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A comparison of homogenous and separated flow assumptions for adiabatic capillary flow

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HIGHLIGHTS

► A homogeneous and a separated flow model are applied to capillary flows.
► A density-based discretization is used for the homogeneous model.
► The models are validated for different refrigerants, capillary geometries.
► The error shows clear non-normal tendencies and bias.
► Non-parametric statistical tests confirm the benefits of the separated flow model.

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ABSTRACT

Homogenous and separated flow models are investigated for use in modeling one-dimensional adiabatic capillary tube flow. While these methods have been utilized extensively within the literature, the current work provides a rigorous, quantitative comparison of their accuracy using recent experimental data. Simulations utilizing the working fluids R134a, R600a, and R744 are performed for both methods and validated against experimental data. The mean error of the homogenous flow method is 8.55%, 5.4%, and 8.13%, respectively for R134a, R600a, and R744. The mean error of the separated flow method is 5.77%, 4.57%, and 8.03%, respectively for R134a, R600a, and R744. The separated flow method was found to have a smaller mean error and to perform better than the homogenous method as determined by non-parametric statistical tests.

1. Introduction

Capillary tubes have been extensively researched over the years due to their multiple uses for fluid expansion and refrigerant control within small and household refrigerator systems, freezers, dehumidifiers, and air conditioners [1–3]. Under adiabatic conditions, the expansion simplifies to Fanno flow, which governed by viscous choking can be categorized as either critical or sub-critical flow. Critical flow occurs when the pressure ratio from the inlet to the outlet of the capillary is sufficiently large enough to cause a Mach 1—or choked—outlet condition. Once the critical pressure ratio is reached, further reduction of the outlet pressure will have no effect on the flow conditions within the capillary tube [4]. Sub-critical flow occurs when lower pressure ratios are present and the choke point for the expansion would occur beyond the physical outlet of the capillary tube. Within industrial applications, pressure ratios are often sufficiently high enough to ensure critical flow.

The expansion of a working fluid and subsequent reduction in pressure along the capillary tube causes the fluid to undergo a flashing process, where the pressure is reduced below the vapor pressure and condensation occurs. Initial experiments conducted by Bolstad and Jordan [5] identified two regimes within the capillary tube, a single-phase and a two-phase regime. Later experiments conducted by Mikol [6], Li et al. [2], and Lin et al. [3] identified an additional flow regime, the metastable region, between the single-phase and two-phase regions that consists of a single-phase and a two-phase region. A metastable flow occurs when the system is not in thermodynamic equilibrium, delaying the vaporization of the working fluid such that the pressure of the flow is decreased below the equilibrium saturation pressure before vaporization [7]. The flow regimes present in a typical capillary tube are summarized as: (1) the single-phase region, (2) the single-phase metastable region, (3) the two-phase metastable region, and (4) the two-phase region. The metastable region is typically assumed to be negligibly small, resulting in a flow that is in thermodynamic equilibrium everywhere.

Beyond these initial works, the literature has provided only limited results for capillary flow in both quantity of experiments

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