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Research Paper

Experimental investigation on pressure drop characteristic of R410A through short tube orifices

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HIGHLIGHTS

- The short tube orifice throttling semi-empirical model with refrigerant R410A was set up for the first time.
- The semi-empirical impedance model $\left(\Delta P = \left[s_1 + s_2\left(\frac{L}{D^5}\right)\right]G^2\right)$ was established.
- The short tube orifice throttling model has a high precision and a large scope working condition.

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ABSTRACT

The pressure drop characteristic experiments of R410A through short tube orifices (diameter ranged from 0.7 to 1 mm, and length ranged from 5 to 15 mm) were performed under specific condensing pressure, evaporating pressure and sub-cooling degree conditions. A quadratic regression semi-empirical benchmark model was established based on the impedance calculation method. According to the benchmark model, the pressure drop characteristic experiments were performed under condensing pressures ranged from 2500 to 3100 kPa, evaporating pressures ranged from 900 to 1200 kPa and sub-cooling degrees ranged from 3 to 9 °C. A semi-empirical universal model of pressure drop characteristic of R410A through short tube orifices is developed. The model can cover the test range of working conditions and refrigerant mass flow rate. The model is used to predict the pressure drop of R410A through two kinds of the short tube orifices under a variety of working conditions, and the deviation between the predicted value and the measured value is within ±10%. The experimental results of air conditioner matching validation experiments show that the air conditioning system don't need to adjust with the short tube orifices replace the capillary tubes.

1. Introduction

Short tube orifice is a new throttling element. It has the advantages of low cost, high reliability and easy flow adjustment. Due to these advantages, increasing attentions have been paid to it by both refrigeration equipment manufacturers and researchers. Short tube orifice has already been widely used in the automobile air conditioner, household air conditioner and heat pump water heater. However, there are only a few researches committed to the short tube orifice's pressure drop characteristic, especially with R410A as the working medium. García-Valladares and Santoyo [1] performed a one-dimensional numerical modelling of the fluid-flow inside short tube orifices, and successfully validated the modelling results against a wide range of mass flow rate measurements reported using R-134a as refrigerant. Afterwards, they carried out a comprehensive comparison analysis between numerical simulation data and experimental measurements obtained using R-407C and R-410A as refrigerants to extend the applicability of the same mathematical model. Average deviations of ±11.1% and ±7.3% were found between numerical model and experimental data for R-407C and R-410A, respectively [2]. Sangrok et al. [3] presented a new discharge coefficient correction method for the orifice equation for R-123 two-phase flows. The results showed that the quality of flow downstream of the orifice can be calculated using the enthalpy difference between the inlet and outlet of the evaporator. Nilpueng and Wongwises [4] investigated the flow mechanisms of R-410A inside short tube orifices. The results showed that the refrigerant flow mechanisms in the entrance region and inside a short tube orifice agree with

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Nomenclature

ΔP	overall pressure drop (kPa)
T	temperature (°C)
G	refrigerant mass flow (kg/h)
Q	refrigerating capacity (W)
C	a function about φ
x	vapor quality
v	specific volume (m^3/kg)
S_1	impedance in the entrance of short tube orifice
S_2	dimensionless coefficient of the short tube orifice along impedance
L	length of short tube orifice (mm)
D	pipe diameter of short tube orifice (mm)
k	the correction coefficient of working condition
m	the synthetic influencing coefficient
r	condensing pressure ratio impact factor
s	evaporating pressure ratio impact factor
t	sub-cooling degree ratio impact factor

Greek letters

φ	ratio of the cross-sectional area

Abbreviations

i	inlet
o	outlet
cond	condensing
evap	evaporating
f	fluid
g	gas
sc	supercooling

incompressible flow theory, but the refrigerant flow mechanisms in the exit region were similar to the choked flow in a theoretically compressible flow.

R410A consists of 50% R32 and 50% R125 (mass ratio). Although it has a higher operating pressure, and a higher value of global warming potential (GWP), its ozone depletion potential (ODP) is zero and its liquidity is good in the air conditioning refrigeration system. It also has high heat transfer efficiency. As a type of environment-friendly refrigerants, it has been applied in the air conditioner. It is expected to replace R22 refrigerant in the next few years [5–10]. In order to promote the application of R410A in air-conditioners. The researches on the pressure drop characteristic of short tube orifices with R410A are encouraged to establish a related calculation model. So far, the studies on critical pressure drop characteristic of refrigerant in short tube orifices mainly focus on the experimental test. The pressure drop characteristic experiments with R22, R134a, R407C, R410A and R744 in short tube orifices indicate that it has the following consequence. When the downstream pressure (evaporating pressure) of the short tube orifice is greater than the saturation pressure that corresponding to the upstream temperature (refrigerant inlet temperature), the downstream pressure has a significant influence on the refrigerant mass flow rate in the short tube orifice. The refrigerant will not appear choked phenomenon in the short tube orifice. In which case, it flows with single phase liquid. When the downstream pressure is lower than the saturation pressure that corresponding the upstream temperature. The downstream pressure has little influence on the refrigerant mass flow rate in the short tube orifice. The refrigerant appears choked phenomenon. The refrigerant mass flow rate depends mainly on the upstream stagnation parameters (e.g. upstream pressure and super-cooling degree) and the cross sectional area of the short tube orifices [11–13]. In the refrigeration and heating working condition, the refrigerant will appear choked phenomenon generally in the short tube orifices. It then turned into a two phase critical flow state [14].

The purpose of estabilishing models for the throttling short tube orifices is to predict the critical mass flux in the short tube orifices accurately. So that it can help engineers in matching the refrigeration system components. The throttling short tube orifices model can be classified into two categories: theoretical model and semi-empirical model. The theoretical model can be well adapted to the refrigerant and working conditions well. But the model accuracy is not high, and the solving is complex.

The semi-empirical model is estabilished by introducing the corresponding correction coefficient into critical flow model of single phase. The coefficient of correction is obtained by fitting the experimental data. Therefore, the semi-empirical model is only applied to a specific refrigerant and a certain working condition. The most typical semi-empirical model of short tube orifices with R410A is the Payne model. In this model, the diameter of the short tube orifice is from 1.09 to 1.94 mm. The disadvantage of the Payne model is that it has too many state parameters, which lead to the computation complicated [5]. With the improvement of the throttling short tube orifices processing technology, and meanwhile in order to further reduce the cost of materials. The pipe diameter of the throttling short tube orifices used in household air conditioner is generally below 1 mm (the minimum pipe diameter can reach 0.6 mm) [15]. At present, only a few studies on pressure drop characteristic use short tube orifices with diameter below 1 mm. What's more, there is no semi-empirical model on pressure drop characteristic using R410A.

In this study, the pressure drop characteristic experiments were performed in short tube orifices using R410A as refrigerant. The main purpose of this study is to establish a semi-empirical model that can be adapted to a certain range working conditions and refrigerating capacities. What's more, a semi-empirical benchmark model was established based on the impedance computing method with single phase flow under a specific working condition. Then the benchmark model was further validated and improved against experimental results obtained under different conditions.

2. Benchmark model under specific conditions

2.1. Benchmark model building

Fig. 1 shows the short tube orifice structure diagram. The flowing pressure drop of refrigerant in the short tube orifice is shown in Fig. 2. As can be seen in Fig. 2, the overall pressure drop (ΔP) is composed of three components: partial drop of pressure in the entrance to the sudden shrinkage ($\Delta P_1 = P_{cond} - P_i$), pressure drop along the short tube orifice ($\Delta P_2 = P_i - P_o$) and partial drop of pressure

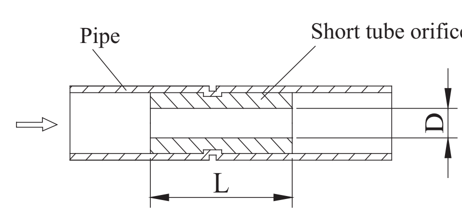

Fig. 1. Schematic diagram of short tube orifice.