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Flow regimes and two-phase pressure gradient in horizontal straight tubes: Experimental results for HFO-1234yf, R-134a and R-410A

Miguel Padilla, Rémi Revellin *, Philippe Haberschill, Ahmed Bensafi, Jocelyn Bonjour

Université de Lyon, CNRS;
INSA-Lyon, CETHIL, UMR5008, F-69621, Villeurbanne, France;
Université Lyon 1, F-69622, France

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A B S T R A C T

Two-phase flow regime visualizations of HFO-1234yf and R-134a in a 6.70 mm inner diameter glass straight tube have been simultaneous investigated by top and side views with a high speed high resolution camera. No major difference was observed between both refrigerants. HFO-1234yf flow regimes were satisfactorily predicted by the Wojtan et al. [1] flow pattern map. In addition, 819 pressure drop data points measured during two-phase flow of refrigerants HFO-1234yf, R-134a and R-410A in horizontal straight tubes are presented. The tube diameter (D) varies from 7.90 to 10.85 mm. The mass velocity ranges from 187 to 1702 kg m^{-2} s^{-1} and the saturation temperatures from 4.8 °C to 20.7 °C. The results are compared against 10 well-known two-phase frictional pressure drop prediction methods. For the entire database, the best accuracy is given by the method of Müller-Steinhagen and Heck [2] with around 90% of the data predicted within a ±30% error band. An analysis was carried out on the maximum pressure gradient and on the corresponding vapor quality. A statistical analysis for each flow regime was also carried out.

1. Introduction

Nowadays, there is a growing interest in refrigeration, heat pump and air conditioning industries to protect the environment from refrigerants with high Global Warming Potential (GWP). This has led to a demand of new environmental friendly refrigerants, so called next-generation refrigerants with low GWP. This will result in a significant reduction of the environmental footprint associated with air conditioning, heat pump and refrigeration systems. In 2007 were developed refrigerants that should meet the new regulations related to environmental impact, such as a global warming potential below 150. In this sense, the HydroFluoroOlefin (HFO) 1234yf, with a GWP of 4, was the result of the industrial efforts to give a solution able to provide efficient and effective cooling with a near drop-in replacement for the current refrigerant R-134a. Among its interesting characteristics, HFO-1234yf has an atmospheric lifetime of only 11 days, compared to 13 years for R-134a.

As shown in the following, in spite of numerous investigations, none of the existing methods for predicting two-phase pressure drops seem to be widely considered as general and reliable, however, an accurate prediction of two-phase pressure drop in direct-expansion evaporators is of great importance for the design and optimization of refrigeration, air-conditioning and heat pump systems. If an evaporator is inaccurately designed with a two-phase pressure drop higher than the real value, this leads to an oversize evaporator. On the other hand, if the predicted pressure drop is lower than the real value, then the system efficiency will suffer from the larger than expected drop in saturation temperature and pressure through the evaporator.

1.1. Existing experimental studies

Frictional two-phase pressure drops in internal geometries have been experimentally investigated over the last 30 years by several authors. Fig. 1 shows the number of data points found in the open literature (122 articles) for 23 refrigerants since 1980 [3]. As can be noted, almost all studies were carried out using R-134a which can be considered as a reference fluid since it has been extensively studied over the last 15–20 years.

Ould Didi et al. [4] compared the two-phase pressure gradient data obtained in two horizontal tubes (D = 10.92 mm and D = 12.00 mm) for five refrigerants (R-134a, R-123, R-402A, R-404a and R-502). They found that the methods proposed by Müller-Steinhagen and Heck [2] and that developed Grönnerud [5] provide the most accurate predictions. Later, Wongsa-ngam et al. [6] experimentally investigated two-phase heat transfer coefficient and pressure drop during evaporation of R-134a in smooth and microfin tubes. The outer diameter was 9.52 mm width and the

* Corresponding author. Tel.: +33 4 72 43 72 31; fax: +33 4 72 43 88 10.
E-mail address: remi.revellin@insa-lyon.fr (R. Revellin).

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