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Nucleate boiling and critical heat flux of HFE-7100 in horizontal narrow spaces

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ABSTRACT

The pool boiling heat transfer and critical heat flux *CHF* of saturated HFE-7100 at atmospheric pressure on a confined smooth copper surface were experimentally studied. The horizontal upward boiling surface was confined by a face-to-face parallel unheated surface. We analysed the effects obtained by changing the diameter of the unheated surface and the gap between the boiling surface and the adiabatic surface. The gap values investigated were $s = 0.5$, 1.0, 2.0, 3.5 mm. To confine the circular boiling surface ($d = 30$ mm), two different Plexiglas discs were used: one with a diameter $D = 30$ mm, equal to that of the copper boiling surface, and the other with a diameter $D = 60$ mm, equal to that of the overall test section support. For each configuration, boiling curves were obtained up to the thermal crisis. For both configurations, it was observed that, at low wall superheat, the effect of confinement was not significant if $Bo > 1$, while for $Bo \leqslant 1$ the heat transfer coefficient increased as the channel width s decreased. By contrast, at high wall superheat, a drastic reduction in both heat transfer and *CHF* was seen when the channel width s decreased; this reduction was less pronounced when the smaller confinement disc ($D = 30$ mm) was used. *CHF* data were also compared with the values predicted by literature correlations.

1. Introduction

As pool boiling is a very efficient means of thermal control in several applications, nucleate pool boiling heat transfer and critical heat flux *CHF* have aroused increasing attention, especially with regard to confined geometries. Moreover, the use of dielectric fluids in nucleate pool boiling is often applied in thermal systems, as it allows heat to be removed while keeping surface superheat relatively low. The use of dielectric fluids offers several further advantages: (a) low saturation temperatures at atmospheric pressure; (b) good thermal contact with all components, even in narrow spaces; (c) excellent chemical compatibility with many materials; (d) low toxicity and good environmental characteristics. Confined pool boiling has become a research subject of great importance, as it is frequently encountered in many practical situations, such as high-performance compact heat exchangers and the cooling of electronic components. The effects of confinement on pool boiling depend on the complex interaction among geometry, channel width, heat flux and fluid properties.

This paper reports an experimental study on the confined pool boiling of HFE-7100, a hydrofluoroether dielectric fluid ($C_4F_9OCH_3$). The effects of confinement conditions (channel width s and unheated confinement disc diameter D) on a horizontal upward-facing boiling surface were systematically investigated.

A criterion for analysing the confinement gap effect has been proposed in the literature, and is based on the Bond number Bo, which is defined as the ratio between the channel width s and the capillary length L; the capillary length L is often assumed to be proportional to the departure diameter of isolated bubbles, as it relates capillary and gravitational forces; it is calculated by:

$$L = \sqrt{\frac{\sigma}{g(\rho_l - \rho_v)}}.$$

The capillary length for HFE-7100 (3M^{TM} Novec^{TM} Engineered Fluids [1]) at atmospheric saturation pressure is about 0.88 mm, which corresponds to Bo numbers ranging between $Bo = 0.57$ ($s = 0.5$ mm) and $Bo = 4.0$ mm ($s = 3.5$ mm).

2. Previous research

The first studies on the effects of confinement date back to the end of the 1960s. Ishibashi and Nishikawa [2] studied the nucleate boiling of water and ethyl alcohol in vertical annuli at pressures from 1 atm (channel width 1–20 mm) to 10 atm (channel width 0.6–2 mm). In saturated boiling heat transfer in a narrow space, they found, in addition to the isolated bubble region, a coalesced bubble region with markedly different characteristics; they proposed a new type of correlating equation for the coalesced bubble region.

Later, Katto et al. [3] studied the boiling of saturated water at atmospheric pressure on a horizontal upward-facing circular

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