Short Tube Orifice Design Methodology for an Air Conditioning Application

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Abstract

In recent years, regulations on air conditioning systems have resulted in energy efficient systems. Greater efforts are required to redesign such systems. This leads to increased experimental testing. Short tube orifice is a commonly used expansion device in automotive and residential air conditioning, which is selected based on trial and error. In this study, an effort has been made to compare the generalised correlations presented in literature to formulate a methodology for short tube orifice sizing. The correlations were chosen such that they are applicable for a variety of refrigerants and can be used for wide operating conditions. Experiments were performed in a psychrometric laboratory with R410a as the refrigerant, to validate the methodology for short tube orifice sizing.

Introduction

The expansion device is an important component in vapor compression based refrigeration systems. There are two types of expansion devices: the variable-restriction type and the fixed-restriction type. In variable-restriction type devices, flow opening is controlled by the control system such as in electronic expansion or thermostatic expansion. In the latter, the flow opening is fixed; for example, a capillary tube, short tube orifice, or ejector.

For automotive and residential air conditioning, short tube orifice is used widely because of low cost, high reliability, ease of installation, pressure equalisation during off cycle and elimination of additional check valve for flow direction change in heat pump applications [5]. In residential air conditioning applications, short tube orifices are made from extremely small bore hollow brass ingots with 10–13 mm length and L/D ratio in the range of 3–20. However, for automotive air conditioning, the inner diameter is in the range of 1–2 mm and L/D ratio falls in the 21–35 range [6].

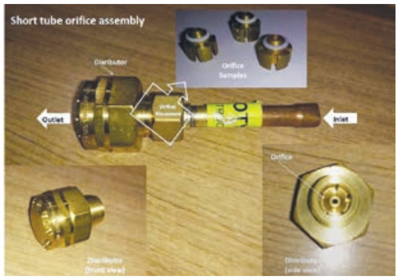

Figure 1: Short tube orifice assembly used in air conditioning model

Table 1: Short tube orifice and test parameters

Description	Parameter
Length (mm)	12.1
Diameter range (mm)	1.016 to 2.159
Inlet pressure (MPa)	2.590 to 4.148
Outlet pressure (MPa)	0.942 to 1.269
Inlet temperature (°C)	37.05 to 61.69

Figure 1 shows the typical short tube orifice assembly used in residential air conditioning. The assembly consists of an inlet pipe connected to the condenser outlet, short tube orifice and distributor for flow distribution in evaporator. The side view of the distributor shows the placement of short tube orifice upstream of the distributor. *Table 1* shows the short tube orifice geometry and test parameters for this analysis.

Many researchers have experimentally studied the flow of refrigerants in short tube orifice [1, 3, 4, 5, 6, 8, 9, 10]. Most of the studies on short tube orifice have focused on formulating mass flow rate correlation based on experimental data generated individually. Choi J. et al. [2] used published experimental data to formulate a generalised equation for a variety of refrigerants (R12, R22, R134a, R407c, R410a and R502) applicable over a wide range of operating conditions. The correlation presented for sub-cooled inlet is given by:

$$\pi_1 = 0.1378 \times \pi_2^{-0.950} \pi_3^{0.033} \pi_4^{0.769} \pi_5^{0.082} \pi_6^{-0.099} \pi_7^{-0.104} \pi_8^{0.554} \pi_9^{-0.034} \quad (1)$$

For two phase inlet condition, the correlation suggested is:

$$\pi_1 = 0.0720 \times \pi_2^{-0.09} \pi_3^{0.406} \pi_6^{-0.149} \pi_8^{-0.099} \pi_{10}^{-0.013} \pi_{11}^{0.283} \quad (2)$$

Where, $\rho_{mean} = \dfrac{1}{\dfrac{1-x_{in}}{\rho_f} + \dfrac{x_{in}}{\rho_g}}$

Recently, Yang and Zhang [11] developed a generalised local power law correlation for short tube orifice based on the previous experimental database of refrigerants (R12, R22, R134a, R407c, R410a and CO_2 (R744)). The correlation is given by:

$$\pi_1 = \left(\frac{1 - 3.651 \times \pi_2^{-1.425}}{-11.481 \times \pi_3^{0.0005964} - 1 - 4.529 \times \pi_4 \pi_5^{-0.2902} \pi_3^{-0.0678}} \right)^{0.5} \quad (3)$$

For two phase inlet condition, inlet densities and viscosities are calculated as:

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$$\rho_{in} = \frac{1}{\frac{1-x_{in}}{\rho_f} + \frac{x_{in}}{\rho_g}} \text{ and } \mu_{in} = (1-x_{in})\mu_f + x_{in}\mu_g$$

All non-dimensional groups (groups) used in *Equations* (1), (2) and (3) are given in *Table 2*.

Table 2: Non-dimensional groups of the correlations under study

Non-dimensional group	Yang and Zhang, 2014	Choi J., 2004
π_1	$\frac{1.273m}{D^2\sqrt{\rho_{in}p_{in}}}$	$\frac{m}{D^2\sqrt{\rho_f p_{in}}}$
π_2	$\frac{p_{sat}}{p_{in}}$	$\frac{p_c - p_{in}}{p_c}$
π_3	$\frac{\rho_f}{\rho_g}$	$\frac{p_c - p_{out}}{p_c}$
π_4	$\frac{L}{D}$	$\frac{p_c - p_{sat}}{p_c}$
π_5	$\frac{D\sqrt{p_{in}\rho_{in}}}{\mu_{in}}$	$\frac{\Delta T_{sub}}{T_c}$
π_6	-	$\frac{L}{D}$
π_7	-	$\frac{\rho_f}{\rho_g}$
π_8	-	$\frac{\mu_f - \mu_g}{\mu_g}$
π_9	-	$\frac{\sigma}{Dp_{in}}$
π_{10}	-	$\frac{x_{in}}{1-x_{in}}$
π_{11}	-	$\frac{\rho_{mean}}{\rho_f}$

Experimentation

Experiments were performed in an 11 TR psychrometric laboratory. The laboratory consists of indoor (IDU) and outdoor (ODU) chambers with separate conditioning apparatus (see *Figure 2*). The short tube orifice was installed in the IDU chamber along with the indoor unit. Tests were conducted with R410a as a refrigerant. *Table 3* shows various test conditions created in the laboratory to generate the database for validation. Air enthalpy method was used for capacity calculation. Capacity rating of the laboratory (both cooling and heating) is in the range of 0.879 to 17.68 kW (0.25 TR to 5 TR). Indoor unit airflow range is 0.094 to 1.416 m³/s (200~3000 cfm). The laboratory conforms to ISO 5151; ISO 13252; ISO 15042; ISO 16358; EN 14511-1,2,3,4; EN 14825; AHRI 210/240; AHRI 1230; SASO 2681; SASO 2682; UAE.S.ISO 5151; UAE.S.ISO 13252; GSO 1005; GSO ISO 1006; GSO ISO 5151; ASHRAE 37; IS 8148.

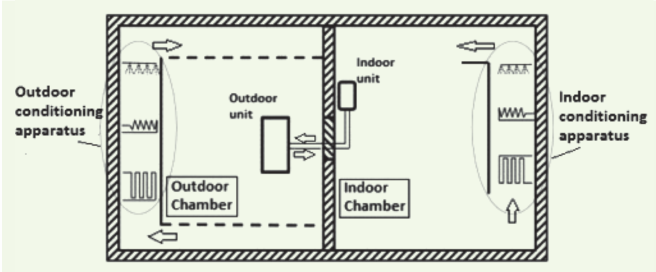

Figure 2: Psychrometric laboratory schematic

Table 3: Laboratory test conditions

Test condition	Outdoor DBT (°C)	Indoor		No. of data points
		DBT (°C)	WBT (°C)	
AHRI A*	35	27	19	22
T3**	46	29	19	12
Hot	52	29	19	5
* Per AHRI Standard 210/240				
** Per ISO 5151 Standard				

Short Tube Orifice Sizing Methodology

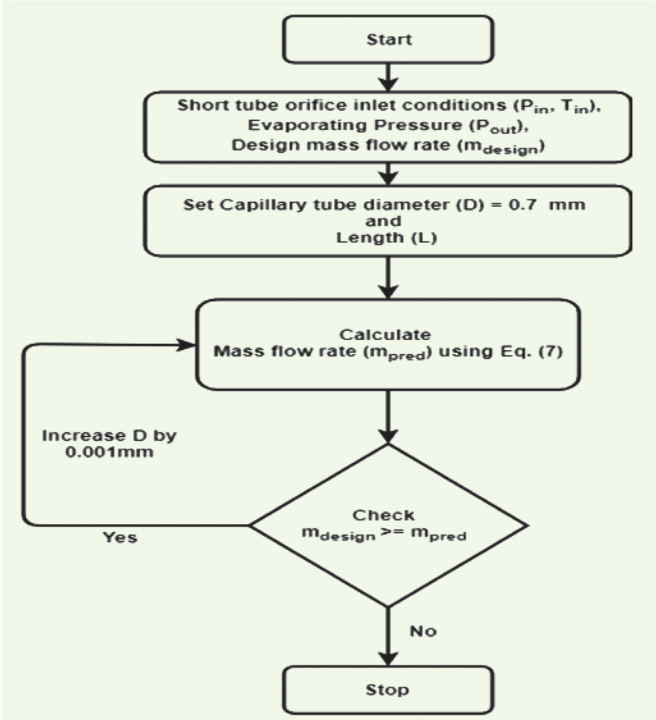

Figure 3: Flowchart for short tube orifice sizing

Figure 3 shows the flowchart for short tube orifice sizing. Using this methodology, the short tube orifice inner diameter can be predicted using the given set of operating conditions and design mass flow rate. In this methodology, the initial guess for short tube orifice inner diameter is taken as for a given length of short tube orifice. In order to achieve the designed mass flow rate, the diameter is increased in steps of 0.001 mm and the new mass flow rate is compared with the designed mass flow rate. Design mass flow rate is calculated using refrigeration capacity and specific enthalpy difference across the evaporator, given as:

$$m_{design} = \frac{Q_{refrigeration}}{h_{suction} - h_{in}} \quad (5)$$

As soon as the predicted mass flow rate reaches the designed mass flow rate, the short tube orifice diameter at last calculation is considered as the design diameter of short tube orifice.

Validation

Figure 4 shows the correlation comparison between Yang and Zhang (2014) and Choi J. et al. (2004). Prediction error is defined with respect to the experimental short tube orifice inner diameter, and is given by:

$$Error(\%) = \frac{D_{predicted} - D_{experiment}}{D_{experiment}} \times 100$$

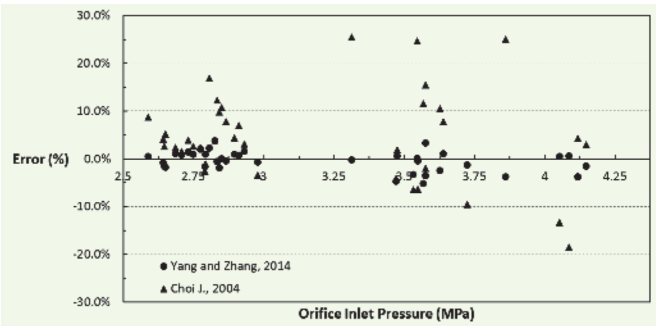

Figure 4: Comparison between inner diameter predictions using correlations under study

It is observed that the predictions made by Yang and Zhang (2014) are in good agreement with experimental data. The variation observed is well within 5.1%; this makes the correlation more suitable for design purpose. However, higher deviation is observed in the correlation of Choi J. et al. (2004). In cases where sub-cooling is closer to zero, the prediction of Choi J. et al. shows a large error as seen by three triangular point above the +20% error line. Comparison between the correlations shows that Yang and Zhang (2014) correlation is a good choice for selecting short tube orifice for air conditioning applications because of its generality over a wide range of operating conditions.

Conclusion

Comparison between the correlations presented in literature shows that correlation by Yang and Zhang [11] gives a good prediction. Also, this correlation is more general in terms of broad operating parameters affecting the mass flow rate and tested for a variety of refrigerants. Finally, short tube orifice sizing methodology is presented for air conditioning application and validated with respect to experimental database generated.

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Nomenclature

D	short tube orifice inner diameter (m)
h	enthalpy (J kg^{-1} K^{-1})
L	short tube orifice length (m)
m	mass flow rate (kg s^{-1})
ρ	pressure (N m^{-2})
Q	refrigeration capacity (Watts)
T	temperature (°C)
ΔT	temperature difference (°C)
x	quality

Greek symbols

ρ	density (kg m^{-3})
π	non-dimensional group
μ	dynamic viscosity (kg m^{-1} s^{-1})
σ	surface tension (N m^{-1})
v	specific volume (m^3 kg^{-1})

Superscripts and Subscripts

c	critical point
f	saturated liquid state
g	saturated gas/vapor state
in	short tube orifice inlet
out	short tube orifice outlet
pred	predicted
sub	sub-cooled
sat	saturation