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Influence of nanoparticle surface coating on pool boiling

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ABSTRACT

The purpose of this work is to study the effects of nanostructured surface coatings on boiling heat transfer and CHF. Boiling experiments are performed on a 100 μm diameter platinum wire immersed in saturated water or pentane at 1 bar. Nanostructured surface coating is obtained by deposition of charged γ-Fe_2O_3 nanoparticles (average diameter of 10 nm) on the platinum wire. Two different processes are compared: vigorous boiling and electrophoresis.

The deposition of nanoparticles onto the heated surface induces a significant increase of the boiling critical heat flux (CHF) related to the increase of wettability. It also induces a decrease of the heat transfer coefficient when the wire is entirely covered with nanoparticles. The critical heat flux enhancement depends on the wettability of the fluid compared with the bare heater. Different physical mechanisms are also studied to explain the evolution of the characteristic parameters of the boiling on nanostructured surfaces.

1. Introduction

Nanostructured surfaces are surfaces bearing nano-sized features that have characteristic lengths ranging on a scale of a few (or a few tens) to a few hundreds of nanometers. Nanostructuration of surfaces is considered as a promising track in many micro-thermo-fluidic applications (e.g. from electronic cooling or medical diagnostics to thermal barrier coating), as it is expected to allow noticeable heat transfer enhancement or hydraulic resistance reduction. The main mechanism of hydraulic resistance decrease is the change of the fluid wettability on the surface when it is nanostructured. The change of wettability of a surface is also known to modify phase-change heat transfer during boiling. Highly hydrophilic surface should permit an increase in the boiling critical heat flux (CHF) and affect the boiling heat transfer coefficient (HTC) [1].

A large number of enhanced surfaces (coated, plated, roughened, extended, etc.) have been manufactured and tested during the past few decades in order to enhance boiling heat transfer. These surfaces were obtained with various techniques: abrasive treatments, etching, attached wire, screen promoters, etc. These techniques were reviewed by Webb in 1994 [2]. Mechanical methods (e.g. abrasive treatment, printing of grooves, etc.) exhibited a heat transfer enhancement of 2–4 times with respect to the untreated surface, while chemical methods (e.g. chemical etching, coating of a porous layer, etc.) showed even higher enhancement factors. The latest developments within the field of enhanced boiling have come from the electronics cooling sector. Several studies have been performed on porous structures consisting of small (1–50 μm) sized aluminum, copper, silver and diamond particles that have been sprayed or painted on a aluminum substrate showing heat transfer coefficient enhancement of up to nine times in FC-72. Porous structures have been proven to be very effective in enhancing the nucleate boiling heat transfer. It must however, be highlighted that these heat transfer enhancement methods are based on manufactured micrometric structures, without knowledge of the possible existence of nanometric features introduced by the manufacturing process, for instance because of the disordered nature of the particle configuration. Thus, it is not possible to discern whether nanoscale boiling enhancement mechanisms were also present. Recent results seem to show that not only micro-scale, but also nano-scale structures are important to the boiling performance of a surface since they can reduce the nucleation energy barrier observed at the onset of nucleate boiling [3,4], and therefore the boiling incipience temperature.

Several processes may be used to perform surface nanostructuration, such as: chemical vapor deposition, physical vapor deposition, or nanofluid evaporation. Some of these techniques were used by Phan et al. [5] who also discussed the impact on

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