

# Effect of Nanofluids on the Saturated Pool Film Boiling

Dogan Ciloglu, Abdurrahim Bolukbasi, Kemal Comakli

**Abstract**—In this study, the effect of nanofluids on the pool film boiling was experimentally investigated at saturated condition under atmospheric pressure. For this purpose, four different water-based nanofluids ( $\text{Al}_2\text{O}_3$ ,  $\text{SiO}_2$ ,  $\text{TiO}_2$  and  $\text{CuO}$ ) with 0.1% particle volume fraction were prepared. To investigate the boiling heat transfer, a cylindrical rod with high temperature was used. The rod heated up to high temperatures was immersed into nanofluids. The center temperature of rod during the cooling process was recorded by using a K-type thermocouple. The quenching curves showed that the pool boiling heat transfer was strongly dependent on the nanoparticle materials. During the repetitive quenching tests, the cooling time decreased and thus, the film boiling vanished. Consequently, the primary reason of this was the change of the surface characteristics due to the nanoparticles deposition on the rod's surface.

**Keywords**—Heat transfer, nanofluid, nanoparticles, pool film boiling

## I. INTRODUCTION

BOILING heat transfer continues to be a subject of ongoing research because of its potential to remove large amounts of heat at low temperature differences. Boiling occurs in a variety of engineering applications such as heat treatments of steel, core safety of nuclear reactors, and the rapid solidification processing. In this process, in the case of the surface superheat is high enough; the heat transfer from a solid wall to adjacent liquid is blocked by the vapor blanket over the surface. Thus, the acceleration of the transition from film boiling to nucleate boiling is often desirable, as it results in a much higher heat transfer rate [1]. Since traditional heat transfer fluids such as water, ethylene glycol and oil are not sufficient to acquire the desired heat transfer rate, nanofluids are expected to accelerate this process.

Nanofluids are a new kind of heat transfer fluids within which nanometer-sized particles are uniformly and stably suspended [2]. They are suggested for various uses in important fields such as power generation, chemical production, air-conditioning (HVAC), transportation and microelectronics. To the best of our knowledge, the few reported studies have investigated the effects of nanofluids on pool boiling and even film boiling performance [1]-[10], and so there is still a serious lack in this domain.

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The present paper is aimed at an experimental study of pool film boiling heat transfer of nanofluid under atmospheric conditions.

## II. EXPERIMENTAL APPARATUS AND PROCEDURE

Four types of nanoparticles were used in this study,  $\text{Al}_2\text{O}_3$ ,  $\text{SiO}_2$ ,  $\text{TiO}_2$  and  $\text{CuO}$ . These particles were purchased from NanoAmor<sup>®</sup> in powder form and their thermo-physical properties were given in Table 1. The base fluid was deionized water. The nanofluids were prepared by mixing these particles directly with deionized water, without the addition of dispersant and surfactant. First the nanoparticles' weight was measured using an Ohaus balance. Then the particles were suspended in a specified volume of the base fluid. A magnetic stirrer was used to homogenize the suspension. For the purpose of deagglomerating the nanoparticles, the suspension was then put in an ultrasonic bath for about 2 h just before the experiments. No sedimentation was observed after several hours. The prepared solutions are shown in Fig.1.

TABLE I  
THERMO-PHYSICAL PROPERTIES OF THE NANOPARTICLES

Material	Purity (%)	APS (nm)	$\rho$ ( $\text{kgm}^{-3}$ )	$c$ ( $\text{Jkg}^{-1}\text{K}^{-1}$ )	$k$ ( $\text{Wm}^{-1}\text{K}^{-1}$ )	SSA ( $\text{m}^2\text{g}^{-1}$ )
$\text{Al}_2\text{O}_3$	99.5	27-43	3970	765	36	35
$\text{SiO}_2$	99.5	20	2220	745	1.38	$160 \pm 20$
$\text{TiO}_2$	99+	10-30	4157	710	8.4	$210 \pm 10$
$\text{CuO}$	99+	30-50	6310	535.6	76.5	13

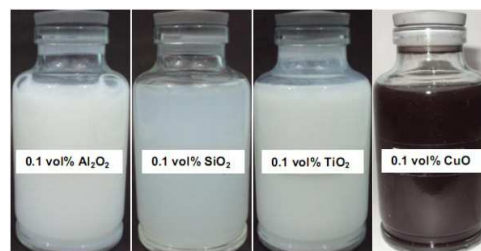


Fig. 1 The nanofluid suspensions prepared in 100ml beakers

Fig.2(a) and 2(b) show the schematic of the experimental apparatus and the test rod (made up of brass material), respectively. The main components are a Pyrex quench pool (diameter 100x200 mm), a radiant furnace (diameter 400x200 mm), a pneumatic piston, and a data acquisition system.

After preparation of the nanofluid with the specified concentration (0.1% by volume), the nanofluid was injected into the quench pool, and heated up to saturated condition using a thermostat-controlled electrical heater. To immerse the rod into the pool under atmospheric pressure, a pneumatic piston was used. Before immersing it abruptly into the quench pool, the test rod was heated to about 600°C in the furnace. The nitrogen gas was injected into the furnace while the rod was being heated to reduce the oxidation on the heated surface. The center temperature of rod and the temperature of the suspension were measured by using K-type thermocouples. The uncertainty in temperature measurements is  $\pm 0.1^\circ\text{C}$ . An Advantech ISA PCL-818HG data acquisition system was used for recording the temperature-time data. When the temperature of rod and quench pool was in thermal equilibrium conditions, the test was finished. The quenching tests were consecutively performed three times in order to investigate the surface effect on pool film boiling. Before starting to the next nanofluid experiments, the rod' surface was polished to remove the contaminations formed on the surface by using emery paper (1200 mesh).

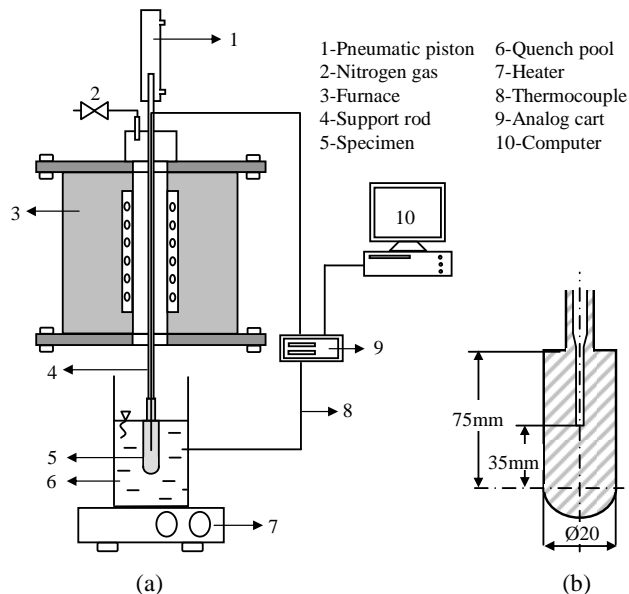


Fig. 2 (a) The experimental apparatus, (b) the test rod

### III. RESULTS AND DISCUSSION

Fig.3 shows the quenching curves with the repetition tests in nanofluids. We observed that the quenching behavior of nanofluids was similar to that in pure water. The film boiling region is also marked on Fig. 3(a). After this region, the vapor film collapses and the quenching process is ended with the phases of transient boiling, the nucleate boiling and the single-phase convection heat transfer, respectively. As seen in Fig. 3, a stable vapor film is consistently observed in the first run for all nanofluids. We can conclude from these observations that the presence of nanoparticles in the base fluid has no meaningful effect on the quenching behavior of rod with a fresh surface, as indicated in the study of Kim et al. [1].

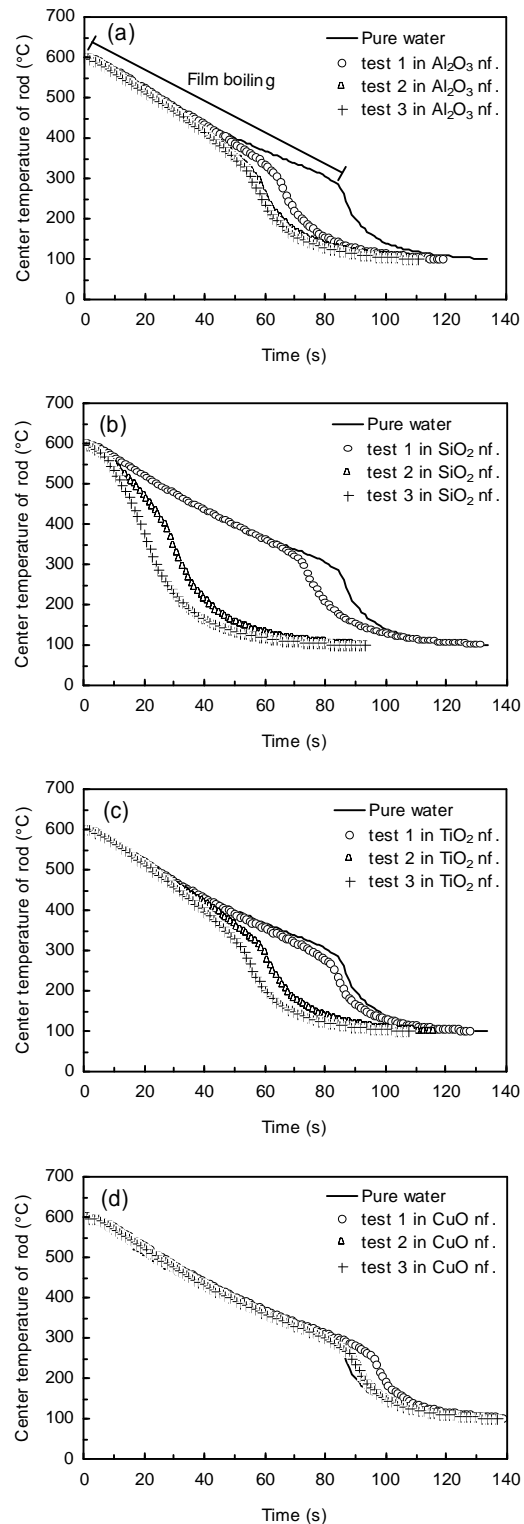


Fig. 3 The quenching curves in (a) Al<sub>2</sub>O<sub>3</sub>, (b) SiO<sub>2</sub>, (c) TiO<sub>2</sub> and (d) CuO nanofluid

However, during the repetition tests, there is a shifting in the curves to the left. This situation means that there is a premature collapse of the vapor film and a quenching

acceleration. Therefore, the cooling time was considerably shortened and the film boiling disappeared. This behavior is strongly dependent on the type of nanofluid. For example, as seen in Fig. 3(b), this situation is more explicit with the  $\text{SiO}_2$  nanofluid. On the other hand, no considerable change for CuO nanofluid is observed in the repetitive quenching tests. This can be attributed to the lack of surface-particle interaction.

There are some studies in the literature indicating that the nanoparticles change the surface properties due to the deposition during the pool boiling [1], [5]-[10]. After the quenching tests, we observed also the nanoparticles deposited on the rod's surface. Fig.4 shows the rod's surface for fresh surface, quenched surface in pure water and quenched surface in  $\text{SiO}_2$  nanofluid. This nanoparticles deposited on the surface have caused an earlier collapsing of vapor film with a few microns thickness. As a consequence, the main reason for the shifting in the curves is due to the change of surface characteristics.



Fig. 4 The photographs of rod, (a) fresh rod, after test in (b) pure water, (c) 0.1vol.%  $\text{SiO}_2$ -water nanofluid

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