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Effect of surface particle interactions during pool boiling of nanofluids

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ABSTRACT

The pool boiling characteristics of nanofluids is affected by the relative magnitudes of the average surface roughness and the average particle diameter. In the present work, an attempt has been made to study the interactions between the nanoparticles and the heater surface. The experimental methodology accounts for the transient nature of the boiling phenomena. The boiling curves of electro-stabilized Al_2O_3 water-based nanofluids at different concentrations on smooth and rough heaters and the burn-out heat flux have been obtained experimentally. Extensive surface profile characterization has been done using non-intrusive optical measurements and atomic force microscopy. A measure of the surface wettability has been obtained by determining the advancing contact angle. These results give an insight into the relative magnitudes of dominance of the prevalent mechanisms under different experimental conditions. Boiling on nanoparticle coated heaters has been investigated and presented as an effective solution to counter the disadvantageous transient boiling behavior of nanofluids.

1. Introduction

Thermal management is one of the most important technical challenges in diverse technological applications such as micro-electronics and micro-manufacturing. Advances in technology have called for the development of efficient heat removal techniques. Phase change heat transfer is an effective mode that has been investigated by several researchers and attempts have been made to study the boiling process experimentally as well as by using theoretical approaches to quantify it. One of the methods for enhancing boiling heat transfer and the critical heat flux is the alteration of the surface profile by means of various deposition processes. Though water is one of the common heat transfer fluids, it is not generally suited for use in ultra-high heat flux applications. Nanofluids are a class of engineered suspensions comprising of particles having an average dimension in the scale of a few hundred nanometers, dispersed in a basefluid. They have gained popularity in recent years owing to their enhanced thermal properties and hence their expected potential to improve heat transfer when used as the working fluid. In addition, the problems such as sedimentation and clogging are less pronounced in the case of nanofluids as compared to slurries. However, ensuring their stability is still a challenge and alternative techniques like the use of surfactants or electro-stabilization are generally required. When dealing with nanofluids and phase change heat transfer, the enhanced thermal properties turn out to be only a necessary condition, but not a sufficient one. Changes in the surface characteristics due to the presence of nanoparticles are more responsible for the observed boiling behavior. These modified surface characteristics have also been known to cause an enhancement in the critical heat flux. To economically develop an efficient phase change heat transfer system operating with nanofluids, a clear knowledge of the different mechanisms that are prevalent is required which has been the focus of most nanofluid boiling studies conducted recently.

Since the pioneering study by Das et al. [1], several research groups have studied the pool boiling characteristics of nanofluids and over a period of time, the reported results show enhancement, deterioration and also in some cases an insignificant effect due to the presence of nanoparticles. A comprehensive review was presented by Taylor and Phelan [2] covering a broad spectrum of observations in the area of pool boiling of nanofluids. In general, a consensus has been reached with regard to the fact that in addition to the effective thermal properties of the nanofluid, surface modification is one of the crucial factors affecting the boiling phenomena which is mainly responsible for the observed deviations in the boiling behavior of nanofluids as compared to the basefluid. Kim et al. [3] proposed a theory which was later verified experimentally by Sang et al. [4] that the surface modification is caused mainly due to particle deposition on the surface during the microlayer evaporation phenomenon. Surface characterization using techniques such as SEM/XDS/EDS indicate that this coating is mainly composed of nanoparticles, which primarily affect the

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