論文の内容の要旨

論文の題目 『Fluid Flow and Convective Heat Transfer of Gas-Liquid Two-Phase Flow in a Micro Tube』

（マイクロ管内気液二相流と対流熱伝達に関する研究）

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Gas-liquid two-phase flow in micro channel provides a novel way for heat transfer enhancement. With the features of extremely large surface-to-volume ratio, dominance of surface tension force and mixing by the two phases, the resulted heat transfer coefficient is on the order of 10^4. Without the explosion due to phase change, the flow is fairly stable and pressure drop increase is also moderate. To achieve better designs, the detailed information on flow and heat transfer as well as more accurate models for prediction are crucial.

For gas-liquid two-phase flow in micro scale, surface tension force is dominating. In the simulations of these flows, tiny errors in numerical representation of surface tension force would result significant parasitic flows by using the conventional methods. In the present work, the Phase Field method is employed to capture the interface between phases, while the chemical potential formulation is used to represent the surface tension force. By this way, the energy transfer between surface tension energy and kinetic energy is accurately formulated, and the parasitic flow is significantly suppressed.

This method is applied to simulations of bubbly and slug flows in a micro tube.　For wetting flow, the gas bubble moves faster along the tube center. Averagely, the relation of void fraction α and volumetric gas flow ratio β is read as $\alpha = 0.833\beta$. From this, a constant thickness of residual film can be reached as $\delta/R = 0.087$. Circulation is commonly found in liquid slug as well as in gas bubble, as results in the heat transfer enhancement. Significant pressure drop is caused associated with the gas bubble caps, which is strongly affected by two-phase Reynolds number. Consequently, the resulted two-phase pressure drop represented as two-phase multiplier, Φ_L^2, as a function of the Lockhart-Martineli parameter X spans wide region between $\Phi_L^2 = 1$ and $C = 21$ by Chisholm correlation. Concerning heat transfer, all the thermal energy inputted can be deemed to be transferred only by liquid phase due to the much lower thermal capacity of gas phase. For flows of small Peclet number, diffusion dominates the heat transfer and the heat transfer characteristic is qualitatively similar to that for single-phase flow at entrance region. For flows with high Peclet number, the heat transfer is dominated by circulation in liquid slug.

Simulations of two-phase flow with dry-out are also carried out. The contact line is moved by diffusion that is driven by chemical potential gradient. Without the effects of gas bubble caps, the

pressure drop is smaller as comparing to wetting flows. The presence of dry-out patch increases the wall temperature in both gas and liquid phase regions. Consequently, the global heat transfer is dramatically decreased. The Nusselt number in liquid slug is much higher than single-phase flow. The mechanisms of heat transfer enhancement are due to the larger-temperature-gradient at slug center and radial heat transfer in the regions beside the gas-liquid interface, as are the results of circulation.

Models and associated semi-empirical correlations are proposed for two-phase pressure drop and heat transfer, respectively. The pressure drop, two-phase Nusselt number as well as heat transfer enhancement are predicted under the studied conditions. It is found that the gas bubble works to generate the circulation inside liquid slug. The pressure drop and heat transfer in the center region of long gas bubble are negligible. Once blocking the tube to generate the circulation, the short gas bubble and high Reynolds number are preferred in terms of heat transfer enhancement, while long liquid slug and low Reynolds number are recommended for higher heat transfer efficiency.