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The quenching of silver rod in boiling carbon nano tube–water nanofluid

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ABSTRACT

It is well established that nanofluids increase or decrease heat transfer in boiling phenomenon. The study acquired Quenching curve and boiling curve in two different surface roughnesses in two fluids: deionized water and the nanofluid MWCNT–water with four different concentrations.

The cylinder was made of silver and two surface roughnesses of 129 and 690 nm. It was heated up and soaked in the fluid mentioned above. Temperature was recorded by a drilled to install thermocouple. The experiment was replicated in five times. To calculate the heat transfer quotient, assuming the cylinder to be thermally homogeneous, the Lumped capacity method was applied. The obtained results during quenching process indicated that CHF in nanofluids was less than deionized water. It was also observed that in identical circumstances by repeating the test, the quenching time of the sample in both deionized water and CNT nanofluid decreased. The comparison between the two surface roughnesses revealed that the cylinder with higher surface roughness quenched faster and roughness had a significant effect. The subsequent test was conducted in order to investigate the effect of surfactant dissolved in deionized water. The result indicated that the quenching time increased.

1. Introduction

Heat transfer enhancement is a major requirement in many industrial applications such as in steel production and in manufacturing electronic devices. Thermal conductivity in liquids, as compared to solids, is a drawback in heat transfer systems. One of the best methods commonly used for heat transfer enhancement in cooling fluids is the phase change, which is frequently accomplished through a mechanism called immersion cooling, or quenching. Quenching involves the immersion of an object with a much higher temperature than the ambient temperature in a liquid with a temperature much lower than that of the object immersed. However, it should be noted that heat transfer rate during quenching or boiling processes is limited by the Leidenfrost effect, a phenomenon in which a liquid in near contact with a mass significantly hotter than the liquid's boiling point produces an insulating vapor layer which keeps the liquid from boiling rapidly.

Quenching is used in both metal production processes and in cooling nuclear reactors. Many methods have been suggested to boost boiling heat transfer and decrease the Leidenfrost effect. Examples include shaking the heating surface, increasing the heating surface area, and using an electric field to increase bubbles parting speed (Kim et al. [1]). Thanks to recent developments in nanotechnology, a new group of fluids has been produced, called nanofluids, by scattering particles in the nanometer size range in a base fluid. These nanofluids are known to have the capacity to boost heat transfer in fluids.

Research in the field of nanofluids has been basically focused on their thermophysical and heat transfer properties. Studies on heat transfer in different nanofluids have revealed that the type of nanoparticles used and the method applied in their production greatly affect their heat transfer properties (Duangthongsuk and Wongwises [2], Zhu et al. [3], Jiang et al. [4], Oh et al. [5], Wang and Wei [6], Zhang et al. [7], Kwak and Kim [8], Lee et al. [9], Murshed et al. [10]). In producing certain nanofluids, no surfactant has been used (Duangthongsuk and Wongwises [2], Zhang et al. [7]) while an increase has been observed in their heat transfer capability. This is while the use of surfactants in some other studies either increased

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or decreased their heat transfer capability, depending on the type of surfactant used.

From a different perspective, heat transfer studies of nanofluids have been concentrating on their boiling properties.

Lotfi and Shafii [11] conducted experiments on film boiling heat transfer on a sphere in nanofluids with Ag and TiO_2 in base fluid water and pure water. The sphere was made of silver with $d = 10$ mm. It was observed that film boiling heat transfer and CHF were lower in nanofluids at all the densities tested than in pure water. It was found that the steam disappeared faster as the test runs increased without washing the sphere.

Kim et al. [12] performed experiments to study film boiling heat transfer on a sphere of steel 9.5 mm in diameter and one of Zircalloy 10 mm in diameter. They used alumina, silica, and diamond nanofluids at fixed densities to observe that as particles deposited on the hot surface in sequential experiments, film boiling accelerated and CHF increased due to the nanoparticle deposition.

Park et al. [13] investigated film boiling in nanofluids on a sphere of copper with alumina in a water base fluid. The results obtained showed that the rate of film boiling heat transfer in nanofluids was not greater than that in pure water.

Choo et al. [14] experimented with uncoated platinum and silicon coated (nanoparticle deposits) wires with silicon–water used as the nanofluid. They found no significant effects on the silicon–water boiling curve. However, a high rate of heat transfer was observed in transient and nucleate boiling when the wire was coated with silicon.

Xue et al. [15] studied the CNT nanofluid in pure water on a copper sphere. The sphere was heated up to 300 °C before it was plunged into the boiling nanofluid. The results showed that the boiling curve was raised in all areas. It was also observed that the wettability of the sphere surface increased due to the deposition of nanoparticles.

Babu and Prasanna Kumar [16–18] carried out experiments to determine the optimum CNT concentration and bath temperature for maximum heat flux as well as the effect of the surfactant on CNT nanofluid quenching. They found out that the nanofluid produced without the surfactant exhibited a higher heat transfer rate during the quenching process than the one produced with the surfactant used.

Prakash Narayan et al. [19] studied the effect of boiling surface roughness on heat transfer rate in alumina nanofluid with particles of different diameters and found that higher values of boiling surface roughness resulted in higher heat transfer rates. In addition, they observed that the ratio of average particle size to average roughness of the boiling surface was effective in heat transfer rate in nanofluid pool boiling.

Krishna et al. [20] studied nanofluid pool boiling using a Cu–H_2O nanofluid on a flat copper surface. Their results showed that heat transfer rate varied with nanofluid concentration, heat flux, and heater surface roughness.

In a different study, Prakash Narayan et al. [21] studied the effect of boiling surface orientation on nanofluid boiling heat flux. They used the three different orientations of 0°, 45°, and 90°. The horizontal (0°) and the 45° orientations were found to yield the maximum and minimum heat transfer rates, respectively.

Das et al. [22] investigated the effect of horizontal tube diameter on pool boiling heat transfer rate in Al_2O_3 nanofluid. Their results indicated that the deterioration in tube boiling performance was lower in narrow tubes than in large industrial scale ones, making them less susceptible to local overheating in convective applications.

For the purposes of this study, use was made of a silver cylinder of two different surface roughnesses. In addition to surface roughness, the effects of nanofluid concentration, nanoparticle deposition on the surface, and the surfactant used in the base fluid have been investigated. Following Prakash Narayan et al. [21], the horizontal position was adopted for the boiling surface orientation to achieve the highest heat transfer rate. Results showed that roughness had considerable effects on the properties of the curve.

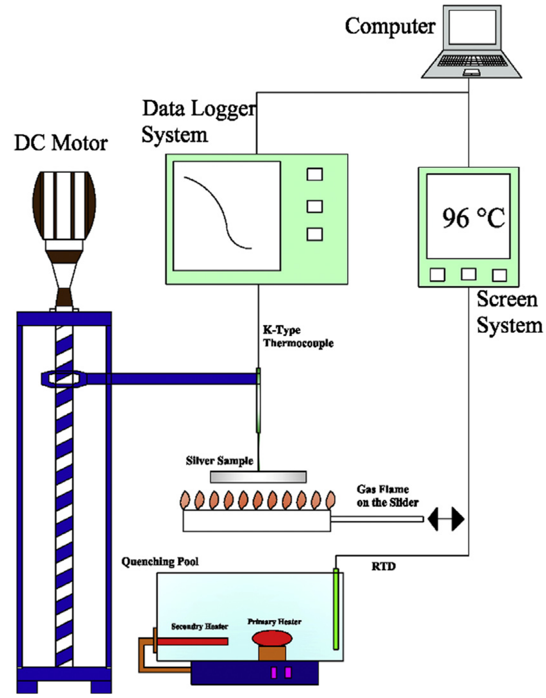

Fig. 1. Schematic diagram of the experimental setup (not to scale).

2. Equipment

2.1. Apparatus

The mechanism used in this experiment includes two silver cylinders with different roughnesses, two K-Type thermocouples, a lifter jack, an engine, a fluid pool, two electric heaters, one RTD[1] thermometer, and a data acquisition system (Fig. 1).

To avoid disturbances and to reduce heat transfer from sample supports, the number of cylinder supports had to be kept to a minimum. Thus, the thermocouple in the center of the cylinder was used as a support for the cylinder. A rigid cover (reinforcement tube) with an external diameter of 1 mm was used on the thermocouple wire to hold the cylinders in the horizontal position throughout the experiments. The ratio of the diameter of the thermocouple support to that of the cylinder was 0.1, which is small enough for the heat loss through the support to be neglected.

A data acquisition system (LOGOSCREEN 955010) operated at a frequency of 8 Hz was used to record transient temperatures in the center of the heated cylinder. The data collected was then transferred to a computer for analysis.

The pool (100 × 100 × 200 mm) included two primary and secondary heaters. The pool measuring system and the size of the silver samples were such that the effects of the rims on boiling could be ignored. In the worst case, the uncertainty in heat flux values mainly associated with the sampling rate of the data acquisition system was estimated to be less than 6.8 °C.

[1] Resistance Temperature Detector.