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The Effect of Capillary Tube Length on the Performance of Vapour Compression Refrigeration System

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Abstract: The design of capillary tube plays a very important role in the performance of a vapour compression refrigeration system. Optimized design is possible through theoretical calculations, however may fail due to the reason that the uncertainties in the formulation of pressure drop inside the capillary tubes. Hence experimental investigations are the best in terms of optimization of certain design parameters. Components of the vapour compression refrigeration system never work in isolation; change in performance of one component affect the performance of the other components and in turn overall performance of the system. Performance of the system also depends on the type, quantity of the refrigerant charged. In the present work, an attempt is made to optimize Length of capillary tube for refrigeration unit of capacity 30lts; with R-134a as refrigerant and hermetic sealed compressor of capacity 0.14H.P.and this study examined the effects of lengths capillary tubes on the performance of a vapor compression refrigeration system. It is found that 4.5feet Length of capillary tube gave a better performance. Both inlet and outlet pressure and temperature of the test section (capillary tube) were measured and used to estimate the coefficient of performance (COP) of the system. The parameters stated above can be further optimized in order to enhance the performance of the refrigeration system.

Keywords: Capillary Tube, Efficiency, Diameter of Capillary Tube.

I. INTRODUCTION

A. Vapour Compression Refrigeration System

The vapour compression system is the most widely used refrigeration system in practice. This refrigeration system adopts the vapour compression cycle. This cycle requires the addition of external work for its operation. Basically it consists of four processes namely:

- Isentropic compression.
- Constant pressure heat rejection.
- Isenthalpic expansion.
- Constant pressure heat addition.

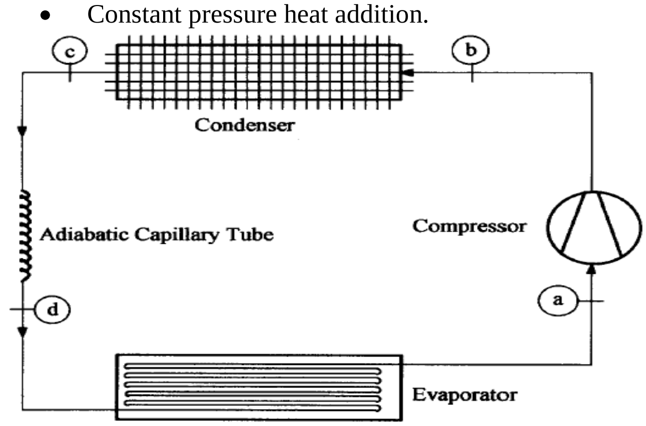

Fig.1. Schematic diagram of vapour compression refrigeration system.

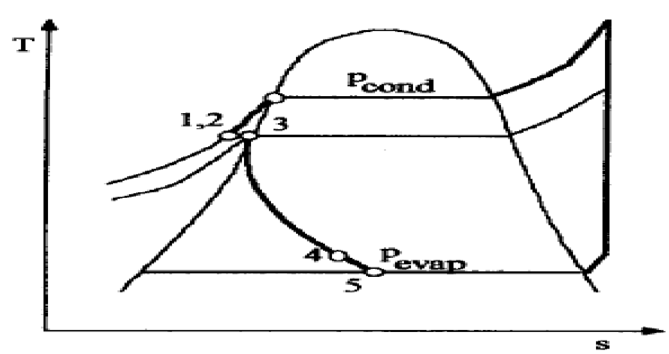

Fig.2.(a) VCR cycle on T-s coordinates.

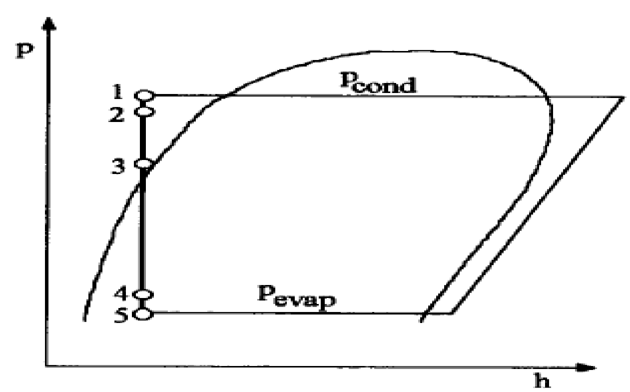

Fig.2.(b) VCR cycle on p-h coordinates.

Change of state from (c) to (d) in Fig1 represents the expansion process using an expansion device. The purpose of the expansion device is twofold: it must drop the pressure of the liquid refrigerant, and also regulate the flow of refrigerant to the evaporator. Some common types of expansion devices are capillary tube, super heat controlled expansion valve, float valve and constant pressure expansion valve. Fig2(a) and 2(b) shows simple vapour compression refrigeration cycle on T-s and p-h co ordinates. The capillary tube is used in almost all small refrigeration systems. Liquid refrigerant enters the capillary tube and as it flows through the tube, the pressure drops because of friction and acceleration of the refrigerant. Some of the liquid flashes into the vapour as the refrigerant flows through the tube. Once the capillary tube has been selected and installed, it cannot adjust to the variations in discharge pressure, suction pressure or load. Compressor and expansion device must arrive at suction and discharge conditions such that the compressor pumps the same flow rate of the refrigerant from the evaporator that the expansion device feeds. The designer of a new refrigeration unit employing a capillary tube must select the bore and length of the tube so that the compressor and its components operate under balanced operating condition at the desired evaporator temperature. Method of calculating the necessary bore and length of a capillary tube is presented later based on fundamental laws.

B. Advantages and Disadvantages of Capillary Tube

Usage of capillary tube has the following advantages over the other methods of expansion.

- Predominant enough for universal acceptance of factory sealed systems.
- Simple and have no moving parts.
- Inexpensive and are compact in size.
- Capillary tubes allow the pressures in the system to equalize during the off cycle.

This type of expansion device suffers with following disadvantages

- The capillary tube’s ability to adjust to load fluctuations is limited
- Choking of the tube may take place due to the presence of foreign matter.
- Charges required to be limited

C. Alternative Refrigerants

Refrigerant R134a is hydro fluorocarbons (HFC) that has zero potential to cause the depletion of the ozone layer and very little greenhouse effect. Let us see the various properties of this refrigerant and how it replaces R12.

- Refrigerant R134a
- R134a as Replacement for R12

II. THEORETICAL STUDIES

A. Vapour Compression Refrigeration System

The vapour compression system is the most widely used refrigeration system in practice and its schematic diagram is shown in Fig1. This system adopts vapour compression cycle described in Fig2 on p-h and T-s co-ordinates. This standard cycle constitutes mainly four processes namely:

- Reversible and adiabatic compression from state (a) to state (b)
- Reversible rejection of heat at constant pressure from state (b) to state (c)
- Irreversible expansion at constant enthalpy from state (c) to state (d)
- Reversible addition of heat at constant pressure from state (d) to state (a).

Change of state from (c) to (d) in Fig1 represents the expansion process by using the component namely an expansion device. The purpose of the expansion device is twofold: it reduces the pressure of the liquid refrigerant from condenser pressure to low pressure for realizing refrigeration at low temperatures, and regulates the flow of refrigerant to the evaporator. Different types of expansion devices are in vogue namely capillary tube, super heat controlled expansion valve, float valve and constant pressure expansion valve.

B. Actual Vapour Compression Cycle

Due to the friction and momentum change in some areas, refrigerant flow through the condenser, evaporator, piping etc there will be drops in pressure. In addition there will be heat loss or gain depending on the temperature difference between the refrigerant and the surroundings. Further, compression process will be irreversible polytrophic with friction and heat transfer instead of isentropic. The actual compression cycle is shown in p-h diagram in Fig2.

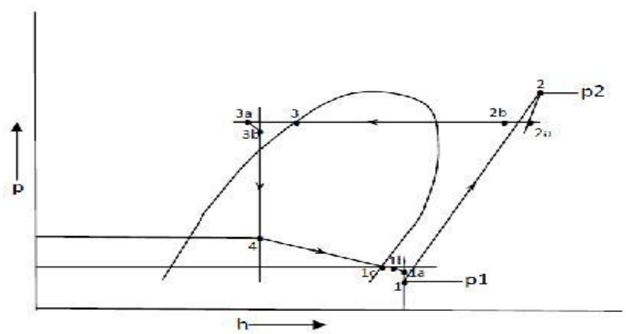

Fig.3.Actual vapour compression refrigeration cycle.

- Superheating of vapour in the evaporator, 1c-1b.
- Heat gain and superheating of the vapour and pressure drop in the suction line, 1b-1a
- Pressure drop due to wire drawing at the compressor suction manifold and valve,1a-1.
- Polytrophic compression 1-2 with friction and heat transfer
- Pressure drop and heat loss at the compressor discharge manifold and valve, 2-2a
- Pressure drop and heat loss in the discharge line, 2a-2b
- Heat loss and desuperheating of the vapour in the delivery line, 2a-2b.

- Cooling in the condenser, 2b-3
- Sub cooling of the liquid in the condenser or sub cooler, 3-3a.
- Heat gain and pressure drop in the liquid line, 3a-3b.
- Pressure drop in the evaporator, 4-1c

Capillary tube serves almost all small capacity refrigeration systems extend up to 10 kW. Liquid refrigerant enters capillary tube and as it flows through the tube, pressure drops because of friction and change in momentum of the refrigerant. Some portion of the liquid flashes into vapour, as refrigerant flows through the tube. While using capillary tube as an expansion device it has its own advantages and disadvantages as listed here under. Designer of a refrigeration system employing a capillary tube must select the bore and length of the tube to be selected suitably by considering the operating range.

C. Expansion Devices

The expansion device (also known as metering device or throttling device) is a important device that divides the high pressure side and low pressure side of refrigeration system, it is incorporated between receiver and the evaporator (if receiver not used in the system, the expansion device is introduced between condenser and evaporator). It is usual practice proved a filter and drier before the expansion device in order to prevent contaminants clogging the refrigerant flow passage. The expansion device performs the following functions:

- It reduces the high pressure liquid refrigerant to low pressure refrigerant before being fed to the evaporator.
- It maintains the desired pressure difference between the high and low pressure sides of the system, so that the liquid refrigerant vaporizes at the designed pressure in the evaporator.
- It controls the flow of refrigerant according to the load on the evaporator.

D. Types of Expansion Devices

- Capillary tube,
- Hand operated expansion valve,
- Automatic or constant pressure expansion valve,
- Thermostatic expansion valve,
- Low side float valve and
- High side float valve.

III. EXPERIMENTAL INVESTIGATIONS

A. Description of the Experimental Setup

Test rig is a single stage vapour compression refrigeration system of 30 LTRS capacity. Fig5 shows the schematic diagram of the experimental setup. This test rig mainly consists of compressor, condenser, expansion device, and evaporator. The high-pressure gas from compressor flows through an oil separator where the compressor lubricant oil and refrigerant are separated and oil is fed back to the compressor. Compressed high-pressure gas is condensed in an air cooled condenser. The liquefied and sub cooled refrigerant from the receiver enters into the expansion valve. A manually controlled needle valve with a capillary in parallel is used to maintain constant pressure in the evaporator.

Fig. 4. A view of Digital thermometer.

Temperatures at various locations were measured using digital thermo meter. Various locations at which temperature was measured are shown in TableI.

TABLE I: Temperature Measuring Location

Channel no	Measuring location
T1	Compressor inlet
T2	Compressor outlet
T3	Condenser outlet
T4	Evaporator inside

Pressures of the refrigerant are measured using pressure gauges at 3 locations in the system as given below.

- Suction pressure of compressor
- Discharge pressure of compressor
- Pressure at the outlet of condenser

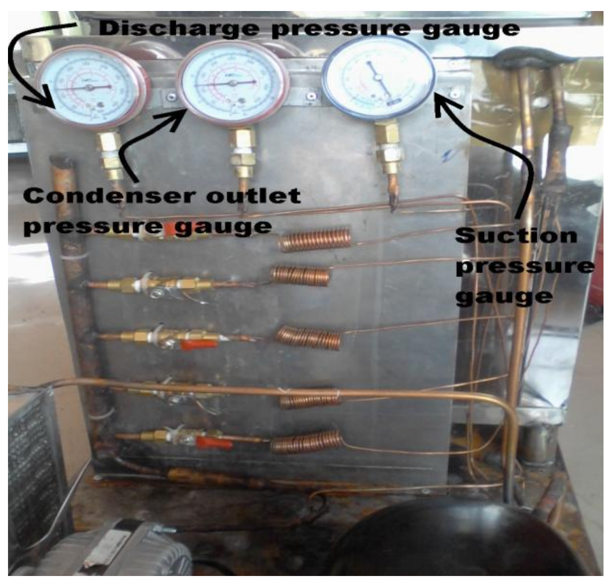

Fig.5.Location of pressure gauges and Pictorial view of the all capillary tubes.

Fig.6. Pictorial view of the single capillary.

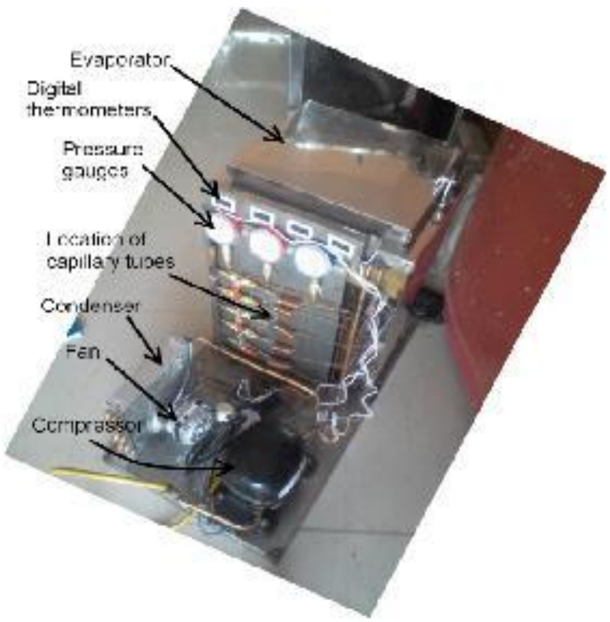

Fig. 7. Pictorial front view of the experimental setup.

IV. EXPERIMENTATION

A. Charging the System

The entire system was pressure tested using nitrogen gas pressurizing to 30 bar. The system was left at that pressure for a period of 24 hours. System was evacuated using a vacuum pump. By adapting triple vacuum technique it was ensured that the non-condensable gases present in the VCR system were removed. Vacuum was held for 24 hours and finally estimated quantity of R134a in liquid form was charged into the system and ensured that the pressure is measured while system is at steady state operating condition.

B. Experimental Conditions

Experiments were carried out for various capillary tubes using refrigerant R134a. Extensive data were collected and tabulated for various operating conditions. Flow behavior of refrigerant flow in capillary tubes depends on capillary tube length, capillary tube diameter, capillary coil diameter, capillary tube inlet pressure and the type of refrigerant. Experiments were conducted at the following conditions

- All the measurements were taken only after the system reached the steady state.
- Set of experiments is done by keeping evaporator temperature at a specified level and varying the condensing temperature and vice versa.
- Measurement of all operating parameters were taken at every 20 min.

C. Experimental Procedure

Experimental procedure, which is carried out during the experiment, is given below:

- The vapour compression refrigeration unit is switched on
- The required evaporator temperature is attained, by adjusting the expansion valve and maintained constant
- The data acquisition system at frequent intervals
- Temperature at inlet and outlet for the components.
- Pressure at the inlet and exit for the components.

Parameters which affect the performance of the system are flow rate of refrigerant, capillary inner diameter, tube length, and capillary coil diameter, condensing pressure, and sub cooling.

D. Performance Evaluation

With the data collected in experiments, different performance parameters are calculated as follows

1) Net Refrigeration Effect (NRE) = H1 – H2 KJ/Kg

Where

H1 = Enthalpy of Suction line

H2 = Enthalpy of Discharge line

2) Mass flow rate obtain, one TR, Kg/min (mr) = 210 / NRE Kg/min

Where

NRE = Net Refrigeration Effect

3) Work of compression W = H2 – H1 KJ/Kg

Where

H1 = Enthalpy of Suction line

H2 = Enthalpy of Discharge line

4) Heat equivalent of work of compression per TR = mr X(h2-h1) KJ/min

Where

mr = Mass flow rate

H1 = Enthalpy of Suction line

H2 = Enthalpy of Discharge line

5) Theoretical power of compression = KJ/min / 60 KW

6) Co-efficient of performance (COP) = NRE / work of compression

Where

NRE = Net Refrigeration Effect

7) Heat to be rejected in the condenser = H2- H3 KJ/Kg

Where

H2 = Enthalpy of Discharge line

H3 = Enthalpy of Liquid line

8) Heat rejection per ton of refrigeration (TR) = (210/NRE) X (H2- H3) KJ/min

Where

NRE = Net Refrigeration Effect
H2 = Enthalpy of Discharge line
H3 = Enthalpy of Liquid line

9) Compression pressure ratio = Pd / Ps

Where

Pd = Discharge pressure
Ps = suction pressure

V. CALCULATIONS

TABLE II: Tabular Columns of Performance Parameters

S. No	Performance Parameter	Length Of Capillary Tube In Feets				
		4	4.5	5	5.5	6
1	Compressor Suction Pressure P1(Bar)	0.965	0.896	1.103	1.344	1.448
2	Compressor suction Temperature T1 (Oc)	10.5	10.2	11.5	12.3	12.8
3	Compressor Discharge Pressure P2 (Bar)	9.998	10.34 2	11.03 2	11.72	11.93
4	Compressor Discharge Temperature T2 (0 C)	62.1	62.9	63.6	64.4	63
5	Condenser Pressure P3 (Bar)	9.653	9.998	10.68 7	11.873	11.58
6	Condenser Temperature T3 (0c)	383	39.6	41.1	42.5	42.3
7	Evaporator Temperature T4(0c	19	16.8	15.9	12.2	12
8	Enthalphy Of Suction H1(Kj/Kg)	411	410.3	411	411.5	412
9	Enthalphy Of Discharge H2(Kj/Kg)	445	443	443.7	444	445
10	Enthalphy Of Condenser H3(Kj/Kg)	256	255	258	260	260.8
11	Net Refrigerating Effect (Nre)(Kj/Kg)	155	155.3	153	151.5	151.2
12	Mass Flow Rate Of Refrigerant (Mr) (Kg/Min)	1.355	1.352	1.372	1.386	1.389
13	Work Of Compression(W) (Kj/Kg)	34	32.7	32.7	32.5	33
14	Heat Equivalent Of Work Of Compression(Kj/Min)	46.07	44.21	44.86	45.04	45.83
15	Theoretical Power Of Compression (Kw)	0.768	0.737	0.748	0.751	0.764
16	C.O.P	4.559	4.749	4.679	4.661	4.582
17	Heat To Be Rejected In Condenser(Kj/Kg)	189	188	185.7	184	184.2
18	Heat Rejection Per T.R (Kj/Min)	256.09	254.1 7	254.7 8	255.02	255.85
19	Compression Pressure Ratio	10.35	11.54	10	8.72	8.24

VI. RESULT AND DISCUSSIONS

A. Performance of a Simple Vapour Compression Refrigeration Cycle

The performance of vapour compression refrigeration cycle varies considerably with the length of capillary tube has greater effect. To illustrate these effects the calculated values for different length of capillary tube have been plotted on the graphs. The relationships between length of capillary tube and performance parameter have been compared and shown in the following graphs.

1. Effect of Length of Capillary Tube on Coefficient of Performance:

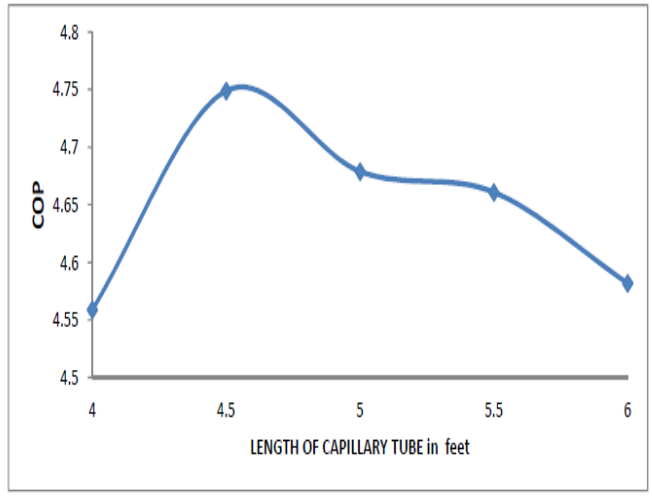

Fig.8.

Referring to graph-1, it is seen that the performance of the Refrigeration system increases as the length of the capillary tube increases. But at the length = 4.5 feet's the performance of the system starts to decrease, because of further increase in pressure due to friction, the specific volume, and velocity increase in the capillary tube. It increases the mass flow rate of refrigerant and unbalanced conditions can be avoided.

2. Effect of Length of Capillary Tube on the Mass Flow Rate of Refrigerant:

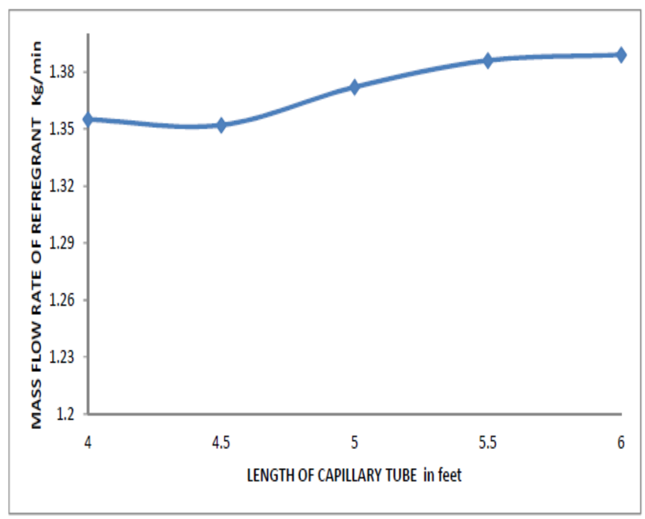

Fig.9.

Referring to the graph-2, it is seen that mass flow rate of refrigeration system decreases as the length of capillary tube increases. But at the length = 4.5 feet's the performance of the system starts to decrease, because of further increase in pressure due to friction, the specific volume, and velocity increase in the capillary tube. It increases the mass flow rate of refrigerant.

3. Effect of Length of Capillary Tube on Compressor Suction Pressure:

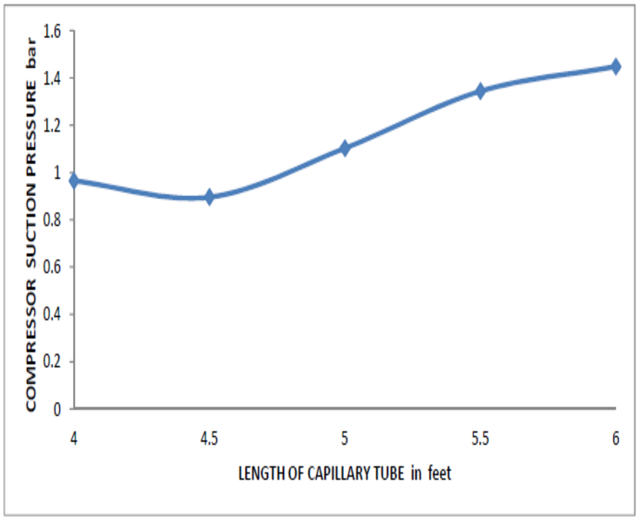

Fig.10.

Referring to the graph-3, the compressor pressure decreases as the length of the capillary tube increases. But at the length = 4.5 feet's the performance of the system starts to decrease, because of further increase in pressure due to friction, the specific volume, and velocity increase in the capillary tube. It increases the compressor suction pressure.

4. Effect of the Length of Capillary Tube on Compressor Power:

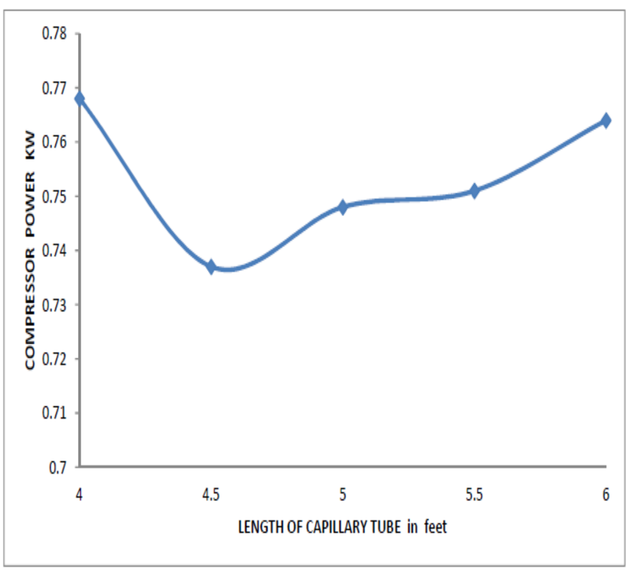

Fig.11.

Referring to the graph-4, it is seen that compressor power decreases as the length of the capillary tube increases. But at the length = 4.5 feet's, the compressor power starts to increase due to further pressure drop in suction vapour, temperature and increase the specific volume of the suction vapour to the compressor, thus increases the volume of vapour compressed.

5. Effect of the Length of Capillary Tube on Net Refrigerating Effect:

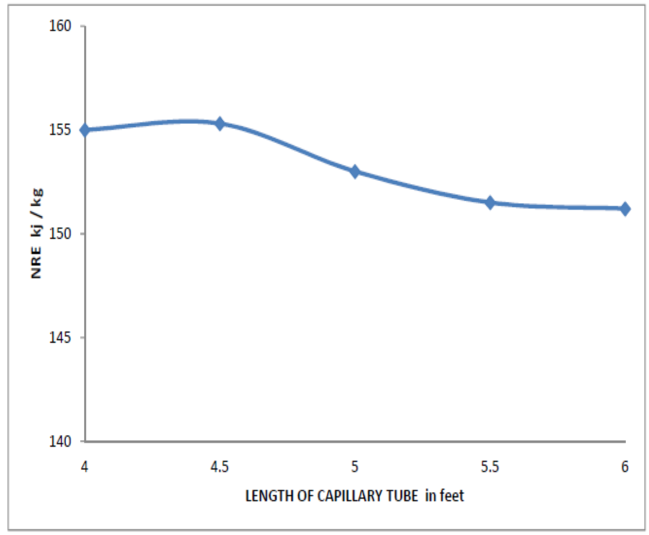

Fig.12.

Referring to the graph-5, it is seen that the net refrigerating effect increases as the length of the capillary tube increases. But at the length = 4.5 feet's, the net refrigerating effect starts to decrease because of choked flow the mass flow rate of refrigerant also decreases up to certain level again it starts to increase.

6. Effect of Length of Capillary Tube on Compressor Pressure Ratio: Referring to the graph-6,it is seen that the compressor pressure ratio increases as the length of capillary tube increases, But at the length = 4.5 feet's the performance of the system starts to decrease, because of further increase in pressure due to friction, the specific volume, and velocity increase in the capillary tube. It increases the compressor pressure ratio.

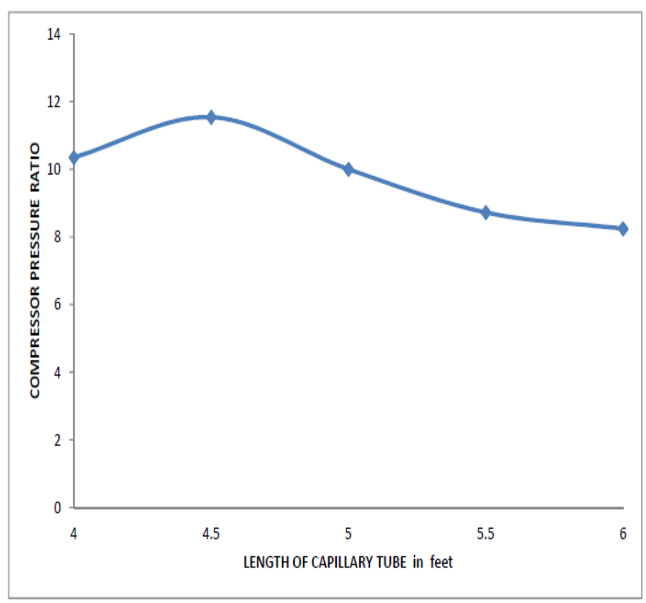

Fig.13.

VII. CONCLUSION

Experimental studies have been carried out to evaluate the system performance under various operating conditions. A separate Experimental set up has been used for determining the pressure, temperature and coefficient of performance along the length of the coiled capillary tubes. From the investigations, the following conclusions are drawn:

- In the present work the length of capillary tube is optimized for a vapour compression refrigeration unit of capacity 30lts, with R-134a as refrigerant through experimental investigations.
- This study investigated the performance of capillary tube geometries having R-134a as the working fluid.
- Experimental computations are made and compared and found that the optimum length of capillary tube is 4.5 feet. At length = 4.5feet, the performance of the system is good in all aspects i.e... Coefficient of performance, refrigeration effect, power of compressor, mass flow rate of refrigerant and compressor pressure ratio.
- Test results shows significant improvement in the performance of the Refrigeration system for the length of capillary tube 4.5 feet.
- It is seen that mass flow rate of refrigeration system decreases as the length of capillary tube increases.
- The compressor pressure decreases as the length of the capillary tube increases. It is seen that compressor power decreases as the length of the capillary tube increases.
- Test results shows significant improvement in the net refrigerating effect increases as the length of the capillary tube increases.
- It can be concluded that at length = 4.5feet, the performance of the system is good in all aspects i.e., Coefficient of performance, refrigeration effect, power of compressor, and mass flow rate of refrigerant.

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