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# Condensation pressure drop characteristics of various refrigerants in a horizontal smooth tube ☆

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ABSTRACT

The two-phase pressure drop characteristics of the pure refrigerants R410a, R502, and R507a during condensation inside a horizontal tube-in-tube heat exchanger were investigated to determine the two-phase friction factor, the frictional pressure drop, and the total pressure drop. The two-phase friction factor and frictional pressure drop are predicted by means of an equivalent Reynolds number model. Eckels and Pate's experimental data, presented in Choi et al.'s study provided by NIST, were used in the analysis. In their experimental setup, the horizontal test section was a 3.81 m long countercurrent flow double tube heat exchanger with refrigerant flowing in the inner smooth copper tube (8.01 mm i.d.) and cooling water flowing in the annulus (13.7 mm i.d.). Their test runs were performed at saturated condensing temperatures from 38.33 °C to 51.78 °C while the mass fluxes were between 119 and 617 kg $m^{-2}$ $s^{-1}$ for the horizontal test section. The separated flow model was modified by ten different void fraction models and correlations, as well as six different correlations of friction factors, in order to determine the best combination for the validation of the experimental pressure drop values. Carey's friction factor was found to be the most predictive. The refrigerant side total and frictional pressure drops were determined within $\pm$30% using the above friction factor and the void fraction combinations of Carey, Baroczy, and Armand for R410a; and those of Carey, Spedding and Spence, and Rigot for R502 and R507a. The equivalent Reynolds number model was modified using the void fraction correlation of Rigot in order to determine the frictional condensation pressure drop and the two-phase friction factor. The effects of vapor quality and mass flux on the pressure drop are discussed in this paper. The importance of using the alternative void fraction and friction factor models and correlations for the separated flow model is also addressed.

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## 1. Introduction

Condensation phenomena inside horizontal tubes represent an important issue in the chemical process and power industries. Shell-side condensation is rarely preferred to tube-side condensation when the coolant is air or a process gas, or when the condensing refrigerant is at high pressure, dirty or corrosive. For tube-side condensers, the horizontal orientation is most commonly applied. Due to its importance, there have been a number of investigations into the in-tube condensation heat transfer coefficient and pressure drop in the literature. The frictional, acceleration, and gravitational components form the two-phase total pressure drop in tubes. Determination of the void fraction is necessary for computing the acceleration and gravitational components, and similarly, determination of either the two-phase friction factor or the two-phase frictional multiplier is necessary for computing the frictional component of the pressure drop. Generally, empirical methods have been offered to compute the condensation heat transfer coefficients in smooth tubes. Most of these proposed models such as Akers et al. [2], Cavallini and Zecchin [3], and Shah [4] are modifications of the Dittus–Boelter single-phase forced convection correlation [1].

The heat transfer characteristics of the flow in condenser tubes are affected by the heat transfer resistance of the condensate. Accordingly, Bellinghausen and Renz [5] confirm that the local heat flux and the film thickness are two of the main parameters to consider. First of all, Nusselt [6] presented a well-known model which is valid for smooth films at low vapor velocities regarding the prediction of the Nusselt number and film thickness for laminar films. Choi et al. [7] proposed a correlation from an experimental database consisting of the following pure and mixed refrigerants: R125, R134a, R32, R410A, R22, R407C and R32/R134a (25/75% mass). The new correlation was derived by replacing the friction factor and the tube-diameter in the Bo Pierre [8] correlation with a friction factor obtained from pressure drop data for a micro-fin tube and the hydraulic diameter, respectively. The Lockhart and Martinelli [9], Chisholm [10], and Friedel [11,12] correlations are generally used to determine pressure

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