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Bubble growth and departure from an artificial cavity during flow boiling

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Abstract Wall nucleation research has mainly focused on natural surface nucleation sites whose geometry is unknown and the effects of nucleation cavity geometry and size on flow boiling are not clear. The current research studies the effect of a blind hole with diameter 200 μm and depth 1 mm on bubble nucleation in a channel with water flow boiling. The boundary conditions were constant heat flux of 18.8 kW/m^2, wall superheat of 8.7°C, water inlet temperature of 93.8°C and uniform velocity profile of 0.21 m/s at the inlet of the channel with cross-section of 30 mm x 10 mm, leading to a Reynolds number of 10038. High-speed imaging of the bubble behavior allowed the measurement of the bubble temporal and spatial evolution and quantified the bubble growth period and waiting period between departure and new growth and associated fluctuations. The bubble growth period reaches up to 40 seconds with a corresponding waiting time of 0.9 ms. It is observed that a wave front is induced by the breakage of the bubble neck which propagates through the bubble, resulting in distortions that serve as initial trigger of bubble movement along the nucleation wall.

Keywords: Surface Nucleation Cavity, Flow Boiling, Bubble Growth

1. Introduction

Boiling has attracted numerous studies in a wide range of applications since it enhances heat transfer. Performance depends on various underlying mechanisms, which are not fully understood. As a consequence, developed computational models are mainly based on semi-empirical correlations, which deviate from experimental data associated with different flow geometries. It was found that the nucleation cavity geometry and size could enhance [1] or weaken [2] boiling heat transfer performance. The required heat flux at the incipience of boiling at artificial nucleation sites could be lower than expected values at natural sites [3], and a liquid microlayer, observed between the bubble and the surface at naturally occurring surface nucleation sites, could not exist [4]. However, most studies in the literature on flow boiling in channels are associated to natural nucleation sites, whose geometry and size are unknown. Therefore, the effect of cavity geometry and size on boiling requires additional study. The current study is designed to fill this gap and improve understanding on the effect of cavity with known geometry on flow boiling.

2. Experimental methods

A simplified sketch of the ambient pressure experimental arrangement is presented in Fig. 1. The test section of the flow channel has a rectangular cross-section with dimensions 30 mm x 10 mm and length 100 mm with a heated bottom stainless steel wall. The flowrate of deionized water was controlled by a calibrated rotameter. This was supplied to a flow conditioning channel upstream of the test section, which includes series of varying aperture size meshes and a honeycomb section. The flow is then accelerated through a contraction section, which is connected to the test section with an adaptor of 10 mm length, delivering a flow with uniform velocity profile to the test section. Downstream of the test section a diffuser section was added. The stainless-steel wall is attached to a heated copper block that supplies constant heat flux. An artificial cavity was drilled in the middle of the polished stainless steel surface (Ra=0.164 μm) with diameter 200 μm approximately 40 mm downstream of the entry. The cavity was cleaned in an isopropanol bath and by blowing compressed air; this ensured that the heated

surface and cavity were free of contaminants, encouraging boiling at the cavity.
The input heat flux, nucleation wall temperature and water inlet temperature are calculated using the readings of seven K-type thermocouples. Results are presented for water inlet temperature 93.8°C, input heat flux 18.8 kW/m^2. Bubble behavior was recorded by a high-speed camera (Photron FASTCAM SA1.1 model 675K-M1)

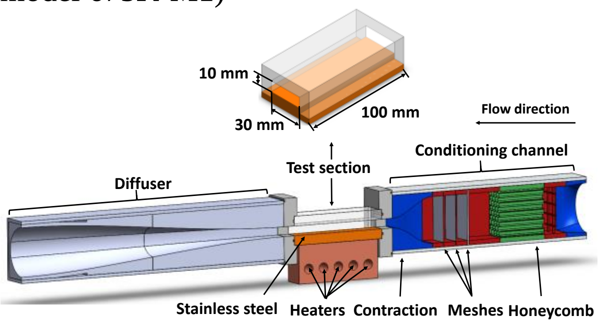

Fig. 1. The simplified schematic of experimental rig

3. Experimental results

As expected, bubbles grow and depart from the artificial cavity. The bubble growth and departure times were recorded with rate of 50 and 5400 frames/s respectively and spatial resolution of 6.61 μm/pixel and their mean and fluctuation values were obtained from 20 events.

3.1 Bubble growth phase

After the departure of a fully grown bubble, the remaining liquid-vapor interface inside the cavity expands and gradually reaches into the bulk flow. As the bubble size increases, its contact diameter (the diameter of the liquid-vapor-solid area) expands and exceeds the cavity diameter, which leads to an increased surface tension force that keeps the bubble attached on the nucleation surface.
The bubble growth period, from incipience to departure, was measured from the high-speed images. The mean value of the bubble growth period was 40.6 s with a standard deviation of fluctuations of 2.9 s.

3.2 Bubble departure phase

As the bubble approaches departure, the bubble inclines towards the wall with a neck connected to the cavity (Fig. 2.a). The neck gradually elongates until it breaks. The breakage induces a pressure wave front (Fig. 2.b), which propagates from the neck position to the bubble top and results in bubble shape distortions, which initiated the bubble motion in the direction of the flow. The propagation velocity of this wave front along the bubble surface is ~125 cm/s. A typical propagation speed of ~63 cm/s for a wave induced by a thin liquid film breakage between two bubbles is found in the literature [5].

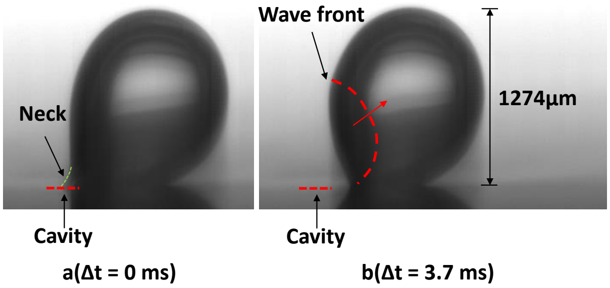

Fig. 2. Example bubble images at the departure phase

Later, due to inertia, the bubble moves ahead with gradually decreasing contact diameter, leading to reduced surface tension force and eventually, lifts off from the wall.
The mean waiting time, the time interval from departure to incipience, is on average ~0.9 ms, much shorter than the corresponding growth phase.

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