Experimental Investigation of the Capillary Tubes of Same Length with Different Diameter on the VCR System

Bhandarkar S.L.[1], Gavali G.G.[2], Kale A.B.[3], Bhagwat P.S.[4]
[1, 2, 3, 4] Department of Mechanical engineering
[1, 2, 3, 4] Madhav Institute of Technology, Kusgaon (Bk), Lonavala

Abstract- *In this paper, the performance analysis of the capillary tube of different diameter and same length was studied where the cooling of fixed mass of water from 20^{o}C to 5^{o}C is done using VCR system. It is observed from the software the capillary of diameter 1.27mm and length 1.87m is good for the given VCR system. Experimentally, select the one capillary has greater Diameter of 1.52mm than the capillary of diameter 1.27mm and another capillary has smaller diameter of 1.11mm. In the experimental setup takes these three capillary having same length 2500mm. From the experimental analysis and results it is conclude that the capillary of Diameter 1.27mm gives the higher average COP as well as the capillary of greater diameter gives 2nd best results than the smaller one.*

Keywords- Capillary tube, VCR system, COP.

I. INTRODUCTION

The Capillary tube is a constant area expansion device used in a vapour compression refrigeration system. It is long and narrow tube connecting the condenser directly to the evaporator whose function is to reduce the high pressure in the condenser to low pressure in the evaporator. The pressure drop through the capillary tube is due following two factors: I. Friction, due to fluid viscosity, resulting in frictional pressure drop. II. Acceleration due to the flashing of the liquid refrigerant into vapour resulting in momentum pressure drop. [1] The cumulative pressure drop must be equal to the difference in pressure at the two ends of the tube. for the given state of refrigerant, the pressure drop is directly proportional to the length and inversely proportional to the bore diameter of the tube. The refrigerant flows from condenser through the capillary tube, pressure drops to the evaporator condition by the fluid friction with simultaneous drop of saturation temperature, internal energy and enthalpy, but gain of specific volume, velocity and hence kinetic energy through phase change. In fact the flow through capillary tube is actually adiabatic not an isenthalpic.

The refrigerant temperature remains constant as long as it is in liquid state and as the flashing of refrigerant occurs (at point '3a') the pressure as well as temperature falls rapidly. As the flow through the capillary tube is adiabatic, the enthalpy of refrigerant remains constant till the flashing occurs. As a result of flashing, a part of enthalpy is used to increase the kinetic energy of the refrigerant. Therefore, as the vaporization progresses the enthalpy of refrigerant falls in the two-phase flow region of the capillary tube. The refrigerant often enters the capillary in a sub cooled liquid state. As the liquid refrigerant flows through the capillary, the pressure drops linearly due to friction while the temperature remains constant. As the pressure of refrigerant falls below the saturation pressure a fraction of liquid refrigerant flashes into vapor. The fluid velocity increases because of the fall in density of the refrigerant due to vaporization. Thus, the entire capillary tube length seems to be divided into two distinct regions. The region near the entry is occupied by the liquid phase and the other as the two-phase liquid vapour region.

The flow inside the capillary tube of a refrigeration system can be divided into a sub cooled liquid region from the entrance to the point in which the fluid reaches saturated conditions, and a two phase flow region after that point until the end of the capillary tube. The pressure falls linearly in the liquid region of the capillary tube while the temperature remains constant as the flow through capillary tube is considered adiabatic. Further, as the pressure falls below the saturation pressure, Ps, with the onset of vaporization both temperature and pressure starts falling rapidly until the choked flow conditions are attained. However, in reality, after the flow reaches the saturation pressure, there is a short region in which the evaporation does not start yet and the refrigerant becomes superheated. The liquid in this region is not in thermodynamic equilibrium but under metastable condition. This region ends up quite suddenly and the liquid starts to evaporate approaching thermodynamic two-phase equilibrium conditions.

II. EXPERIMENTAL SETUP AND PROCEDURES

The experimental set up of a simple vapor compression refrigeration system used in study is shown in "Fig.1". The evaporator is fabricated as shell and tube type heat exchanger . Refrigerant R-134a flows through the copper tube of outside diameter and inside diameter as 9.5mm and 8.5mm of length 3meter throughout the evaporator. supply water can flow through the shell of evaporator. However, inlet and outlet valve of evaporator shell are closed and a fixed mass of water is fitted in the shell which is cooled from initial temperature 20^{o}C to final refrigerator temperature 5^{o}C. The condenser is the fin and tube type heat exchanger which is connected to the blower for increasing the heat transfer rate of condenser. Refrigerant is flows through the tubes and fins is act as the extended area of the tube which transfer the heat to the surrounding air by force convection. Compressor used is Emerson Copeland Model No. KDF419HAG.Capillary tubes are fitted parallel in between the condenser and evaporator as shown in the" Fig.1". The diameter of the capillary tube is 1.27mm, 1.52mm and 1.11mm and have same length 2500mm. Hand operated valve is provided before the each capillary tube to start and stop the refrigerant flow through the capillary tubes.

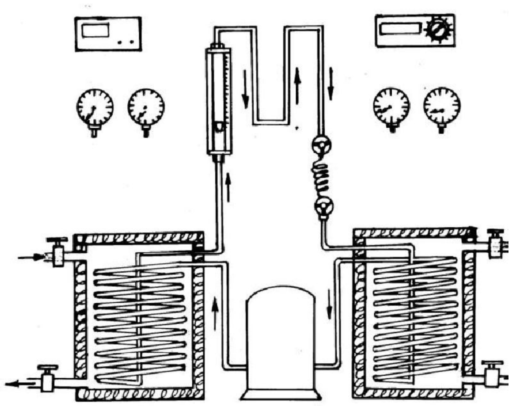

Fig. 1- Experimental Setup

The pressure and temperature readings of refrigerant were taken at four strategic points 1, 2, 3 & 4 as indicated in the theoretical and actual vapour compression cycle shown on pressure enthalpy chart in "Fig.2 and Fig 3" and also in "Fig.1" of the actual experimental set up. The temperature at a various point is measured by the RTDs. Temperature of fix mss of water filled in the evaporator shell are also been recorded in the same way. pressure of refrigerant is measured at various point by the pressure gauges. A digital wattmeter gives the instant value of power consumption of compressor. Many trials of cooling a fix quantity of water in the evaporator from initial room temperature to final refrigeration temperature were taken with different size capillary tubes. Readings of various parameters at different positions in the system were taken at a number of temperature points, separated by a fix temperature interval during one working period of the machine between consecutive start and stop.

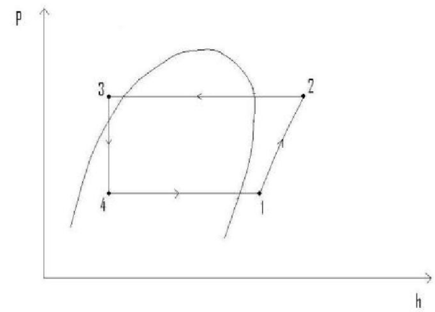

Fig 2 **:** Theoretical vapor compression cycle

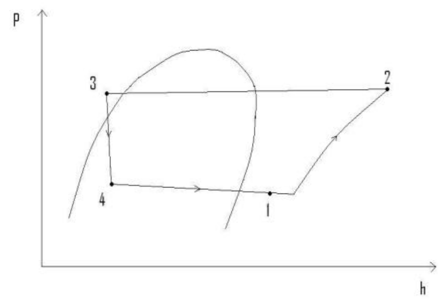

Fig 3**:** Actual vapour compression cycle

III. DATA REDUCTION

All the readings of pressure, temperature, time required for cooling, power consumption etc. as suggested before are noted down at each temperature point 'τ' separated by fixed temperature interval 'Δτ' through the total time period of one trial. In one trial of system for cooling a fixed mass of water from initial room temperature to final refrigeration temperature taking place under transient conditions, a large data was recorded. Many trials were conducted with each capillary tube. All this data was transformed in the Excel worksheets. Other performance parameters of the system are also calculated for each time point as per the procedure given below:

Heat transfer rate or refrigeration rate in evaporator at a temperature point 'τ' is given as:

$$Q_{e,r} = M_w C_{p,w}\left(t_{w,\tau-\Delta\tau} - t_{w,\tau}\right) = m_r(h_{1\tau} - h_{4\tau})$$

Refrigerant effect of evaporator at a temperature point 'τ' is given as

$$Re = \frac{M_w C_{p,w}\left(t_{w,\tau-\Delta\tau} - t_{w,\tau}\right)}{Time\ required\ for\ temperature\ drop}$$

Power consumption by the compressor at a temperature point 'τ' is given as

$$W_c = \frac{No.of\ fleashesh\ \times 3600}{Time\ for\ flashesh\ \times 3200}$$

Coefficient of performance of the VCR system at a temperature point 'τ' is given as

$$COP = \frac{R_e}{W_c}$$

Mass flow rate refrigerant through the capillary from condensing temperature to evaporating temp can calculated is given as

$$\dot{m} = \frac{R_e}{h_1 - h_4}$$

IV. RESULTS AND ANYLYSIS

1. COP variation with time and with different size Capillary tubes

The variation in COP values of vapour Compression refrigeration system with different size capillary tubes is shown in the following figures. The sizes of three different capillary tubes are given in table 1.

Table 1. Sizes of capillary tube used in VCR system

Capillary Tubes	Available sizes	
	Internal Diameter (mm)	Length (m)
Tube 1	1.27	2.5
Tube 2	1.52	2.5
Tube 3	1.11	2.5

The results of the capillary tube 1 is given in the table 2. The average COP of capillary tube 1 is highest than the other capillary tube as well as the less cooling time is required for the temperature drop of water from 20ºC to 5ºC. from the graph fig.4 it is clear that to achieve maximum cop 3.65 time required is 70 sec. The average Cop of Capillary tube 1 is 2.64.

Table 2. Result of the capillary tube 1

Sr. No.	Cooling Capacity(w)	Consumption of power	COP Actual
1	837	230	3.65
2	803	230	3.50
3	674	230	2.93
4	410	230	1.79
5	326	245	1.33
Average	610	233	2.64

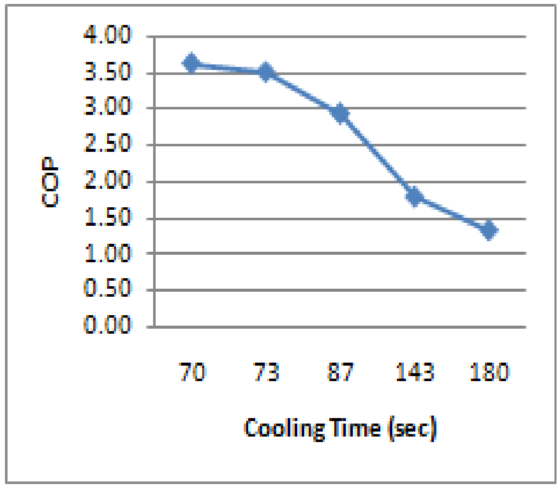

Fig.4. COP vs Cooling time of capillary tube 1

To achieve the maximum COP whatever pressure drop required across the capillary tube can be achieved by the perfect combination of its diameter and length.

The capillary tube 1 gives proper frictional pressure drop and flashing of the liquid refrigerant into vapour resulting into momentum pressure drop within the less time. hence this capillary provide highest COP than the other capillary tube.

The results of the capillary tube 2 is given in the table 3. from the graph fig.5 it is clear that to achieve maximum COP 1.37 time required is 167 sec. To achieve maximum COP it requires more Cooling time because it requires more length than 2.5m. Due to the large diameter and less length of the Capillary tube , less amount of refrigerant is in the contact with the wall of the capillary tube. Hence the required pressure drop can not be achieved within the cooling time requires for the capillary tube 1. Due to this the more time is required to achieve the desire frictional pressure drop.

Table 3. Result of the capillary tube 2

Sr. No.	Cooling Capacity(w)	Consumption of power	COP Actual
1	337	256	1.32
2	257	256	1.01
3	210	256	0.82
4	165	256	0.65
5	122	250	0.49
Average	218	255	0.86

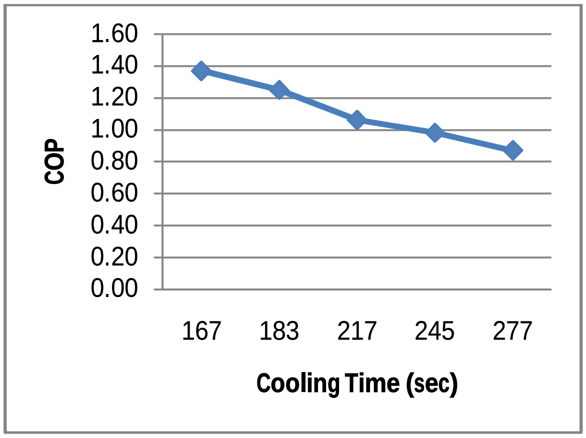

Fig.5. COP vs Cooling time of capillary tube 2

The result of the Capillary tube 3 is given in the table 4. from the graph fig.6 it is clear that to achieve maximum COP 1.32 time required is 174 sec. The average COP is 0.86 and it requires the highest cooling time because the length of this capillary is more than it required. due to the flash vaporization of refrigerant temperature drop across the capillary is less. so that to achieve required pressure drop across the capillary tube it requires more cooling time.

Table 4. Result of the capillary tube 3

Sr. No.	Cooling Capacity(w)	Consumption of power	COP Actual
1	337	256	1.32
2	257	256	1.01
3	210	256	0.82
4	165	256	0.65
5	122	250	0.49
Average	218	255	0.86

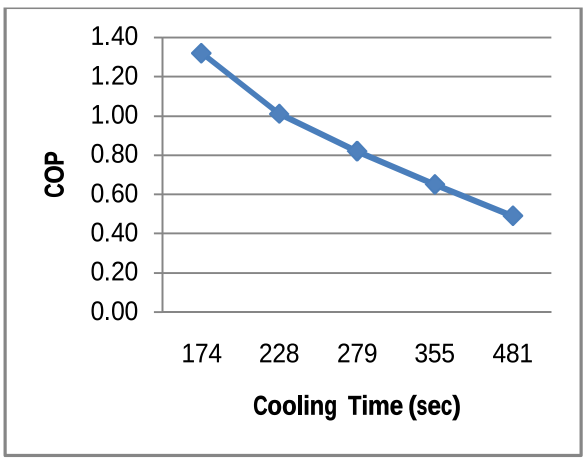

Fig.6. COP vs Cooling time of capillary tube 3

V. CONCLUSION

The diameter of the capillary is directly related with the length for producing the desired pressure drop. From the results it is observed that the capillary of diameter 1.27 mm has higher average COP than the another two capillary. Because the length of that capillary is suitable for the given diameter of capillary which drops the condensing pressure to evaporator pressure by consuming less power and produce the more refrigerant effect.

Then the another capillary has greater diameter 1.52 mm is gives the another best than the capillary has smaller diameter of 1.11mm .

The capillary of diameter 1.11 mm gives smallest average COP . Because the length of capillary is greater than it required. Because the greater length of capillary produces the flash vaporization effect which reduces refrigerating effect.

REFERENCES

[1] Arora C.P.,1981. Refrigeration and air conditioning, Tata McGraw Hill Publishing Co., New Delhi, pp.331-338.

[2] Sahoo K.C., Das S.N., 2014. Theoretical design of adiabatic capillary tube of a domestic refrigerator using refrigerant R-600a.

[3] Dabas J.K., Dodeja A.K., 2011. Performance characteristics of vapor compression refrigeration system under real transient conditions, ISSN 0976-4860.

[4] Y Raja Kumar, Dr. P. Usha sri,2013. CFD flow analysis of a refrigerant inside adiabatic capillary tube. ISSN 2278-0181

[5] Chen Z.J., Lin W.H., 1991. Dynamic simulation and optimal matching of a small scale refrigeration system 14, 329-335

[6] Chen L., Wu C., Sun F. 1999. Finite time thermodynamic optimization or entropy generation minimization of energy systems, J. Non-Equilibrium Thermodynamics, 24, 327-359.