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Experimental Research and Theoretical Analysis on Throttling Characteristics of Electronic Expansion Valve in Series with Capillary Tubes

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ABSTRACT

The mass flow rate of R32 and volumetric flow rate of dry air in an electronic expansion valve (EEV), in two different capillary tubes (CTs) and in one expansion valve in series with two different capillary tubes were tested, and the theoretical volumetric flow rate of dry air in one EEV in series with different CTs were predicted through a theoretical throttling model built in this paper. The results showed that the mass flow rate of R32 or volumetric flow rate of dry air of the serial throttling component was lower than but close to that of the EEV in low openings and that of the CTs in full opening, respectively, when the operating conditions were comparable. The flow rate ratio of the serial throttling component to the EEV decreased significantly as the opening increased, and the flow rate ratio of the refrigerant was obviously lower than that of the dry air. The refrigerant mass flow rate of EEV in series with CT upstream was higher than that of the same EEV in series with the same CT downstream.

1. INTRODUCTION

As the main throttling components in household inverter air conditioner, EEVs will be applied more and more frequently as the result of the execution of new energy efficiency standards. EEVs in series with capillary tubes are used in most household inverter air conditioners, to reduce the noise through the connecting pipe to the indoor side and increase the universality in different cooling capacity. The flow behavior of refrigerant shows a significant change through the EEV in series with capillary tubes, but there are no published reports on it, lacking of engineering design guidance and selection.

The mass flow rate of R32 and volumetric flow rate of dry air in one EEV in series with capillary tubes were first tested and analyzed in this paper. Furthermore, this paper compares the mass flow rate of refrigerants and volumetric flow rate of dry air in an EEV and in capillary tubes in the same condition, and builds a gas throttling model for an EEV in series with capillary tubes in order to predict the theoretical air flow in serial throttling components for the first time.

2. EXPERIMENT

2.1 Experimental prototype

There are six test samples listed in Table 1, while EEV1.65 represents the valve diameter of a certain type EEV to be 1.65mm, Cap1.37×550 represents the inner diameter and length of capillary tubes to be 1.37mm and 550mm, respectively. The EEV or capillary tubes were welded to generic fittings for connecting and changing test series combination easily before the experiment. In order to measure the intermediate pressure of sample#4-#6 in the experiment, a pressure pore is drilled on the transitional tube of the EEVs and capillary tube.

Table 1 samples

samples number	type
1#	EEV1.65
2#	Cap1.37×550
3#	Cap 1.63×500
4#	EEV1.65+ Cap1.37×550
5#	EEV1.65+ Cap 1.63×500
6#	Cap 1.63×500+ EEV1.65

2.2 Experimental conditions

Experimental conditions for refrigerant and air are showed in Table 2. R32 and compressed dry air are used. The inlet temperature and the humidity ratio are controlled by the inlet fluid , due to the short test duration, a small range of temperature fluctuations and low humidity ratio，which bring negligible influence on experimental results.

Table 2 experimental conditions

	unit	R32	dry air (t_{dew}<-20℃)
inlet pressure	kPa	2795	100（gauge pressure）
inlet temperature	℃	39	28±3
outlet back pressure	kPa	1107	0（gauge pressure）

R32 throttling flow experiments are conducted using refrigerant throttling characteristics experimental system. The experimental system is equipped with high-precision mass flowmeters, manometers and platinum resistance thermometers. Inlet pressure, inlet subcooling and the outlet back pressure can be regulated independently. Dry air throttling flow experiments are conducted using electronic expansion valve gas flow experimental system, equipped with high-precision volume flowmeter and pressure gauges, and inlet gauge pressure can be regulated.

3. GAS THROTTLING PRESSURE-DROP MODEL

According to the JB/T 10212-2011 "Direct-driven electronic expansion valves for air-conditioning equipment", the inlet gauge pressure of dry air or nitrogen is 0.1MPa in the EEV flow characteristics experiments. Therefore, dry air and nitrogen can be considered as ideal gases. In this paper, the dew point temperature of dry air is lower than -20 ℃ under atmospheric pressure.

The derivation process is omitted here. Gas throttling pressure-drop model equations of the EEV, capillary tubes and series components are shown below.

The EEV gas throttle pressure-drop model:

$$\Delta p_{eev} = 0.5 C_D^{-2} \rho_i^{-1} G^2 \tag{1}$$

Where C_d is the coefficient of gas flow rate, obtained from the experimental data; ρ_i is the density of the inlet gas; G is the mass flow flux. The relationship between G and mass flow rate is presented in equation (5).

The capillary gas throttle pressure-drop model:

$$\Delta p_{cap} = f\frac{\Delta L}{d_h}\frac{G^2}{2\rho} + (C_i - 1)\frac{G^2}{2\rho_i} + (C_o + 1)\frac{G^2}{2\rho_o} \quad (2)$$

Where ΔL and d_h are the length and inner diameter of CTs, respectively; C_i and C_o are the local flow resistance coefficient of inlet and outlet, obtained from the Engineering Handbook or experimental data; ρ_i, ρ_o and ρ are inlet, outlet and average density, respectively; f is the friction coefficient, described by:

$$f_{cap} = 0.3164\mu^{0.25}d_h^{-0.25}G^{-0.25} \quad (3)$$

Where μ is the gas dynamic viscosity; d_h is the inner diameter of CTs.

EEV in series with capillary gas throttling pressure-drop model:

$$\Delta p = \Delta p_{eev} + \Delta p_{cap} \quad (4)$$

$$G_{eev}A_{eev} = G_{cap}A_{cap} = M \quad (5)$$

Where, A_{eev} and A_{cap} are the EEV and capillary tube flow channel area. The EEV flow channel area is the minimum area of the valve needle with the valve port, determined by the geometry.

According to the ideal gas equation of state:

$$\rho^{-1} = R_g T / p \quad (6)$$

Where, R_g is the gas constant (287.1 J/kg·K for air); T is the absolute temperature of the fluid. Considered as isenthalpic throttling process, the temperature of dry air reduces by about 0.22 ℃ from the inlet gauge pressure 0.1MPa to the outlet gauge pressure 0. The temperature change between the inlet and the outlet is ignored in order to simplify the solving process.

Sutherland gas dynamic viscosity equation:

$$\mu = 1.458\times10^{-6}T^{3/2}/(T + 110.4) \quad (7)$$

According to the experimental conditions in Table 2, with the outlet pressure and inlet temperature known, assumption of mass flow rate is needed to solve gas throttling pressure-drop model equations iteratively in order to obtain the mass flow rate of EEV in series with capillary tubes. The convergence criterion is the relative deviation less than 10^{-4} between the calculated value and the given value.

As to the EEV in series with capillary tubes downstream, if the mass flow rate is assumed, electronic expansion valve pressure drop can be solved by the formula (1). The inlet pressure of the CT equals to the electronic expansion valve outlet pressure. As to the EEV in series with capillary tubes upstream, electronic expansion valve inlet pressure is unknown, so the aforementioned method is no longer applicable. The formula (1) is converted into the equation (8), then the electronic expansion valve inlet pressure and capillary tube outlet pressure will be obtained by the assumed value of the mass flow rate. The mass flow rate of EEV in series with capillary tubes upstream is obtained finally.

$$p_{eev,i} = 0.5\left[p_o + \left(p_o^2 + 2R_gTC_D^{-2}G_{eev}^2\right)^{0.5}\right] \quad (8)$$

The influence of the temperature fluctuations and low humidity ratio mentioned above can be analyzed by combining the formula (1), (5) and (6). The electronic expansion valve inlet pressure, pressure drop, flow coefficient under the same opening degree and area of cross-section are constant. It turns out that:

$$M \propto \left(R_g T\right)^{-0.5} \tag{9}$$

The gas constant expression of moist air is:

$$R_g = 15.935 \times \left(18.015 + 28.963d\right) / \left(1 + d\right) \tag{10}$$

Where d represents the humidity ratio.

The humidity ratio is 6.35×10^{-4}kg/kg when the pressure and the dew point of the moist air are 0.1MPa and –20℃, respectively. The relative flow deviation of moist air to the dry air at 28 ℃ is ± 0.5%, combined with formula (9) and (10), where the influence of humidity ratio is less than 0.02%.

4. EXPERIMENTAL AND THEORETICAL RESULTS AND ANALYSIS

The experimental results and predicted results using gas throttling pressure-drop model are shown in Fig.1 to Fig. 4. Abscissa is the valve opening degree of EEV and EEV in series capillary tubes, which is defined as the ratio of the number of pulses and the full number of pulses.

Fig 1 shows the comparison with experimental and predicted air flow rate of the EEV, capillary tubes and series components according to gas throttling pressure-drop model. The predicted values are in good agreement with the experimental values, since the prediction error of CTs is less than 4%.

Fig 1 shows the air flow difference between sample 5# and 1# increases with the increment of opening degree. Besides, the smaller inner diameter and longer length of series the capillary tube has (i.e. sample# 4), the more different flow rate is. In full opening degree, the air flow rate of series component 5# is lower than series component 3#, even much lower than the series component 1#. In low opening degree cases, the air flow rate of series component 5# is lower than that of series component 1#, much lower than capillary tubes flow rate.

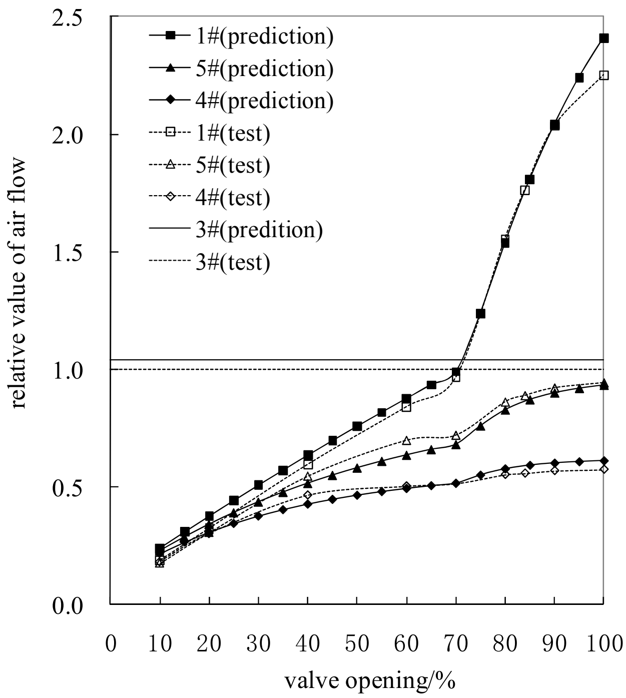

Fig 1: air flow test value and prediction value

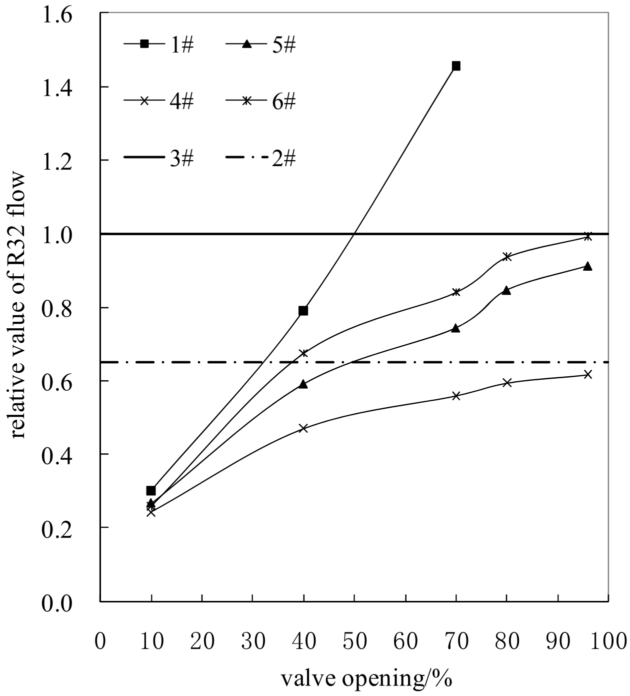

Fig 2: R32 flow rate in EEV, capillary and series components

Taking R32 flow rate in sample 3# (Cap1.63×500) as the reference value, the relative flow rate of samples listed in Table 1 vs opening degrees is shown in Figure 2. R32 flow rate in EEV 1# in series with capillary tubes 2# and 3# has a different degree of reduction. In the same opening degree, R32 flow rate in serial samples declines more significantly if the CTs are thinner and longer. In low opening degrees, R32 flow rate in series components is close to but still lower than R32 flow rate in the EEV, even much lower than that in capillary tubes. In high EEV opening degrees, R32 flow rate in series components is closed to but lower than R32 flow rate in capillary tubes, and much lower than in EEV. R32 flow rate in sample 6# is higher than sample 5#, as the capillary tube located in the upstream of the EEV.

The relative changes of refrigerant flow rate and air flow rate in samples with different locations of CTs are showed in Fig. 3. The ordinate values represent the relative flow rate of R32 (or air), which are normalized using the absolute flow rate in the cases with the EEV alone under corresponding opening degrees. The relative values of R32 and air flow rate in series components decrease with the increasing opening, and the relative values of R32 flow rate are lower than air in the same series component and the same opening degree. Under the experimental conditions mentioned in this study, and the expansion valve opening degree ranging from 10% to 70%, the relative R32 flow rate is lower by15%~20% than air flow in EEV1.65 in series with cap1.37×550 and cap1.63×500 down flow.

Figure 4 shows the change of EEV's relative contribution to the total throttling pressure drop with the EEV opening degree, both in R32 experimental cases and air prediction cases. The results show that in cases of EEV1.65 in series with Cap1.37×550 and Cap1.63×500 down flow, EEV's relative contribution forR32 and air pressure drop is reducing with opening degree increasing. It implies that the EEV is the major throttling component when the opening of the EEV is small. On the contrary, the capillary tubes are the major throttling component when the opening degree is large. In the same opening degree, the longer and thinner the capillary tubes are, the smaller EEV's contribution on the pressure drop is. Figure 4 also shows that EEV's contribution on the R32 pressure drop is smaller than that of air, because the two-phase specific volume and the liquid phase dynamic viscosity of refrigerant with capillary tubes located in downstream is smaller than that of air.

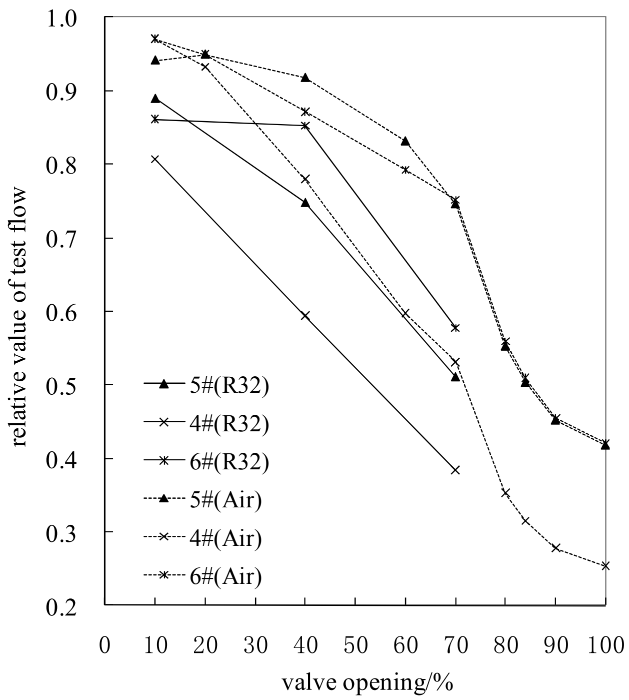

Fig 3: R32 and air flow in series component relative to EEV

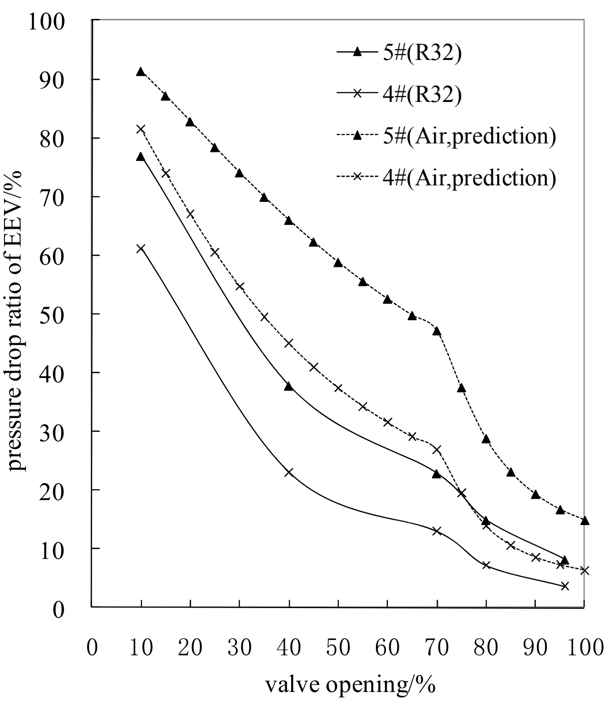

Fig 4: pressure drop ratio of EEV in series component

5. CONCLUSIONS

This study conducted R32 and air flow experiments in the EEV, capillary tubes and series components, obtained the theoretical predictions based on gas throttling pressure-drop model, and characterized the R32 and air throttling behaviors in series components quantitatively for the first time.

To the best of our knowledge, the gas throttling pressure-drop model is established in this study for the first time, which can be used to predict the air flow rate of EEVs, capillary tubes and series components. It provides the theoretical basis to design the flow curves of electronic expansion valve and choose the sizes of capillary tubes in the series components with important engineering application value.

REFERENCES

Gree Electric Appliance, Inc. of Zhuhai. electronic expansion valve and the refrigeration unit having it. China: CN203163367U, 2013.08.28.

JB/T 10212-2011. Direct-driven electronic expansion valves for air-conditioning equipment.