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THE ROLE OF BUBBLE DYNAMICS IN THE ENHANCEMENT OF FALLING FILM REFRIGERANT BOILING

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1. ABSTRACT

The nature of the heat transfer enhancement seen in the boiling of thin falling liquid films is still a matter of some debate. This paper is a preliminary experimental investigation into the role bubble dynamics play, focusing on the bubble departure diameters and bubble growth after departure while sliding in the falling films. The bubble departure diameter did appear to be materially affected by the falling film conditions in comparison to pool boiling, while the bubble sliding growth was less clear.

2. INTRODUCTION

Falling film evaporators operating in the boiling regime tend to outperform their flooded counterparts, provided they do not experience dryout [1]. Various reasons for this improved performance have been suggested, and it is likely that under different conditions, some mechanisms may become more prominent than others. Cerza and Vernas [2] previously argued that the growth of the bubble after nucleation while sliding in the falling film may be a significant contributor to the heat transfer enhancement seen.

Recently Zhang et al. [3] argued that the bubble diameter and frequency are influenced when boiling occurs in a thin falling film as opposed to pool boiling and may thus be a contributor to the falling film enhancement seen. In a series of tests using water boiling on the outside of a horizontal tube, they compared measured falling film bubble departure diameters and frequencies to those predicted by pool boiling correlations and found bubble departure diameters were larger than that calculated for pool boiling studies, while the frequency was smaller than that calculated for pool boiling studies. Zhang et al. argued that the larger bubbles may be the cause of this falling film enhancement, with the bursting of these larger bubbles causing larger quenching heat fluxes.

This study is a preliminary attempt at similarly understanding the influence that bubble dynamics may have on the falling film heat transfer process through comparison to pool boiling but using refrigerant as the working fluid.

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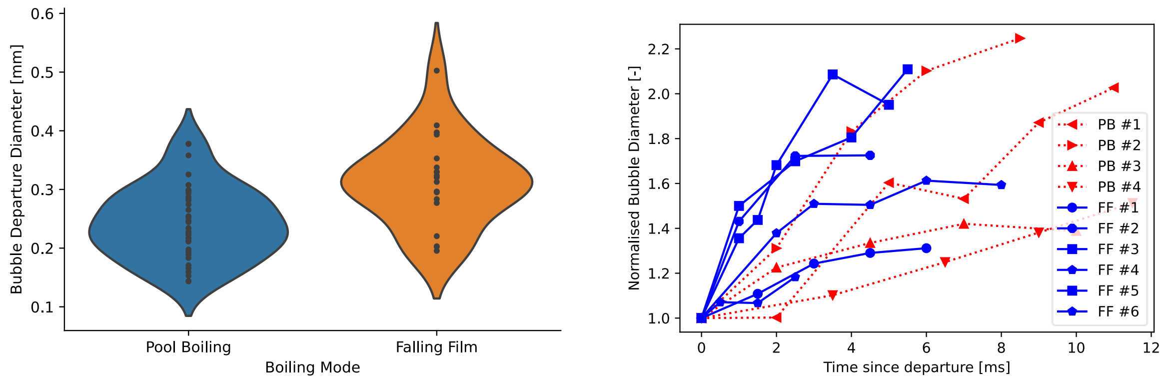
Both the bubble departure diameter as well as the bubble growth of the falling film bubble while sliding in the liquid film are investigated.

3. METHDOLOGY

A polished copper tube (average roughness R_a of 0.12 µm) was tested under falling film and pool boiling conditions with refrigerant R-245fa at a saturation temperature of 20°C and a heat flux of 20 kW/m^2. The tubes were internally heated by water. The overall heat transfer coefficient was determined by measuring the internal water temperature profile as well as the external saturation temperature of the refrigerant. The external heat transfer coefficient was subsequently determined with the aid of a Wilson plot. The images used in this study were taken using a high-speed camera (Photron Fastcam Mini UX 50) at 2000 fps and bubble dimensions were manually measured. The full experimental campaign is documented in Bock et al. [4].

4. RESULTS

The same nucleation site was monitored under falling film and pool boiling conditions, and the bubble departure diameters were measured. The results are shown in a violin plot in Figure 1 (a). There is a relatively large spread of diameters, but the average departure diameter was 0.31 mm for falling film conditions and 0.24 mm for pool boiling and so the falling film conditions did tend to produce larger bubbles, which aligns with the findings of Zhang et al [3]. This may be because the bubbles are trapped by the thin liquid film and are thus able to grow larger as a result of increased opportunity for evaporation into the bubble. This would suggest a decrease in bubble frequency, which could not be confirmed from this study's data. Zhang et al [3] did in fact predict that the falling film bubbles had a reduced frequency compared to the pool boiling counterparts.

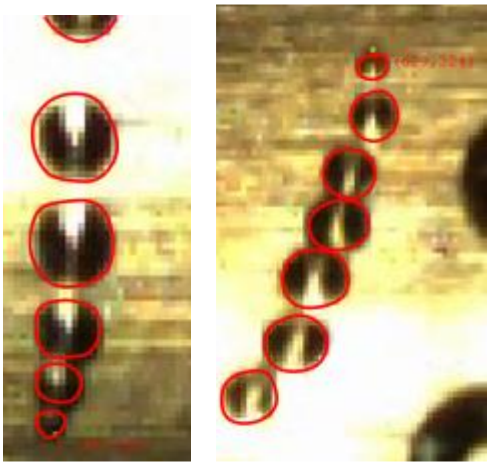


(a) Departure diameters of the same nucleation site (b) Growth after nucleation

Figure 1. Bubble diameters of the same nucleation site under pool boiling and falling film boiling conditions

The growth of the bubbles after nucleation was tracked for several nucleation sites under falling film and pool boiling conditions and normalised to the bubble departure diameter and is shown in Figure 1 (b). Both conditions show an increase in bubble diameter after departure from the nucleation site with growth curves that are very similar, although the falling film bubbles may grow fractionally quicker. A comparison of bubble streams from nucleation sites in Figure 2 shows that the bubbles emerging from a nucleation site under both pool boiling and falling film boiling show similar bubble growth progression. Considering that for bubbles in falling water films under laminar conditions, Cerza and Vernas [2] recorded bubble diameters growing from an initial 1 mm to about 4 mm over a time space of 50 ms, while in this study bubbles grew from about 0.2 mm to 0.4 mm in 5 ms, it is clear bubbles in refrigerant and water films operate under very different time and size scales.

It should be noted that the cause of bubble growth is likely to be different under the two conditions. The bubbles under pool boiling may still be within some portion of the superheated boundary layer near the tube surface, but they are also floating upwards, resulting in reduced liquid pressure head, which should cause bubble growth. The falling film bubbles are sliding downwards, and thus their growth is only as a result of being trapped in the superheated falling liquid film. Thus, despite having similar growth paths, the falling film sliding growth should be contributing to the falling film heat transfer more than the pool boiling bubble growth.



(a) Pool Boiling (b) Falling Film

Figure 2 Illustration of a stream of bubbles leaving a nucleation site (bubbles outlined in red)

5. CONCLUSIONS

Initial analysis of the bubble departure diameter and growth after bubble departure under falling film boiling conditions of refrigerants suggests that bubble departure may be materially influenced by the falling film conditions to enhance heat transfer in comparison to pool boiling. The bubble growth during sliding may contribute somewhat to the enhancement, but not to the same extent it would if water was the working fluid. This preliminary investigation suggests further detailed analysis of the bubble departure dynamics is warranted.

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