Performance Analysis of Domestic Refrigerator Using Variable Capillary Length

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Abstract— This paper presents an experimental investigation for the flow of domestic refrigerator inside an variable capillary tube. The effect of various geometric parameters like capillary tube diameter, length and coil pitch for different capillary tube inlet sub cooling on the mass flow rate of R-134a through the variable capillary tube geometry has been investigated.

Key words: R-134 With Spiral Capillary Tube

I. Introduction

Capillary tubes are being used as an expansion device in the low capacity refrigerating machines like domestic refrigerators and window type room air conditioners. These are narrow drawn copper tubes of 0.5–2.0mm bore and 2–6m length. Owing to the simplicity, low cost, zero maintenance and requirement of a low starting torque motor to run the compressor, capillary tubes have been used in a variety of vapour compression systems. The various flow aspects of the capillary tube were investigated by a number of researchers since past six decades. Bolstad and Jordan (1948) pioneered the investigations on capillary tubes. They studied the effect of oil entrainment on the mass flow rate through the capillary tube. It was found that the use of oil separator in the system decreases the flow rate by 8% in comparison to that when no oil separator was used. Mikol (1963) carried out an extensive experimental investigation on the capillary tube to explore the various flow phenomena like metastability and choking. They developed a friction factor correlation by flowing water through the same capillary tube .The effect of coiling on the refrigerant mass flow rate of the refrigerant has been discussed by a few investigators. Kuehland Goldschmidt (1990) have conducted experiments on the flow of R-22 through adiabatic capillary tubes of straight and coiled geometries. They have concluded that because of the oiling of capillary tube, the refrigerant mass flow rate was reduced by not more than 5%. Kim et al. (2002) have studied the flow of R-22 and its alternatives, viz., R-407C and R-410Athrough the straight and helically coiled adiabatic capillary tubes. They have observed 9% reduction in refrigerant mass flow rate through a coiled tube in comparison to that in straight tube of same length. Zhou and Zhang (2006a) conduct an experimental investigation on helically coiled capillary tubes for the flow of refrigerant R-22. In addition a numerical model using Mori and Nakayama friction factor correlation (Mori and Nakayama, 1967) was also proposed. It was concluded that for the mean coil diameter beyond 300 mm, the change in mass flow rate was insignificant.

The experimental studies on spiral capillary tubes are not available in the literature. However, only Khan et al. (2007) have proposed a numerical model for the computation of length of adiabatic spiral capillary tube. It has been found that because of coiling the length of the capillary tube is reduced considerably for a given set of input conditions.

Previous researchers have also proposed a number of correlations to predict the refrigerant flow rate for a given capillary tube. For instance, correlations for the mass flow rate of different refrigerants proposed by Wolf et al. (1995) are available in ASHRAE Handbook (2006). Another important study regarding the flow of newer refrigerants inside capillary tubes has been carried out by Melo et al. (1999). They proposed separate correlations for R-12, R-134a and R-600a and a combined mass flow rate correlation for all three refrigerants for the flow inside an adiabatic capillary tube. Choi et al. (2003) have proposed new dimensionless parameters and developed a correlation for the prediction of mass flow rate through the capillary tubes.

Since, experimental data for the flow of R-134a refrigerants through variable capillary tube are not available in the literature, an experimental investigation has been undertaken to study the flow of R-134a through a variable capillary tube.

II. Experimental Set-up and Procedure

The schematic diagram of a experimental set-up has been shown in Fig. 1. The test-section was a copper capillary tube, in which the refrigerant expands from high pressure side to low pressure side. The spirally coiled tube's testsection in the experimental apparatus was put in horizontalc position. From capillary tube refrigerant entered the evaporator consisting of a copper coil submerged in a water tank. A 5.0 kW capacity electric heater was fitted in the evaporator tank to provide heat load to evaporator. The heating load was varied through a variac. An agitator was also provided in the tank to maintain the uniform bulk temperature of water. The vapors emerging from the evaporator were sent to liquid accumulator in order to avoid liquid refrigerant to enter the compressor. The compressor was run by means of three phase electric pressure superheated vapors emerging from the compressor entered through the oil separator. After several trial runs, the visual inspection from the sight glass revealed no trace of oil. As an additional check, the capillary tube was tear open and the inside surface was rubber with white absorbent paper. Again, there was no trace of oil. The oil free vapors from separator were condensed in the water cooled condenser. The cooling water was circulated in the condenser bymeans of a centrifugal pump. The high pressure saturated liquid from condenser was collected in a receiver to ensure a continuous supply of refrigerant to the capillary tube. The unwanted solid particles and moisture in refrigerant were removed through drier-cum-filter. The bank of four rotameters with one digital rotameter (DR) and three float type rotameters (R1, R2 and R3) of different ranges was installed after the drier-cum-filter. The mass flow rate data have been acquired by digital rotameter (DR) whereas other three rotameters were placed in parallel to cross verify the mass flow rate measured by digital rotameter. A refrigerant subcooler was provided after the rotameters. The chilled water to the subcooler was supplied by means of a separate chiller unit based on the vapour compression cycle with R-22 as a working fluid. The chiller consisted of a hermetically sealed compressor, an air cooled condenser, and a tank for cooling water. A centrifugal pump was used to circulate chilled water through the subcooler. To vary the degree of subcooling at the capillary tube inlet, a preheater followed the subcooler.

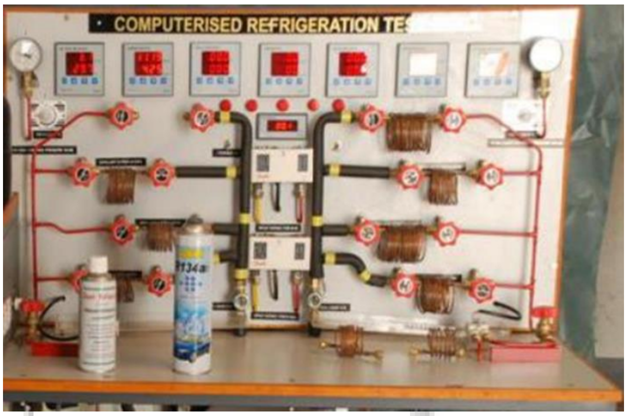


Fig. 1: Experimental Layout (Planned)

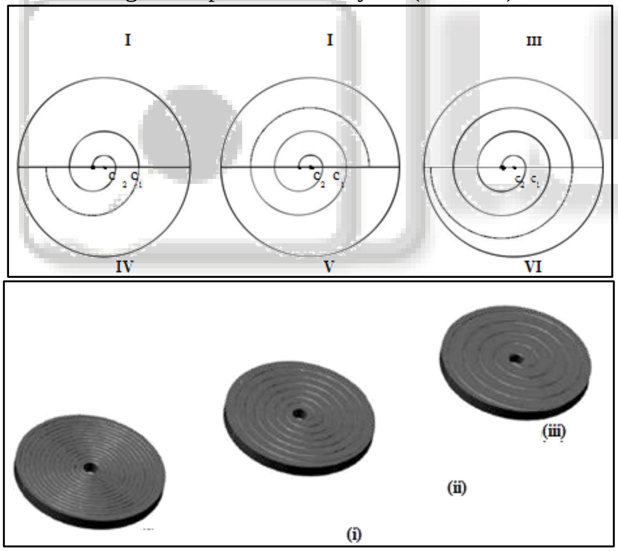
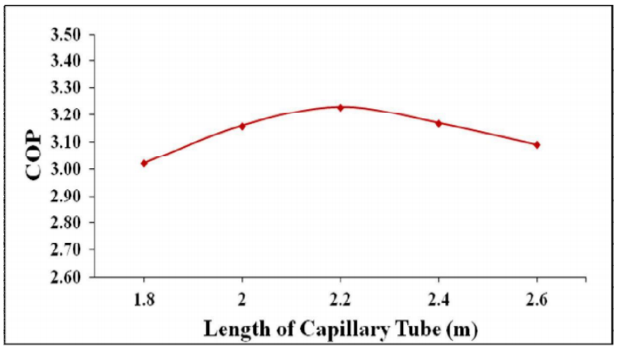


Fig. 2: (a) Step-by-step procedure for generating spiral. (b) Spiral patterns for three pitches: (i) 20 mm (ii) 40 mm, and (iii) 60 mm

III. RESULT AND DISCUSSION

First of all, a comparison of experimental results of straight capillary tube with the correlation of Melo et al. (1999) has been made to check the integrity of the experimental set-up. Melo et al. (1999) correlation for mass flow rate of R-134a is given below: A comparison of experimental results of straight capillary tube has been made with those predicted by the widely accepted Meloet al. (1999) correlation to establish the integrity of present experimental set-up. Fig. 4 has been drawn taking measured experimental refrigerant mass flow rate in a straight capillary tube as abscissa and that predicted by Melo et al. (1999) correlation for the present experimental input conditions as ordinate. It has been found that Meloet al. (1999) correlation overpredicts the experimental data of both instrumented (with pressure taps) and non-instrumented (without pressure taps) straight capillary tubes in an error band of 0 to þ20%. Further, more than 75% data are in agreement with Melo et al. (1999) correlation in the error band of 0 to þ15%. It is to be noted that Melo et al. (1999) correlation has predicted their own experimental data in an error band of _15%. Therefore, it can be concluded that the data acquired from the present experimental set-up are in good agreement with predictions of Melo et al. (1999) correlation. This establishes the integrity of experimental set-up.



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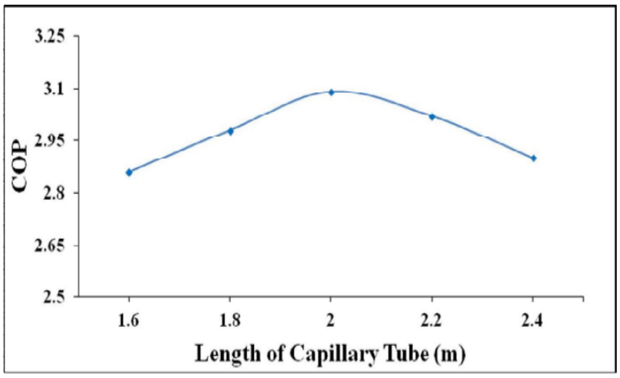

Fig. 4:

The cumulative effect of coil pitch, capillary tube diameter, the inlet subcooling and capillary tube length on the refriger-ant mass flow rate has been presented in Fig. 7.

It can be ob-served that with a slight increase in capillary tube diameter the refrigerant mass flow rate increases drastically. At 10 C in-let subcooling, when the diameter is increased from 1.12 mm to 1.63 mm the refrigerant mass flow rate is increased in range of 170 5% for all capillary tube lengths. At the same inlet sub-cooling of 10 C, as the capillary length is reduced from 6.4 m to 2.4 m, the refrigerant mass flow rate is increased in the range of 50 5% for all tube diameters. Similarly, if the inlet subcool-ing is increased from 0 C to 10 C, the refrigerant mass flow rate is increased in a range 45 2% for all capillary tube diam-eters, lengths and pitches. In fact, the length of liquid region increases with the rise in inlet subcooling. Since the pressure drop is less in liquid region as compared to that in the two-phase region, the refrigerant mass flow rate increases with the rise in inlet subcooling.

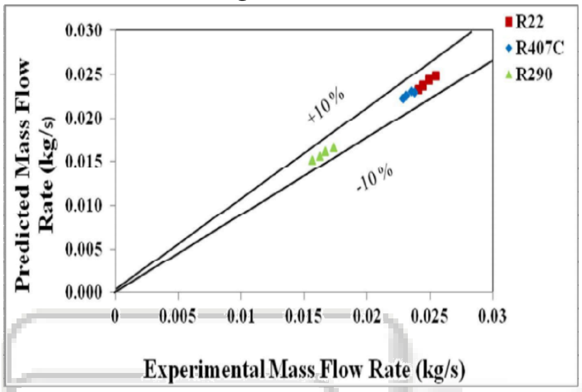

Fig. 5:

All the available correlations in the literature are mostly derived for straight capillary tubes. The mass flow rate of re-frigerant through the adiabatic spiral capillary tube depends upon the capillary tube diameter, length, coil pitch, roughness and the inlet subcooling. As the capillary tubes are available in a limited band of roughness, the roughness effect is ignored in the development of correlation. Therefore, the roughness is not considered in the development of the correlation. Other parameters like inlet pressure, the density, the viscosity and specific heat of the refrigerant have also an influence on the mass flow rate. The REFPROP 7.0 database (McLinden et al., 2002), has been used to determine the thermodynamic and transport properties of the refrigerant R-134a, appearing in Eq. (3). The mass flow rate can be represented as a function

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The theoretical modeling of capillary tube is carried out on the basis of work done by Choi et al (2003). They identified that the flow through CT is function of 11 parameters as given in equation below:

$$\dot{m} = f_1\left((p_i - P_{sat}), \Delta T_{sub}, L, D, \rho_f, \rho_g, \mu_f, \mu_g, \sigma, h_{fg}, C_{pf}\right)$$

The generalized correlation is generated in a power law form as:

$$\pi_8 = C_0 \cdot \pi_1^{C1} \cdot \pi_2^{C2} \cdot \pi_3^{C3} \cdot \pi_4^{C4} \cdot \pi_5^{C5} \cdot \pi_6^{C6} \cdot \pi_7^{C7}$$

The pressure drop in capillary tube with the help of Darcy equation:

$$h_f = \frac{fLV^2}{2gd}$$

Eight dimensionless pi-groups are derived by Choi et al (2003) and they are presented as:

Pi-group	Definition	Effect/ Consideration
π_1	$\frac{D^2 \rho_f (P_i - P_{sat})}{\mu_f^2}$	Inlet Pressure
π_2	$\frac{\Delta T_{sub}}{Tc}$	Inlet Sub cooling
π_3	$\frac{L}{D}$	Tube Geometry
π_4	$\frac{\rho_f}{\rho_g}$	Density
π_5	$\frac{\mu_g}{\mu_f}$	Friction, Bubble Growth
π_6	$\frac{D \rho_f \sigma}{\mu_f^2}$	Surface Tension, Bubble Formation

Table 1:

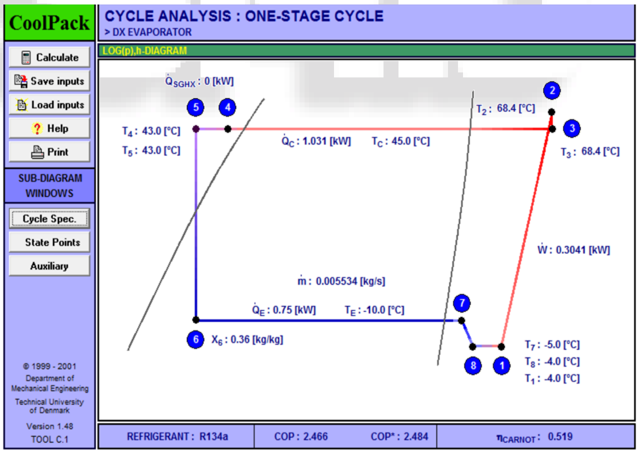

Fig. 6: Simulation for Domestic Refrigerator by using R134a

STATE POINT	TEMPERATURE [°C]	PRESSURE [kPa]	ENTHALPY [kJ/kg]	DENSITY [kg/m^3]
1	-4.0	196.8	246.1	9.6
2	68.4	1175.1	295.6	50.5
3	68.4	1160.0	295.9	49.7
4	43.0	1160.0	109.6	1134.7
5	43.0	1160.0	109.6	1134.7
6	-10.0	200.7	109.6	-----
7	-5.0	200.7	245.1	9.9
8	-4.0	196.8	246.1	9.6

Fig. 7: Pressure drop across capillary tube 9.6 bar (11.6 bar – 2 bar)

IV. CONCLUSIONS

The following conclusions can be drawn

1) The effect of taps on the mass flow rate through the capillary tube is insignificant. Virtually, there is no effect of pressure taps on the refrigerant mass flow rate in straight and spiral capillary tube as well.
2) Parametric study has been conducted for the mass flow rate of R-134a through the capillary tubes of straight and coiled geometry. The effect coiling on refrigerant causes the refrigerant mass flow rate to reduce by 5–15%.
3) The semi-empirical correlations to predict the refrigerant mass flow rate through straight as well as spiral capillary tube have been proposed.

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