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Determination Of Critical Heat Flux In Pool Boiling Using ZnO Nanofluids

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Abstract

CHF creates inconvenient compromises between economy and safety in most industries, related to thermal systems such as nuclear power plants. In this study, pool boiling experiments were performed with water based nanofluid with Zinc Oxide nano particles from various concentration of 0.01 volume percent (%v) to 0.0001volume percent (v%) on an electrically heated Ni-Cr wire of 0.4 mm diameter at atmospheric pressure. The results showed that the water-based nano-fluids significantly enhanced CHF compared to that of pure water. The CHF values of the ZnO nano fluids were enhanced from approximately 70% to 80% of pure water. During the test it is found that, a sizable layer of nano particle deposits formed on heater surface. The CHF enhancement using deposition of nano particles are related to surface wettability of the heating surface during pool boiling. It is supposed that CHF enhancement in pool boiling of nano-fluids is mainly caused by the nanoparticles coating of the heating surface.

Keywords: *Nano-fluids; Nanoparticles surface coating; Pool boiling; Critical Heat Flux (CHF), Nickel- chromium (Ni-Cr). Deionized water (DI)*

1. Introduction

Nucleate pool boiling phenomenon is very effective & efficient mode of heat transfer, due to its ability to transfer large amounts of heat with relatively small temperature differences. Conventional and enhanced boiling of liquids have a wide range of industrial applications that include power generation, chemical and petrochemical industries, air conditioning, refrigeration and cryogenics, metallurgical quenching process, desalination of seawater and in nuclear power plants, either for heating or electricity generation. Recent applications of boiling heat transfer in cooling of electronics devices show many promises.

At present, the whole world pays great attention to energy efficiency improvement and environmental protection due to global warming caused mainly by excessive use of fossil fuels. One of the fundamental ways of alleviating global warming is to increase the efficiency of the boilers in power plants, evaporators in refrigeration system, and various heat exchangers for commercial and domestic use. Especially, nucleate boiling heat transfer occurs in many of these heat exchangers and hence while incorporating this, it is imperative that CHF should not exceeded.

CHF in pool boiling is defined as the peak heat flux under which a boiling surface can sustain nucleate boiling. On attaining the CHF, transition from nucleate boiling regime to film boiling regime occurs, which is undesirable and causes temperature of the heated surface to reach the melting point, so that it creates inconvenient compromises between economy and safety in most industries, related to thermal systems. Therefore, an enhanced CHF is advantageous not only for increasing the safety margin of the thermal system, but also to design compact and efficient cooling systems required for electronic devices, nuclear and chemical reactors, air conditioning, etc. Therefore, much effort has been focused on clarifying the mechanism underlying CHF occurrence and improving the CHF through the using nanofluids.

You et al. [1] showed 200% enhancement in CHF for copper heater immersed in Al_2O_3-water nanofluid. Vassallo et al. [2] conducted CHF experiments in pool boiling indicating some possible surface interaction between wire and nanoparticles because of silica coating of 0.15 – 0.2 mm observed at the end of experiment. Bang and Chang [3] showed that CHF enhancement due to change in surface characteristics like surface roughness and nucleation site density by deposition of nanoparticles. Madhushree Kole [10] observed ~117% CHF enhancement at 2.6% volume concentration of ZnO in ethylene glycol Nanofluids. This enhancement is attributed to thin layer nonmaterial on constantan wire heater. Same result is obtained for Fe_3O_4 nanofluids with Ni-Cr wire heater by M. Sheikhbahai [7]. Moreno [16] reported a large enhancement in CHF by 240% with 0.5 g/L concentration of ZnO nanoparticles in aqueous nanofluids. CHF of water–Al_2O_3 nanofluids on a Ni-

Cr heater has 176% CHF enhancement at 10^{-3}% concentration [4]

2. Experiment

2.1 Preparation of Nano Fluid

Preparation of nano fluids is the first key step in applying nanophase particles to changing the heat transfer performance of conventional fluids. The nanofluid does not simply refer to a liquid-solid mixture. Some special requirements are necessary, such as even suspension, stable suspension, durable suspension, low agglomeration of particles, no chemical change of the fluid. In general, one of the effective methods used for preparation of suspensions is to use magnetic stirrer. This technique aims at changing the surface properties of suspended particles and suppressing formation of particles cluster in order to obtain stable suspensions. In order to ensure a stable, uniform, continuous suspension, the dispersion solutions are vibrated on a magnetic stirrer about 3 h just before the boiling test is performed.

Water-based nano-fluids can vary according to the type of nanoparticles dispersed in the water. In the present investigation, ZnO nanoparticles, which can be commercially mass-produced, were used to make the nano-fluids. The ZnO nanoparticles used in this work are produced using a sol-gel process by Nanoshell LLC Product Corporation (USA). Generally, the properties of the nano-fluid depend on the properties of the nano-particles, and the surface molecules taking part in the heat transfer procedure depend on the size and shape of the particles themselves, which are also affected by the agglomeration of the particles. As shown in the figure 1 taken by transmission electron microscopy (TEM), the size has a normal distribution in a range from 80 nm to 200 nm (50 nm avg. diameter is given from the manufacturer). Characterization was done by X-ray diffraction measurement in θ^{o}–$2\theta^{o}$ configuration in the range of 10^{o}–80^{o}. The graph shown in Figure 2 depicts the X-ray diffraction spectra has highest intensity of 9177 counts at 36.39^{o}. It is also observed that all zinc nanoparticles remained in pure zinc state.

It is known that the flow phenomenon of a liquid–solid solution depends on the hydrodynamic force acting upon the surface of solid particles. Therefore, volume fraction of the solution is considered a more important factor than mass fraction. Also, the following conversion formula is used conventionally, as it is very difficult to measure the precise true volume of nanoparticles.

$$\emptyset_v = \frac{1}{1+\left(\frac{1-\emptyset_m}{\emptyset_m}\right)\frac{\rho_p}{\rho_f}} \quad \text{……. (1)}$$

Where ϕ_m is the mass concentration of nanoparticles, ρ_p is the nanoparticles density and ρ_f is the fluid density, and ϕ_v volume fraction.

Figure 1 TEM image of ZnO nanoparticles

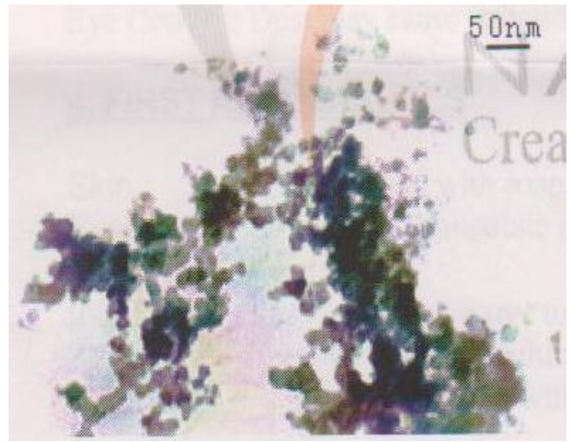
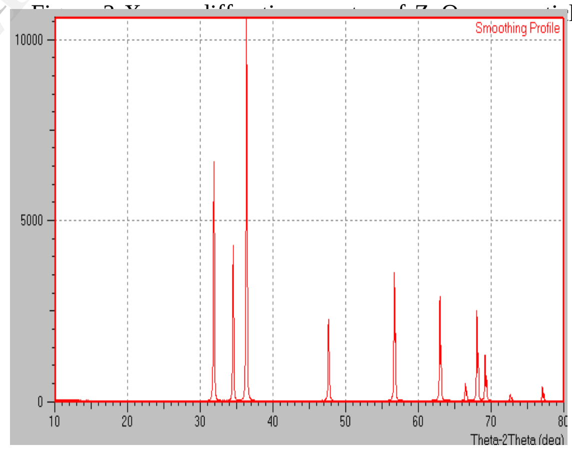


Figure 2 X-ray diffraction pattern of ZnO nanoparticles



An electronic scale with accuracy of 0.0001 gram is used weighting proper amounts of ZnO nano powder. The nanofluids were prepared at varying concentrations: 0.01%, 0.001%, 0.0001%, by volume. The corresponding mass fraction for using proper amount of nano powder is determined by the equation (1)

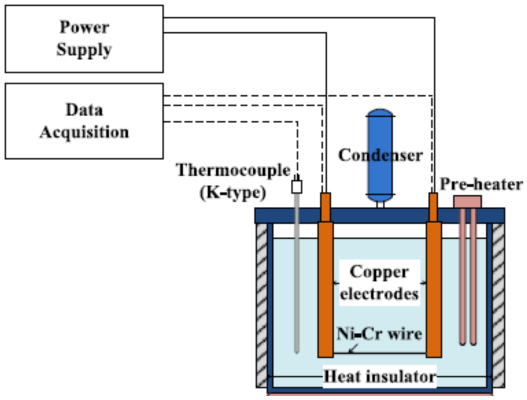


Figure 3 Schematic of the pool boiling apparatus

2.1 Experimental apparatus and procedure

Figure 3 shows a schematic illustration of the experimental apparatus. The pool boiling CHF experiment facility consists of a 250 x 100 x 230 mm rectangular main vessel, which is made of glass. A pre-heater is used to maintain a saturated condition in the pool. The copper electrodes of 12mm diameter and 155 mm long, a thermocouple (K-type) to measure the pool bulk temperature. The reflux condenser on the top of test cell helps to keep the pressure at atmospheric and prevents evaporation of the liquid inside the test cell, which changes the concentration of the fluid in the test cell during the experiment. An Ni–Cr wire with a 0.4 mm diameter and a 100 mm length is used as the heated surface and heated by the AC power supply with a 230 V, 50 A. The signals of the voltage, the current and the temperature are measured with a National Instrument data acquisition system.

All pool boiling experiments are performed after the working fluid is maintained at the saturated temperature (100 ± 0.5°C) and atmospheric pressure. The experiment is performed by gradually increasing the electric power supplied to the wire with a regular pattern. The power is initially increased in large steps. When the expected CHF value is reached, the power is increased in small steps. The resistance of the Ni–Cr wire sharply increased, and the wire became red-hot or broken suddenly when the CHF occurred. The CHF is calculated by Eq. (2) using the data obtained immediately before the sharp increase of the Ni–Cr wire resistance.

$$q'' = \frac{V\ X\ I}{\pi DL} \qquad \text{........ (2)}$$

Where V is the inputted voltage (Volt), I is the input current (Amp), and D and L represent the wire diameter (m) and the wire length (m), respectively.

The pool boiling CHF experiments are first performed with DI water, for validation of the experiment. To validate the repeatability of the experimental results, the experiments are performed more than 5 times. In addition, the measured CHF values are compared with the results of Eq. (3), known as the Zuber's CHF correlation [14], which has been widely used to predict the pool boiling CHF for pure water at 1 atm. Pressure. The averaged experimental result (1090 kW/m^2) agrees well with the predicted value (1144 $kW/\ m^2$) within approximately 5%.

$$Q'' = \frac{\pi}{4}\rho_g h_{fg}\left[\frac{g\sigma(\rho_f - \rho_g)}{\rho_g^2}\right]^{1/4} \qquad \text{.............. (3)}$$

where Q'' is the heat flux, ρ_g and ρ_f are the gas density and the fluid density, respectively, h_{fg} is the latent heat of vaporization, g is gravitational acceleration, and σ is the surface tension.

2.4 Experimental Uncertainty

Considering the uncertainty in calibration, the uncertainty in heater surface temperature measurement was ±0.5 K. The total nucleate boiling heat flux uncertainty (considering uncertainties in voltage, current, and heater surface area) is estimated as less than 5%.

3. Results and discussion

In the experiment it is observed from, figure 4 and figure 5, that, CHF for nanofluids is greater than that of base liquid. Figure 4 shows the measured CHF for nanofluids with different volume fractions of nanoparticles and comparison with DI water. The maximum CHF enhancement was about 80% obtained for nanofluid containing 0.01% (by volume) of ZnO nanoparticles. This observation is similar to that reported for many different types of Nanofluids.

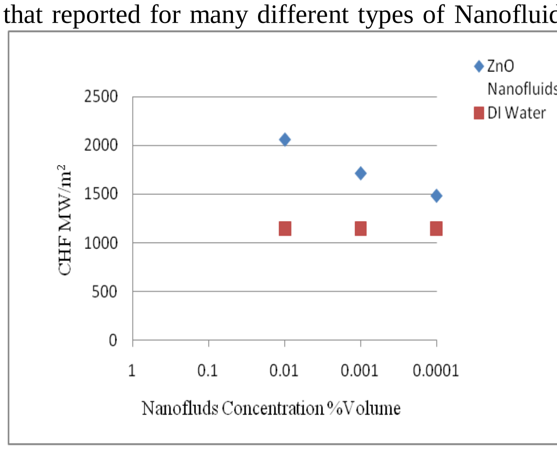
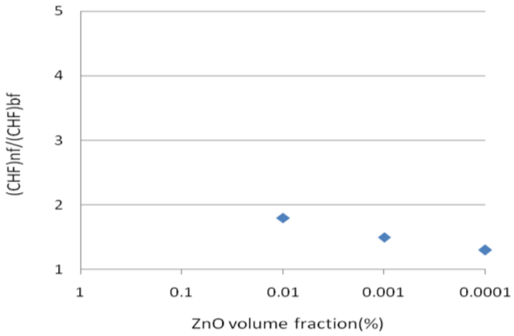


Figure 4 CHF for nano fluids with different volume fraction

A close look at the wire surfaces at the end of the boiling experiments reveals that the surfaces get coated with a thin layer of material. This is consistent with the mechanism proposed by Kim et al. [15] that



the nano-coatings formed during nanofluid boiling are created as the vapor bubbles' micro layers evaporate; leave behind the nanoparticles which then bond to the hot heater surface. Presence of this thin layer indicates a change of heater wire surface morphology between the start and the end of the boiling experiments. Figure 6 a and b show the scanning electron micrographs of the wire surface after CHF experiments in DI and nanofluid containing 0.01% volume fraction of ZnO nanoparticles respectively. It is clearly observed that the wire surface after boiling in the nanofluid develops more number of dark dots, compared to that after CHF measurements in base fluid DI water. Increasing number of dark dots on the wire surface indicates increasing surface roughness with more peaks and valleys and is responsible for the observed CHF enhancement. As from figure 6 (a) and figure 6 (b), it may be noted that the coating crumbles off when it is dry indicating that they are weakly bound to the wire surface.

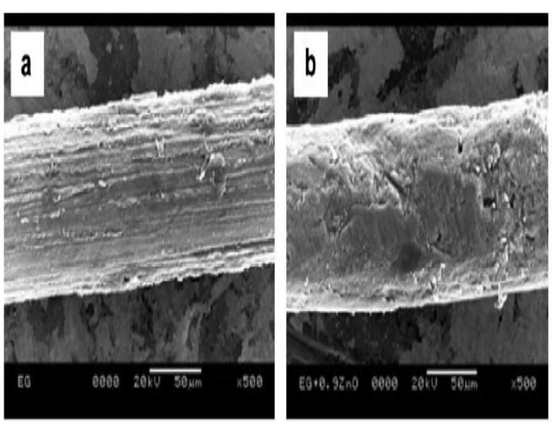


Figure 6. SEM pictures of the wire surface after CHF experiments in (a) pure water (b) nanofluid containing 0.01% volume fraction of ZnO nano particle respectively

remain and are deposited on the heated surface after the bubbles depart from the nucleated site. New vapor bubbles then form on the surface again. The heated surfaces were changed by the deposition of nanoparticles. The deposited nanoparticles generated a porous layer on the Ni–Cr wire, which can improve the wettability of the wire. In other words, it is easy to rewet the hot spots and to cool the heated surface. This rewetting capability enhances the CHF of the Nanofluids. Furthermore, the degree of CHF enhancement increased as the amount of deposited nanoparticles increased. Therefore, the CHF was more enhanced at higher nanoparticles concentrations.

4. Conclusion

In this study, the characteristics of CHF enhancement using ZnO Nano fluid are investigated experimentally. The main findings of this study are as follows:

(1) In the pool boiling experiments, considerable amounts of nanoparticles are deposited on the wire. Thus, the surface wettability, which is important parameter for CHF enhancement, is changed and the CHF is also enhanced.

(2) The CHF measured using a thin Ni-Cr wire display appreciable increase with increasing ZnO concentration and reaches a maximum of 80% corresponding to 0.01% volume fractions of ZnO nanoparticles.

5. References

[1] S.M. You, J.H. Kim, K.H. Kim, Effect of nanoparticles on critical heat flux of water in pool boiling heat transfer, Appl. Phys. Let. 83 (2003) 3374–3376

[2] P. Vassallo, R. Kumar, S. D'Amico, Pool boiling heat transfer experiments in silica-water nanofluids, Int. J. Heat Mass Transfer 47 (2004) 407–411

[3] I.C. Bang, S.H. Chang, Boiling heat transfer performance and phenomena of Al2O3-water nanofluids from a plain surface in a pool, Int. J. Heat Mass Transfer 48 (2005) 2407–2419.

[4] Hyungdae Kim, Jeongbae Kim, Moo hwan Kim "Effect of nanoparticles on CHF enhancement in pool boiling of nano fluids" International Journal of Heat and Mass Transfer 49 (2006) 5070–5074

[5] Yimin Xuan, Qiang Li "Heat transfer enhancement of Nanofluids" International Journal of Heat and Fluid Flow 21 (2000) 58-64

[6] Hyungdae Kim, Jeongbae Kim, Moo hwan Kim "Experimental study on CHF characterstics of Water-

TiO2 Nanofluids" Nuclear Engineering and Technology, vol.38 No.1 February 2006

[7] M. Sheikhbahai, M. Nasr Esfahany, N. Etesami "Experimental investigation of pool boiling of Fe_3O_4/ethylene glycolewater nanofluid in electric field" International Journal of Thermal Sciences 62 (2012) 149 -153

[8] Dongsheng Wen a, Guiping Lin b, Saeid Vafaei a, Kai Zhang," Review of nanofluids for heat transfer applications" Particuology 7 (2009) 141–150 Available online at www.sciencedirect.com.

[9] Jong Hyuk Lee a, Taeseung Lee a, Yong Hoon Jeong, "Experimental study on the pool boiling CHF enhancement using magnetite-water Nanofluids" International Journal of Heat and Mass Transfer 55 (2012) 2656–2663

[10] Madhusree Kole, T.K. Dey, "Investigations on the pool boiling heat transfer and critical heat flux of ZnO-ethylene glycol Nanofluids" Applied Thermal Engineering 37 (2012) 112-119

[11] S.K.Das, Stephen U.S.Choi, Hrishikesh E. Patel, "Heat transfer in Nanofluids – A review" *Heat Transfer Engineering*, 27(10):3–19, 2006 Copyright _C Taylor and Francis Group, LLC ISSN: 0145-7632 print / 1521-0537

[12] Saeed Zeinali Heris, "Experimental investigation of pool boiling characteristics of low-concentrated CuO/ethylene glycol–water Nanofluids" International Communications in Heat and Mass Transfer 38 (2011) 1470–1473

[13] S.J.Kim "pool boiling heat transfer characteristics of Nanofluids" MS Thesis, MIT, USA

[14] N. Zuber, Hydrodynamic Aspects of Boiling Heat Transfer, Thesis. Univ. of California, LA, 1959.

[15] S.J. Kim, I.C. Bang, J. Buongiorno, L.W. Hu, Surface wettability change during pool boiling of nanofluids and its effect on critical heat flux, Int. J. Heat Mass Transf. 50 (2007) 4105-4116

[16] G. Moreno Jr., Investigation of Pool Boiling Heat Transfer with Nanofluids, M. S Thesis, University of Texas, Arlington, December 2005.

[16] R. Kathiravan a, Ravi Kumar a, Akhilesh Gupta a, Ramesh Chandra , 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 54 (2011) 1289–1296

[17] R. Kathiravan, Ravi Kumar Akhilesh Gupta a, Ramesh Chandra, "Preparation and pool boiling characteristics of copper nanofluids over a flat plate heater" International Journal of Heat and Mass Transfer 53 (2010) 1673–1681