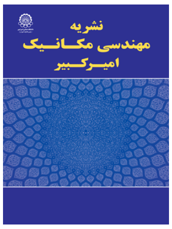

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Experimental study of CuO/Water nanofluid pool boiling on the copper flat surface and measurement of the critical heat flux

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ABSTRACT: Boiling heat transfer is one of the most applicable heat transfer processes in the industry. In recent years, many studies have been investigated in nanofluid pool boiling field and reported some contradictory results. This research is a qualitative and quantitative investigation to understand the behavior of nanofluid during pool boiling heat transfer. For this purpose, a low concentration (up to 1000mg/l) of CuO-water nanofluid and a copper plate surface heater with a diameter of 10 mm and surface roughness of 7.5 nm were used. CuO-water nanofluids have been created by 40nm nanoparticles and 1 to 1000 mg/l of concentrations are used in this research. The measurement of critical heat flux at different concentrations of nanofluid showed that critical heat flux has improved 92% in optimized concentration of 100 mg/l compared to distilled water. Atomic force microscopy, scanning electron microscopy and contact angle measurements have been done for analyzing properties of surface and nanocoated which are formed after nanofluid boiling. Results demonstrate that there is a positive effect in increasing roughness and a negative impact of thickness enhancement on critical heat flux.

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1. Introduction

Boiling is one of the most complex processes in engineering science. Due to the large latent heat of evaporation of the fluid in boiling process, A lot of energy is dissipated from the surface at the lowest temperature difference between the surface and the fluid. This important feature of boiling is used in many industrial applications.

Critical heat flux which leads to film boiling, is one of the limitations in boiling heat transfer. One of the techniques to improve heat transfer in boiling and enhancement of critical heat flux is adding nanoparticles to the base fluid that is named nanofluid. Nanofluid was first used by Choi [1] in 1995. This fluid is made by adding 1-100 nm solid particle powder to the base fluid, which is in the liquid phase. Since 2003, nanofluid boiling has become an important topic of nanofluid research [2-4].

Nazari et al. [5, 6] used an electrochemical coating process called anodizing to create a porous coating of aluminum oxide nanostructure on the flat surface of aluminum sample. At this stage by controlling anodizing parameters such as temperature and voltage and using different acid electrolyte solutions, porous nanostructures with different pore sizes are formed on the surface of aluminum samples. Then the pool boiling test with distilled water is performed on them. The results obtained in this experiment showed that the use of anodized samples increases the heat transfer coefficient and the critical heat flux.

Nazari et al. [7] performed a pool boiling test of water-aluminum oxide nanofluid with low concentrations of nanoparticles up to 1000 mg/l on aluminum samples with smooth and uncoated surface. The experimental results show that the use of nanofluids generally increases the critical heat flux and decreases the boiling heat transfer coefficient. At a concentration of about 100 mg/l, the critical heat flux has the highest value and shows a 26% increase compared to distilled water.

The overall aim of this study is to better understand the effect of copper oxide nanocoating on critical heat flux.

2. Material and Methods

2.1. Preparation of nanofluids

The procedure used for the preparation of nanofluid in this research is the two-step method. In this research, copper oxide nanopowder and distilled water-based fluid have been used to produce nanofluids. Copper oxide nanoparticles with a purity of 99.9% and with an almost spherical shape and a size of 40 nm have been used. Also, to prevent the changing of the thermal properties of the nanofluid, no stabilizing material was added to the base fluid. The mass of nanoparticles was measured using a scale (accuracy 0.0001). For stability and uniform distribution of nanoparticles in the base fluid, first, a magnetic stirrer for 12 hours and then an ultrasonic device with a power of 400 watts and a frequency of 40 kHz for 8 hours were used. Nanofluids were prepared in 7 different

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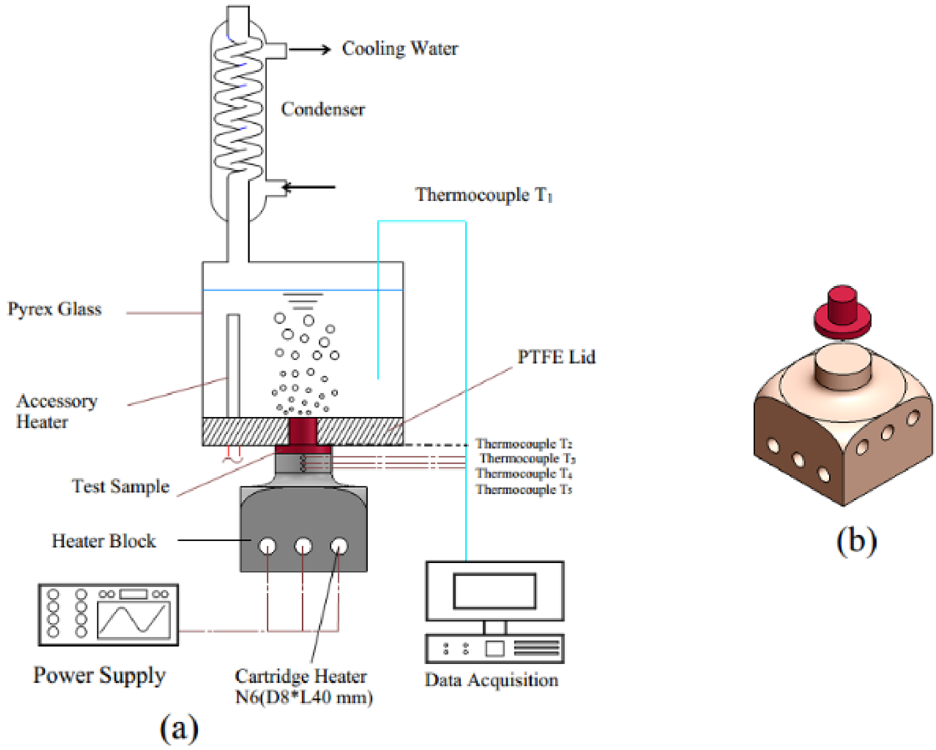

Fig. 1. a) A schematic diagram of experimental setup for pool boiling test. b) Copper block and Copper sample

concentrations including 1, 5, 10, 50, 100, 500 and maximum concentration of 1000 mg/l. To prevent settling nanoparticles, nanofluid was used in pool boiling test immediately after preparation.

2.2. Experimental setup and measurement

Pool boiling experimental setup has a cylindrical tank with a volume of almost 700 cubic centimeters. As it is shown in Fig. 1, the wall of tank is made of Pyrex glass, thus it is possible to observe the boiling phenomenon. In order to supply high heat flux, a copper heater is used and six cartridge heaters, each one with a diameter of 8mm, a length of 4cm, a power of 200W, capable of generating a thermal power of 1200W in total, are inserted into the holes made in the copper heater. In order to control heat flux, a power supply with voltage variation capability is used along with a multimeter for measuring voltage or current. Four type K thermocouples, namely T_1, T_2, T_3, and T_4 are employed for temperature measurement at different points. T_1 is used for measuring the fluid temperature, T_2 for surface temperature, and T_3 and T_4 for heat flux.

At the beginning of the experiment, almost 500 cubic centimeters of prepared nanofluids were poured into the Pyrex cylindrical tank. The heater was then turned on in order to increase the fluid temperature more quickly and to arrive at saturation temperature.

Then, the data logger system was switched on, so that the temperatures of T_1, T_2, T_3, and T_4 would be recorded in the memory. Voltage was gradually increased at several stages. As voltage or heat flux was increased, the boiling regime gradually changed and a column of bubbles formed on the surface of the sample. At the critical heat flux point, surface temperature abruptly increased over 100 ◦Cin less than three seconds, with a stable film of bubbles formed on the surface. Thus, as soon as the abrupt increase in temperature was observed, heat flux was stopped and the heater was turned off. The results of measured critical heat flux at various concentrations of nanofluids are shown in Fig. 2. All tests were carried out in atmospheric pressure and environment temperature (86 K.Pa and 27℃).

Assuming heat transfer in the top of the copper heater is one dimensional and by measuring temperatures T_3 and T_4, the heat flux can be calculated using Fourier's law of heat conduction as follows:

$$q'' = K\frac{T_4 - T_3}{l} \tag{1}$$

Here, l is the distance between thermocouples T_4 and T_3 and is equal to 7 millimeters. The surface temperature T_w of copper sample can be extrapolated by measuring the temperature T_2 that is 10 mm lower than the surface of the heater and using Fourier's law of heat conduction.

3. Results and Discussion

The results of the boiling test and the measurement of the critical heat flux of distilled water and nanofluid at different concentrations are shown in Fig. 2. An increase in critical heat flux is evident for all concentrations, but the changes in critical heat flux with nanofluid concentrations are so that at a concentration of 1 mg/l, the critical heat flux increased by 23% compared to distilled water and at a concentration of 100 mg/l this increase reached 92%. Then the critical heat flux

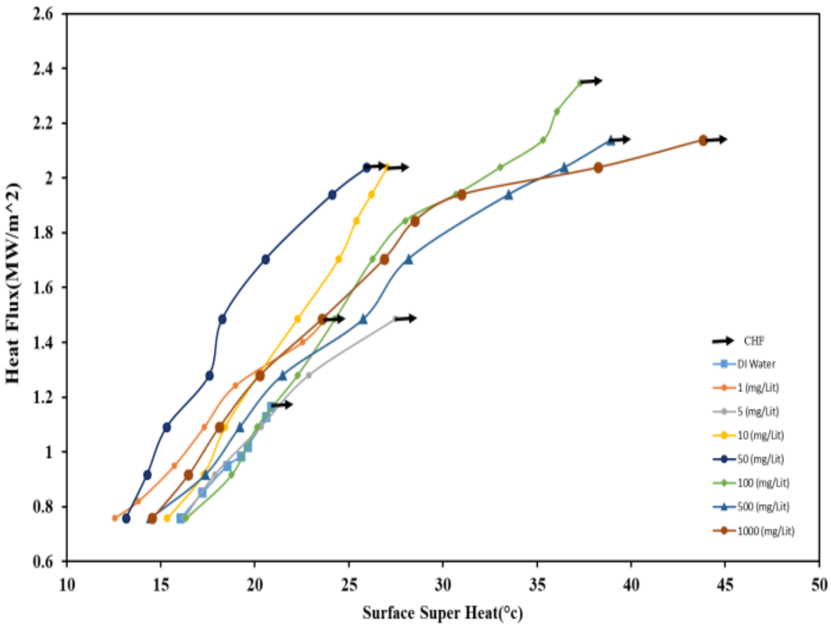

Fig. 2. Changes in the heat flux with superheat temperature in the experiment of boiling distilled water and nanofluid water-copper oxide at different concentrations

decreases with increasing surface superheat temperature at two concentrations of 500 mg/l and 1000 mg/l. . In addition, with the accuracy of Figure 2, it can be seen that .At the same heat flux, the temperature difference of the superheated region at all concentrations except 100 mg/l is less than that of distilled water. In addition, the highest surface temperature obtained is related to the maximum concentration of 1000 mg/l. This temperature is recorded at the critical heat flux point, 140.78 °C.

4. Conclusions

In the boiling of copper oxide nanofluids, the deposition of nanoparticles on the surface increases the heat transfer coefficient of the boiling and at higher concentrations of nanoparticles, due to the increase in the thickness of this layer, the boiling heat transfer coefficient decreases.

References

[1] S.U. Choi, J.A. Eastman, Enhancing thermal conductivity of fluids with nanoparticles, Argonne National Lab., IL (United States), 1995.

[2] S.M. Kwark, R. Kumar, G. Moreno, J. Yoo, S.M. You, Pool boiling characteristics of low concentration nanofluids, International Journal of Heat and Mass Transfer, 53(5-6) (2010) 972-981.

[3] M.S. Lee, D.H. Kam, Y.H. Jeong, Effects of silica nanoparticles and low concentration on the deterioration of critical heat flux in a pool boiling experiment with a flat-type heater, International Journal of Heat and Mass Transfer, 144 (2019) 118420.

[4] M. Sarafraz, T. Kiani, F. Hormozi, Critical heat flux and pool boiling heat transfer analysis of synthesized zirconia aqueous nano-fluids, International Communications in Heat and Mass Transfer, 70 (2016) 75-83.

[5] A. Nazari, S. Saedodin, Porous anodic alumina coating for optimisation of pool-boiling performance, Surface Engineering, 33(10) (2017) 753-759.

[6] A. Nazari, S. Saedodin, Critical heat flux enhancement of pool boiling using a porous nanostructured coating, Experimental Heat Transfer, 30(4) (2017) 316-327.

[7] A. Nazari, S. Saedodin, An experimental study of the nanofluid pool boiling on the aluminium surface, Journal of Thermal Analysis and Calorimetry, 135(3) (2019)

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