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To Optimize the Effect of Various Parameters on the Performance of Vapor Compression Refrigeration Cycle

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***Abstract-* The current study had been done "To Optimize The Effect Of Various Parameters On The Performance Of Vapor Compression Refrigeration Cycle" it has been observed that refrigerant's and material of coil capillary tube significantly influences the performance of vapor compression refrigeration cycle. There are four parameter's were consider in this study i.e. refrigerant, shape, temperature and material of coil capillary tube. The levels of each parameter's have been selected in three levels, i.e. refrigerant (R-134a), (R-404a) and (R-22). Shape (helical), (Serpentine) and (cubic), Temperature (35°c), (45°c) and (55°c) and material of coil capillary tube copper and aluminum. The output parameters are coefficient of performance of vapor compression refrigeration cycle. Taguchi method is used to create L_9 orthogonal array of input variables, coefficient of performance are found out and the effects of input variables on these characteristics are studies in this experiment. After the results have studied it is found that the performance of vapor compression refrigeration cycle mainly affected by refrigerant and material of coil capillary tube. According to the L_9 orthogonal array the change in the level of refrigerant from (R-134a) to (R-404a) it is observed that the performance is higher in level 2 (R-404a). Another two parameter's i.e. temperature and shape of coil capillary tube were the sub significant parameters for affecting the performance of vapor compression refrigeration cycle.**

Keyword's:- Refrigerant, shape, temperature, material.

I. INTRODUCTION TO REFRIGERATION

Refrigeration may be defined as the process of achieving and maintaining a temperature below that of the surroundings, the aim being to cool some product or space to the required temperature one of the most important applications of refrigeration has been the preservation of perishable food products by storing them at low temperatures. Refrigeration systems are also used extensively for providing thermal comfort to human beings by means of air conditioning. Air Conditioning refers to the treatment of air so as to simultaneously control its temperature, moisture content, cleanliness, out dour and circulation, as required by occupants, a process, or products in the space. The physical process where heat is removed from substance resulting in decrease in the temperature or keeping it constant is known as cooling. The process can be performed in two ways naturally by utilizing medium of a temperature lower than temperature of substance to be cooled and artificially by utilizing thermodynamics process of working medium producing low temperature.

II. VCRC

The most widely used cycle in the field of refrigeration and air–conditioning is the vapor compression cycle. The vapor compression refrigeration cycle is completed with four refrigeration processes, Compressor, Condenser, Expansion, and Evaporation. A vapor compression refrigeration system is an improved type of air refrigeration system in which a suitable working substance, termed as refrigerant, is used. It condenses and evaporates at temperatures and pressures close to the atmospheric condition. Since low pressure vapor refrigerant from the evaporator is changed into high pressure vapor refrigerant in the compressor, therefore it is named as vapor compression refrigeration system. The detail processes and functions are listed below.

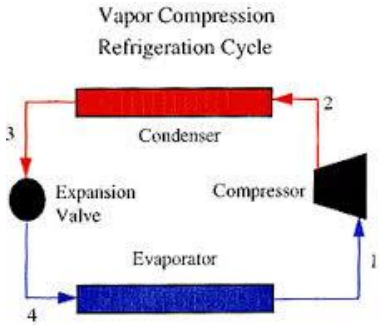

Fig.1:- Vapor Compression Refrigeration Cycle

- *COMPRESSION*

In this process the vapors are compressed adiabatically in the compressor. The temp and pressure of the vapor are raised due to work done on the vapors and refrigerant vapors flow through the hot gas like to the condenser. The vapor refrigerant at low pressure p_1 and temperature T_1 is compressed isentropic ally to dry saturated vapor as shown by the vertical line 1-2 on figure no 2 T-s diagrams and by the curve 1-2 on P-h diagram in figure no 2. The pressure and temperature rises from p_1 to p_2 and T_1 to T_2 respectively. The work done during isentropic compression per kg of refrigerant is given by

$W = h_2 - h_1$

H_1=enthalpy of vapor refrigerant at temperature T_1, i.e. at suction of the compressor.

H_2= enthalpy of the vapor refrigerant at temperature T_2, i.e. at discharge of the compressor.

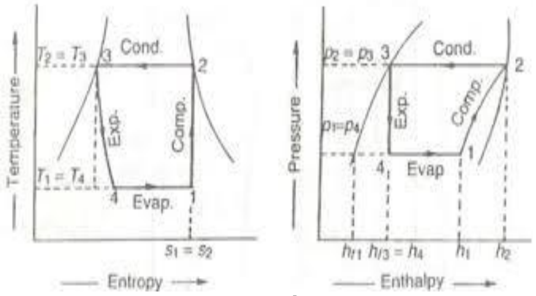

Fig.2:- P V and T S Diagram

- *CONDENSATION*

In this process the vapors are cooled at a constant pressure and converted the vapor into the liquid state. So heat is given to the condensing fluid. The high pressure and temperature vapor refrigerant from the compressor is passed through the condenser where it is completely condensed at constant pressure P_2 and temperature T_2, as shown by the horizontal line 2-3 on T-S and P-H diagram in figure no 2.The vapor refrigerant is changed into liquid refrigerant. The refrigerant, while passing through the condenser gives its latent heat to the surrounding condensing medium.

- *EXPANSION*

The liquid refrigerant from the condenser passed through the expansion device where it is throttled to lower pressure and at constant enthalpy. After throttling we get liquid refrigerant partly vaporized at lower temp. The liquid refrigerant at pressure P_3=P_2 and temperature T_3=T_2 is expanded by a throttling process through the expansion valve to a low pressure P_4=P_1 and temperature T_4=T_1 as shown by the curve 3-4 on t-s diagram and by the vertical line 3-4 on P-H diagram on figure no 2. Some of the liquid refrigerant evaporates as it passes through the expansion valve, but the greater portion is vaporized in the evaporator. During the throttling process, no heat is absorbed or rejected by the liquid refrigerant.

- *EVAPORATION*

In the evaporation the partly vaporized refrigerant completely evaporates at constant pressure by absorbing latent heat from the space. The liquid vapor mixture of the refrigerant at pressure P_4 =P_1 and temperature T_4= T_1 is evaporated and changed into vapor refrigerant at constant pressure and temperature as shown by the horizontal line 4-1 on T-s and p-h diagram as shown in figure no 2. During evaporation, the liquid- vapor refrigerant absorbs its latent heat of vaporization from the medium (air, water or brine) which is to be cooled. This heat which is absorbed by the refrigerant is called refrigerating effect.

III. IMPORTANT PARAMETER FOR THE PERFORMANCE OF VCRC

A number of studies have been carried out to investigate the effect of various parameters on the performance of vapor compression refrigeration cycle. In the vapor compression refrigeration cycle the two important external parameter i.e. refrigerants and expansion device have higher effect on the performance of vapor compression refrigeration cycle are listed below.

IV. REFRIGERANT

A refrigerant is a substance or mixture, usually a fluid, which is capable to change the phase at low temperature or it, is used in the heat pump and refrigeration cycle. In most cycles it undergoes phase transition from a liquid to a gas and back again. Many working fluids have been used for such purpose. There is no general rule governing the selection of refrigerant. It depends upon the thermo physical properties, technological and economical aspects, safety and environmental factor. [Wankhede, 2012]. According to the [Bolaji, 2010] the chlorofluorocarbon (CFC_S) and hydro chlorofluorocarbon ($HCFC_S$) refrigerants are being replaced by hydro-fluorocarbons (HFC_S) due to environmental concerns about depletion of the earth's protective stratospheric ozone layer and global climate change. A refrigeration system using new alternative refrigerants must be modified or newly designed because the thermo-physical properties of these alternative refrigerants differ from those of conventional refrigerants. In order to maintain or improve the performance of the cycle.

Due to the environmental concern the depletion of ozone layer and global warning, CFC (chlorofluorocarbon) and HCFC (hydro chlorofluorocarbon) are being phased out from refrigeration industry. As a result HFC (hydro fluorocarbon), HC (hydrocarbon) and HFC (hydro fluorocarbon) mixture have emerged as an alternative to R-12 and R-22. In fact, the earth is enveloped in a thin shell of ozone layer which prevents the earth from the harmful ultra-violet radiation coming from the sun. The chlorine present in conventional refrigerants is responsible for the depletion of the protective layer of ozone in the upper atmosphere. This leads to increased level of ultraviolet radiation reaching the earth's surface, which result in higher rates of skin cancer, eye cataracts and damage to people's immune system. [Singh, 2012]

V. EXPANSION DEVICE

Expansion valve is also known as throttle valve or refrigerant control valve. The function of the expansion valve is to allow the liquid refrigerant under high pressure and temperature to pass at a controlled rate after reducing its pressure and temperature. Some of the liquid refrigerant evaporates as it passes through the expansion valve, but the greater portion is vaporized in the evaporator at the low pressure and temperature. Capillary tube is one of the most commonly used throttling devices in the refrigeration and air conditioning systems. The capillary tube is a copper tube of very small internal diameter. It is of very long length and it is coiled to several turns. So that it would occupy less space. Capillary tube used as the throttling device in the domestic refrigerators, deep freezers, water coolers and air conditioners. When the refrigerant leaves the condenser and enters the capillary tube its pressure drops down suddenly due to very small diameter of the capillary. In capillary the fall in pressure of the refrigerant takes place not due to the orifice but due to the small opening of the capillary.

VI. EXPERIMENTAL APPARATUS

Figure (3) is the schematic diagram of the experimental setup for the capillary tube test .the experimental setup composed of compressor, condenser, evaporator, and the capillary tube as the vapor compression system is. The airtight compressor is the reciprocal type of (1/4) hp. A receiver of refrigerant is placed before the compressor in order to protect the compressor from the saturated liquid. Mass charge from 0.60 kg to 0.62 kg. The air condenser with copper tube is a fin and tube type designed for this experiment. The thermal load of the condenser is controlled by the flow rate and the temperature of the cooling air. The evaporator with copper tube is a fin and tube type. The thermal load of the evaporator is supplied from heated refrigerant.

Several coil capillary tube of different coil numbers are selected with uniform inner diameters and length. And this was measured by using pin gauge.

A roto-meter type effect volume flow meter is used to measure the volume flow rate from (0 to 0.65 kg/min). in order to prevent vapor from flowing into the flow meter , it is controlled by the valve and located between the condenser and capillary tubes. The pressure at the inlet capillary (condenser pressure) can be measured by using high pressure gauge and the outlet capillary (evaporator pressure) is measured by using low pressure gauge.

The schematic diagram of experimental set-up has been shown in fig.2. The test- section was a copper capillary tube bonded with suction from middle. From capillary tube the refrigerant entered the evaporator consisting of a copper coil submerged in a water tank. A 5-kw capacity electric heater was fitted in the evaporator tank to provide heat load to evaporator. The heating load was varied by means of a variance. An agitator was also fitted in the tank to maintain the uniform bulk temperature of water

The present experimental investigation has been carried out to investigate the effect and parametric optimization of coiled capillary tube on a vapor compression refrigeration system.

Fig. 3:- Vapor Compression Refrigeration Test Rig.

The pressure- enthalpy (p-h) diagram of a simple vapor compression refrigeration cycle is shown in figure 2. In this theoretical vapor compression cycle, the refrigerant enters the compressor at state 1 at low pressure, low temperature and saturated vapor state. From state 1 to 2, the refrigerant is compressed by the compressor and is discharged at state 2 as a high pressure, high temperature and super heated vapor. At state 2, it enters the condenser where it releases heat to the environment. The refrigerant leaves the condenser at state 3 at high pressure and saturated liquid state. From state 3, the refrigerant enters the expansion device where its pressure is reduced from high pressure (condenser pressure) to low pressure (evaporator pressure). After this it enters the evaporator at state 4 where it absorbs heat from the conditioned space and it leaves the evaporator at low pressure, low temperature and saturated vapor (state1).

In the theoretical cycle, it is also assumed that there is no super heating in the suction line and no sub-cooling in the liquid line. It also assumed that steady states and uniform flow condition exits throughout the element of this simple vapor compression refrigeration cycle and changes in kinetic, potential energies, and heat loss from the compressor are negligible. Therefore specific work of compression (W_{COMP}) for the compressor is given

$$W_{COMP} = h_2 - h_1$$

Where h_1 and h_2 (kj/kg) are enthalpies at the compressor inlet and exit, respectively.

The isentropic efficiency of the compressor is given as

$$\eta_{is} = W_{IS} / W_{INPUT}$$

Where, W_{IS} = isentropic work of compression per second (W); and W_{input}= compressor power input (W). During the throttling process in the expansion device, it is assumed that there is no heat transfer to the environment, which results in:

$$h_3 = h_4$$

The refrigeration capacity of the cycle can be calculated from the rate of enthalpy change in the evaporator.

$$Q_E = h_1 - h_4$$

Where Q_E is the specific refrigeration load of the refrigeration cycle in(kj/kg). the rate of heat rejection (Q_E) can be calculated from the rate of enthalpy changed in the condenser;

$$Q_C = h_2 - h_3$$

The coefficient of performance of the refrigeration cycle

$(COP_{\text{system}}) = Q_E/W_{COMP}$

The coefficient of performance of the carnot refrigeration cycle (COP_{carnot}) is the ratio of the minimum temperature (T_e) to the difference between the maximum and the minimum temperatures in the cycle (T_C-T_E), therefore,

$COP_{CARNOT} = T_E/T_C - T_E$

The relative efficiency is obtained

$\eta_r = COP_{\text{system}}/COP_{\text{carnot}}$

Enthalpy table for serpentine coil capillary tube from pressure vs. enthalpy diagram

VII. RESULT AND DISCUSSION

The result were found from the experiments were analysis by using Taguchi L_9 orthogonal array and ANOVA, which helps to determining the significant of the input parameters for any function. It is indicated that which is the most effective or influencing parameters or factors. It specifies the most influencing set of parameters as per experimental design. The studied in this experimental works are coefficient of performance on the vapor compression refrigeration cycle.

TABLE 1 RESULT OF PERFORMANCE OF VCRC

Experiment No		Refrigerant	Shape	Temperature	Material	COP	Average	S/N ratio
E1	A	R-134a	circular	35	Copper	4.56	4.62	13.11362
	B	R-134a	circular	35	Copper	4.63		
	C	R-134a	circular	35	Copper	4.67		
E2	A	R-134a	serpentine	45	aluminum	4.22	4.09	12.2206
	B	R-134a	serpentine	45	aluminum	4.02		
	C	R-134a	serpentine	45	aluminum	4.02		
E3	A	R-134a	cubic	55	aluminum	4.54	4.62	13.11362
	B	R-134a	cubic	55	aluminum	4.62		
	C	R-134a	cubic	55	aluminum	4.70		
E4	A	R404a	circular	45	Copper	8.47	8.40	18.48063
	B	R404a	circular	45	Copper	8.27		
	C	R404a	circular	45	Copper	8.45		
E5	A	R404a	serpentine	55	Copper	8.29	8.33	18.40122
	B	R404a	serpentine	55	Copper	8.09		
	C	R404a	serpentine	55	Copper	8.60		
E6	A	R404a	cubic	35	aluminum	8.47	8.58	18.66241
	B	R404a	cubic	35	aluminum	8.47		
	C	R404a	cubic	35	aluminum	8.79		
E7	A	R-22	circular	55	aluminum	7.32	7.44	17.37141
	B	R-22	circular	55	aluminum	7.49		
	C	R-22	circular	55	aluminum	7.71		
E8	A	R-22	serpentine	35	Copper	7.87	7.40	17.35117
	B	R-22	serpentine	35	Copper	7.32		
	C	R-22	serpentine	35	Copper	7.02		
E9	A	R-22	cubic	45	Copper	7.80	7.67	17.68825
	B	R-22	cubic	45	Copper	7.41		
	C	R-22	cubic	45	Copper	7.80		

TABLE 2 ANALYSIS OF THE VARIANCE FOR MEANS

Source	D.O.F	Sum of square	Adjusted Sum of square	Mean of square	F	P	Significant value
Refrigerant	2	26.2051	13.10	11.2045	67764.89	0.003	Significant
Shape	2	0.1856	0.0928	0.1118	675.94	0.027	Significant
Temperature	2	0.0328	0.0164	0.0195	117.81	0.065	Non- significant
Material	1	0.0433	0.0433	0.0433	262.08	0.039	Significant
Residual error	19	0.0002	0.00001	0.0002			
total	26	26.4670					

$F_{(critical)}$ (2, 19, 0.05) = 3.52, $F_{(critical)}$ (1, 19, 0.05) = 4.38

TABLE 3 RESPONSE TABLE FOR MEANS

Level	Refrigerant	Shape	Temperature	Material
1	4.440	6.819	6.866	7.283
2	8.433	6.606	6.718	6.181
3	7.506	6.954	6.796	-
Delta	3.993	0.349	0.148	1.102
Rank	1	3	4	2

"HIGHER IS BETTER"

From the value of F (critical), it is indicated that all the four parameters are significant but according to the value of p (at 95% confidence level), the parameter temperature is non- significant and parameters Refrigerant, Shape of capillary tube and Material are significant.

- *MAIN EFFECTS PLOT FOR MEANS*

The fig.4 Shows the main effects plot for means of performance of Vapor compression refrigeration cycle and it is also indicated in the variation in the performance corresponding to the changing the input parameters i.e. refrigerant, shape, temperature and material . The X- axis is represented by the change in refrigerant, change in shape, change in temperature and change in material and Y-axis is represented by the change in the performance of VCRC. From fig.4 it is clear that the performance of VCRC is increasing with refrigerant -2 (R-404a). And performance of VCRC is increasing with cubic shape but almost non-significant. It is clear from the fig .4 there is no effect of temperature on the performance of vapor compression refrigeration cycle. The performance of VCRC is increasing with significantly with changing the material of coil capillary tube.

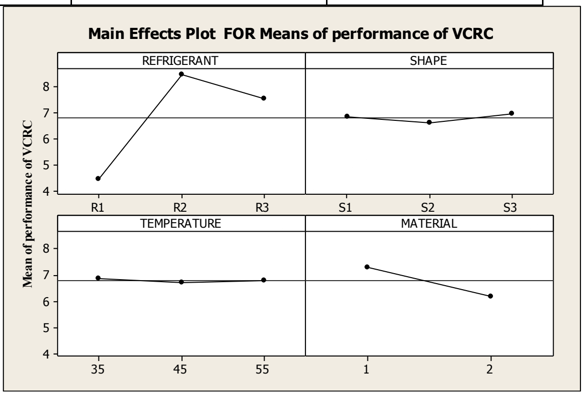

Fig.4:- Main Effect plot for means of performance of VCRC

From the fig.4 the refrigerant R-404a gives the maximum performance due to its chemical configuration. The shape of coil capillary tube (cubic) gives maximum cop because in the cubic shape of coil capillary tube the number of turn are higher and hence pressure drop is higher as compared to the other coil capillary tube shapes. The material of coil capillary tube copper performance is higher as comparison to the aluminum.

TABLE 4 Analysis of variance for S/N ratios

Source	D.O.F	Sum of square	Adjusted Sum of square	Mean of square	F	p	Significant value
Refrigerant	2	55.2300	27.615	23.3079	31721.94	0.004	Significant
Shape	2	0.3842	0.1921	0.2503	340.70	0.038	Significant
Temperature	2	0.0943	0.04715	0.0649	88.32	0.075	Non- significant
Material	1	0.1597	0.1597	0.1597	217.35	0.043	Significant
Residual error	1	0.0007	0.0007	0.0007			
Total	8	55.8690					

$F_{(Critical)}$ (F (2, 1, 0, 05) =199.50, $F_{(Critical)}$ (F (1, 1, 0, 05) =161.45

TABLE 5 Response Table for S/N ratios

Level	Refrigerant	Shape	Temperature	Material
1	12.82	16.32	16.38	17.01
2	18.51	15.99	16.13	15.34
3	17.47	16.49	16.30	-
Delta	5.70	0.50	0.25	1.66
Rank	1	3	4	2

"HIGHER IS BETTER"

From the value of F (critical), it is indicated that all the four parameters are significant but according to the value of p (at 95% confidence level), the parameter temperature is non- significant and parameters Refrigerant, Shape of capillary tube and Material are significant.

- *MAIN EFFECT PLOT FOR S/N RATIOS*

The fig. 5 shows the main effect plot for S/N ratio of performance of VCRC and it is also indicated the variation in the performance of vapor compression refrigeration cycle corresponding to the changing the input parameters i.e. refrigerant, shape, temperature, and material of coil capillary tube. The x- axis is represented by the change in refrigerant, change in shape of coil capillary tube, change in temperature, and change in material of the coil capillary tube and Y- axis is represented by the change in the signal to noise ratios. From fig. 5 it is clear that the signal to noise ratios is increasing that the performance of VCRC is increasing with the refrigerant (R-404a) i.e. significant parameter and performance of VCRC is increasing with cubic shape but almost non- significant. It is clear from the fig .5 there is no effect of temperature on the performance of vapor compression refrigeration cycle. The performance of VCRC is increasing with significantly with changing the material of coil capillary tube.

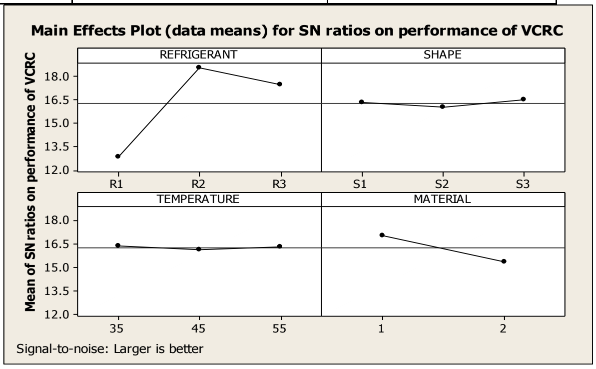

Fig. 5:- Main effects plot for S/N ratios of performance of VCRC

From the fig.5 the refrigerant (R-404a) gives the maximum performance due to its chemical configuration. And shape of coil capillary tube (cubic) gives maximum cop because in the cubic shape of coil capillary tube the no of turn higher as compare to other coil capillary tube. The material of coil capillary tube copper performance is higher as comparison to the aluminum.

VIII. CONCLUSION

The experimentation was performed according to the Taguchi Technique L9 orthogonal array. The influences of the input parameters i.e. refrigerant, shape, temperature and material of coil capillary tube on the performance of vapor compression refrigeration system were calculated by using ANOVA. In this the main effects plot for mean value and S/N ratio value were found/developed and analyzed. The purpose of the analysis of variance (ANOVA) and significant factors were to identify the optimal solution of the performance of vapor compression refrigeration cycle. I used soft ware MINITAB 15 to find the S/N ratio and plots for mean and S/N ratio. The conclusions are given below:

The study investigated the performance of capillary tube geometry having R-134 a, R- 404a and R-22 as the working fluids. Four parameters were examined these are different refrigerant, shapes, temperature and material of coil capillary tube. The obtained result shown that the level of refrigerant has significant on the system performance as the refrigerant changes level one to level two then the coefficient of the performance of vapor compression refrigeration system is increase with respect to other three parameters.

1. Test rig is working effectively and significantly improved the COP.
2. The refrigerant is the significant parameters in influencing the performance of vapor compression refrigeration cycle after ANOVA and S/N ratio.
3. The result was found that the shape (cubic) of coil capillary tube have an effect on the performance of vapor compression refrigeration system.
4. The temperature variation has non-significant effect on the system performance.
5. The study were examined the copper coil capillary tube gives high performance as compare to Aluminium coil capillary tube after ANOVA and S/N ratio.

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