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Heat transfer through a vertical liquid film in upward and downward flows

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Flow boiling experiments were performed in a 6mm diameter tube in upward and downward vertical flows. The working fluid used was HFE-7000 and the range of vapour quality, mass flux and heat flux investigated were 0.15 – 0.7, 75 – 400 kg/(m^{2}s) and 0.5 – 3.0 W/cm^2, respectively. Flow pattern were characterised from high-speed visualisations. Void fraction, wall and interfacial shear stresses as well as heat transfer coefficient were measured [1]. A modelling of the wall shear stress in flow boiling was proposed.

A theoretical model for predicting the heat transfer coefficient in upward and downward annular flow is proposed. Based on the wall shear stress value and an eddy viscosity profile in the liquid film, the mean liquid velocity profile was calculated. To account for interfacial damping, Mudawwar and El-Masri [2] introduced an interfacial damping function into the expression of the turbulent eddy diffusivity expression. This interfacial damping is due to the presence of roll waves at the interface of the liquid film. The exponent in the damping function was found to be proportional to the velocity of the roll waves. The velocity and frequency of the roll waves were characterised by image processing, allowing a space time diagram of the roll waves to be constructed. Expressions for the velocity and frequency of the roll waves have been recently proposed based on the Weber numbers of the liquid and the vapour phases and the Martinelli parameter. These expressions are in good agreement with previous experiments of the literature with gas-liquid flow [3, 4, 5]. The heat transfer coefficient was calculated from the integration of the temperature profile in the liquid film using a turbulent diffusivity profile derived from the turbulent viscosity profile [6]. The proposed models predicted over 96% of the measured heat transfer coefficient to within $\pm 20\%$ in both upward and downward flows and also reproduced the heat flux dependence of the measured heat transfer coefficient. The heat flux dependence was particular important for $Re_l < 4000$ where nucleation was present in the annular liquid film.

Keywords: annular flow, roll waves, liquid film.

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