International Communications in Heat and Mass Transfer 95 (2018) 98–105

Contents lists available at ScienceDirect

International Communications in Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ichmt

# Pool boiling characteristics of silica/water nanofluid and variation of heater surface roughness in domain of time

Faezeh Rostamian, Nasrin Etesami*

*Department of Chemical Engineering, Isfahan University of Technology, Isfahan 84156-83111, Iran*

ARTICLE INFO

*Keywords:*
Pool boiling
Nanofluid
Period of time
CHF
BHTC
Surface roughness

ABSTRACT

In present study, boiling of water-silica nanofluid on circular flat plate heater was carried out to investigate the variation of heater surface and characteristics of nanofluid boiling at periods of time. Boiling region of nanofluid was divided into four periods of time, and the results showed that as the boiling time increases, the nanofluid boiling behavior differs from boiling of DI water. Evaluation of heater surface roughness in different periods of time showed that the surface roughness increases with time duration of boiling. It was found that boiling heat transfer coefficient (BHTC) enhances with nanofluid concentration (< 0.01 vol%) and indicated an optimum in 0.007 vol%, especially at higher period. Critical heat flux (CHF) increases compared to DI water for all concentrations. In addition, influence of duration time of nanofluid boiling at constant heat fluxes on surface roughness and on performance of the boiling of DI water on the obtained surface was investigated. The results showed that when boiling time is extended in a constant heat flux, surface roughness increases, and BHTC of DI water on the nanocoated surface obtained depending on value of constant heat flux may increase or decrease.

## 1. Introduction

Nucleate boiling is known as one of the most effective mechanism of heat transfer. In many engineering applications that need to high heat fluxes, nucleate boiling is the best process. Efficiency of energy should be increased for saving the energy. Primary studies on nucleate boiling demonstrate that nanoparticles and nanostructure surfaces can be useful for enhancing the heat transfer efficiency. Boiling behavior of nanofluid depends on several factors, including type, size and concentration of nanoparticles, characteristics and geometry of the surface heater, presence of surfactants and pressure [1–3]. There are several studies which investigate the effect of these factors on critical heat flux (CHF) and boiling heat transfer coefficient (BHTC).

You et al. [4] as an initial study reported a 200% CHF enhancement using alumina–water nanofluid. A similar study was done by Jo and Jeon [5] who also reported significant CHF enhancement using silver–water nanofluid. Ever since these initial findings were first reported, many other studies have also reported CHF enhancement using nanofluid composed of various nanoparticle types and base fluids [6–11]. Thus, extensive amount of research has confirmed that nanofluid can enhance CHF. According to results, several researchers have tried to understand why CHF increases in boiling of nanofluids.

Jong et al. [12] studied the effects of magnetite-water nanofluid boiling on CHF enhancement using an Ni–Cr wire as a heater. They showed that in the nucleate boiling of nanofluid, the heated surface was 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 surface. In other words, it is easy to wet the hot spots and to cool the heated surface. This wetting capability enhances CHF of the nanofluid. Furthermore, the degree of CHF enhancement increased as the amount of deposited nanoparticles increased. Therefore, CHF was more enhanced at higher nanoparticles concentrations. Kim et al. [13,14] conducted pool boiling experiments with nanofluid containing alumina, zirconia, and silica. They characterized the nanoparticle-coated surfaces according to the contact angle, which is a measure of wettability. It is well known that the contact angle decreases with increasing in wettability. Kim et al. [13] reported that a thin layer of deposited nanoparticles changed the surface energy and surface morphology, and that was closely related to the observed contact angle. Later, other researchers [15–17] reconfirmed that the wettability effect of nanoparticles on the heater surface influenced CHF enhancement. It also explained that CHF was increased by the enhancement of surface wettability using the prediction of Kandlikar's model [18], which expressed the effect of surface wettability on CHF.

In addition of the investigation of the effect of nanoparticle on surface wettability and boiling heat transfer, furthermore various techniques to modify surface wetting characteristics have been

* Corresponding author.
*E-mail address:* netesami@cc.iut.ac.ir (N. Etesami).

https://doi.org/10.1016/j.icheatmasstransfer.2018.04.003

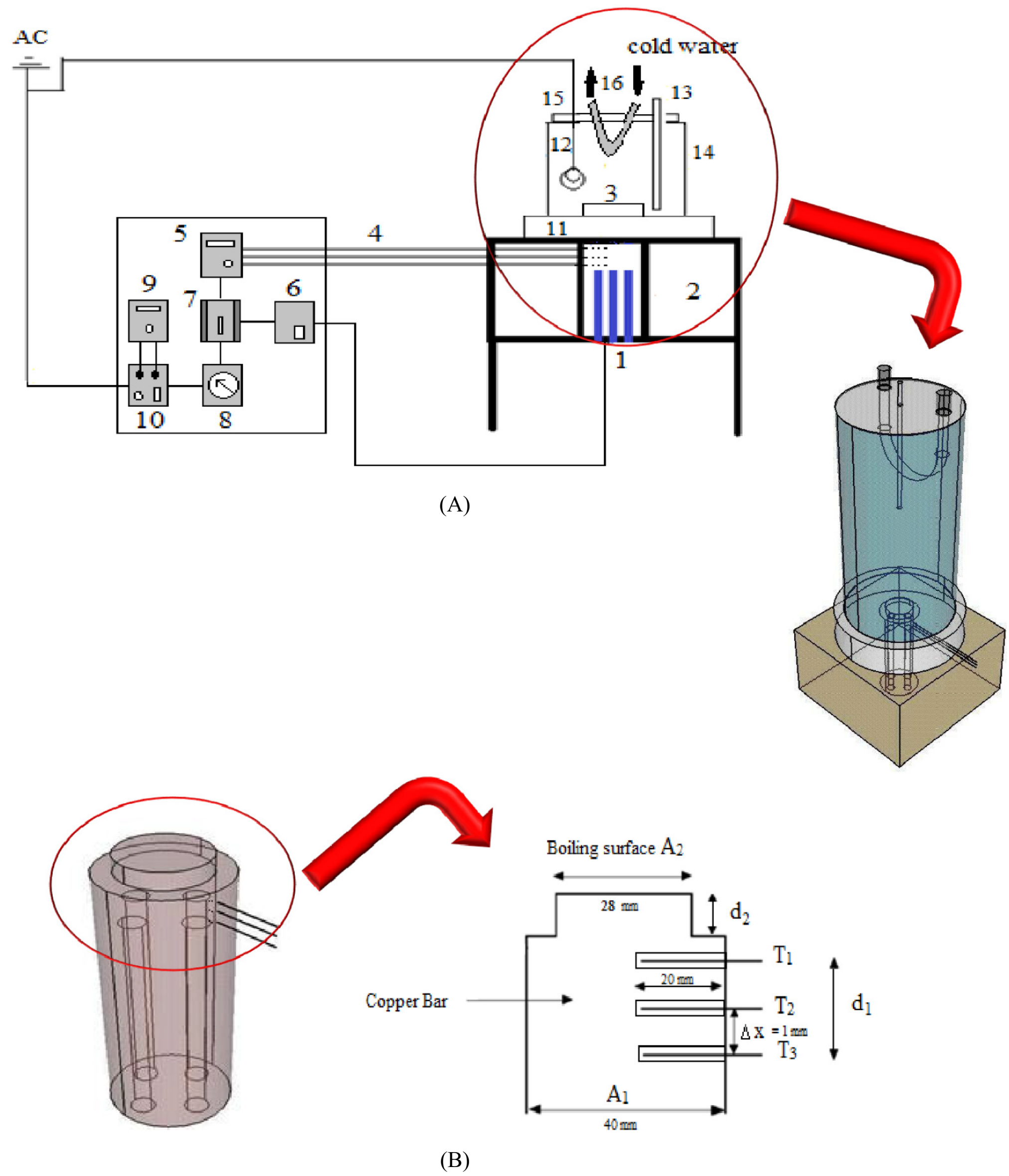


**Fig. 1.** Experimental setup: A) 1 - heater cartridge, 2 - isolation set, 3 - heating surface, 4 - thermocouple, 5 - thermostat, 6 - on/off switch, 7 - contactor 3 phase 9 A, 8 - amperemeter, 9 - voltmeter, 10 - dimmer, 11 - Teflon, 12 - pre-heater, 13 - thermometer, 14 - boiling vessel, 15 - Teflon cap, 16 - copper coil for vapor condensing. B) Copper bar with thermocouples embedded inside it.

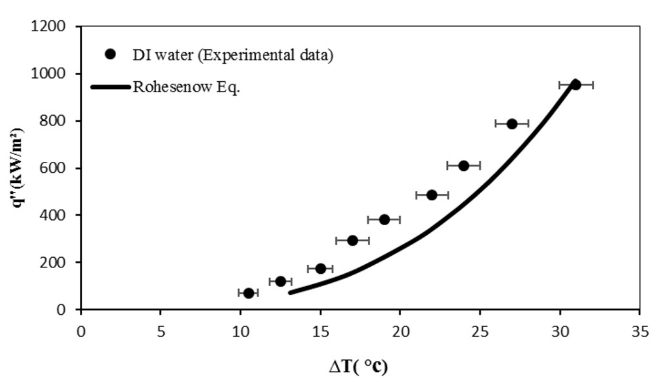


**Fig. 2.** Comparison of experimental data with Rohsenow's correlation.

considered including oxidation, plating, and UV irradiation [18–21].

In spite of CHF, boiling heat transfer coefficient shows inconsistent and different behaviors. Zeinali [22] reported a 55% increase in BHTC using CuO-water nanofluid. While in the studies by Sarafraz and Hormozi [23], Kwark et al.'s [24–26], Kim et al.'s [7,27] and Shahmoradi et al.'s [28] who conducted pool boiling experiments using alumina–-water nanofluids, the BHTC decreased. In these studies, BHTC degradation is attributed to either a "smoothening" of the heater surface as nanoparticles collect in surface cavities or an increase in the thermal resistance as nanoparticles form a thin layer on the heater. Similarly, other studies [4,14,16,29,30] have also reported that nanofluids either have no effect or degrade BHTC.

The background of studies shows that numerous investigations in the field of boiling of nanofluid and the effect of nanoparticles on CHF and BHTC have been accomplished. While still there are conflictions in variation of BHTC. It shows that the mechanism of nanofluid boiling is so complicated. Also there are not any studies about boiling behavior of nanofluid in different periods of time and deposition of nanoparticles on the heater surface during boiling. So in order to understand the mechanism of boiling of nanofluid deeply, it merits further study on the effective parameters on nanofluid boiling characteristics, especially the roughness of heater surface during the boiling in different regions of