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Review on Dynamic enhanced double efficient boiling heat transfer coefficient using electrophoretic deposition from a ZnO-propylene glycol based Nano fluid.

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***Abstract*—A relatively new class of coolants created by suspending 1-100 nm sized particles in a base fluid, have been shown to improve a fluid's thermal properties. My research focuses on two methods using nano fluids to deposit nanoparticles for the creation of enhanced surfaces for boiling heat transfer. Since many of these thermal management systems require a non-conductive fluid, the electrical conductivity of nano fluids is also studied.**

Pool boiling studies of nanofluids have demonstrated either enhanced or diminished boiling heat transfer, yet have been unable to distinguish the contributions of increased surface roughness and suppression of bubble transport by suspended particles. This uncertainty is resolved by studying the boiling performance of a surface exposed to a series of boiling tests that alternate between water and a water-based nano fluid. The boiling performance of the coated surfaces increases significantly with each cycle. The measured surface roughness of the intervening nanoparticle layers is used with a model to explain the measured increase in performance. The results demonstrate that the effect of increased surface roughness due to nanoparticle layering can enhance boiling for the base fluid.

"A novel method to create enhanced boiling surfaces is electrophoretic deposition of nanoparticles from a nano fluid. A surface was coated using electrophoretic deposition from a ZnO-propylene glycol based nano fluid. With adequate coating time, such a surface modification method can increase the boiling heat transfer coefficient by about 200%, which was correlated to an increase in the nucleation site density."

***Keywords*—nanofluid, critical heat flux, nanostructure, microstructure, electrophoretic deposition**

I. INTRODUCTION

Nanofluids are dilute liquid suspensions of nanoparticles with at least one of their principal dimensions at the nanoscale level. From previous investigations, nanofluids have been found to pos-sess enhanced thermo-physical properties, such as thermal con-ductivity, thermal diffusivity, viscosity, and convective heat transfer, compared to base fluids, such as oil or water .These particles can be metallic (Cu, Au), metal oxides ($Al2O3$, $TiO2$, $SiO2$, $ZnO2$), carbon (diamond, nanotubes), or other materials. The typical base fluid alone has a low thermal conductivity. Nanoparticles can be dispersed in the base fluid and remain suspended in the fluid to a much greater extent than was previously achieved with microparticles or larger-sized particles. Brownian motion of nanoparticles in the base fluid allows the nanoparticles to maintain their dispersed state and to enhance the thermo-physical properties of the fluid.[8]

It showed that nanofluids, containing only 0.005 g/l of alumina nanoparticle, make the dramatic increase ~200%) in CHF in pool boiling at the pressure of 2.89 psia (Tsat=60). They concluded that the abnormal CHF enhancement of nanofluids cannot be explained with any existing models of CHF. Vassallo performed the experimental studies on pool boiling heat transfer in water-SiO2 nanofluid under atmospheric pressure. They showed a remarkable increase in CHF or nanofluid and also found that the stable film boiling at temperatures close to the melting point of the boiling surface are achievable with the nanofluid. H.D. Kim aid a CHF enhancement mechanism in the nanofluids hat is based to surface effect using a wire heater supplying a power as electric DC power. But nanoparticle deposited phenomena may be asked whether by boiling procedure, or by electric filed effect on the surface. So the flat plate experimental apparatus supporting only thermal heating is developed to perform the CHF enhancement experiment with nanofluid in pool boiling. The copper surface was used as heater surfaces and nanofluid was created with Al2O3, TiO2 nanoparticles and deionized water by 2-step methods. And CHF in deionized water enhances on nanoparticles deposited surface. So, CHF enhancement an nanofluid is also achieved by the surface effect. For his result, surface investigation (SEM, contact angle and roughness) about the nanoparticle coated surface was performed.

In addition, on chip cooling techniques require low conductivity coolants. However, the electrical conductivity of nanofluids has not been widely studied. The particle size and concentration effects on nanofluid electrical conductivity were experimentally investigated and compared to a model based on colloidal suspensions in a salt-free medium. The results showed the electrical conductivity increased with increasing volume fraction and decreasing particle size. At higher volume fractions, the increase of electrical conductivity begins to level off, which is attributed to ion condensation effects in the high surface charge regime Recently, there has been increasing interest in boiling nanofluids and their applications. Among the many articles that have been published, the critical heat flux (CHF) of nanofluids has drawn special attention because of its dramatic enhancement. This article includes recent studies on CHF increasing during the past decade by various researchers for both pool boiling and convective flow boiling applications using nanofluids as the working fluid.

The heat transfer characteristics and thermal properties of nanofluids have been investigated more intensely in the past couple of decades for different heat transfer applications by various researchers.

II. POOL BOILING CHF ENHANCEMENT WITH NANOFLUIDS

Wettability, high critical heat flux (CHF), and high heat transfer coefficient are among the most desirable characteristics of a sur-face in the field of boiling heat transfer. So far tremendous amount of research has been done to investigate the boiling characteristic of different materials. [7]

Many researchers have tried to improve the boiling characteris-tics of surfaces by nanostructure coating. For instance, Saeidi and Alemrajabi [1] used nano structured surface which were prepared by anodizing method and surveyed contact angle and boiling traits like CHF and heat transfer coefficient. They employed atomic force microscope (AFM) images to study surface characteristics and observed enhancement in heat transfer coefficient of up to 159%. Wetting under different conditions was studied by Jo et al. [2].

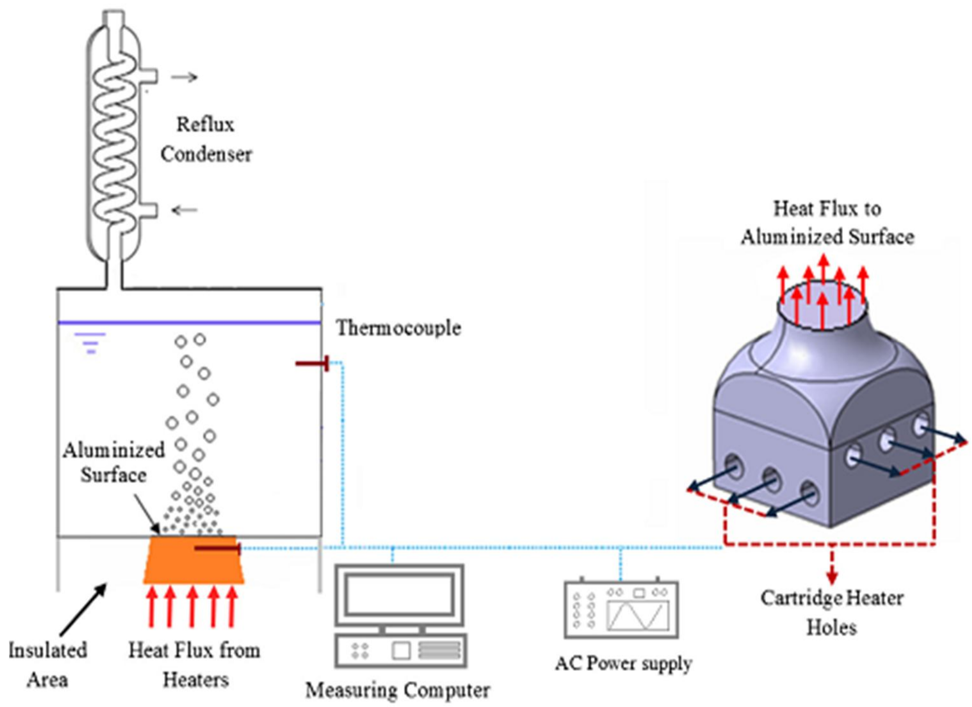

Fig. 1. Schematic diagram of the experimental apparatus and copper block containing 6 holes for cartridge heaters

Their observation in nucleate pool boiling indicated that hydro-phobic surfaces have better boiling heat transfers attribute in very low heat flux regimes than do hydrophilic surfaces.

A. Test procedure

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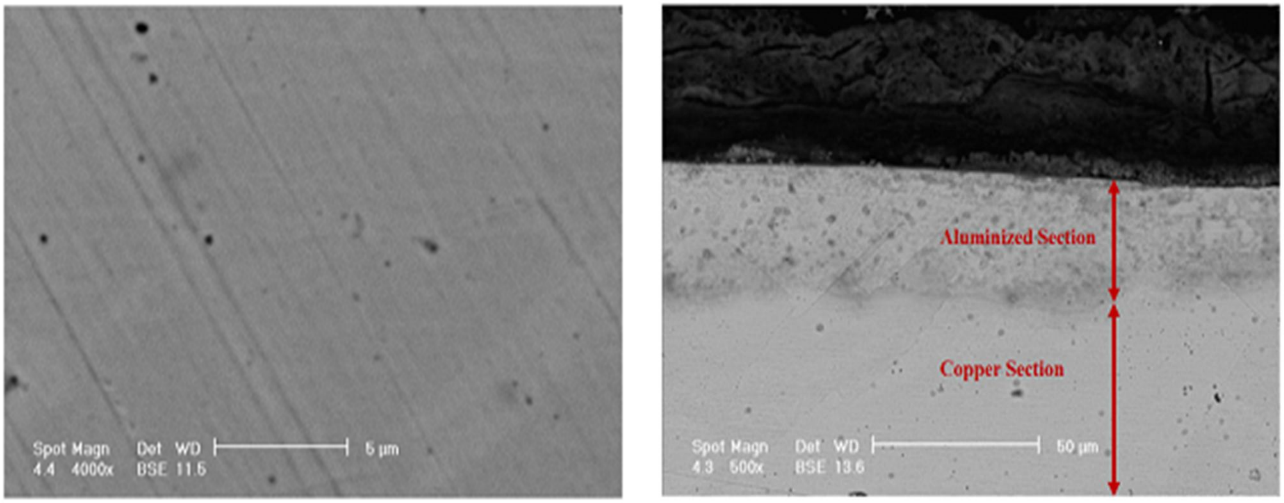
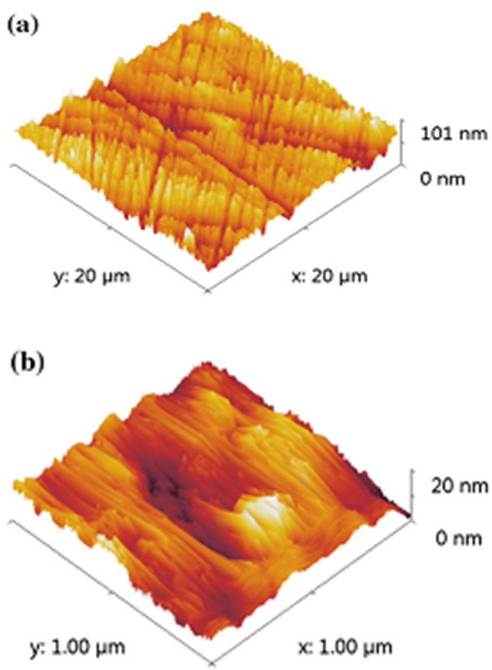
Considering that surface characteristics may have principal roles in boiling heat transfer features, contact angle on all specimens was measured. Measuring contact angle was placed after cleaning entire specimens by acetone. All tests and measurements were carried out at room conditions, i.e. 23 C and atmospheric pressure of 82,526 Pa (616 mmHg). At this pressure the saturation temperature of water is 94.1 C .



(a) (b)

B. Results

In order to identify the quality of the aluminized surface, one can study the Back Scattering Electron (BSE) mode on a Scanning Electron Microscope (SEM). The top view of aluminized surface is shown in Fig. In the BSE image, the dark spots are indicative of heavier element which is copper in the current case.



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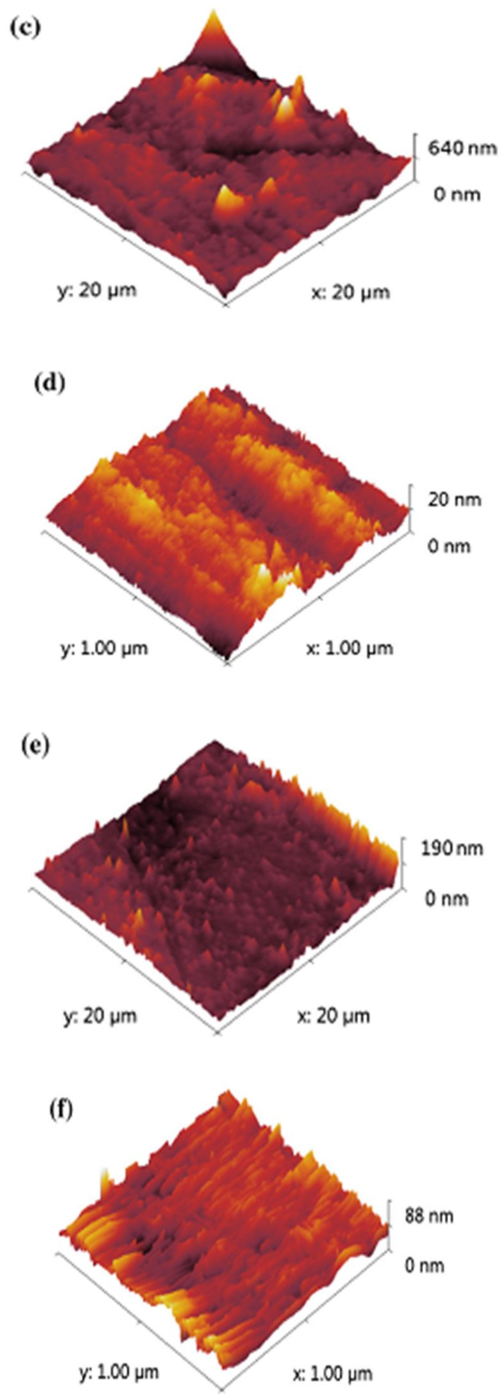

Fig. 2. 3D AFM image for (a) and (b) aluminum (c) and (d) aluminized (e) and (f) copper.

III. THERMODYNAMIC AND HEAT TRANSFER PROPERTIES OF AL2O3 NANOLUBRICANTS

In vapor compression cycles, a small portion of the oil circulates with the refrigerant throughout the system components, while most of the oil stays in the compressors. In heat exchangers, the lubricant in excess penalizes the heat transfer and increases the pressure losses: both effects are highly undesired but yet unavoidable. Nanoparticles dispersed in the excess lubricant are expected to provide enhancements in heat transfer. While solubility and miscibility of refrigerants in polyolesters (POE) lubricant are well established knowledge there is a lack of information regarding if and how nanoparticles dispersed in the lubricant affect these two

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properties. [6]

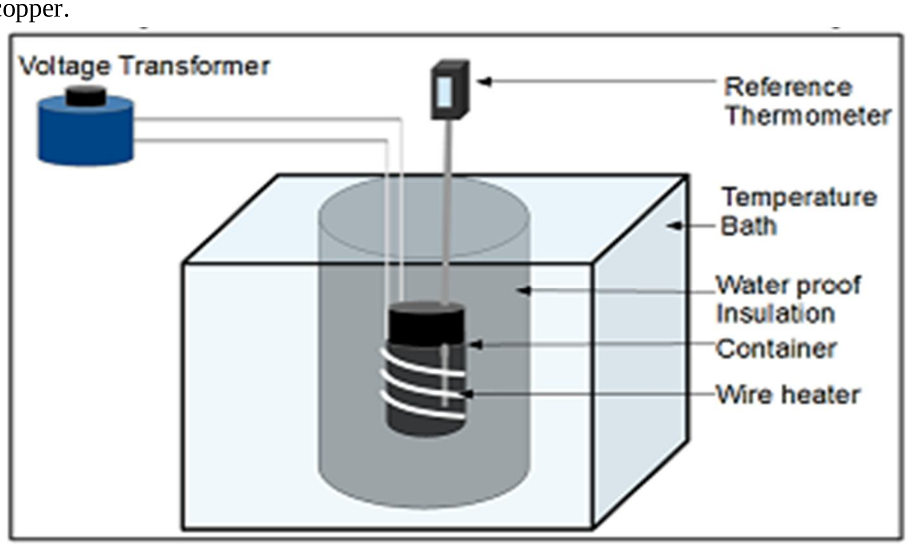
It presents experimental data of solubility and miscibility of three types of Al2O3 nanolubricants with refrigerant R-410A. The nanoparticles were dispersed in POE lubricant by using different surfactants and dispersion methods. The nanolubricants appeared to have slightly lower solubility than that of R-410A but actually the solid nanoparticles did not really interfere with the POE oil solubility characteristics. High viscosity suspensions are expected to stabilize the nanoparticles and avoid clustering. This aspect was verified in the present paper for the Al2O3 nanolubricants and long term stability and the degree of agglomeration, when present, were measured. The data identified optimum combinations of surfactants to achieve stable and uniform nanolubricant dispersions for several months. Surfactants affected slightly the thermal conductivity, specific heat, viscosity, and solubility properties of the nanolubricants. The specific heats of the nanolubricants were lower than that of POE oil at temperatures from 0°C to 20°C while they were similar at 40°C.

A. Nanoparticle sedimentation and agglomeration in large clusters

Two critical factors that must be characterized when developing nanolubricants for heat transfer enhancement are the potential for agglomeration of the nanoparticles in large clusters and for sedimentation of the nanoparticles on the heat transfer surfaces. The sedimentation due to clustering and agglomeration of nanoparticles was observed for some nanofluids (Wen and Ding, 2004). Agglomeration and sedimentation of nanoparticles in the lubricant might interfere with the heat transfer process (Das et al., 2003). Enhanced heat transfer surfaces increase heat transfer by using internal micro- and nano-grooves to augment turbulence near the tube wall (Cieslinski and Targanski, 2007). Nanoparticles that are immersed in the heat transfer fluid might deposit in the grooves creating a smoother surface (Bang, 2004). According to Das et al. (2003) the resulting smoother surfaces can cause a considerable deterioration of the heat transfer coefficient. From previous studies, it was observed that stable suspensions of nanoparticles had minimum sedimentation. To develop such stable suspensions, the base fluid had high viscosity such as the case with POE oils. The addition of dispersants and surfactants could prevent clustering and findings the correct combination of surfactants and dispersion methods often required a trial and error approach. The size of nanoparticles in suspensions is commonly measured by using a dynamic light scattering (DLS) method, also referred to as quasi-elastic light scattering technique.

B. Equipment for measuring the solubility of refrigerant R-410A in nanolubricants

The equipment for measuring the solubility of refrigerant in nanolubricant was custom build in the present work and it is schematically shown in Figure 1b. It consisted of mainly four components: a temperature bath, a large reservoir, a smaller sample bottle, and a pressure transducer. A vacuum pump was used for depressurization of the large reservoir. A precision scale with an accuracy of ±0.2g measured the weights. The large reservoir was a stainless steel tank with a working pressure of 1800 psig (12410 kPa) and with a 1 gallon (0.0037 m3) volumetric capacity. The smaller sample bottle was a custom made 500mL leak proof tank made out of copper.



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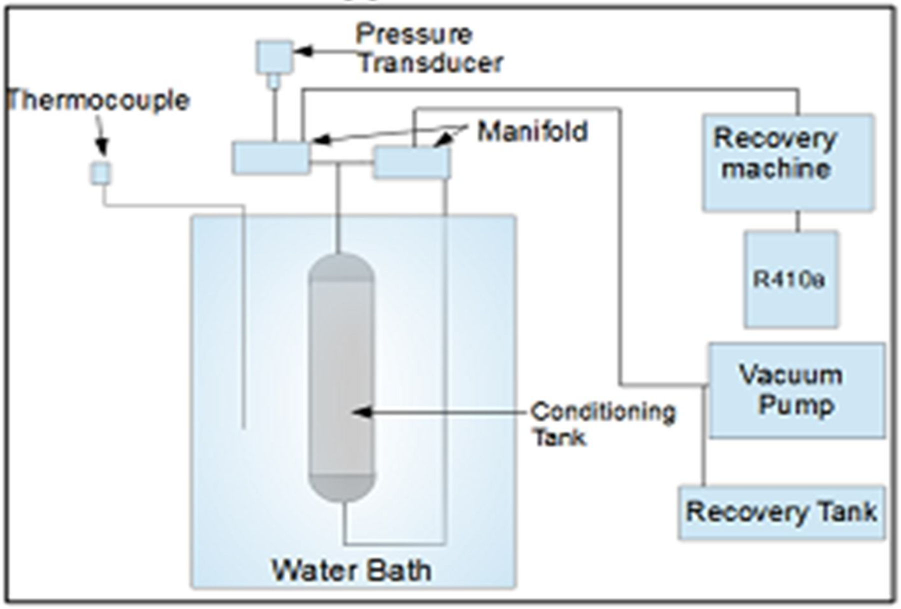

Figure 3: Experimental setups for measuring specific heat (a) and solubility (b) of nanolubricants

Table 1: Uncertainty of the experimental measurements of the nanolubricants proprieties

Test	Measurement objective	Max Uncertainty
Sedimentation	Nanoparticle size	±2%
Solubility	Weight percent of refrigerant in the nanolubricant	±1.2%
Specific Heat	Specific heat of the nanolubricant	±2.3%
Thermal Conductivity	Thermal conductivity of the nanolubricant	±7.2%

IV. THE EFFECT OF CONCENTRATION ON TRANSIENT POOL BOILING HEAT TRANSFER OF GRAPHENE-BASED AQUEOUS NANOFLUIDS

Transient pool boiling experiment s were performed by quenching of stainless steel spheres in dilute aqueous nanofluids in the presence of grapheneoxide nanosheets (GON s) at various concentrations (by weight) up to 0.1 wt.% . All the experiments were performed for saturated boiling at atmospheric pres-sure. Quenching and boiling curves were obtained for the nanofluids in comparison to the base line case of pure water. It was shown that quenching is accelerated upon increasing the concentration of GON s.

The enhanced boiling heat transfer by the nanofluids was interpreted in relation to the modified surface properties, including morphology, wettability, and roughness, on the quenched surfaces. Unlike the findings in available relevant studies that point to surface wettability change, however, the primary cause

of critical heat flux (CHF) enhancement was observed to be related to the increased surface roughness serving as paths to facilitate solid liquid contacts. The increases of both nucleation site density and liquid agitation intensity as a result of the presence of porous structures at relatively high concentrations were also found to be responsible for t he enhanced CHF.

A. Experimental

The surface roughness of the quenched spheres was examined using a profilometer with a sensitivity of 0.0 01 mm. The measure-ments were performed directly on the quenched spheres with a scanning span of 0.2 mm.

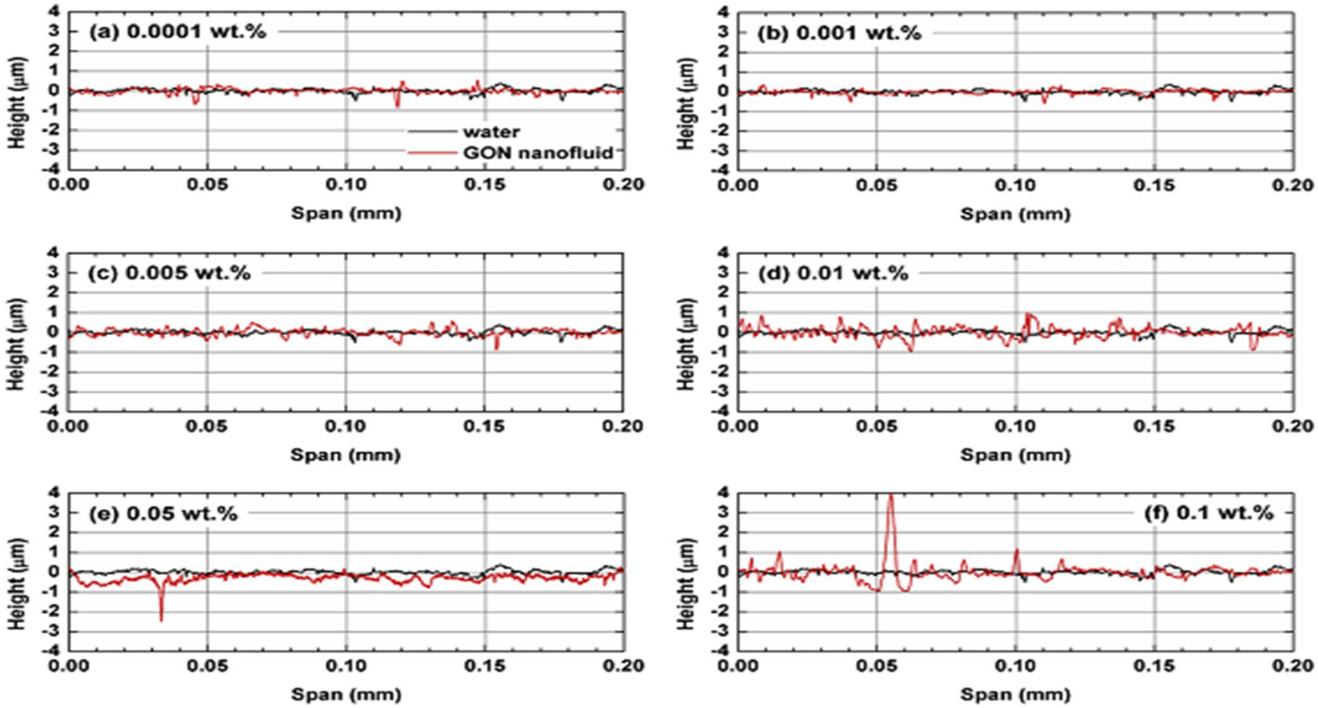

Fig. 4. Comparison of measured surface roughness (orthogonal height) on the quenched spheres in the aqueous GON nano fluids at the concentration of (a) 0.0 0 01 wt.%, (b) 0.0 01 wt.%, (c) 0.0 05 wt.% , (d) 0.01 wt.%, (e) 0.05 wt.%, and (f) 0.1 wt.% , where the baseline case in pure water is given for each concentration

V. CONCLUSIONS

A model developed for colloidal suspensions in a salt-free medium was used to model the large increases in the electrical conductivity of ZnO/PG nanofluids. The data for the 20 nm and 40 nm suspensions fit well, while the model under predicted the 60 nm. Both the experimental data and the model showed the electrical conductivity increases with increasing volume fraction and with decreasing particle size at the same volume fraction. Also, at higher volume fractions, the increase of electrical conductivity begins to level off, which may be attributed to ion condensation effects in the high surface charge regime. The electrokinetic radius was found to be less than 1, which implies a large double layer thickness.[9]

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