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Quick and empirical correlations for refrigerant pressure drop in mobile air conditioning system evaporators

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ABSTRACT

In heat exchanger design and simulation, a precise refrigerant pressure drop prediction is difficult because of limited correlation's accuracy. In the present paper, several quick and accurate empirical correlations for refrigerant pressure drop of the typical evaporators (laminated plate evaporator and minichannel parallel flow (MCPF) evaporator) used in mobile air conditioning (MAC) system were proposed. A factor which was related with the refrigerant mass flow rate, thermodynamic properties and refrigerant status was introduced. The types of evaporator and refrigerant were considered in the correlations which were available under typical MAC evaporator application conditions. The analysis results showed the refrigerant pressure drops were implied in a linear relationship with the proposed factor. The predicted data agreed with the experimental data very well. For laminated palate evaporators, the average deviations were 1.8% and 0.7% for R134a and R1234yf, respectively. For MCPF evaporator, the average deviations were 4.5% and 0.6% for R134a and R1234yf, respectively.

Corrélations rapides et empiriques pour la chute de pression de frigorigène dans les évaporateurs de système de conditionnement d'air mobile

Mots clés : Chute de pression ; Evaporateur ; Frigorigéne ; Corrélation empirique

1. Introduction

The car manufacturers are facing the pressures of energy consumption and emission reductions. A higher efficiency mobile air conditioning (MAC) system will reduce the whole vehicle fuel consumption, especially for electric vehicles (Qi, 2014). Refrigerant pressure drop in MAC system will influence component and system performances. No matter component simulation or system design, pressure drop

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Nomenclature

b	coefficient in Eqs. (1) and (4) (kPa)
C	coefficient in Eqs. (1) and (4) ($m^{-4} \times 10^9$)
$\dot{m}$	mass flow rate ($g\ s^{-1}$)
P	pressure (kPa)
ΔP	pressure drop (kPa)
R^2	coefficient of determination (–)
X	factor in Eqs. (1) and (4) ($g\ m^3\ s^{-2} \times 10^{-3}$)
x	vapor quality (–)

Greek letters

ρ	density ($kg\ m^{-3}$)

Subscripts

cor	corrected
crit	critical
in	inlet
l	liquid
m	mean
out	outlet
ref	refrigerant
TXV	thermal expansion valve
v	vapor

should be considered seriously, especially in evaporator design and simulation. Evaporator in MAC system removes heat load from car compartment and it is one of the key components in MAC system performance enhancement. Currently laminated plate and minichannel parallel flow (MCPF) evaporators are widely used in MAC systems.

Evaporation two phase pressure drop in tube/plate is mainly studied by experimental method. After a thorough experiments, a general correlation would be proposed available for the test ranges. Jung and Radermacher (1989) compared their experimental data with Pierre's correlation (1964) and found the deviation was about 20%. They draw a new correlation and prediction agreed with the data with a mean deviation of 8.4%. Yan and Lin (1998) investigated R134a evaporation heat transfer and pressure drop in a horizontal small circular tube (inner diameter was 2.0 mm) and proposed a two phase pressure drop correlation. The average deviation comparing their experimental data was about 17%. Zhang and Webb (2001) experimentally studied the single phase and adiabatic two phase flow pressure drop of R134a, R22 and R404A flowing in several tubes with different hydraulic diameters and materials. Their proposed correlation could predict with a mean deviation of 11.5% comparing with 119 experimental data. But for the different refrigerant, the deviation was different. Yin et al. (2001) simulated the CO_2 pressure drop in gas cooler including frictional and acceleration loss in microchannel tube, inlet/outlet header, contraction and expansion loss and inlet/outlet tubes. There was a serious underprediction between measured data and predicted data if the manufacturing defects were not considered. Chen et al. (2002) compared their experimental data carried out in small diameter tubes with previous correlations and found the mean deviation was 34.7% with the homogeneous model. If introducing the Bond number and Weber number to the modified correlation, the deviation would be reduced to 19.1% based on 1484 data points. Hsieh and Lin (2003) experimentally studied R410A evaporation flow in a vertical plate heat exchanger and drawn a correlation for pressure drop. The comparison implied that the average deviation of pressure drop prediction is about 18%. Most of these correlations only work for the tube/plate not including heat exchanger inlet/outlet pipes and headers.

There are thousands of correlations for different tubes, flow conditions and refrigerants. Kim et al. (1999) collected 38 correlations for non-boiling (evaporation) conditions and found the correlations deviations were varied. Mendoza-Miranda et al. (2015) compared R134a and R1234yf evaporation characteristics in shell and tube heat exchangers with variable correlations in heat transfer and pressure drop. It was concluded that the predicted parameter with maximum deviations was the evaporating pressure. For example, the average deviations of Thome et al. (1997) and Cavallini et al. (2006) correlations were 24.16% and 14.33% for R134a, respectively.

Based on the above analysis, it is clear that much data and design correlations for frictional pressure drop are already available in the literature (Wang, 2005). But the real engineering problem is not resolved. For example, it is very hard for evaporator design engineers to pick out the right correlation or data for their needs. And how to calculate the header, inlet/outlet pipes and elbows in evaporator? The practical application of these correlations are still suffering from significant departure from the prediction and design (Wang, 2005).

With the development of technologies, the heat exchanger are improving and new refrigerant is coming to the industry. For example, the depth of laminated plate evaporator has been reduced from 92 mm (Nelson and Hrnjak, 2002) to 45 mm (Qi, 2013). The main purpose of the present paper was to draw several new empirical correlations of refrigerant pressure drop to fulfill the more compact MAC evaporators (laminated plate evaporator and MCPF evaporator) using R134a and R1234yf as working fluids under typical vehicle conditions based on experimental data. These correlations will account all the pressure drops in evaporators and will be applied in classic MAC evaporators directly without two-phase flow analysis. It will help the design engineers to perform a quick and convenient pressure drop prediction during component design and system simulation.

2. MAC evaporators and experiments

So far, the laminated plate evaporators are dominant in MAC systems. It is consisted of laminated plates, louver fins and tanks. Several refrigerant passes can be designed as shown in Fig. 1(a). Because of more compact and higher performance (Qi et al., 2009, 2010), MCPF evaporators are growing in new vehicles as shown in Fig. 1(b). MCPF evaporator is consisted of minichannel tubes, louver fins and headers. It also can be designed into several refrigerant passes. The advantages of MCPF evaporator and its influence on MAC system performance can refer to Qi et al. (2009, 2010) studies. The main geometries of the evaporators in this study were shown in Table 1. For each type, 3 evaporators' samples were tested