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Effects of external electric field on pool boiling: Comparison of terrestrial and microgravity data in the ARIEL experiment

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ABSTRACT

Pool boiling in microgravity, in the presence of an electric field or less, was investigated in ARIEL test setup, integrated in Fluidpac facility, on Foton-M2 orbital mission. The nucleate boiling curve with FC-72 was measured in terrestrial and reduced gravity conditions, on a heated surface whose size was relevant from a technical point of view, for various degrees of fluid subcooling and high heat rates. An external electrostatic field was also added to investigate its use as a possible replacement of buoyancy. Counterpart tests were carried out in the same apparatus in normal gravity, before the mission. The present paper deals in particular with the comparison between boiling performance in normal and reduced gravity in the entire experimental range.

1. Introduction

In pool boiling heat transfer, buoyancy is the main force lifting the bubbles away from the surface, and giving way to fresh liquid to replace them. In the lack of gravity, detachment of bubbles occurs anyway; however, once detached, bubbles are no more driven by buoyancy and tend to slow down and coalesce in the proximity of the heated surface, originating a large mass of vapor. Due to the low surface-to-volume ratio, this big bubble is difficult to condense, and prevents liquid renewal close to the surface. These aspects of boiling in microgravity have been constantly observed by all the experimenters (e.g. [1,2]) and may lead to impairment of heat transfer performance and anticipated dryout of the surface, precluding application of boiling heat transfer in micro-g. Several experimental campaigns conducted worldwide, and reviewed by Kim [3], Ohta [4], and Di Marco [5], showed the potential of boiling heat transfer in microgravity, along with the limitations outlined above. Unfortunately, due to the space and power constraints, intrinsic in microgravity campaigns, experiments in this field were often limited to small surfaces and/or low heat rates.

The ARIEL apparatus, described in the following, was able to partly overcome these limitations, attaining heat flux up to 200 kW/m^2 over a flat surface 20 $\times$ 20 mm. Additionally, an electrostatic field (EF in the following) was applied during part of the tests to provide an additional volume force able to replace buoyancy. The detailed mechanism of action of the electric field is described e.g. by Di Marco and Grassi [6,7]. The effectiveness of this technique was already demonstrated by several experiments carried out in microgravity, both in gas–liquid systems [8,9] and in boiling systems [10–12]. Furthermore, it has been assessed that the electric field destabilizes the liquid–vapor interfaces, reducing their Taylor oscillation wavelength [6]. The overall effect is the generation of smaller and faster bubbles, with a reduced probability of coalescence and an increased condensation rate, due to their larger surface-to-volume ratio, as shown also by a previous sounding rocket experiment on a heated wire [11]. This in turn decreases the void fraction in the proximity of the surface, and also the probability of surface dryout, restoring boiling conditions more similar to terrestrial ones.

2. Experiment description

2.1. Experimental apparatus

The ARIEL experiment and the related test sequence were already described in detail elsewhere [13,14,7,15], hence only a brief highlight will be given here.

The ARIEL experimental facility was part of the Foton-M2 unmanned space mission, organized by ESA in cooperation with Russian Space Agency. The entire apparatus had an overall mass of about 9.5 kg and was housed inside the Fluidpac reusable facility [16], containing a total of four fluid-physics experiments, sharing power subsystems, sophisticated optical diagnostics and data storage.

The apparatus, shown in Fig. 1, consisted mainly in an aluminum container of about 1 l volume, containing the test fluid, FC-72, manufactured by 3 M and generally used for electronics

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