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Interactions between bubble formation and heating surface in nucleate boiling

Andrea Luke *

Technical Thermodynamics, University of Kassel, Kurt-Wolters Str. 3, 34125 Kassel, Germany

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ABSTRACT

The heat transfer and bubble formation is investigated in pool boiling of propane. Size distributions of active nucleation sites on single horizontal copper and steel tubes with different diameter and surface finishes have been calculated from heat transfer measurements over wide ranges of heat flux and selected pressure. The model assumptions of Luke and Gorenflo for the heat transfer near growing and departing bubbles, which were applied in the calculations, have been slightly modified and the calculated results have been compared to experimental investigations by high speed video techniques. The calculated number of active sites shows a good coincidence for the tube with smaller diameter, while the results for the tube with larger diameter describe the same relative increase of the active sites. The comparison of the cumulative size distribution of the active and potential nucleation sites demonstrates the same slope of the curve and that the critical radius of a stable bubble nuclei is smaller than the average cavity size.

1. Introduction

Fundamental processes promoting heat transfer enhancement in nucleate pool boiling are not fully understood until now. Although a great variety of commercially available enhanced surfaces have been working successfully for years, basic understanding of the enhancement processes appears to be at the beginning, obviously because the individual shapes of the surfaces on the market are too complex to resolve their overall effect on heat transfer into local convective or evaporative contributions without introducing severe simplifications. Therefore, the interactions of convection with evaporation are studied by means of surface preparations of plain tubes resulting in defined roughness structure. The boiling liquids (R134a, Propane) have been chosen in order to vary the saturation pressure p_s over a wide range. They are interesting fluids for refrigeration, air conditioning and heat pump applications. The investigations on enhanced steel tubes are the subject of the paper of Kruck and Luke [1].

The value of the heat transfer coefficient α in nucleate pool boiling is mainly determined by the heat flux q, the saturation pressure p_s, the thermophysical properties of the saturated liquid and by the material and roughness of the heating surface. The long-term aim in design of modern evaporators is to find a correlation based on the phenomena of vapour bubble formation on the heating surface.

The heat transfer and the bubble formation is studied simultaneously on horizontal copper tubes with fine sandblasted or emery ground surface and on a mild steel tube with drawn or polished surface. The tube diameter is varying from $D = 8$ mm to 25 mm. The heat transfer experiments discussed in this paper have been performed over wide ranges of heat flux (100 W/m^2 to 10^5 W/m^2) and saturation pressure (5–80% of the critical pressure p_c). The activation of nucleation sites, the bubble departure diameter d_A and frequency f are examined by high speed video techniques at selected conditions of the heat transfer measurements.

The site densities $(N/A)_C$ calculated with different correlations from the literature of d_A and f, and with a new correlation considering the experimental results are compared with the measured site densities $(N/A)_{exp}$. The model assumptions are mainly based on the heat transfer models of Mikic and Rohsenow [2], Han and Griffith [3], and Schömann et al. [4], but the additional heat transfer by evaporation into the bubbles sliding along the tube surface is incorporated in the model [5]. The comparison with the experimental data indicates a promising agreement, although the model contains various assumptions about growing and departing bubbles.

2. Results for the heat transfer

The heat transfer measurements were carried out in the "Standard Apparatus" for pool boiling, see [6,7]. The main parts of the apparatus are

– the dc-heated, horizontal test tube in the evaporator,
– evaporator and condenser combined in a natural circulation loop for the test fluid and placed in a PID controlled chamber in which the air temperature is adjusted to the saturation temperature T_s of the liquid in the evaporator.

* Tel.: +49 0561 804 3268; fax: +49 0561 804 3993.
E-mail address: luke@uni-kassel.de

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