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Generalized adiabatic pressure drop correlations in evaporative micro/mini-channels

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ABSTRACT

Existing database in literature on the adiabatic two-phase frictional pressure drop in evaporative micro/mini-channels were reviewed. The collected database contains 769 data points, covering 12 fluids, for a wide range of operational conditions and channel dimensions. The whole database was analyzed using five existing correlations to verify their respective accuracies. The importance of the Bond number, which relates the nominal bubble dimension or capillary parameter with the channel size, was revealed. A particular trend was observed with the Bond number that distinguished the entire database into three ranges. Using the Bond number, improved correlations of adiabatic two-phase pressure drop were established for small Bond number regions. The newly proposed correlations can predict the database well for the region where $BoRe_l^{0.5} \leqslant 200$.

1. Introduction

Two-phase flow in micro/mini-channels is encountered in energy and process systems including miniature heat exchangers, cooling of high-powered electronic systems, catalytic reactors, cooling of plasma-facing components of fusion reactors, miniature refrigeration systems, fuel injection systems of some internal combustion equipment, and evaporator components of fuel cells, to name a few [1]. They are characterized by high heat-flux dissipation and compactness. Single-phase flow in micro/mini-channels is limited by the small temperature rise of working fluids. Two-phase evaporative flow is more attractive due to the utilization of latent heat and the higher heat transfer coefficient. However, the negative point is the higher pressure drop related to micro/mini-channels.

Theoretically, there are four major forces related to two-phase flow in channels: gravitational, inertia, viscous, and surface-tension forces. The basic reason for the difference between conventional channels and micro/mini-channels is the relative significance of the four forces, which are included in our calculation in the dimensionless numbers: Bond number Bo, Weber number We, Froude number Fr, and Reynolds number Re.

The comparison of the channel dimension and the nominal bubble size can be expressed in terms of the Bond number. The Bond number is a measure of the importance of body forces (almost always gravitational) compared to surface-tension forces. A high Bond number indicates that the system is relatively unaffected by surface-tension effects; a low Bond number indicates that surface tension dominates. Intermediate numbers indicate a non-trivial balance between the two effects.

The Weber number is often useful in analyzing fluid flows where there is an interface between two different fluids, especially for multiphase flows with strongly curved surfaces. It can be thought of as a measure of the relative importance of the fluid's inertia force compared to its surface tension. The Froude number is a dimensionless parameter measuring the ratio of the inertia force on an element of fluid to the weight of the fluid element – the inertial force divided by gravitational force.

The Reynolds number gives a measure of the ratio of inertia forces to viscous forces and consequently quantifies the relative importance of these two type of forces for given flow conditions. Reynolds numbers play important roles in characterizing different flow regimes, such as laminar or turbulent flow: laminar flow occurs at low Reynolds numbers where viscous forces are dominant, while turbulent flow occurs at high Reynolds numbers and is dominated by inertia forces.

We collected a large number of experimental data of different fluids for adiabatic two-phase pressure drop. Then, the whole database was analyzed using various existing correlations to verify their respective accuracies. The four dimensionless numbers were analyzed to generate new correlations which have the potential to predict the existing datasets covering a wide range of channel dimensions, working fluids and operational conditions.

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