# HEATED SURFACE NANOSTRUCTURED BY BOILING PROCESS: A ANALYSIS THE NANOFLUID CONCENTRATION EFFECTS ON ROUGHNESS, WETTABILITY, AND THERMOGRAPHIC PROFILE

Alex Pereira da Cunha, Igor Seicho Kiyomura, Elaine Maria Cardoso

eng.alexpcunha@gmail.com; igorseicho@gmail.com; elaine@dem.feis.unesp.br

**Abstract:** *This article focuses mainly on the effect of surface roughness and nanofluid concentration on: wettability and thermographic profile of the test surface. It also discusses the their effects on the heat transfer coefficient (HTC). Copper heating surfaces with different roughness values, in order to analyze the interaction between the surface roughness and nanoparticles deposited on the heating surface. Nanostructured surfaces were produced through nanofluid boiling process by depositing alumina nanoparticles in different mass concentration. The surfaces were analyzed by using, roughness, wettability and thermography. The superficial roughness nanocoated was a function of the concentration of nanofluid boiled. As the nanofluid concentration increases, the surface roughness also increases and the contact angle decreases, showing a hydrophilic behavior. It was observed that the smooth surface has the lower values in respect of the heat transfer coefficient, in comparison with the other samples. The nanolayer formed on rough surfaces increases the thermal resistance of the surface, reducing the heat transfer; but for smooth surfaces, the deposition of nanoparticles increases cavities radius, increasing the boiling heat transfer. However, this phenomenon occurred only for the low concentrations of nanofluid*.

**Key-Words***: pool boiling, heat transfer coefficient, nanofluid, wettability, thermographic analysis.*

**Introduction:** Studies on the influence of nucleated pool boiling encouraged the scientific community to investigate new techniques for intensifying the boiling heat transfer coefficient (HTC), such as the use of nanoparticles suspended in a base fluid (nanofluids) and micro and nano-structured surfaces.

The use of nanofluids in the nucleate pool boiling has been extensively investigated because of its ability to change the wettability due to the formation of nanoscale structures deposited on the heating surface. However, the influence of nanofluid on the HTC was not fully understood. Quan et al. (2017), Manetti et al. (2016) and Shahmoradi et al. (2013) studied the influence of the nanostructured surface on the wettability, varying the nanofluid concentration.

The deposition rate of nanoparticles is proportional to the concentration of nanofluid, i.e., for high concentrations of nanofluid it leads to decrease in the number of active nucleation sites and then increase the thermal resistance on the heating surface (Vafaei, 2015). Sarafraz et al. (2013) reported that wettability increased due to deposition of nanoparticles, reducing nucleation sites and degradation the HTC.

Based on the literature review, this work focuses on thermographic analysis of different surfaces, a comparison between nanofluid concentration and wettability, and how all these factors influence HTC.

**Experimental:** The tests were performed based on Manetti et al. (2016) data, which was carried out on copper cylinders heating surfaces with different roughness values, corresponding to a smooth surface (Ra = 0.05 μm, namely SS) and a rough surface (Ra = 0.23 μm, namely RS). Six different copper surfaces, four of them being nanocoated were analyzed; two smooth surfaces with nanoparticle deposition, at low and high concentration of Al2O3-water nanofluid (namely Al-SS-LC, and Al-SS-HC) and two rough surfaces with nanoparticle deposition, at low and high concentration of Al2O3-water nanofluid (namely Al-RS-LC and Al-RS-HC).

Nanocoated surfaces were obtained by boiling process of Al2O3-water nanofluid, applying a heat flux range of 100 to 800 kW/m². In order to verify the influence of nanolayer thickness on the surface roughness and wettability, two different nanofluids concentrations, 0.029 g/l (corresponding to low nanofluid concentration) and of 0.29 g/l (corresponding to high nanofluid concentration), were used.

The Al2O3-water based nanofluid, with an average particle size of 10 nm, was prepared by the two-step method and then submitted to ultrasonic agitation (25 kHz) during three hours to ensure full dispersion of nanoparticles.

Three techniques were used to obtain the surfaces characteristics, prior and after each test: structural and chemical information by scanning electron microscopy (SEM); average surface roughness (Ra), static contact angles measured by analysis of pictures of a sessile droplet (20 µl of deionized water) using an experimental apparatus developed.

Thermographic analysis was used on the six surfaces tested in order to observe if there was or not local temperature decrease.

**Results and discussion:** The experimental results shows that enhancement or deterioration of nanofluids in boiling heat transfer is affected by surface morphology and the interactions between the relative size of the nanoparticles with the heating surface.

Thermographic analysis of the images shows that there is qualitatively a change in the temperature distribution; the tests showed that quantitatively this variation is numerically small, being close to the uncertainty of the thermocouples used to measure the actual temperature of the test surface.

The temperature gradient obtained in the thermographic images corroborates the HTC curves on rough surfaces for flows greater than 400 kW / m² in which it shows that the water had better surface cooling performance and the high concentration nanofluid had a lower performance.

After the boiling process it was realized deposition of nanoparticles for all surfaces tested, being stepped up to high heat fluxes (higher than 400 kW/m²). The increased surface roughness is one of the effects of the deposition of nanoparticles but also changes the characteristics of the surface wettability.

Both nanofluids increase the surface wettability due to change on surface tension, caused by the addition of nanoparticles on the base fluid as presented by Bhuiyan et al., 2015.

**Conclusion:** Through an analysis of the effect of concentration of nanofluid and surface roughness on the wettability and HTC. A metallographic characterization, roughness, wettability and thermographic profile before and after nanofluid pool boiling tests. The main conclusions are: The nanofluids decrease the static contact angle, and this behavior is most notable in nanocoated surfaces, produced after nanofluids boiling process; Surface roughness and the static contact angle depends on the nanofluid concentration used; as a result, nanofluid concentration increases the surface roughness, wettability and thickness nanolayer also increase by changing the temperature gradients also in surface thermographic profile. In this work it was realized that the original surface features had less influence on the behavior of wettability; The thermal analysis showed the behavior when the surface is submitted to flux greater than 400 kW / m², with decrease in HTC with the increase of the nanofluido concentration.

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Refererences: J. van der Geer, J.A.J. Hanraads, R.A. Lupton, The art of writing a scientific article, J. Sci. Commun. 163 (2010) 51–59.

W. Strunk Jr., E.B. White, The Elements of Style, fourth ed., Longman, New York, 2000.

G.R. Mettam, L.B. Adams, How to prepare an electronic version of your article, in: B.S. Jones, R.Z. Smith (Eds.), Introduction to the Electronic Age, E-Publishing Inc., New York, 2009, pp. 281–304.

KIYOMURA, I. K.; MANETTI L.L.; CUNHA A.P.; RIBATSKI G.; CARDOSO E.M., An analysis of the effects of nanoparticles deposition on characteristics of the heating surface and on pool boiling of water, Int. J. Heat. Mass Transf. (2016)

VAFAEI, S. Nanofluid pool boiling heat transfer phenomenon. Powder Technology, v. 277, p. 181–192, 2015.

SARAFRAZ, M.M., HORMOZI, F. and PEYGHAMBARZADEH, S.M., 2016. “Pool boiling heat transfer to aqueous alumina nanofluids on the plain and concentric circular micro-structured (CCM) surfaces”. Experimental Thermal and Fluid Science, Vol. 72, pp. 125-139.

SHAHMORADI, Z.; ETESAMI, N. and ESFAHANY, M. N., 2013. “Pool boiling characteristics of nanofluid on flat plate based on heater surface analysis”. International Communications in Heat and Mass Transfer, Vol. 47, pp. 113-120

QUAN, X.; WANG, D. and CHENG, P., 2017 An experimental investigation on wettability effects of nanoparticles in pool boiling of a nanofluid. International Journal of Heat and Mass Transfer. Vol. 108, pp. 32-40