An Experimental Study of a Simple Vapour Compression Refrigeration System with Varying Parameters

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Abstract: **The study of the simple vapour compression refrigeration (VCR) cycle is much important in order to understand the overall performance of the system with parameters affecting it. The experimental study we had made on the VCR cycle with different parameters such as the capillary tube configuration, capillary tube diameter, variation in condenser fan speed and type of refrigerant. It can be concluded from the results below that capillary tube of 31 gauge (0.226 mm) and 36 gauge (0.130 mm) each with three different capillary (expansion valves) configurations i.e. helical coiled tube, straight coiled tube and serpentine coiled tube configuration. The overall performance of the system was studied with the effect of the coil configuration and capillary tube diameter on it. The refrigeration effect and heat transfer rate was found to be max for the helical coiled tube structure and was found to be least for straight coiled configuration whereas the performance was in between for serpentine type coil. Refrigerant selection and its effect on performance of VCR cycle shows that heat carrying capacity for R-134a and R-22 are much more than R-717. Also condenser fan speed has been studied and it can be noted that as condenser fan speed increases condenser performance increases but up to certain extent and then rate decreases.**

KEYWORDS: ***Capillary Tube, configuration, condenser fan, refrigerant, refrigeration system, ODP, GWP, HRR.***

I. INTRODUCTION

A simple vapour compression refrigeration system consists of mainly five components namely compressor (Hermetically sealed), condenser, expansion device, evaporator and a filter/drier. The following study is focused towards finding out the effect of different parameters such as the capillary tube configuration, capillary tube diameter, variation in condenser fan speed and type of refrigerant on the performance of the refrigeration system. A capillary tube with small diameter tube is used for the expansion of the flowing fluid. The diameter may be 31 gauge, 36 gauge, 40 gauge.

As we know that the pressure difference between the entry and exit points of the capillary tube is always equal to the pressure difference between the condenser side and the evaporator. The diameter of the capillary tube used in the refrigeration appliances varies from 0.5mm to 2.5mm. Capillaries with 3 different configurations viz. helical, straight and serpentine type of configuration are used. The performance of the capillary tube has been investigated by many of researchers in the past and interesting results were obtained. Many of the countries had banned the use of HCFC as refrigerants from Ist January 2010, although it is allowed to used up to 2015 if it comes through recycling process. Therefore there is a need to have development in new working fluids which can replace the HCFC in the refrigeration plants which are now in operation.

Among all the HCFC's used upto year 2010, R22 is the most widely used and has wide range of applications, especially in the air conditioning which we are comparing with HFC R-134a and R-744 having less ODP. Condenser efficiency can be checked by arranging a regulator which will change fan performance.

II. OBJECTIVE

a. To study the performance of system with the effect of capillary tube configuration on it.
b. To investigate the performance of system with the effect of capillary tube diameter on it.
c. To investigate the effect of condenser fan speed on the performance VCR cycle.
d. To study the effect of different refrigerants within same range on performance of system.

III. XPERIMENTAL SETUP AND PROCEDURE:

An experimental study was made in the refrigeration and air conditioning laboratory in the best possible controlled environment. Hermetically sealed compressor unit with capacity of 0.75HP the condenser is the forced air-cooled type for which condenser fan and motor has been provided. The outside diameter of condenser is 3/8". Size of condenser as per standard specification is 11" x 10" x 3 Rows. The evaporator unit was properly insulated to the best of the effort such as to minimize the heat leakage into the system from the surrounding. Overall dimension of Copper tubes (Bore x Length) = 0.36" x 5" x 1 were used for providing the supply and return lines to the flowing fluid in the system. The Capillary tube diameters with different diameter range are used. Refrigerant R134a, R22, R744 was used as the cooling fluid alternately. A filter/drier, specific for R134a, R22 and R744 was installed just after the condenser unit in order to avoid any situation which causes choking of the flow lines. The filter/drier does not allow the flow lines to form ice by absorbing all the moisture particles present in the flowing fluid. Two analogue pressure gauges are used to determine the pressure of the flowing fluid in the high pressure and the low pressure line **Pressure Gauge (0 to 300 PSI**.): Bourdon type pressure gauge which is used to get pressures at discharge point of compressor exit.

Compound Gauge. (-30 to 150 PSI.): Bourdon type pressure gauge which shows both negative pressure (Vacuum) as well as positive pressure in the VCR system. This is used to measure pressures at suction point of compressor. The pressure gauge in the high pressure line was installed just next to the filter/drier and just before the capillary tube. Another pressure gauge was installed in the low pressure return line to measure the pressure of the fluid returning back to the compressor. The temperatures at different points in the VCR system are measured by using RTD (PT – 100 Resistance Temperature Detectors) which operates on the principle of change in Resistance with change in temperature of the coil. A digital thermometer was used to determine the temperatures that were to be used in the analysis of the system. The readings of the temperature and pressure of VCR were plotted on the P-H chart and the corresponding enthalpies were noted down and from the values of the enthalpies obtained, the parameters such as refrigeration effect and the compressor work were determined. The carnot or ideal COP of the system was determined by using the temperature limits of the system and the actual COP of the VCR system was calculated by considering the ratio of the refrigeration effect and the compressor work obtained from the PH chart. Refrigerants used for the analysis of VCR system are R22, R134a and R744 alternatively.

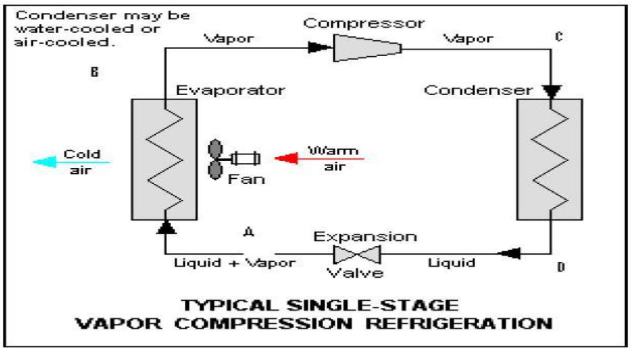

Figure 1: Schematic of simple VCR Cycle

Figure 2: Photograph of simple VCR cycle

Parameters to be study:

1. Capillary tube Diameter
2. Capillary tube Configuration
3. Condenser fan speed
4. Forced/Natural air cooled condenser
5. Refrigerant

1. **Capillary tube Diameter:** Capillary tube with diameters 31 gauge, 36 gauge, 40 gauge are used separately and its effect on performance of VCR cycle are tabulated in table and graphical form in following sections. The length of test section every time is kept constant.

2. **Capillary tube Configuration:** Capillary tube with different configuration such as helical tube, straight tube and serpentine type tube are used. It can be showed that the refrigeration effect was found to be max in case of helical coiled configuration and was noted least for straight coiled configuration. Also it can be found that mass flow rate is max for straight capillary and least for the helical coiled type tube.

3. **Condenser fan speed:** Condenser fan speed can be varied by arranging a regulator such that speed can be changed from 0 speed i.e. fan is off thus we can say that condition as natural cooled condenser to maximum speed which we can say that the condition is forced air cooled condenser.

4. **Forced/Natural air cooled condenser:** As mentioned in above point fan may be kept ON or OFF which results in either Natural air cooled or Forced air cooled condenser. Thus detailed effect of these will be studied in upcoming section.

5. **Refrigerant:** Out of so many refrigerant three refrigerants will be considered for the experimental study and its effect on the performance of the system will be studied. The refrigerants studied are R22, R134a and R744 alternatively.

EXPERIMENTAL OBSERVATION AND RESULT

1. Capillary tube diameter and Configuration Capillary tubes of dimensions 31 gauge (0.226 mm) and 36 gauge (0.13 mm) were used as the test sections. The length of each test section was kept constant to 1.5m. For each test section, readings were taken for three alternate configurations i.e. helical coiled, straight coiled and serpentine coiled. Every set of readings consists of minimum five readings such as, two for no load condition and 600ml, 1200ml and 1800ml condition as loaded condition.

Readings for 31 gauge-helical coiled capillary tube

S.No.	Condition	P1 (psi)	P2 (psi)	P_2/P_1	Te (°C)	Tc (°C)	COPcarnot	R.E. (KW)	Wc (KW)	COPactual
1.	No Load	15	166	11.06	1.7	46.3	6.16	0.472	0.195	2.42
2.	No load	14	162	11.57	1.6	46.1	6.17	0.464	0.195	2.37
3.	600ml Load	17	166	9.76	3	48.2	6.112	0.468	0.191	2.424
4.	1200ml Load	17	167	9.82	7.4	48.38	6.84	0.481	0.173	2.75
5.	1800ml Load	17	168	9.88	11.2	49.06	7.51	0.529	0.161	3.375

Fig 3: Effect of configuration on the refrigeration effect for 31 gauge capillary tube and 36 gauge capillary tube

Readings for 31 gauge-serpentine coiled capillary tube

S.No	Condition	P1 (psi)	P2 (psi)	P_2/P_1	Te (°C)	Tc (°C)	COPcarnot	R.E. (KJ/Kg)	Wc (KJ/Kg)	COPactual
1.	No Load	13	172	13.23	0.8	44.2	6.320	0.459	0.194	2.37
2.	No load	15	169	11.26	0.5	44.8	6.125	0.447	0.191	2.34
3.	600ml Load	16	174	10.87	1.8	45.3	6.328	0.464	0.183	2.537
4.	1200ml Load	17	178	10.47	3.3	45.4	6.574	0.438	0.168	2.61
5.	1800ml Load	17	180	10.58	6.2	45.4	7.135	0.475	0.157	3.03

Table 3: Readings for 31 gauge – serpentine coiled capillary tube

Readings for 36 gauge-helical coiled capillary tube

S.No.	Condition	P_1 (psi)	P_2 (psi)	P_2/P_1	T_e (°C)	T_c (°C)	COPcarnot	R.E. (KJ/Kg)	W_c (KJ/Kg)	COPactual
1.	No Load	12	160	13.3	0.2	45.6	6.05	0.442	0.182	2.43
2.	No load	12	162	13.5	0.2	45.2	6.08	0.430	0.181	2.38
3.	600ml Load	13	166	12.76	1.31	46.3	6.10	0.435	0.173	2.52
4.	1200ml Load	14	168	12	1.71	46.7	6.11	0.423	0.164	2.58
5.	1800ml Load	14	169	12.07	2.55	46.7	6.25	0.433	0.156	2.84

Table 4: Readings for 36 gauge – helical coiled capillary tube

Readings for 36 gauge-straight coiled capillary tube

S.No.	Condition	P_1 (psi)	P_2 (psi)	P_2/P_1	T_e (°C)	T_c (°C)	COPcarnot	R.E. (KJ/Kg)	W_c (KJ/Kg)	COPactual
1.	No Load	13	158	12.15	1.4	44.3	6.40	0.461	0.19	2.38
2.	No load	12	156	13	0.3	44.6	6.18	0.448	0.19	2.36
3.	600ml Load	14	158	11.28	2.3	45.2	6.42	0.452	0.18	2.417
4.	1200ml Load	15	160	10.66	4.1	45.3	6.73	0.454	0.17	2.57
5.	1800ml Load	15	161	10.73	5.8	45.3	7.07	0.448	0.16	2.735

Table 5: Readings for 36 gauge – straight coiled capillary tube

Readings for 36 gauge – serpentine coiled capillary tube

S.No.	Condition	P1 (psi)	P2 (psi)	P_2/P_1	Te (°C)	Tc (°C)	COPcarnot	R.E. (KW)	Wc (KW)	COPactual
1.	No Load	13	159	12.23	0.7	46.3	6.01	0.467	0.186	2.51
2.	No load	14	157	11.21	1.4	46.1	6.14	0.464	0.181	2.37
3.	600ml Load	16	159	9.93	2.6	48.2	6.17	0.468	0.191	2.424
4.	1200ml Load	16	161	10.06	5.7	48.38	6.5	0.471	0.173	2.75
5.	1800ml Load	16	157	9.88	8.3	49.06	6.9	0.512	0.181	2.922

Table 6: Readings for 36 gauge – serpentine coiled capillary tube

Effect of configuration on the refrigeration effect for 31 gauge capillary tube:-

Y axis in the following bar graph shows the refrigeration effect produced in the system in kj/kg.

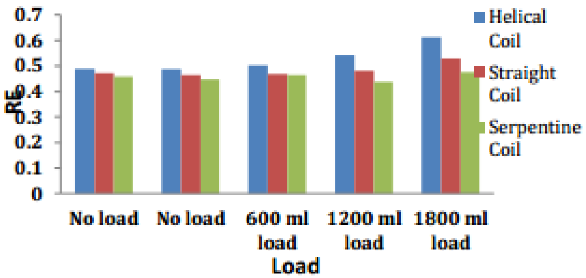

fig 3: Bar graph of Effect of configuration on the refrigeration effect for 31 gauge capillary tube

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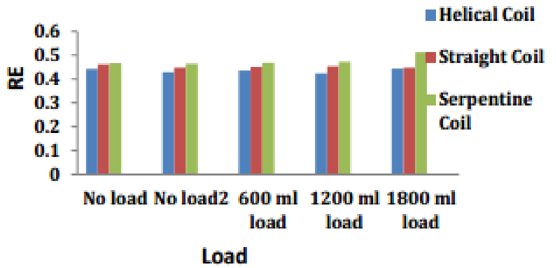

Fig. 4: Bar graph of Effect of configuration on the refrigeration effect for 36 gauge capillary tube

Fig 5 explains that the result of ratio P2/P1 on ordinate to Load condition on abscissa. It shows that ratio P2/P1 is maximum for helical coil at 1200 ml load condition but as load increases after that the ratio P2/P1is decreasing. This shows that it is efficient at 1200 ml load for helical coil, 600 ml load for straight coil and i n between for serpentine coil.

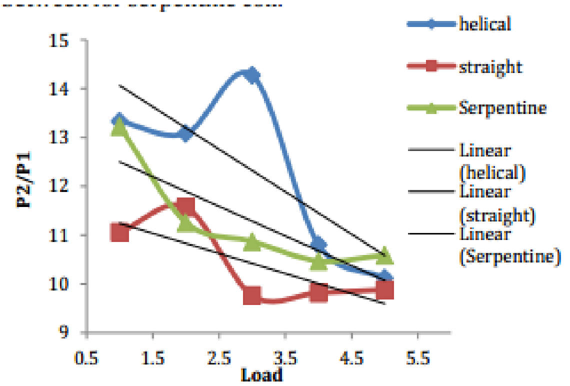

Fig 5: Graph of Relation between pressure ratio and (COP)a for 31 gauge helical coiled capillary tube

2. Refrigerants Selection

In the last decade tremendous changes were found in the choosing and utilization of refrigerants, mainly in concern with the environmental aspects such ozone layer and global warming or greenhouse effect known as ODP and GWP. Previously there was not much discussion about the scientific selection of refrigerant which is to be used, as the majority of applications could be confirmed by the well known HFC's refrigerant, R11, R22, R502 and ammonia (R717). At the time of selection of refrigerant with their chemical, physical properties and at the time of selection we have to know that condensing temperature and evaporating temperature i.e.temperature range of application. Before selection of compressor and condenser we should know about refrigerant. We had considered different refrigerant for study out of which some we will use. As the operating pressure of equipment is should be within this range. between 0.5 bar to 3 bar, the refrigerant Thus from table 7 Ammonia R717, Tetra fluro ethane R134a and Chlorodifluoromethane R22 are selected alternatively. The main advantage of R-134a is that it is a single-component refrigerant i.e. it does not have any smooth movement on the other hand has difficulty of having its relatively low capacity as compared to refrigerants likeR-22. R134a is an inert gas used primarily as "high-temperature" refrigerant for automobile air conditioning and domestic refrigeration.

Sr. no	Name of Refrigerants	Evaporating Temp. °C	Pressure (bar	Condensing Temp. °C	Pressure (Bar)
1	Ammonia (R717)	-35	1	30	12
2	Tetra fluro ethane (R134a)	-26	1	30	7.7
3	Difluromethane (R407C)	-36	1	30	13
4	R502	-40	1	30	13.8
5	Carbon	-15	19	30	72
6	Chlorodiflorome thane(R22)	-40	1	55	22

Table 7: Selection of refrigerant according to working pressure

Effect of refrigerant temperature on performance of VCR

The effect of refrigerant on performance of VCR is shown in graphical form in graph 4. Graph 4 shows the Relation between Saturated temp and Liquid Density for R-22, R-134a and R-717.It shows that density of R-717(NH3) is much less as compare to R-22 and R-134a which, indicates that Heat carrying capacity for R-717 is less than other.

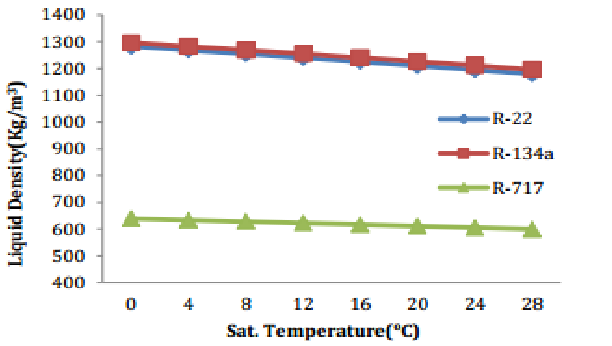

Fig 5: Graph of Relation between Saturated temp and Liquid Density for R-22, R-134a and R-717.

Effect of Condenser fan speed on performance of system

It is found that at higher fan speed, convection coefficient increased thus increasing heat transfer within the evaporator and also condenser with the surroundings, thus reducing the work of the compressor to the refrigerant. VCR cycle was more efficient with fans of evaporator and condenser at highest speeds. Following graph shows the relation between condenser fan speed and COP of system. The curve is drawn on the basis of HRR (Heat Rejection Ratio). From following it can be noted that COP of Helical Coil is maximum all over graph for same input values.The curve for Serpentine type coil has results in-between helical and Straight. It can be shown from the graph 5 that increase in the slope of all coils is decreasing as condenser fan speed decreasing.

$$HRR = \frac{Q_c}{Q_e} = \frac{Q_e + \dot{W}_c}{Q_e} = 1 + \frac{1}{COP}$$

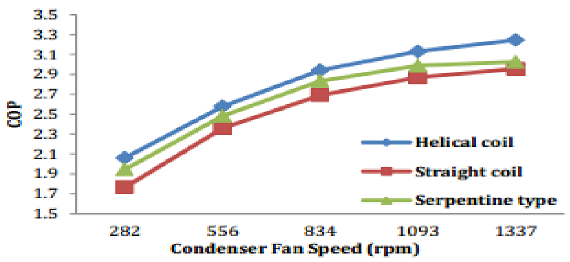

Fig. 6: Graph of Relation Between COP and condenser fan speed for all capillary configurations

IV. RESULT AND DISCUSSION

The above mentioned experimental study of VCR system involved a thorough observation and analysis of the readings and the values obtained. Every graph and every curve is self-explanatory in itself and points out towards a specific outcome from the study. The above shown readings, calculations, graphs and curves do point out towards some distinct conclusions and inferences which are stated below:-

1. The refrigeration effect produced in VCR system is maximum for the helical coiled capillary tubes whereas is least for straight capillary tubes for each test section.

2. It can also be shown from geometry of tubes that the mass flow rate of refrigerant is maximum in the case of straight capillary tubes and least for helical coiled capillary tubes for each test section.

3. The performance in the case of serpentine coiled capillary tubes all results are laying between to that with helical coiled capillary tube and straight coiled capillary tube.

4. As we decrease the capillary tube diameter from 31 gauge to 36, the refrigeration effect produced tends to decrease.

5. It can be shown from above discussion that Refrigerant R-717 has much less liquid density than others, which indicates that heat carrying capacity in case of R-717 is much less.

6. It can be said from above discussion that as condenser fan speed increases the performance of the system increases upto certain extent but then the slope rate is decreasing.

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