論文の内容の要旨

Liquid Film Thickness in Micro Channel Slug Flow

(マイクロチャネル内スラグ流の液膜厚さに関する研究)

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Two-phase flow in micro channels attracts large attention due to its large expectation in many industrial applications, e.g., electric chip cooling, micro evaporator, micro reactor, MEMS and so on. Especially with using latent heat, flow boiling in micro channels is an attractive method to dissipate high heat flux on electric chips. Low temperature gradient along the fluid flow is another advantage to protect the electric device from breaking. Flow boiling in micro channels is also a good candidate for the effective evaporator.

Several models to predict the heat transfer performance of two-phase flow in micro channels have been proposed. In those models, liquid film thickness is an essential parameter since heat transfer coefficient is usually obtained as the heat conduction through the thin liquid film. Therefore, it is crucial to collect the accurate liquid film thickness data for developing precise heat transfer models. For rectangular, square and triangular channels, liquid film thickness varies along the channel perimeter. Under flow boiling condition, liquid film thickness decreases due to evaporation. Therefore, it is necessary to measure the local and instantaneous liquid film thickness

In the present study, liquid film thickness in micro channels is measured directly with laser focus displacement meter under steady and accelerated conditions. Micro circular tubes with inner diameters of D = 0.3, 0.5, 0.7, 1.0 and 1.3 mm, parallel channels with narrow gaps of H = 0.1, 0.3 and 0.5 mm and micro square channels of H = 0.3, 0.5 and 1.0 mm are used for test channels. In order to investigate the effect of inertial force, water, ethanol and FC-40 are used as working fluids, which enable to cover wide range of Reynolds and capillary numbers.

In micro circular tubes, liquid film thickness varies according to measurement positions due to gravity. However, initial liquid film thickness δ_0 becomes independent of the measuring positions when Bond number and capillary number are small. Liquid slug length has only a weak effect on liquid film thickness. However, liquid film thickness becomes thicker for shorter bubbles, $L_{bubble} < 2D$. At small capillary number, the initial liquid film thickness is determined only by capillary number and the effect of inertial force is negligible. However, the effect of inertial force cannot be neglected as capillary number increases. At small Reynolds numbers, the dimensionless liquid film thickness decreases as Reynolds number increases. As Reynolds number increases further, the dimensionless liquid film thickness takes a minimum and then increases. If Reynolds number becomes larger than roughly 2000, liquid film thickness becomes nearly constant and shows some scattering due to the flow transition from laminar to turbulent.

Under accelerated condition, the increase of liquid film thickness with capillary number is restricted by the bubble acceleration. When the viscous boundary layer is thick, liquid film thickness can be determined by the steady condition prediction. However, when the viscous boundary layer is thin, liquid film thickness becomes thinner due to the acceleration effect. An empirical correlation for the liquid film thickness in a micro circular tube applicable to both steady and accelerated conditions is proposed. The present correlation predicts the experimental values within ±15% accuracy.

In micro square channels, it is observed that the liquid film formed on the channel center becomes very thin and the bubble interface is not axisymmetric at small capillary number. However, as capillary number increases, the interface shape becomes axisymmetric. Transition capillary number from non-axisymmetric to axisymmetric interface decreases as Reynolds number becomes larger. As the case of micro circular tubes, liquid film thickness becomes thicker with Reynolds number at the same capillary number. An empirical correlation based on capillary number and Weber number is proposed.

The proposed correlation is assessed for the applicability to flow boiling condition. It is observed that when wall superheat is larger than 5°C, liquid film thickness becomes thinner than the adiabatic case due to the decrease of viscosity near the wall. It is confirmed that the present experimental correlation is applicable also to the flow boiling condition if the liquid viscosity at wall temperature is used.