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POOL BOILING & OPTIMIZATION ANALYSIS OF CRITICAL HEAT FLUX BY USING NANOFLUID (A REVIEW)

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ABSTRACT

Nucleate boiling is efficient heat transfer mode using the vaporization of a liquid. However, it is well known that there exists a critical value of the heat flux at which the heat transfer mechanism changes from the highly efficient nucleate boiling to extremely inefficient film boiling. This limiting heat flux is called Critical Heat Flux (CHF). CHF is the condition where the vapor generated by nucleate boiling becomes so large that it prevents the liquid from reaching and rewetting the surface, therefore it is an undesirable phenomenon causing an excessive increase of the temperature in the boiling phenomenon. It is important to enhance the CHF in order to improve the safety margin and economic performance in a thermal system. With the surge of nanofluids as potential candidates for cooling fluids, many studies have been reported on CHF enhancement using nanofluids. Nanofluids are colloidal dispersions of nanoparticle in a base fluid which is water, oil, bio-fluid and ethylene. Such nanofluids have the capability to enhance the CHF significantly about three times.

Over the past decade lots of experiments were performed on the nucleate boiling CHF of nanofluids. The objective of this paper is to provide an exhaustive review of these experiments. The effects of six parameters (i.e. Nanoparticle material, size, concentration, heater size and geometry, heater surface orientation) on CHF enhancement in nanofluids are systemically presented. Nanoparticle material which has shorter Rayleigh-Taylor wavelengths when coated on heater surface shows higher CHF enhancement. For nanoparticle size within nano range there is no significant variation in CHF. But comparing particle size within nano and micro range there is enhancement in CHF for particle size in nano range than particle size in micro range. With increasing concentrations CHF enhancement occurs up to certain concentration then CHF enhancement decreases with increase in nanoparticle concentration. There is lack of work which can give the effect of stabilizer on CHF. More work is required in this area. Higher value of CHF found on smaller heater size, also CHF on cylindrical wires is higher than that of the ribbons heaters. CHF values are higher for horizontal heater.CHF decreases as angle of inclination of heater surface increases. Finally, future research needs are identified.

Keywords: Critical heat flux (CHF), Nanoparticle, Nanofluid, Concentration, Rayleigh Taylor wavelength.

I. INTRODUCTION

Nucleate boiling is a very efficient mode of heat transfer owing to the large energy required to realize the phase change from liquid to vapor. Therefore, several important industrial applications utilize nucleate boiling to remove large heat fluxes from hot surfaces. These include nuclear reactors, miniature electronic devices, refrigeration and cryogenic systems, chemical and thermal reactors, among others. However, it is well known that there exists a critical value of the heat flux at which the heat transfer mechanism changes from the highly efficient nucleate boiling to extremely inefficient film boiling [2]. This limiting heat flux is called Critical Heat Flux (CHF). This is the highest heat flux where boiling heat transfer sustains its high cooling Performance. When the surface reaches CHF, it becomes coated with a vapor film which isolates the heating surface and the fluid, and the heat transfer decreases dramatically. In these conditions, the wall temperature rises quickly, and if it exceeds the limits of its constituent materials, system failure occurs.

Therefore, in most applications of boiling, the system is required to operate at power levels below that corresponding to CHF. For this reason, every system incorporates a safety margin by running at a heat flux lower than CHF, but this approach reduces system efficiency. This compromise between safety and efficiency is

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a very serious problem in the industry. For this reason, a vast amount of work has been carried out to understand nucleate boiling CHF conditions, and to increase the CHF point [1]. A higher value of CHF allows for higher power density in thermal systems, which in turn makes these systems more compact and ultimately more economic. One way to increase CHF is to suspend a small amount of nano particles in the base fluid to form a suspension called Nanofluid [2].

II. CHF ENHANCEMENT

Ciloglu and Bolukbasi [1] performed a survey of the experimental investigations of the HT and CHF on a no fluid pool boiling in the literature and discussed the effects of various parameters on nanofluid pool boiling, based on which they presented the following conclusions: The nanoparticle concentration has remarkable influence on the HTC and CHF of nanofluid pool boiling ,and there Is an optimum value of nanoparticle concentrations, where the CHF enhancement reaches maximum while the HTC does not deteriorate. The HTC and CHF increase with increasing nanoparticle concentration before the optimum value, and the HTC deteriorates and the CHF remains stable with further increasing nanoparticle concentration after the optimum value. During the pool boiling process of nanofluids, nanoparticles continuously deposit on the heated surface. At low concentrations, the deposited nanoparticle layer causes an enhancement in HTC because the effect of thermal conductivity of nanofluids is more dominant than the effect of the nanoparticle layer. At high concentrations, however, the reduction in the number of active nucleation site sand the formation of an extra thermal resistance caused by the deposited nanoparticle layer become more dominant than the effect of the thermal conductivity of nanofluids, resulting in the deterioration of the HTC. The enhancement or deterioration of pool boiling HTC I salso dependent on the surface particle interaction. It increases by multiplying the nucleate sites and creating the active cavities, while decreases due to the blocked nucleation cavities. _ The primary reason for the CHF enhancement is the change of the microstructure and to pography of the heated surface due to the nanoparticle deposition during the boiling process, not because of the nanofluid. The deposited nano particle layer improves the characteristics of the heated surface,suchasthe surface wettability,roughness,and capillary wicking performance, resulting insignificant CHF enhancement.Kamatchi and Venkatachalapathy [2] conducted a detail review on the CHF nanofluid pool boiling.They concluded that the deposition of nanoparticles on the heater surface during boiling of nanofluids was the major fact or for the CHF enhancement, and that the delay in the occurrence of CHF was in consistent among different search groups. They indicated that no comprehensive theory explained the mechanism of CHF enhancement over a wide range of nanoparticle sizes and concentrations.

Over the past decade, a considerable amount of research has been carried out in the area of nucleate boiling critical heat flux (CHF) in nanofluids. In the present paper review of studies published over the past decades is summarized in terms of the effects of six parameters on CHF enhancement in nanofluid boiling as follows:

Effect of Nanoparticle material on CHF

- Effect of Nanoparticle size on CHF
- Effect of Concentrations on CHF
- Effect of Nanoparticle coating on CHF
- Effect of heater size and geometry on CHF
- Effect of heater surface orientation on CHF

III. Effect of Concentrations on CHF

The effects of nanofluids on pool boiling are often evaluated through changes in the critical heat flux (CHF) and heat transfer coefficient (*h*). While an increase in the CHF is commonly reported (exceptions are reported below), contradictory values for *h* are found in the literature. For example, Bang and Chang [06] observed a reduction in *h* with Al2O3 nanofluids, while Tu *et al*. [0**7**] noted the intensification of *h* with the same nanofluids. Kim *et al*. [**08**], however, did not observe significant changes in *h* on adding TiO2 nanoparticles to the water pool. In the literature review below, it is emphasized the combined effects of nanoparticle type, base fluid and surface material of the heating element on the variation of *h* and CHF, and the explanations and remarks detailed by the researchers. Modifications in heat transfer rates and CHFs are explained in different fashions. Noie *et al*. [**09**] added Al2O3 nanoparticles to water in a copper thermosyphon and attributed the increase in *h* to increasing thermal conductivity of the working fluid (Al2O3-H2O). Nanoparticles suspensions in volumetric concentrations of 1 to 3% were used as working media. Do *et al*. [**10**] attributed an increase in *h* in a copper heat pipe with an Al2O3- H2O working fluid to the deposition of nanoparticles on the heated surface.

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The deposition would result in improved surface wettability and capillary wicking performance, therefore enhancing the heat transfer. Alternatively, Khandekar *et al*. [**04**] obtained reduction in *h* using various water based nanofluids (of Al2O3, CuO and laponite clay) in a two-phase copper thermosyphon. They attributed these results to increasing wettability and the physical interaction of nanoparticles with the nucleating cavities. Nanoparticles were considered to agglomerate and/or accumulate due to vaporization and block the active cavities thereby promoting the reduction of the active site density at a given wall superheat.

Kathiravan *et al*. [**11**] reported increasing heat transfer coefficients with the addition of carbon nanotubes (CNTs) to a water pool boiling experiment over a stainless steel flat plate heater. They showed increasing *h* with increasing CNT concentrations. They explained this result by means of two mechanisms: an increase in the thermal conductivity of the working fluid and the interaction of nanoparticles and bubbles. The particles would break big bubbles at the heated surface into smaller ones, modifying the frequency of the occurrence of bubbles. It was also observed that the CHF of nanofluids decreases with increasing CNT concentrations. Effects of nanofluid-surface interaction on pool boiling were investigated by Cieslinski and Kaczmarczyck [**12**] during the testing of nanofluids with water as a base fluid with a low concentration of nanoparticles of alumina (Al2O3-H2O) or copper (Cu-H2O) over two plates: one copper and the other stainless steel. The results indicated a decrease in *h* values independent of the nanoparticle concentrations with the smooth copper tube.

Nevertheless, *h* values were increased for stainless steel tube with the same heat flux density. A thin solid coating (detected by eye) was observed on copper tubes after tests with water-Al2O3 and water-Cu nanofluids. Increasing coating thickness was related to increasing nanoparticle concentration at the end of testing. The authors did not mention coating over the stainless steel sample. You *et al.* [**13**] reported nucleate boiling heat transfer coefficients for water-Al2O3 nanofluids while boiling on copper plate to be roughly the same as for the base fluid On the other hand, CHF has been increased up to 200%. The CHF enhancement could not be explained by the authors. Wen and Ding [**14**] studied boiling of water-Al2O3 nanofluids on a stainless steel disc with 150 mm in diameter at atmospheric pressure. Values of *h* increased with increasing particle concentration up to 40% at a particle loading of 1.25% by weight. Explanations for the pool boiling heat transfer behavior were associated with the interactions between nanofluids and boiling surfaces. Particle agglomeration was observed in their studies. Coursey and Kim [**15**] presented no enhancement or degradation of *h* during boiling with ethanol-Al2O3 nanofluids on glass or gold surfaces. This behavior was attributed to the highly wetting nature of ethanol. For water-Al2O3 nanofluids and copper surfaces, increase in CHF was observed up to 37% with minor changes in *h*. For ethanol-Al2O3 nanofluids and copper surfaces, *h* and CHF were improved with increasing nanoparticle concentration, although they could not explain the reasons for the nucleate boiling enhancement. Wen *et al*. [**16**] noted nano particle deposition on the top of a brass heated surface even with the addition of a small volumetric concentration of Al2O3 nano particles (0.001%). Boiling heat transfer coefficients were enhanced for smooth surfaces (about 0.03 μm of mean surface roughness) and kept approximately the same for rough surfaces (~ 0.4 μm of mean surface roughness). They concluded that the enhancement or deterioration of boiling heat transfer by nano fluids is dependent upon different surface modifications that are strongly affected by the relative size between particles suspended in the liquid and the heating surface geometry, and their interactions.

Boiling heat transfer characteristics of nanofluids were studied using four different volume concentrations of alumina Al2O3 measured on a copper flat surface by Bang and Chang [**06**]. A decrease of *h* with increasing particle concentration was observed with the addition of Al2O3 nanoparticles. On the other hand, CHF performance was enhanced to 32% for horizontal flat surface due to delayed boiling activity. It was assumed that the nanoparticles coating promoted the reduction in the number of active nucleation sites. Less active nucleation will generate smaller amount of bubbles and, in turn, less coalescence or large vapor blankets to interfere with the supply of liquid to the surface. This nano-coating could promote trapping of liquid near the surface due to porous characteristics of the coating, breaking up the voids near the surface and preventing blanketing from occurring as easily. Roughness change causes a kind of fouling effect with poor thermal conduction.

Kim *et al*. [**17**] investigated pool boiling CHF characteristics of two water-based nanofluids (Al2O3 and TiO2) using electrically heated NiCr and Ti wires. Experiments were performed with the pool boiling of pure water on a nanoparticle-coated heater and with nanofluids on a bare heater. Deposition was observed on the heating surface during pool boiling

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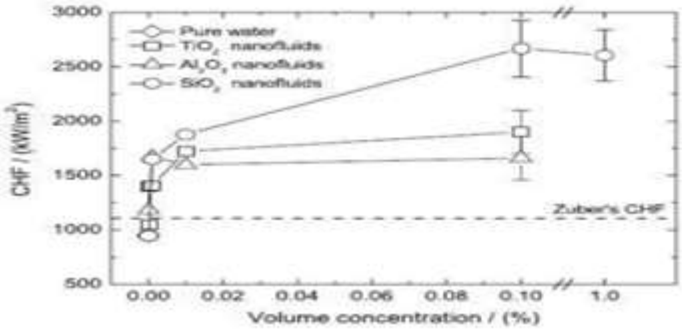

Fig 1. CHF at various nanoparticle volume concentrations.

of nanofluids. For both types of experiments, CHF increased with increasing particle concentration. With nanofluids experiments, the maximum CHF enhancement varied between 70-100%. CHF enhancement was explained by the change of surface microstructure and topography of the heater due to nanoparticle surface coating. With water and TiO2 nanoparticle-coated heater, maximum CHF was about 150%. Kim *et al*. [08] speculated that nanoparticles suspended in nanofluids degraded CHF enhancement obtained by nanoparticle surface coating owing to clogging for the capillary structure and blocking liquid supply. Kim *et al*. [**17**] explained the deposition of nanoparticles by microlayer evaporation underneath a growing vapor bubble with subsequent settlement of the nanoparticles initially contained in it. Forrest *et al*. [**18**] investigated the deposition effect of nickel wires coated with different thin-films of silica nanoparticles over hydrophilic and hydrophobic surfaces. They observed the increasing heat transfer coefficients for hydrophobic surfaces and decreasing coefficients for hydrophilic and super hydrophilic surfaces.

Up to 100% enhancement of the CHF was observed for all surfaces studied. Results were attributed to changes on the surface wettability which changed drastically with the application of these coatings, while causing virtually no change in the surface roughness. Enhancement in boiling heat transfer from hydrophobic surfaces were explained by chemical constituency of the calcinated SiO2 multilayers resulting in a surface with a high advancing and static contact angle. This implied that cavities on the surface were not flooded, but rather, fille with air and vapor. Chen *et al*. [**19**] tested nanowire arrays made of Si and Cu and showed the increase of both the CHF and *h* by more than 100%. Such enhancement was attributed to high nucleate site density, superhydrophilicity, and enhanced capillary pumping effect. Their results concerning *h* are opposite to the results of Forrest *et al*. [18] regarding decreasing *h* for hydrophilic and superhydrophilic surfaces. Vassallo *et al*. [20] tested silica nanosolutions in submerged NiCr wire. Their data showed a marked increase in CHF for both nano-solutions (up to 200%) and micro-solutions (up to 60%) compared to water, but no appreciable differences in *h* for powers less than CHF.

S.D. Park and I.C. Bang used six types of Nanofluids with ZnO, SiO2, SiC, Al2O3, graphene oxide (GO) and CuO at 0.01% volume concentration in distilled water in order to find the effect of nanoparticle material on CHF. At 0.01% volume concentration there was not significant change in the properties of dilute nanofluids compared with a base fluid, but the CHF in nanofluids was enhanced in comparison with distilled water. Figure 1presents the CHF enhancement ratio for nanofluids. Each of the nanofluids has a different value. The CuO nanofluid shows the largest CHF enhancement of about 160%. The lowest CHF enhancement took place in the ZnO nanofluid, measured at 90%. Reasons for CHF enhancement in nanofluid compared with water on the basis of hydrodynamic instability theory [**21**]. The observed distance between the bubbles was different for each nanoparticle-coated surface. All of the nanoparticle-coated surfaces were having a shorter average distance between bubbles than the bare surface's bubbles. Fluids with high CHF enhancement exhibit short Rayleigh–Taylor wavelengths.

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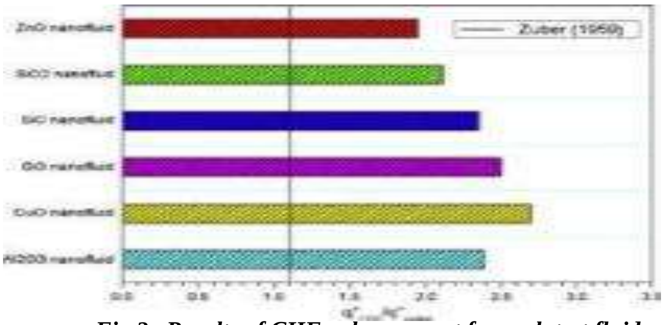

Fig 2. Results of CHF enhancement for each test fluid.

IV. EFFECT OF THE NANOPARTICLE COATING ON CHF ENHANCEMENT

We attempted an ad hoc test with our high-speed visualization setup to validate the effect of the nanoparticle coating layer on the CHF, the bending point in the boiling curve, and the increase in wall temperature just after the CHF is reached. As mentioned previously, the nanoparticle coated surfaces were obtained by boiling a plain copper heater in an an ofluid. Pool boiling experiments were then conducted with the nanoparticle coated surfaces in pure water. 00Fig. 3 shows the boiling curves for a nanofluid boiling and water boiling after the nanoparticle coating was deposited on the heater. The boiling heat transfer performances were all similar. However , the CHF values for nano fluid boiling and water boiling with a nanoparticle coating were 2096 and 1900 kW/m 2, respectively. First, we investigated the nanoparticles on the heater surface using scanning electron microscopy (SEM), as shown in Fig**.**

During water boiling after the nanoparticle coating was deposited; the alumina nanoparticles were partially detached. Since the process of depositing the nanoparticl e coating under nucleate boiling involves the attachment and detachment of nanoparticles during vigorous boiling in a nanofluid [15,20], detachment without subsequent attachment of nanoparticles during water boiling is reasonable. In addition, the enhanced CHF values obtained for nanofluid boiling (136%) and water boiling with a nanoparticle coating (125%) can be explained by this detachment of nanoparticles.We also examined the change in surface wettability caused by the nanoparticle in order to verify our result reported in the previous literature [11–13]. After 1-lL water droplets were suspended Finally, the nanoparticle coating layer could affect the microscopic liquid in flow, which is a possible mechanism behind the in- crease in CHF.According to Kim and Kim [32] and Kwark et al. [20], the microscopic inflow (liquid supply)due to capillary wicking helps increase the CHF significantly. The microscopic liquid inflow on the nanoparticle coating layer would play a role in the formation and maintenance of the thick macro layer

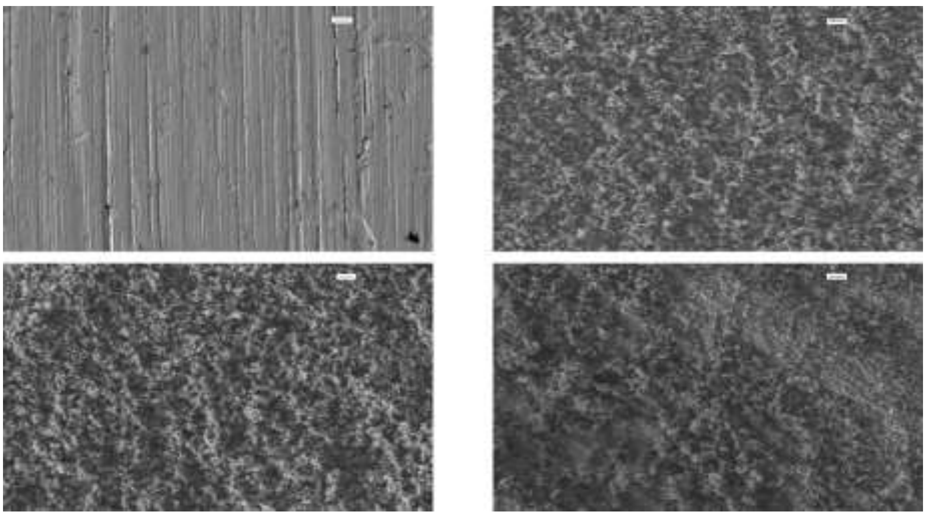

Fig. 3. SEM images of (a) bare heater surface, (b) after alumina nanofluid boiling CHF, (c) after the nanoparticle coating, and (d) after water boiling CHF on the nanoparticles coated heater.

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V. EFFECT OF HEATER SIZE AND GEOMETRY ON CHF

The effects of heater size on pool boiling CHF have been studied by M.C. Lu et al. [**13**] by using heater of sizes 0.5×0.5 cm², 1×1 cm², 1.5×1.5 cm² and 2×2 cm². They obtained CHF on plain Si surfaces and surfaces covered with a dense array of Si nano wires (SiNW). Highest CHF observed on SiNW covered and plain Si surfaces on a heater of size of 0.5×0.5 cm² among all heater sizes. The trend obtained of CHF on plain Si surfaces and SiNW array-coated surfaces with four different sizes of heaters are shown in **Fig.5.** The CHF on SiNW covered and plain Si surfaces for different sizes of heaters clearly indicate that the CHF increases as heater size reduces. D.M. Vazquez and R. Kumar [10] noticed decreasing trend of the average CHF with increasing convective surface area of ribbon heaters. Considering the CHF on smallest and largest ribbons used in experimentations, for an 80% reduction in surface area, the data shows a 28% increase in average CHF.

VI. EFFECT OF HEATER SURFACE ORIENTATION

The effect of heater surface orientation on CHF of pure water was observed by S.M. Kwark et al. [14] conducting experiments over uncoated and nanocoated surface. Figure 6 shows Effect of inclination angle of heater surface on CHF of pure water. For both uncoated and nanocoated surfaces, as the inclination angle increases from 0° to 180°, the CHF values decreases. From 0° to 90°, the effect of inclination angle on CHF seems marginal. But as the inclination angle increases beyond 90° (135°and 180°), the CHF values decrease dramatically. Because beyond 90°, the bubbles cannot detach freely due to the blockage of the heated surface. The bubble residence time against the heated surface therefore increases. As a result, the bubbles flatten, merge with each other forming vapor blanket on the heater surface. This longer dwelling of a vapor blanket results in reaching CHF sooner for inclination angles beyond 90°. I.C. Bang and S.H. Chang [15] investigated CHF for the both horizontal and vertical test section, in pool boiling of Alumina water nanofluid compared to water. For the horizontal test section 32% of CHF increased while for a vertical test section 13% of CHF increased. In case of horizontal heater bubbles can detach freely from surface than inclined heater surface. Hence, In pool boiling on horizontal heater shows more CHF enhancement than inclined heater.

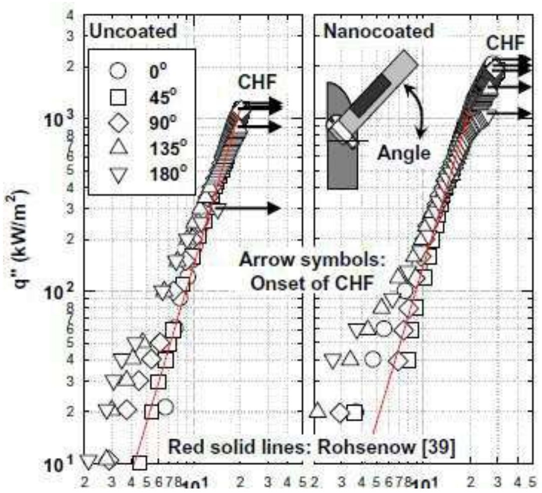

Fig 4.Effect of inclination angle of heater surface on CHF of pure water

VII. CONCLUSION

Over past decades many researcher work on nucleate pool boiling CHF enhancement. It is known that CHF of base fluid can be enhanced by suspending nanoparticles at small concentration. In this paper available studies reviewed and key causes of CHF enhancement are discussed.

- ❖ CHF of nanofluid depends on type of material of nanoparicles. In nanofluid pool boiling nanoparticles deposits on heater surface and form coating. Those nanopaticle material having shorter Rayleigh–Taylor
- ❖ wavelengths when coated on heater surface shows higher CHF enhancement while material having larger Rayleigh–Taylor wavelengths shows lower CHF enhancement.
- ❖ For nano particles size within nano range there is no significant variation in CHF. But comparing particle size within nano and micro range there is significant enhancement in CHF for particle size in nano range than particle size in micro range.

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- With increasing nanoprticle concentrations CHF enhancement occurs up to certain concentration then CHF enhancement decreases with increase in nanoparticle concentration. Concentration affect heater
- surface. Researchers mentioned nanoparticle depositions on heater surface are responsible for CHF enhancement. Detail effect of nanoparticles concentrations on surface modifications needs to be find out which leads to CHF enhancement.
- CHF strongly depends on heater size and geometry.CHF found higher on smaller heater size, also CHF on cylindrical wires is clearly higher than that of the ribbons heaters.
- CHF values are higher for horizontal heater than inclined or vertical. CHF decreases as angle of inclination of heater increases.

VIII. FUTURE WORK

From review of previous studies it is found that nanoparticle depositions on heater surface are responsible for CHF enhancement. But these depositions on heater surface will be different at different nanoparticle concentrations. Hence surface roughness of heater surface will be different at different concentrations. Detail study is required on Effect of nanoparticle concentrations on Surface roughness and its effect on CHF. Also researchers have taken large nanoparticle concentration range for investigations. Evan small amount variations in concentration can significantly affect CHF of nanofluid. Thus in order to utilized nanofluid in practical applications complete database is required considering influence of above discussed parameters as well as heater surface modifications. Hence vastinvestigation is required in the area of CHF enhancement using nanofluid

IX. REFERENCES

[1] Alejandro Mourgues, Virginie Hourtané, Thierry Muller, Marylise Caron-Charles, “Boiling behaviors and critical heat flux on a horizontal and vertical plate in saturated pool boiling with and without ZnO nanofluid”, International Journal of Heat and Mass Transfer 57, pp.595–607, Nov. 2013
[2] Vivek I. Sharma, Jacopo Buongiorno, Thomas J. McKrell, Lin W. Hu,” Experimental investigation of transient critical heat flux of water-based zinc–oxide nanofluids”, International Journal of Heatand Mass Transfer 61, pp. 425–431, March 2013.
[3] S. D. Park, I. C. Bang,” Experimental study of a universal CHF enhancement mechanismin nanofluids using hydrodynamic instability”, International Journal of Heat and Mass Transfer 70, pp.844–850, 2014.
[4] S. Khandekar, Y.M. Joshi and B. Mehta, Thermal performance of closed two-phase thermosyphon using nanofluids, International Journal of Thermal Sciences 47, 2008, pp. 659–667.
[5] I.C. Bang and S.H. Chang. Boiling heat transfer performance and phenomena of Al2O3-water nano-fluids from a plain surface in a pool. International Journal of Heat and Mass Transfer 48(12), 2005, pp. 2407–2419.
[6] J.P. Tu, N. Dinh, T.G. Theofanous, “An experimental study of nanofluid boiling heat transfer” in Proceedings of 6th International Symposium on Heat Transfer, Beijing, China, 2004.
[7] H. Kim, J. Kim and M. Kim, 2006, “Experimental study on CHF characteristics of water-TiO2 nanofluids”, Nuclear Engineering and Technology, Vol. 38, No. 1.
[8] S.H. Noie, S. Z. Heris, M. Kahani and S.M. Nowee, Heat transfer enhancement using Al2O3/water nanofluid in a two-phase closed thermosyphon, International Journal of Heat and Fluid Flow, vol. 30(4), 2009, pp. 700-705.
[9] K.H. Do, H.J. Ha, S.P. Jang, Thermal resistance of screen mesh wick heat pipes using the water-based Al2O3 nanofluids, Int. J. Heat Mass Transf. 53, 2010, pp. 5888-5894.
[10] R. Kathiravan, R. Kumar, A. Gupta, R. Chandra and P.K. Jain, Pool boiling characteristics of multiwalled carbon nanotube (CNT) based nanofluids over a flat plate heater, International Journal of Heat and Mass Transfer, vol. 54 (5-6), 2011, pp. 1289-1296.
[11] J.T. Cieslinski and T.Z. Kaczmarczyk, Pool boiling of water-Al2O3 and water-Cu nanofluids on horizontal smooth tubes, Nanoscale Research Letter, vol. 6(1), 2011, pp. 220.
[12] S. M. You, J. H. Kim, and K. H. Kim, Effect of nanoparticles on critical heat flux of water in pool boiling heat transfer, Applied Physics Letters 83, 2003, 3374-3376.
[13] D. Wen and Y. Ding, Experimental investigation into the pool boiling heat transfer of aqueous based γ-alumina nanofluids, Journal of Nanoparticle Research, 7, 2005, 265–274.
[14] J.S. Coursey and J. Kim, Nanofluid boiling: The effect of surface wettability, International Journal of Heat and Fluid Flow, vol. 29, 2008, pp. 1577-1585.
[15] D. Wen, M. Corr, X. Hu and G. Lin, Boiling heat transfer of nanofluids: The effect of heating surface modification, International Journal of Thermal Sciences, vol. 50 (4), 2011, pp. 480-485.

[16] H. Kim, J. Kim and M. H. Kim, Effect of nanoparticles on CHF enhancement in pool boiling of nanofluids, International Journal of Heat and Mass Transfer 49, 2006, 5070–5074.
[17] E. Forrest, E. Williamson, J. Buongiorno, L.-W. Hu, Mi. Rubner and R. Cohen, Augmentation of nucleate boiling heat transfer and critical heat flux using nanoparticle thin-film coatings, International Journal of Heat Mass Transfer vol. 53, 2010, pp. 58-67.
[18] R. Chen, M.-C. Lu, V. Srinivasan, Z. Wang, H. H. Cho and A. Majumdar, Nanowires for Enhanced Boiling mHeat Transfer, Nano Lett., Vol. 9, No. 2, 2009, 548-553.
[19] P. Vassallo, R. Kumar, S. D'Amico, Pool boiling heat transfer experiments in silica–water nano-fluids, International Journal of Heat and Mass Transfer 47, 2004, 407–411.
[20] S. D. Park, I. C. Bang," Experimental study of a universal CHF enhancement mechanism in nanofluids using hydrodynamic instability", International Journal of Heat and Mass Transfer 70, pp.844–850, 2014.

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