A STUDY OF NUCLEATE BOILING OF NANOFLUIDS

Anandpratap Singh[1], Dhanjeet Singh[2], Neeraj Tiwari[3], P.Thakur[4]
[1]student Saraswati College of Engineering, India, anands810@gmail.com
[2]Student, Saraswati College of Engineering, India, dhanjeetsingh8286@gmail.com
[3]Student, Saraswati College of Engineering, India, neerajt5195@gmail.com
[4]Faculty,Saraswati college of engineering, India, paramjit3010@gmail.com

Abstract: Nucleate boiling of nanofluids has been the phenomenon on the screen since the past few years. Innumerable studies have been done on this phenomenon .Even though, everything about this phenomenon has not been known yet, it has found wide application in areas of heat transfer mechanism.This uprising of application of nucleate boiling of nanofluids in areas like this are due to its excellent heat transfer capabilities. Addition of even 5%v of nanoparticles leads to a tremendous increase of upto 160% in heat transfer rate.Therefore, it necessitates to every concerned person to understand the mechanism of this phenomenon.For this several studies have been carried out. Some exploring mechanism, some modifying existing correlations, some taking into consideration new factors responsible for such high heat transfer, and so on.
This review paper discusses the findings of some such studies.

Key words: **Nanofluids, nanoparticles, nucleate boiling, jet impingement .**

INTRODUCTION

Nucleate boiling is a type of boiling that takes place when the surface temperature is hotter than the saturated fluid temperature by a certain amount but where the heat flux is below the critical heat flux.Of the many liquids available, one which have been extensively studied and which will be discussed in this literature review is the Nano fluids. These fluids have gained large attention in the recent years due to their excellent heat transfer capabilities.Nano fluids are colloidal solution of Nano particles in a base liquid. These bring no great changes in the normal properties but the thermal conductivity is increased upto 160% just by addition of 5%v of Nano particles according to a study by Wang and Mujumdar.[1]The extensive studies done on Nano fluids uptil now indicate that the major reason for such an increase in heat transfer rate was the modification in the surface properties. It was also found that time played an important role in the heat transfer through the Nano fluids as was found in the study of.[2]With time, there were a lot of modifications incorporated in the classical HFP model in order to get more accurate correlations.[3] Some of the papers are discussed as follows:

LITERATURE REVIEW

Effect of jet impingement boiling

The Boiling is a means to increase heat transfer .what would be the effect if one combines jet impingement with boiling . A paper on recent developments on jet impingement nucleate boiling [4] is explained here focusing on the nano-fluid part. Copeland[5] initiated the research on jet impingement boiling. In 1973,katto and kunihiro[6] accidently observed the effects of jet impingement boiling while conducting an experiment. Thus research continued to expand in this area.

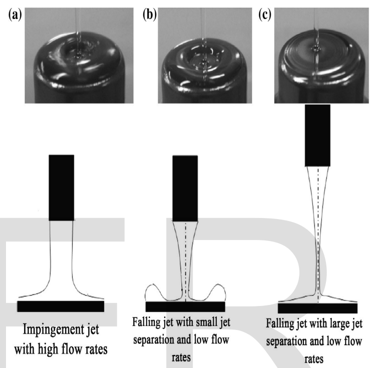


Fig 1. Comparison of flow patterns under high and low flow rates Mahmoudi et al. [7]

Lu Qiu et al [4] observed that boiling curves in case of free/circular planar configuration were independent of the jet parameters. However, the boundaries like the onset of nucleate boiling and critical heat flux were influenced by these. Jet velocity, impact distance, target surface contact angle are just a few to name. In the case of submerged and confined jet impingement boiling, varying results were found. It was found in some cases that in the fully developed regime, boiling curves were affected by these jet parameters while in some cases that did not happen. The heat transfer rate is affected by surface roughness. Microscale surface roughness increased the surface area and thus the heat transfer rate is enhanced. Li Qiu[4] also studued the effect of parameters on boiling heat transfer for free surface circular jet. Boiling curves were independent of jet velocity, because significant bubble generation and collapse induced flow mixing was the major factor in fully developed nucleate boiling regime. For 2 wt% nanoparticle (water-CuO) solution, it was observed that boiling curves were independent of subcooling in fully developed regime(0-74 K and 0-84 K)[4]. Addition of nanoparticles shows that higher super heat was required to achieve the same wall heat flux the heat transfer increased by 25% but remain unaffected when concentration increased more than 1% by weight. On increasing the concentration of nanofluids, the amount of nanoparticles deposited increased, the number of nucleation sites decreases when roughness of the heating surface is equal to particle size because of which heat transfer coefficient decreases.

Effect of milled surface

The presence of nano-particle in the base fluid influence the heat transfer coefficient and the enhancement due to its presence is seen to be higher for lower volume fraction nanofluid. Enhanced boiling heat transfer has great importance in many areas like refrigeration and air conditioning, chemical processing, electronic cooling etc. The boiling heat transfer experiments on vibrating heated surface, periodical cleaning of heated surface, ultrasonic fluid vibration, roughened surface chemically pitted surface, surfaces with complex geometry, porous coated surface etc. have shown significant increase in heat transfer coefficient . E1-Genk [8] reported the saturation and sub-cooled nucleate boiling of dielectric fluids. He found that magnitude of heat transfer coefficient is inversely proportional to the degree of sub cooling. He also observed that boiling heat transfer characteristics increases as the site density increases and continuous increase in the site density shows a diminishing rate of enhancement. Critical heat flux (CHF) increases as the volume fraction increases and same is higher for nanofluid than base fluid. Experiments were performed by scientist in which CuO- pentane nanofluid is chosen as a test fluid for nucleate boiling process, which is conducted on the enhanced surfaces. The main objective was - 1.To study the influence of surface material of the enhanced surfaces 2.To study the influence of nanoparticles on the enhanced surface.

Influence of surface enhancement

It was found that there is percentage increase in boiling heat transfer coefficient of enhanced surfaces compared with that of the smooth surface and it,s seen that coarse surface have decrease of 5 to 10% and fine surfaces have the enhancement of 10 to 15 % in boiling heat transfer coefficient. The enhancement is higher in the fine enhanced surface due to the possibility of capillary action.

Effect of surface material

It was found that presence of increased number of pits and crevices formed results in less number of nucleation sites during the grooving process. Boiling heat transfer coefficient of brass surfaces is found to be higher than that of the similar steel surfaces by 20-30% which may be due to density of active nucleation cavities .

Heat transfer characteristics of TiO2

Nucleate boiling was studied for the case of TiO2 nanofluids at different concentration levels by Adirek Suriyawong[9]. The heating surfaces used were copper and aluminium with surface roughness of .2 and 4 µm. The experiental results for nucleate boiling using the same setup for water and the nanofluids were noted and compared as shown in fig

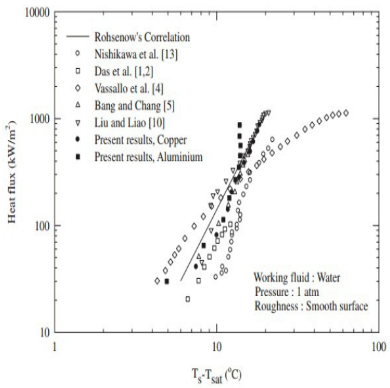
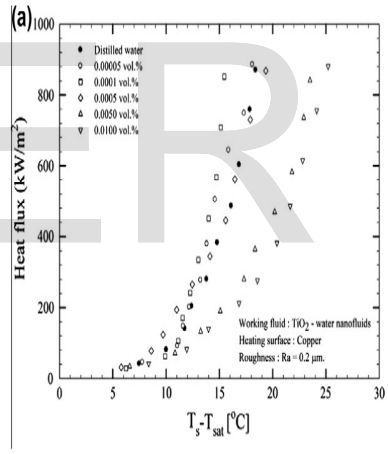


Fig 2. Comparison of present data with Rohsenow's correlation and other researchers.[9]



It was found as seen from the fig that in both the cases, the results tend to go in the same direction as Rohsenow's correlation[10].For the case of copper surface with surface roughness of .2 µm it was found that at nanofluids concentrations of not more than 0.0001 vol.%, there was an increase in heat transfer, compared with base fluid. At the concentration of 0.00005 vol.%, the heat transfer coefficient increased by about 7% and at the concentration of 0.0001 vol. %, the heat transfer coefficient increased by about 15%. In contrast, when the concentration of nanofluids was more than 0.0001 vol.%, the heat transfer decreased when compared with base fluid as shown in fig. For the case of copper surface with surface roughness of 4 µm.The results tend to be similar to the experimental result for the surface with 0.2 µm roughness. That is, at nanofluids concentrations of not more that 0.0001 vol.%, there was an increase in heat transfer. On the other hand, when the nanofluids concentration was more than 0.0001 vol.%, the heat transfer decreased when compared with base fluid. At concentrations of 0.00005 and

0.0001 vol.%, the heat transfer coefficient increased by about 2% and 4%, respectively as shown in fig.

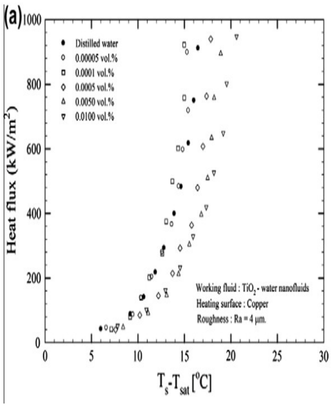


Fig 3.Nucleate pool boiling heat transfer of TiO_2–water nanofluids for copper heating surface with roughness 4 lm at 1 atm.[9]

For the case of surface roughness, for a given material, the material having higher surface roughness has higher heat transfer coefficient (in this case 4µm). this is because high surface roughness increases the area for nucleation sites. While comparing the transfer through different materials(copper and aluminium), it was found that aluminium gave a high heat transfer coefficient than copper.

The effect of heating surface modification

This was a study conducted to check the effect of surface modification on heat transfer characteristics. In this two heat transfer surfaces were manufactured with surface roughness of 25 mm and 420 mm respectively. To compare, DI water and nanofluid of concentration 0.001% were experimented upon in similar conditions on the two surfaces.

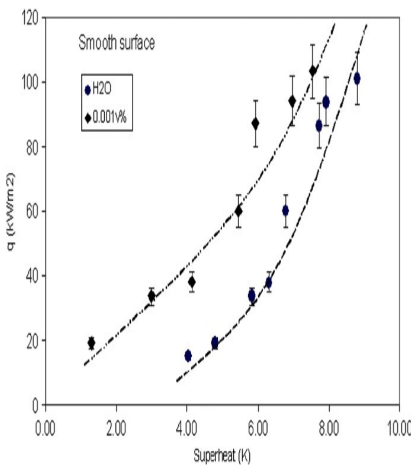


Fig 5 Comparative boiling experimented on smooth surface.[11]

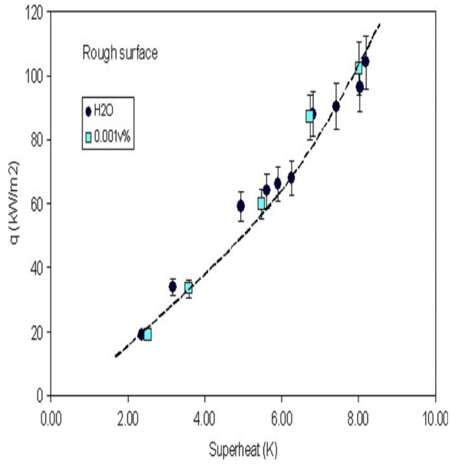


Fig 4. Comparative boiling experimented on rough surface[11]

The results are illustrated as in above figures.

It was found that heat transfer coefficient increased in the case of smooth surface as shown in fig. however, in the case of rough surface no such drastic output were observed and both DI water and nanofluids displayed similar results. To look into details, let us see the AFM images observed by As shown in fig, it can be seen that even though the surface had been cleaned by ultrasonic device for around 3 minutes, the surface still had nanoparticles sticking to it. Thus, the surface was permanently modified despite the low concentrations of nanoparticles present. This might be due to sintering and other factors. This modification would affect further heat transfer characteristics.

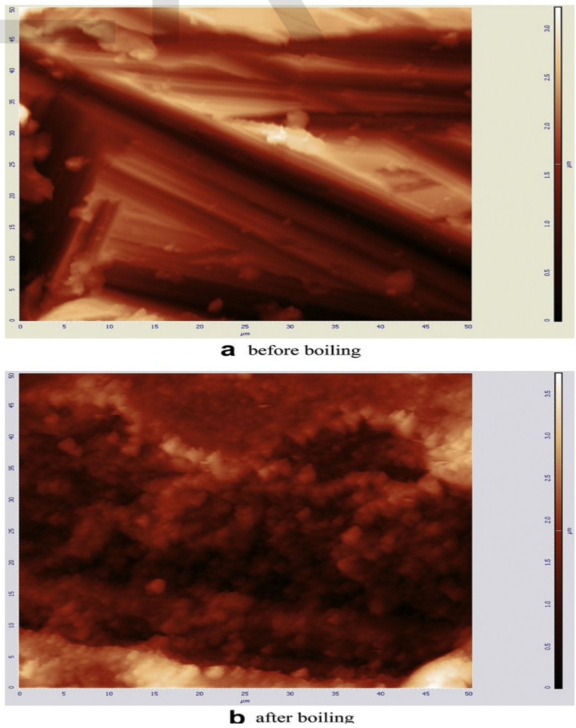


Fig.6 AFM image of the rough surface before and after boiling with nanofluids.[11]

For further detailed analysis, microscale data had been compared for both the surfaces. It was found that in case of rough surfaces there was not much change while in case of smooth surfaces there was a drastic change increasing the peak to peak values upto three folds. Kurtosis value had also increased substantially showing that the sharpness of the peak and fatness of the base had both increased. However, whether it has linkage with boiling performance or not is still being analysed by the author. The data is as given in table

Table 1 [11]

Table 1
AFM characterization of surfaces before and after boiling experiments.

	Rough surface				Smooth surface		
	Before boiling		After boiling		Before boiling		After boiling
Amount of sampling	65536	65536	45675	32032	65536	65536	55430
Max (nm)	2923.37	2868.94	3213.51	3223.15	300.267	249.561	960.579
Min (nm)	0	0	19.6829	299.7	0	0	0
Peak-to-peak, Sy (nm)	2923.37	2868.94	3193.83	2923.45	300.267	249.561	960.579
Ten point height, Sz (nm)	1461.75	1436.11	1615.64	1757.89	148.894	122.099	489.613
Average (nm)	1319	1230.06	1436.06	1425.77	117.289	109.027	540.218
Average roughness, Sa	421.628	425.918	332.939	507.007	27.0047	21.5897	58.3021
Root mean square, Sq (nm)	518.867	522.179	440.499	593.402	34.3611	27.3331	79.2264
Surface skewness, Ssk	0.306605	0.289994	0.476305	0.664552	0.321084	0.009188	−0.68981
Coefficient of kurtosis, ka	0.341002	0.323515	1.27137	−0.61836	0.570419	0.234917	2.38402

Study of alumina nanofluids

There were experiments conducted on alumina nanofluids by M.M Sarafraz to check heat transfer characteristics. For this Alumina nanofluids were stabilized using pH control, stirring and sonication process for about 45 days at pH of 10.2 under sonication of about 270 min at power of 380 W and frequency of 24 kHz). During analysis two domains were observed for heat transfer- one was free convection and the other nucleate boiling. The heat transfer coefficient of both the domains was found to increase with addition of nanofluids, but the extent of increase in nucleate boiling domain was found to be much more compared to the other.

With increasing concentration of nanofluids it was found that the heat transfer tended to reduce. This was because with more nanoparticles covering the surface and the size of the nanoparticle and that of surface roughness being same, the number of nucleation sites reduce, reducing the heat transfer coefficient. It was also seen that fouling resistance was much more in case of nucleate boiling compared to free convection.

Conclusion

In this paper, a few of the various studies have been discussed namely jet impingement boiling in case of nanofluids covering nucleate boiling, heat transfer characteristics of TiO2, and effect of surface modifications on the heat transfer via nanofluids. Compared to the experimental studies, only a small amountof theoretical and numerical works have been reported regarding the jet impingement boiling. In many cases contradicting works exist. In some works, jet parameters have a drastic impact while in others, its impact is negligible. Thus, its study would require more and more research and experiments to be conducted. It is clear that surface parameters do have an impact on the heat transfer as seen in case of TiO2. Variation of roughness resulted in increase in heat transfer by various degrees. The type of material used for nucleate boiling also had a impact. It is found that no solid conclusion can be drawn about the concentration effect. For the rough surface, all concentration curves are found to be similar, which suggest that dominant boiling heat transfer mechanism is the modification of boiling surface, rather than the change of thermophysical properties of different nanofluids. For the smooth surface, experiments show that a further increase in concentrations results in a reduced heat transfer enhancement. The repeatability of the boiling results with nanofluids is found to be poor. In practice, the boiling surface changes every time when nanofluids are boiled although the change is not as extreme as the first time. It is therefore impossible to have reliable repetitive experiments based on only one boiling surface.

REFERENCES

[1] X.Q. Wang, A.S. Mujumdar, "Heat transfer characteristics of nanofluids : a review", Int. J. Therm. Sci. 46 (1) (2007) 1–19.
[2] Tomio Okawa , Masahiro Takamura, Takahito Kamiya, "Boiling time effect on CHF enhancement in pool boiling of nanofluids".
[3] Xiangdong Li , Yang Yuan , Jiyuan Tu, "A parametric study of the heat flux partitioning model for nucleate boiling of nanofluids".
[4] Lu Qiu , Swapnil Dubey , Fook Hoong Choo , Fei Duan , "Recent developments of jet impingement nucleate boiling".
[5] R.J. Copeland," Boiling heat transfer to a water jet impinging on a flat surface".
(Ph.D. thesis), Southern Methodist University, Dallas, TX, 1970.
[6] Y. Katto, M. Kunihiro, "Study of the mechanism of burn-out in boiling system of high burn-out heat flux", Bull. Jpn. Soc. Mech. Eng. 16 (1973) 1357–1366.
[7] S.R. Mahmoudi, K. Adamiak, G.S.P. Castle, "Two-phase cooling characteristics of a saturated free falling circular jet of HFE7100 on a heated disk: effect of jet
Length", Int. J. Heat Mass Transfer 55 (2012) 6181–6190.
[8]V.Umesh and B.Raja, "A study on nucleate boiling heat transfer characteristics of pentane and CuO-pentane nanofluid on smooth and milled surfaces".
[9] Adirek Suriyawong, Somchai Wongwises, "Nucleate pool boiling heat transfer characteristics of TiO2–water nanofluids at very low concentrations".
[10] W.M. Rohsenow," A method of correlating heat transfer data for surface boiling of liquids" , ASME Transactions 74 (1952) 969.
[11Dongsheng Wen a,*, Michael Corr a, Xiao Hua,b, Guiping Lin b,] "Boiling heat transfer of nanofluids: The effect of heating surface modification".
[12] M.M. Sarafraz , F. Hormozi," Nucleate pool boiling heat transfer characteristics of dilute Al2O3–ethyleneglycol nanofluids".