an economic and sustainable process of surface engineering to improve the heat transfer performance.

The objective of this paper is to developing a model to get a increase in heat transfer and also finding the values of surfaces modification with the micro-scale roughness. The copper bare surfaces were having 3 – 8 times lesser than the nano-textured surfaces when comparing to the factors. Many surface modifications used for enhance the CHF and heat transfer rate. Sandpaper, emery-paper, abrasive blasting and porous coatings these are some of the methods used to enhance the heat transfer rate.

In this paper were taken two different surfaces polished by the emery paper such as 1000 and 1200 grade emery paper. The di-water is normally used as a bare surface. As a result of that heat transfer is affected due to the change in surface roughness. We can increase the heat transfer co-efficient by increase in roughness owing to adding more cavities.

The copper is widely used as the heated surface because of their simple and cost-effective. The surface wettability is also placing a major role and classified into two types such as hydrophilic surface, hydrophobic surface. The contact angle is below 90^o, then it is called as hydrophilic surface whereas the contact angle is above 90^o means it's called as hydrophobic surfaces.

When comparing the heat transfer efficiency, the two-phase change heat transfer is better due to latent heat of working fluids. This two-phase change heat transfer is mainly used in nuclear power-plant, electronic chip cooling, etc., Our daily usage of the micro-electronics has made the more amount heat. This thermal management is one of the issue due to the technical challenges. The many researchers have performed the different techniques such as nano coatings, nano fluids, emery surface finished surfaces. The surface finished surfaces have some enhancement in the CHF.

The bubble formation on the surface is one of the reasons for reducing the performance of the heat transfer rate. The key parameters are the influence for determining the heating surface characteristics.

Various surface textures for example nano/micro structures, hierarchical coatings, hydrophilic structures, graphene materials were fabricated to investigate their boiling performances. Finally, in this paper we are made a modification in the heated surface. Moreover, in the nuclear power plants there would be some loss in the coolant. So, it would create a problem in the pressure vessel. Recently, the investigations on different surface. In this paper we are used the microstructure surface as a heater surface to get a CHF enhancement.

Experimental Process

There are main major factors used to enhance the boiling process. There is some kind of micro or nano-size pores present on the surface that makes the nucleation initiation. This porous surface has some cavities. So, the fluids are getting inside to keep nucleation active.

The pool boiling is the process which is characterized by using the bubble dynamics illustrations such as vapor bubble formation and takeoff frequency, vapor bubble diameter, the mean velocity of vapor bubble growth and also surface characteristics. They use the conventional theory for the average heat flux disputation due to the nucleate boiling.

Pool Boiling

The pool boiling heat transfer experiment was performed by the various liquid on the copper surface with different surface roughness. This experimental diagram can explains about the various parts of the experimental setup such as copper heater block, boiling glass vessel, cartridge heaters, high speed camera, cooling system and temperature sensors.

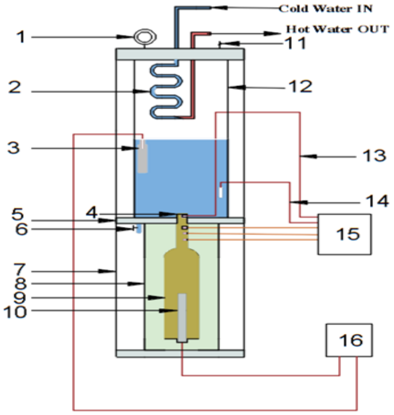

Fig.1

1. Pressure gauge2. Reflux condenser3. Auxiliary heater4. Test surface 5. Teflon Insulation surface6. Drain valve7. Rigid stand8. Glass wool insulation 9. Heater block 10. Main heater11. Pressure relief valve12. Pool boiling chamber 13. Thermocouple for test specimen 14. Thermocouple for water 15. Data logger 16. Power supply unit

This schematic setup of the copper surfaced heater is presented in Fig.2. Forgetting the controllable heat we used the cartridge heaters which is connected to the transformer. For analysing the heat about the heating surface, we are using the three thermo couples such as T1, T2 and T3. These temperatures can view in the acquisition board. The insulations around the copper heater are used which has a thermostability around 450 ◦C. The Teflon and copper surface are been insulated by the silicon glue. The DI water is poured inside the glass vessel and then the calculations are takes place by using this thermo physical properties. Also, a condenser has been used for cooling purpose by letting cold through inlet and hot water in outlet.

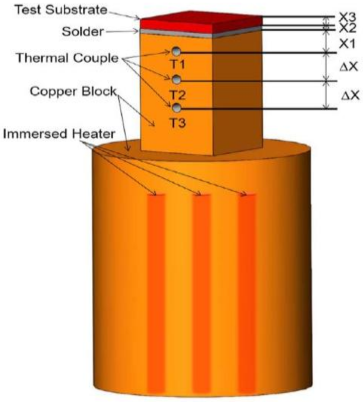

Fig. 2

The below test procedures are performed in this study.
The heat transfer coefficient value has been investigated in the pool boiling heat transfer measurement. Mainly, in this heat transfer experiment the copper is the heated surface. Prepare the surface and heat up the copper heater. At least one hour the DI water has to be heated at the atmospheric pressure.A heat transfer unit of copper along with a heater unit is placed at the lower section of the apparatus, which was then heated up to its saturation temperature 100 ◦C at 1 atmospheric pressure. A condenser are been used inside and on the top of the boiling pool to condense the evaporated water, the experiment conducted under atmospheric pressure. The saturated boiling state of the boiling liquid is maintained by the temperature controller, and the evaporated water is cooled down by the cooling unit with the help of condenser.

At first the entire boiling vessel was heated by an external auxiliary heater surrounding the vessel before starting the boiling experiment for ensuring that the bulk test fluid was kept at a temperature just below the boiling temperature. The test surface (circular dia. 0.009 m) of the top of the copper block and it was directly contacted with test fluid, and Teflon insulation was used to protect the other surfaces from heat loss. The experiment was conducted in steady state condition, while the outer surface temperature of the insulated surface was found to be very close to room temperature. This confirms that no significant radial heat flow was practically occurred.

At the bottom of copper block unit, we have used a cartridge heater. By regulating the input voltage, the heat flux was controlled during the experiments by using a variable transformer unit. Power translator is turned on and it is adjusted using a small increase step at each steady state occurs in the variable transformer. To measure the temperature of heating copper block unit three thermocouples with a diameter of 0.001 m were inserted inside the copper block at three different positions (T1, T2, and T3). The temperatures have been recorded and the data contains T1, T2, T3 and T4 temperature values. The boiling phenomenon and condition at each stable state were recorded using the camera.When the burn-out point attains, the power input from the variable transformer is turned off immediately.

Temperatures (T1, T2 and T3) recorded by three thermocouples which was placed with equal distances in the copper block unit has confirmed the one-dimensional Fourier’s heat conduction law. The linear temperature distribution profile (DT/Dx) was observed and confirming that uniform axial flow of heat transfer. The temperatures Tx, Ty and the surface temperature Ts, at the interface of test liquid is measured using one dimensional heat conduction equation. While the auxiliary heater has turned off, during the experimentthe primary heater was started for the measurement of heat flux and other relevant data.

Surface Preparation

Copper surface that to be tested is taken and for purpose of the fine finishing and polishing of the surfaces it is polished by the different grades of the emery paper. 1000 grit and 1200 grit are the grades of the emery papers. To provide the exact and accurate roughness to the surface the surfaces where been polished in the surface polishing machine. The roughness was tested on the surface tester machines after the polishing of the surface in the polishing machine.

Surface roughness was been tested on the surface tester machine and these were kept on the pool boiling chamber and worked as the boiling surfaces. The heat transfer coefficient was measuredby using the DI water as the working fluid. Due to the change in surface roughnessit is shown that heat transfer is affected. As a result, heat transfer increases in case of the treated surfaces and so surface roughness of the unit plays an important role to produce the nucleation cavity on the heating surface.

The Fig. 3 and Fig. 4represent the surface texture measurements results of the 1000 and 1200 roughness of the copper surfaces.

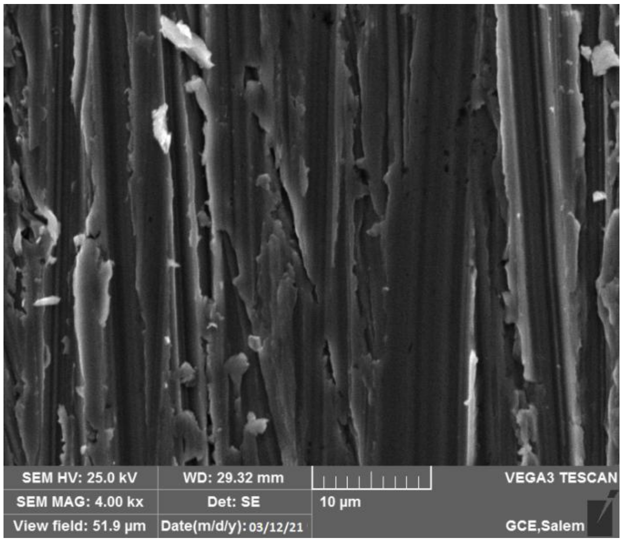

Fig. 3

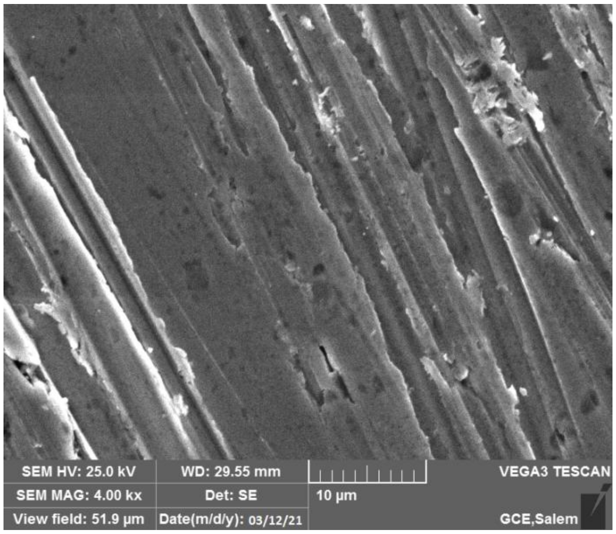

Fig. 4

Characterization

Copper surface where been characterized by employing various advanced techniques for their morphological, structuraland compositional investigations. The morphological studies were done by using the scanning electron microscopic (SEM) measurements, the structural investigations where been carried out by X-ray diffraction (XRD) and the properties were done by using transmission electron microscopic (TEM) measurements.

Results and Discussion

In this section, using two different surfaces finishes in pool boiling experiment have been discussed and explained.
Compared to 1000 surface roughness the 1200grit surface roughness has more nucleation sites. In this manner, compared with other surfaces it shows a better heat transfer comparison. In this way, for the enhancement of boiling heat transfer, surface roughness plays an important role.Other than two surfaces, the surface which has the roughness 1000 shows a better heat transfer. Surface having roughness 1000 shows least HTC, number of nucleation site is less as compared to 1000 surface roughness as its surface is more finished. The enhancement of pool boiling heat transfer

strongly relies upon the nucleation site as vapor bubbles carries the heat from the boiling surfaces and it helps by eliminating vapor bubbles from the surface.
We can increase the heat transfer coefficient and CHF value by changing the wettability nature of the surfaces. The plain surfaces are having high contact angle hysteresis value. The wall superheat temperature can decrease by changing the surface roughness. The normal surfaces are having some cavities. So, it makes the bubble formation on the surface. When we make a smoothen surface then it would not create more bubbles on it.

For analyzing the effect of surface finishes in pool boiling,heat transfer coefficients of distilled water pool boiling and the boiling curves are at different heat flux conditions. Similar behavior of increment in heat transfer coefficient with increasing heat flux and the almost similar boiling curves for various test surfaces has been shown, anywayfor a given heat flux the surfaces finishes the heat transfer coefficient are fundamentally higher. In this manner, with roughness variations an outstanding enhancementin the heat transfer coefficient have been observed. Because of an increase in the number of active boiling sites there is an improvement on the pool boiling heat transfer coefficient in the surfaces.

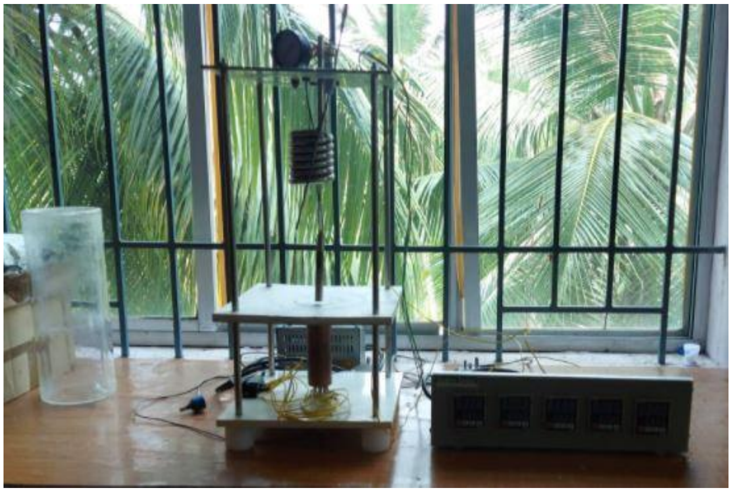

Fig. 5

Table 1

Coppersurface		
Wall Superheat	**HF(W/m2)**	**HTC(W/m2 K)**
5	164911	32982
6	197898	32983
7	231478	33068
8	264842	33105
9	310791	34532
10	360065	36007
11	409982	37271
12	460958	38413
13	510009	39231
14	560125	40009
15	611968	40798
16	664944	41559
17	718189	42246
18	772248	42903
19	827475	43551
20	882478	44124
21	936762	44608

22	991234	45056
23	1045792	45469
24	1095784	45658
25	1143341	45734
26	1191048	45810
27	1238143	45857
28	1264258	45152
29	1292462	44568
30	1322488	44083
31	1366522	44081
32	1365844	42683
33	1429722	43325
34	1462145	43004
35	1506411	43040
36	1552522	43126
37	1596214	43141
38	1622585	42700
39	1679755	43071
40	1698775	42469
41	1694777	41336
42	1709746	40708

Table 2

1000 grit surface		
Wall Superheat	**HF(W/m2)**	**HTC(W/m2 K)**
5	184700	36940
6	221645	36941
7	259255	37036
8	296623	37078
9	348085	38676
10	403272	40327
11	459179	41744
12	516272	43023
13	571210	43939
14	627340	44810
15	685404	45694
16	744737	46546
17	804371	47316
18	864917	48051
19	926772	48777
20	988375	49419
21	1049173	49961
22	1110182	50463
23	1171287	50926
24	1227278	51137
25	1280541	51222
26	1333973	51307
27	1386720	51360
28	1415968	50570
29	1447557	49916
30	1481186	49373
31	1530504	49371
32	1601288	50040
33	1637602	49624
34	1687180	49623
35	1738824	49681
36	1787759	49660

37	1767891	47781
38	1817295	47824
39	1881325	48239
40	1902628	47566
41	1898150	46296
42	1914915	45593

Table 3

1200 grit surface		
Wall Superheat	**HF(W/m2)**	**HTC(W/m2 K)**
5	203170	40634
6	243809	40635
7	285180	40740
8	326285	40786
9	382893	42544
10	443599	44360
11	505096	45918
12	567899	47325
13	628331	48333
14	690074	49291
15	753944	50263
16	819210	51201
17	884808	52048
18	951408	52856
19	1019449	53655
20	1087212	54361
21	1154090	54957
22	1221200	55509
23	1288415	56018
24	1350005	56250
25	1408595	56344
26	1467370	56437
27	1525392	56496
28	1557564	55627
29	1592312	54907
30	1629304	54310
31	1683554	54308
32	1761416	55044
33	1801362	54587
34	1855898	54585
35	1912706	54649
36	1966534	54626
37	1999024	54028
38	2069457	54459

39	2072890	53151
40	2085698	52142
41	2087965	50926
42	2106406	50153

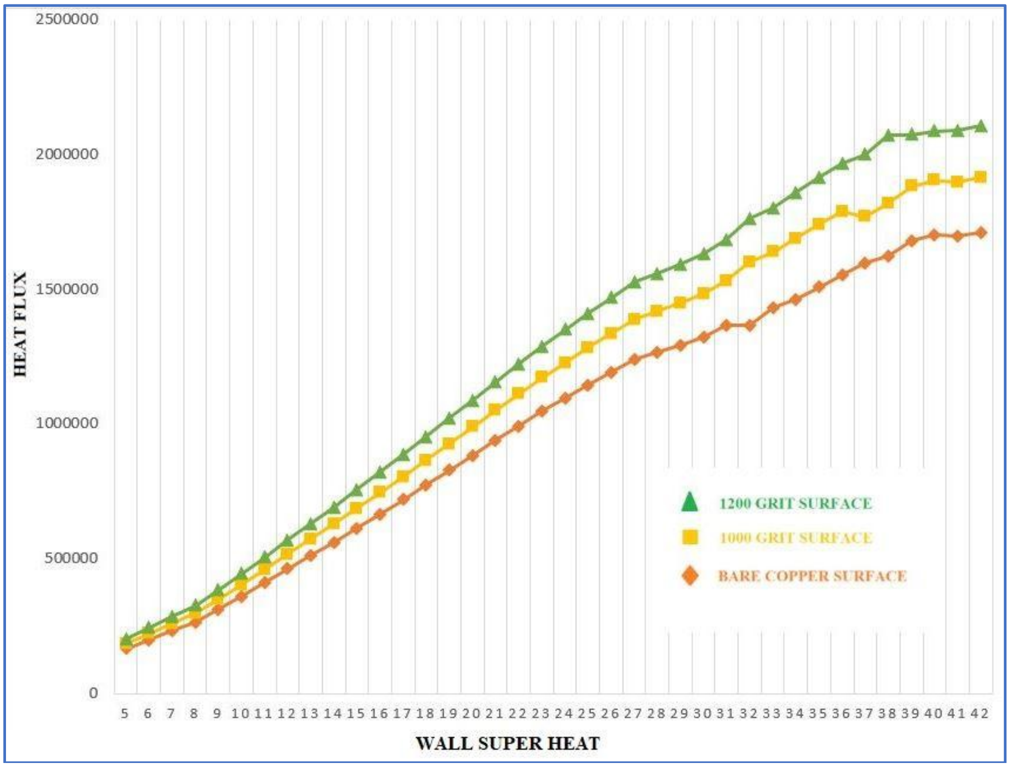

Fig. 6

Conclusion

This research article concludes how the surface roughness affects the enhancement on pool boiling heat transfer.The test was done on the two distinctive surface roughness like 1000 and 1200grades of emery paper. Coppersurface has been polished to improve the heat transfer coefficient of pool boiling.Developments of deep cavities were studied from SEM images.

The copper block which contains two different surface finishes were investigated. The surface was prepared by polishingthem with the use of emery paper with different grades. In this paper, we have to move on by the use of micro structured surfaces to get better performance in the cooling systems. Recently many researchers did the experiment to increase the CHF and all by using nanofluids, nanotubes and solid materials. Now this paper is only focused on the capability to enhance the CHF. In addition, this paper can act as a base experiment of heat transfer surfaces which is in twophase thermal management systems.

A consequent increase in the boiling heat transfer coefficient on different finishes has been observed. This type of surface leads towards high bubble frequency brings a control over in bubble dynamics and also creates a large number of bubble boiling sites. From the investigation of boiling curves at various heat fluxes, it is additionally seen that when the heat flux is applied the heat transfer coefficient is increased.

This leads to the number of active nucleation sites increases.The effect of surface finishes was researched systematically on the heat transfer coefficients and it was found that there is an increment with fine polished surface. It is found that other than the remaining two surfaces working fluid with 1000 surfaceroughness results in a better heat transfer. It is due to the surface has more roughness.

Because of the surfaces has more roughness, it helps in cooling the surfaces and the active nucleation siteincreases and the vapor takes away the heat from the surfaces also it enhances the vapor formation on the surfaces.Such significant improvement in the nucleate pool boiling heat transfer is because of the enhanced surface hydrophilicity, faster bubble release frequency and larger bubble formation sites from the polished surfaces.

We can increase the heat transfer coefficient and CHF value by changing the wettability nature of the surfaces.The wall superheat temperature can decrease by changing the surface roughness. The normal surfaces are having some cavities. So, it makes the bubble formation on the surface. When we make a smoothen surface then it would not create more bubbles on it.

Theseveral characteristics were identified by analyzing the visualization of the bubble formation in the surfaces. The relative magnitudes of the average surface roughness will result in the pool boiling characteristics of stable nanofluids.So, surface roughness has significantly affected the increase of Pool boiling heat transfer.Hence this report is expected to provide a great solution for the efficient energy conversion from the recent global demand.

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