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On the departure behaviors of bubble at nucleate pool boiling

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Abstract

Dimensionless scales of radius and time, proposed by the authors in a previous study, were used to quantitatively analyze the bubble departure radius and time during nucleate pool boiling. The results obtained from dimensional analysis were compared with experimental data reported in many studies. These experimental data are including partial nucleate pool boiling data with constant heat flux and temperature conditions acquired over the past 40 years at atmospheric and sub-atmospheric pressures, as well as data obtained at subcooled, saturated, and superheated pool temperature conditions.

It was shown that the departure radius and time could be well correlated with respect to Jakob number as proposed by the previous studies. And the bubble departure behaviors well categorized between atmospheric and sub-atmospheric pressure, which is occurred from the different growth rate near the departure time partial nucleate pool boiling.

For almost all obtained under atmospheric pressure, the dimensionless departure radius and time scales were about 25 and 60, respectively. For higher Jakob number, the square root of Bond number was proportional to the power of 0.7 of Jakob number, little different from the previous correlations. The dimensional departure radius and time estimated from the relationships proposed in this study were compared with measured departure scales and the results obtained with the previous correlations. And it was shown that the relationships could well predict and describe the departure behaviors of bubble during nucleate pool boiling.

Keywords: Bubble departure radius; Bubble departure time; Nucleate pool boiling; Bond number; Jakob number

1. Introduction

The complete process of liquid heating, nucleation, bubble growth, and departure is the central mechanism of two-phase heat transfer from a superheated wall during nucleate pool boiling. Two features of this process that affect the rate of heat transfer during the ebullition cycle are the bubble radius at departure, R_d, and the frequency at which bubbles are generated and departed, f.

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Since the bubble radius and frequency of departure must be related, the departure radius and the bubble growth rate must be also related. The inverse of the frequency, $\tau = 1/f$, which is the time period associated with the growth of each bubble, must equal the sum of the waiting period and the time required for the bubble to grow to its departure radius:

$$\frac{1}{f} = \tau = t_w + t_d \tag{1}$$

where, t_w is the waiting period and t_d is the departure time.

Therefore, the frequency of bubble departure depends directly on how large the bubble must become in order for it to depart, and, as a consequence, on the growth rate at which the bubble can grow to this size on the heating surface.

The bubble radius at departure is primarily determined by the net effect of forces acting on the bubble as it grows on the surface. Interfacial tension acting along the contact line invariably acts to hold the bubble in place on the surface. Buoyancy is often a major player in the force balance, although its effect depends on the orientation of the surface with respect to the accelerating or gravitational body force vector.

If the bubble growth rate is high, the inertia associated with the induced liquid flow field around the bubble may also tend to pull the bubble away from the surface. When the liquid adjacent to the surface has a bulk motion associated with it, drag and lift forces on the growing bubble may also act to detach the bubble from the surface. In addition, because the rate of bubble growth and the shape of the bubble (hemispherical or spherical) may affect the conditions for bubble departure, the departure radius may be affected by the wall superheat, the contact angle, θ, and the thermodynamic properties of the liquid and vapor phases.

The departure radius of the bubble during nucleate boiling has been the subject of numerous investigations. In experimental studies, the departure radius has typically been determined from high-speed movies of the boiling process. Based on data obtained in this manner, a number of investigators have proposed correlation equations that may be used to predict the departure radius of bubbles during nucleate boiling.

Many of the correlations are written in terms of the Bond number, Bo, defined as

$$Bo = \frac{g(\rho_l - \rho_v)(2R_d)^2}{\sigma} \tag{2}$$

where, g is gravity, ρ_l is the liquid density, ρ_v is the vapor density, and σ is the liquid surface tension.

This same dimensionless group is also sometimes referred to as the Eotvos number.

Cole and Shulman (1966b) proposed a relation in which $Bo^{1/2}$ is simply proportional to the inverse of the absolute pressure,

$$Bo^{1/2} = \frac{1000}{P} \tag{3}$$

where, P is the pressure in mmHg.

This relation contrasts sharply with other relations where the dimensionless departure diameter $Bo^{1/2}$ depends on a complex combination of physical properties. The success of Eq. (3) is apparently a result of the fact that $1000/P$ approximates the combined pressure dependence of the properties that appear in the other relations. In a subsequent study, Cole (1967) proposed

$$Bo^{1/2} = 0.04\ Ja \tag{4}$$

This relation is an extension of Eq. (3) in the sense that the pressure term is taken into account by the inclusion of the vapor density in the Jakob number, Ja, defined as $Ja = \rho_l C_{pl} \Delta T / \rho_v h_{fg}$, based on the temperature difference between the wall and the saturation. In the Jakob number, C_{pl} is the liquid specific heat, $\Delta T (= T_{wall} - T_{sat})$ is the wall superheat, h_{fg} is the latent heat, T_{wall} is the wall temperature, and T_{sat} is the saturation temperature.

Later, Cole and Rohsenow (1968) proposed a new relation as an evolutionary improvement of Eq. (4),

$$Bo^{1/2} = C\ Ja^{c^{5/4}} \tag{5}$$

where $C = 1.5 \times 10^{-4}$ for water, $C = 4.65 \times 10^{-4}$ for fluids other than water.