A Study on Pressure Drop Characteristics of Refrigerants in Horizontal Flow Boiling

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An experimental investigation on the flow pattern and pressure drop was carried out for both an adiabatic and a diabatic two-phase flow in a horizontal tube with pure refrigerants R134a and R123 and their mixtures as test fluids. The observed flow patterns were compared to the flow pattern map of Kattan et al., which predicted well the present data over the entire regions of mass velocity in this study. The measured frictional pressure drop in the adiabatic experiments increased with an increase in vapor quality and mass velocity. These data were compared to various correlations proposed in the past for the frictional pressure drop. The Chisholm correlation underpredicted the present data both for pure fluids and their mixtures in the entire mass velocity range of 150 to 600 kg/m²s covered in the measurements, while the Friedel correlation was found to overpredict the present data in the stratified and stratified-wavy flow region, and to underpredict in the annular flow region.

Key Words: Flow Pattern, Mixture, Pressure Drop, Two-Phase Frictional Multiplier

Nomenclature

\[ D : \text{Tube inner diameter (m)} \]
\[ f : \text{Friction factor} \]
\[ g : \text{Mass velocity (kg/m²s)} \]
\[ L : \text{Tube length (m)} \]
\[ P : \text{Pressure drop (Pa)} \]
\[ q : \text{Heat flux (W/m²)} \]
\[ Re : \text{Reynolds number} \]
\[ X : \text{Mole fraction in liquid} \]
\[ Y : \text{Mole fraction in vapor} \]
\[ z : \text{Axial distance (m)} \]

Subscripts

\[ a : \text{Acceleration} \]
\[ f : \text{Friction} \]
\[ fo : \text{Total flow assumed as liquid} \]
\[ i : \text{Inlet of the heat transfer section} \]
\[ l : \text{Liquid} \]
\[ o : \text{Outlet of the heat transfer section} \]
\[ TP : \text{Two-phase} \]
\[ v : \text{Vapor} \]

Greek Letters

\[ \alpha : \text{Void fraction} \]
\[ \beta : \text{Vapor quality} \]
\[ \rho : \text{Density (kg/m³)} \]
\[ \mu : \text{Viscosity (Pa s)} \]
\[ \Phi : \text{Two-phase frictional multiplier} \]

1. Introduction

In the past decade, experimental studies and empirical and predictive methods were carried out for two-phase pressure drop in tubes, which is an essential element for the design of efficient heat exchanger such as refrigeration and air-conditioning systems. As a result of these efforts, a large number of empirical correlations for two-phase pressure drop in horizontal tube are available, but most of the correlations for the pressure drop were developed based on water-steam or water-air mixtures. Thus, these correlations are difficult to be applied to refrigeration mixtures because the
two-phase flow phenomenon in water–air systems is different from that of refrigeration systems. This may be significantly affected by the fluid properties. Surface tension particularly makes the fluid to minimize its interfacial area. Since the surface tension of water–air is much larger than that of R134a/R123, the flow resistance for fluids having higher contact angle (that is, such as water) is expected to be smaller as reported by Barajas et al. (1993). Conversely, for fluids having smaller contact angle (that is, such as refrigerants), the flow resistance becomes higher.

The measured total pressure drop during two-phase flow boiling consists of the sum of two components, that is, frictional pressure drop and pressure drop due to acceleration. The frictional pressure drop is the most difficult component to predict, and makes the most important contribution to the total pressure drop. On the other hand, the acceleration pressure drop resulting from the variation of the momentum flux caused by phase change is generally small as compared to the frictional pressure drop. The frictional pressure drop during flow boiling is predicted by using two ways: the homogeneous model (1994) assuming equal phasic velocities and the separate model referred to as a slip flow model.

Pierre (1966), based on the homogeneous model, developed the correlation from the measured pressure drop data with R12, R22 and R502. The separate model started from Lockhart and Martinelli (1949) is connected to Martinelli and Nelson (1948) used widely to predict the pressure drop during horizontal flow boiling. Jung et. al. (1989) performed an experimental study on pressure drop during horizontal flow boiling of pure and mixed refrigerants of R22, R114, R12, and R152a, and developed a new correlation with a mean deviation of 8.4% by modifying Martinelli and Nelson’s correlation. The two-phase multiplier, in the two-phase pressure drop correlation of Jung et. al., was expressed as a function of reduced pressure at various qualities. As suggested by Jung et. al., their results indicated no composition dependence of pressure drop with mixed refrigerants.

As suggested in Hosler (1968), knowing the flow pattern in two-phase flow is analogous in single-phase flow to knowing whether the flow is turbulent or laminar. This means that the pressure drop is closely related to the flow pattern.

The objectives of the present study are to obtain the experimental data for flow pattern and pressure drop during flow boiling in horizontal tube with pure refrigerants R134a, R123 and their mixtures. From the result obtained in this study, we are to elucidate the transition quality to annular flow in flow pattern and pressure drop characteristics with respect to vapor quality and mass velocity in pressure drop, and finally to compare the present data with existing various correlations for pressure drop.

2. Experimental Apparatus and Procedure

The experimental apparatus used in the present study is schematically shown in Figure 1. The circulation loop of test fluid consists of a reservoir tank, pump, flow meters, mixing chambers, preheaters, sight glass sections, the test section, condenser and other accessories. Subcooled fluid in the reservoir tank is pumped through a strainer and the 1st preheater to the inlet mixing chamber where fluid temperature and pressure are measured. Then the fluid is heated in the 2nd preheater up to a prescribed enthalpy or vapor quality and then enters the heated test