EXPERIMENTAL ANALYSIS OF REFRIGERATION UNIT FOR OPTIMIZATION OF CAPILLARY TUBE LENGTH

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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.

In the present work, it is attempted 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 it is found that optimum Length of capillary tube gave a better performance of Subsequent atmospheric studies and computer models suggested that ozone was likely to be depleted at a faster rate than had previously thought. In response to the renewed concern over CFC's, manufacturing companies restarted their development programmers for the environmentally acceptable refrigerants. 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.

1. Introduction: Some greenhouse gases occur naturally in the atmosphere, while others result from human activities. Naturally occurring greenhouse gases include water vapor, carbon dioxide, methane, nitrous oxide, and ozone. Certain human activities, however, add to the levels of most of these naturally occurring gases. When sunlight reaches earth's surface some light is absorbed and warms the earth and then it re-radiates heat at longer wavelengths. Some of these longer wavelengths are absorbed by greenhouse gases in the atmosphere before they are lost to space. This absorption of long wave radiation warms up the atmosphere. Greenhouse gases also emit long wave radiation both upward to space and downward to the surface. The downward part of this long wave radiation emitted by the atmosphere is the "greenhouse effect".

1.1 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.

1.1.1 Refrigerant R134a:

The refrigerant R134a is the chemical compound tetra fluoroethane comprising of atoms of carbon, two atoms of hydrogen and four atoms of fluorine. Its chemical formula is CF3CH2F.The molecular weight of refrigerant R134a is 133.4 and its boiling point is -15.1degree F.

Refrigerant R134a is a hydro fluorocarbon (HFC) that has zero potential to cause the depletion of the ozone layer and very little greenhouse effect. R134a is the noninflammable and non-explosive, has toxicity within limits and good chemical stability. It has somewhat high affinity for the moisture. The overall physical and Thermodynamic properties of refrigerant R134a closely resemble with that of refrigerant R12. Due to all the above factors, R134a is considered to be an excellent replacement for R12 refrigerant.

1.1.2 R134a as Replacement for R12:

Refrigerant R12 is the most widely used of all the refrigerants for different refrigeration and air conditioning applications. It is indeed very tough that any refrigerant will be able to replace this highly versatile refrigerant in different operating conditions. However, R134a has been able to replace R12 successfully in Number of applications. Let us see how R134a compares well with R12.

1.2 VAPOUR COMPRESSSION 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

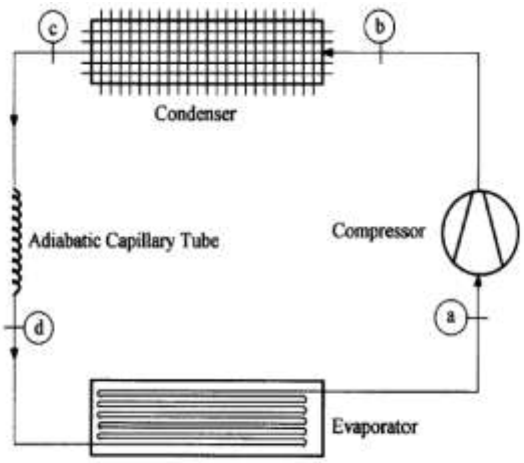


Fig. 1.1 Schematic diagram of vapour compression refrigeration system

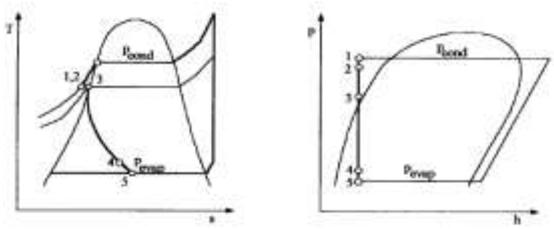


Fig. 1.2(a) VCR cycle on T-s coordinates and VCR cycle on p-h coordinates

2. Literature Review:

Review of the literature gives an insight into the developments in the field of study and helps to identify the problem, techniques and methodologies to be adapted. Developments in the area of fluid flow in straight as well as coiled capillary tubes are presented in this chapter. Also, in this chapter, various developments about, physical models and parametric studies using various working fluids reported in the literature are presented in this chapter.

3. Theoretical Studies:

Fluid flow and heat transfer processes are characterized with suitable mathematical concepts and physical postulates based on fundamental principles. Each mathematical formulation is expressed with operating parameters of a process. These parameters are the governing factors, which are used for identifying and describing the performance of the system. Thus theoretical study on flow through capillary tube helps in enlightening the basic concept of operations and processes involved, arriving at appropriate mathematical formulation and obtaining relevant and articulate solution.

3.2 Expansion Devices:

The expansion device (also known as metering device or throttling device) is an 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:

1. It reduces the high pressure liquid refrigerant to low pressure refrigerant before being fed to the evaporator.

2. 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.

3. It controls the flow of refrigerant according to the load on the evaporator.

3.2.1Typesofexpansiondevices:

1.Capillarytube,
2.Handoperatedexpansionvalve,
3.Automati constant pressure expansion valve,
4.Thermostaticexpansionvalve,

5.Lowsidefloatvalveand
6.High side float valve.

1. Capillary Tube:

The capillary tube is used as an expansion device in small capacity hermetic sealed refrigeration units such as in domestic refrigerators, water coolers, room air-conditioners, especially in small capacity installations. It is a copper tube of small internal diameter and of varying length depending upon the application. The inside diameter of the tube used in refrigeration work is generally about 0.5 mm to 2.25mm and the length varies from 0.5 m to 5 m. it is installed in the liquid line between the condenser and the evaporator. A fine mesh is provided at the inlet of the tube in order to protect it from contaminants.

In its operation, the liquid refrigerant from the condenser enters the capillary tube. Due to the frictional resistance offered by a small diameter tube, the pressure drops, since the frictional resistance offered by a small diameter tube, the pressure inversely proportional to the diameter, therefore lnger the capillary tube and smaller its inside diameter, greater is the pressure drop created in the refrigerant flow, in other words, greater pressure difference between the condenser and evaporator is needed for a given flow rate of the refrigerant. The diameter and length of the capillary tube once selected for a given set of conditions and load cannot operate efficiently at other conditions.

The refrigeration system, using capillary tube, has the following advantages:

1. The cost of capillary tube is less than all other forms of expansion devices.

2. When the compressor stops, the refrigerant continues to flow into the evaporator and equalizes the pressure between the high side and low side of the system. This considerably decreases the starting load on the compressor. Thus a low starting torque motor (low cost motor) can be used to drive the compressor, which is a great advantage.

3. Since the refrigerant charge in a capillary tube system is critical, therefore no receiver is necessary.

4. Capillary tube does not have threaded or moving parts there by the cost of maintenance and repair is almost negligible. The major disadvantage of using capillary tube is the refrigerant must be free from contaminants otherwise they will block the passage and may lead to damage of the system.

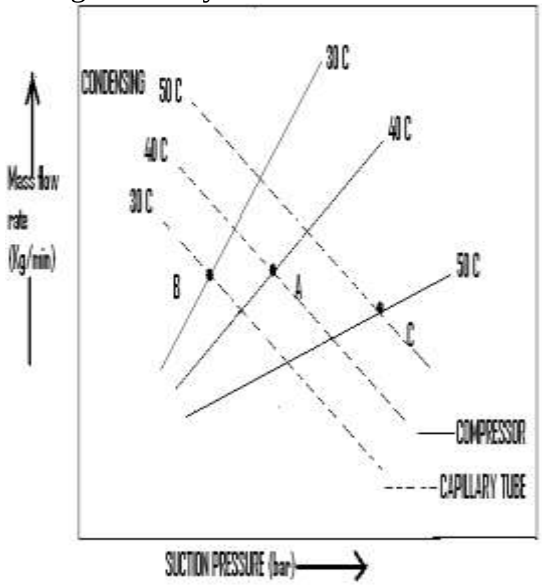


Fig: 3.1(a) Mass flow rate of capillary with varying suction pressure

4. Experimental Investigations:

Experimental study on a system helps to evaluate its performance experimentally under varying operating conditions. Comparing this performance with that of the theoretical studies help in understanding the acceptability limits. In this line, the performance of the helical capillary tubes is studied experimentally. Effects of various parameters like mass flow rate, inner diameter, length, coil diameter, etc over a range of operating conditions are studied. The detailed description of the experimental system, various components of the system, controls and measurement systems and experimental procedure are presented in this chapter.

4.1 Description of the Experimental Setup:

Test rig is a single stage vapour compression refrigeration system of 30

LTRS capacity. Figure 4.1 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.

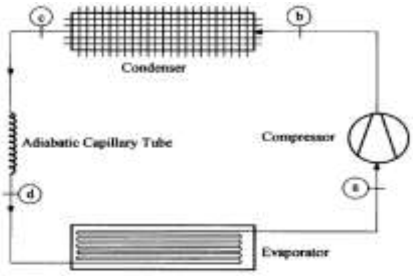


Fig. 4.1 Schematic diagram of the experimental setup

Temperatures at various locations were measured using digital thermo meter. Various locations at which temperature was measured are shown in Table 4.1

Fig. 4.2 a view of Digital thermometer

Table 4.1 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.

1. Suction pressure of compressor
2. Discharge pressure of compressor
3. Pressure at the outlet of condenser

Fig.4.3 Pictorial view of the single capillary

4.2 System Components:

4.2.1 Compressor:

Compressor used in this study is a hermetically sealed type reciprocating compressor with following specifications

Table 4.2 Compressor specifications

1	Displacement Volume	13.3 m3/hr
2	Speed	1440 rpm
3	Phases	Single φ
4	Voltage	400
5	Frequency	50 Hz
6	Maximum pressure	32 Bar
7	Capacity	0.14H.P

4.2.2 Condenser:

Condenser used in this study is an air cooled condenser. Air flow heat exchanger consists of 8X2X8 inch in length of 3/8" copper tube. Refrigerant flows through the tubular space while air is sucked across the tubes by a fan of 5watt 1300rpm with variable speed drive. Digital thermo meters are provided at the inlet and outlet of the condenser to measure the temperature of refrigerant.

Fig 4.4 Condenser and fan

4.2.3 Evaporator:

Evaporator used for the experiments is a shell and coil type. Refrigerant passes through the inner tube while water bottles are placed in cabin. Length of the tube used for the evaporator is 25feets and 6.35mm diameter copper tube.

Fig 4.5 Evaporator

4.2.4 Configuration of capillary tubes:

Table 4.3 Capillary tubes Specifications

1	Lengths	4 feet	4.5 feet	5 feet	5.5 feet	6 feet
2	Diameter	0.8 mm				

4.3 Experimentation:

4.3.1 Charging the system:

The entire system was pressure tested using nitrogen gas pressurizing to 30 bars. 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.

4.3.2 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

1. All the measurements were taken only after the system reached the steady state

2. Set of experiments is done by keeping evaporator temperature at a specified level and varying the condensing temperature and vice versa

3. Measurement of all operating parameters were taken at every 20 min.

4.3.3 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

1. Temperature at inlet and outlet for the components.

2. 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.

4.4. 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

Compressor suction		
Pressure	P1	0.896 bar
Temperature	T1	10.2°C
Compressor discharge		
Pressure	P2	10.324bar
Temperature	T2	62.9°C
Condenser parameters		
Pressure	P3	9.998bar
Temperature	T3	39.6°C
Evaporator parameters		
Temperature	T4	16.8°C

5. Calculations:

Reading No.1

For capillary tube Length of 4 feet (1219.2mm)

h1	410.3 KJ/Kg
h2	443 KJ/Kg
h3= h4	255 KJ/Kg

h1	411 KJ/Kg
h2	445 KJ/Kg
h3= h4	256 KJ/Kg

Compressor suction		
Pressure	P1	0.896 bar
Temperature	T1	10.2°C
Compressor discharge		
Pressure	P2	10.324bar
Temperature	T2	62.9°C
Condenser parameters		
Pressure	P3	9.998bar
Temperature	T3	39.6°C
Evaporator parameters		
Temperature	T4	16.8°C
Pressure	P1	0.965 bar

From P-H chart, we can find out the values of h1, h2, h3, and h4 in KJ/Kg

READING NO: 2

For capillary tube Length of 4.5 feet (1371.5mm)

From P-H chart, we can find out the values of h1, h2, h3, and h4 in KJ/K

5.1 tabular columns of performance parameters:

SL.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	COMPRESSORSUCTION TEMPERATURE T1 (^{0}C)	10.5	10.2	11.5	12.3	12.8
3	COMPRESSOR DISCHARGE PRESSURE P2 (bar)	9.998	10.342	11.032	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	10.687	11.373	11.58
6	CONDENSER TEMPERATURE T3 (^{0}C)	383	39.6	41.1	42.5	42.3
7	EVAPORATOR TEMPERATURE T4(^{0}C	19.0	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 (m_r) (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)	256.095	254.176	254.78	255.02	255.854
19	COMPRESSION PRESSURE RATIO	10.35	11.54	10	8.72	8.24

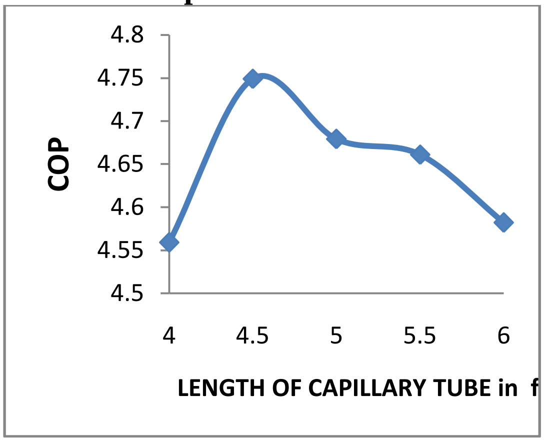
6. Result and Discussions:

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.

6.1 Results and discussions from the following graphs:

1. Effect of length of capillary tube on coefficient of performance:

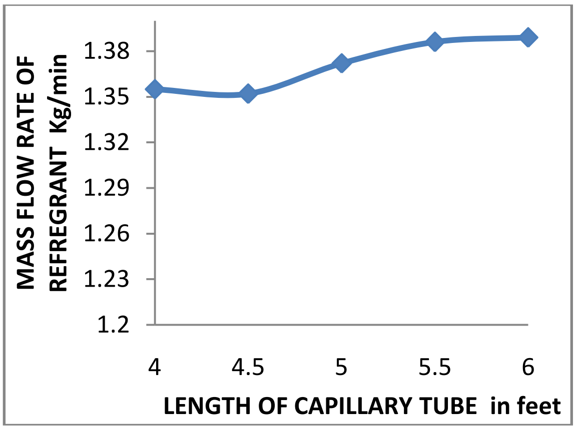


Graph 1.Effect of Length of capillary tube on coefficient of performance

Effect of length of capillary tube on coefficient of performance:

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:

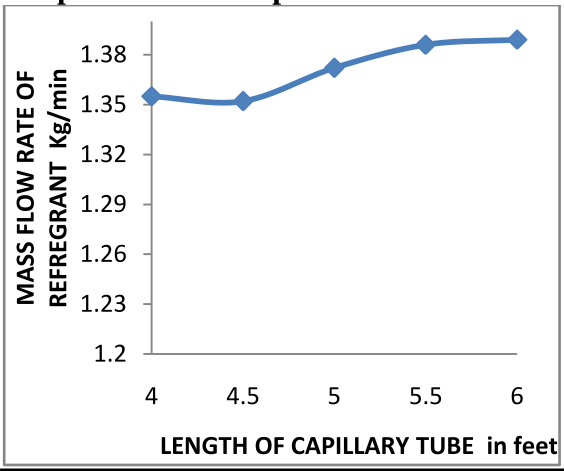


Graph 2. Effect of Length of capillary tube on the mass flow rate of refrigerant

Effect of length of capillary tube on the mass flow rate of refrigerant:

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:

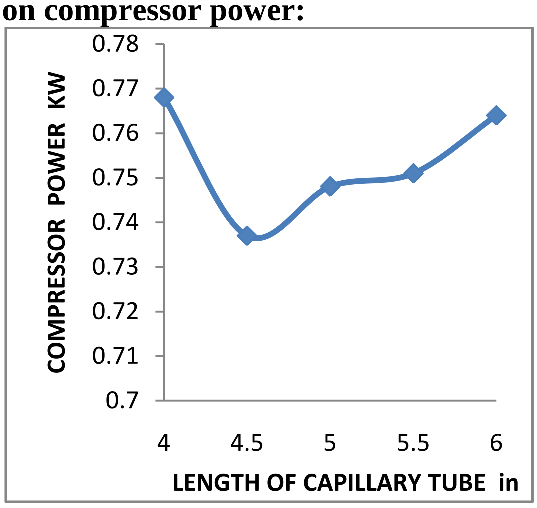


Graph 3. Effect of Length of capillary tube on Compressor suction pressure

Effect of length of capillary tube on compressor suction pressure:

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:



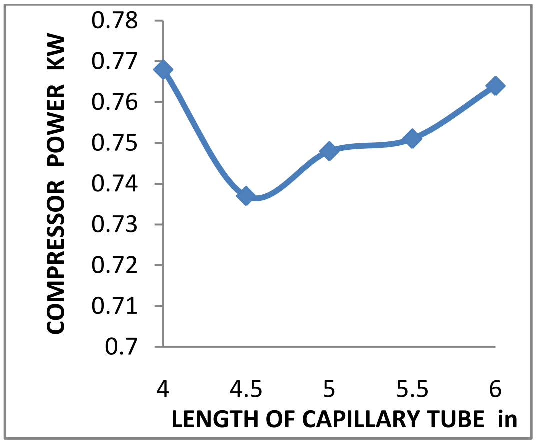
Graph 4. Effect of Length of capillary tube on compressor power

Effect of the length of tube on compressor power:

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:

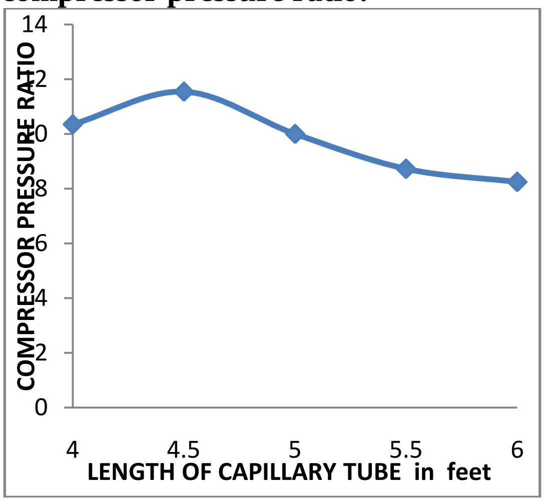
Graph 5. Effect of Length of capillary tube on net refrigerating effect



Effect of the length of capillary tube on net refrigerating effect:

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:



Graph 6. Effect of Length of capillary tube on compressor pressure ratio:

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.

Experimental setup

7. Conclusions:

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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