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Investigation of VCRs System with Heat Exchanger Using R-600a and Phase Change Material

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ABSTRACT

Refrigeration forms the basic essence of living comfort, so it is very necessary to update the technologies in refrigeration system. The COP of the refrigeration system (VCRS) can be increased by increasing the refrigeration effect or by reducing the work done by the compressor. In this work the COP is improved by achieving sub cooling using a heat exchanger which helps in increasing the refrigerating effect. Capillary tube of refrigeration system is wound around the evaporator outlet to make a heat exchanger there by increasing the COP of the system by the effect of sub-cooling. The additional advantage added to this project is use of eco friendly refrigerant R-600a and the phase change material (ethylene glycol) we are reducing the emission of CFCS(chloro - fluoro carbons).The VCRS system with and without heat exchanger was analysed using refrigerants R-134a and R-600a and the deviation in COP was carefully studied. By using the PCM (phase change material) in the evaporator the time for which the desired refrigerating effect that can be maintained is experimentally investigated.

Keywords: *Refrigeration, Cop, VCRS, Sub Cooling, Heat Exchanger and PCM*

I. INTRODUCTION

In this modern world almost all the refrigeration systems are based on the vapour compression refrigeration system cycle. The four processes that involved in vcrs system are isobaric heat addition, isentropic compression, isobaric heat rejection and isenthalpic expansion.

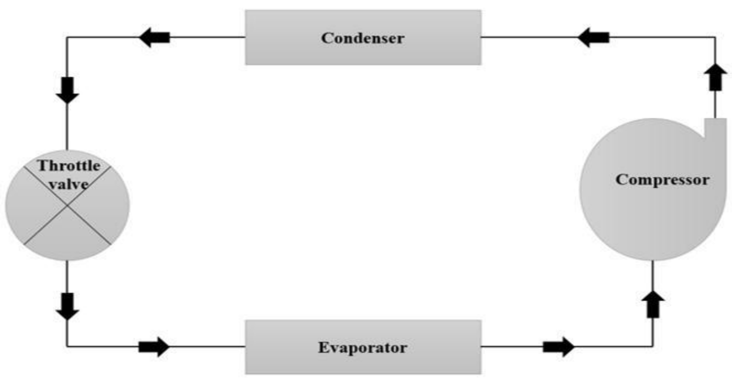

Figure 1 Simple Refrigeration Cycle

Figure 1 show the simple refrigeration cycle. Initially the refrigerant enters the compressor as a gas under low pressure and having a low temperature. Then, the refrigerant is compressed adiabatically, so the fluid leaves the compressor under high pressure and with a high temperature. The high pressure and high temperature gas condenses in the condenser and the refrigerant leaves the condenser as high pressure liquid. The high pressure liquid refrigerant is then passed to capillary tube which causes it to expand. When the refrigerant is forced through throttle, its pressure is reduced. As a result refrigerant now has low pressure and low temperature. The low pressure and low temperature refrigerant enters the evaporator, which is in contact with cold reservoir. Because a low temperature is maintained, the refrigerant is able to boil at a low temperature. So the liquid absorbs the heat from the cold reservoir, it evaporates and enters into the compressor. And the cycle repeats.

SUB- COOLING

Refrigeration is defined as the science of maintaining the temperature of a space lower than the surrounding space. Sub-cooling in refrigeration implies that cooling the refrigerant in liquid state at uniform pressure to a temperature less than saturation temperature, which corresponds to condenser pressure. This can be achieved by incorporating a heat exchanger in the VCRS system.

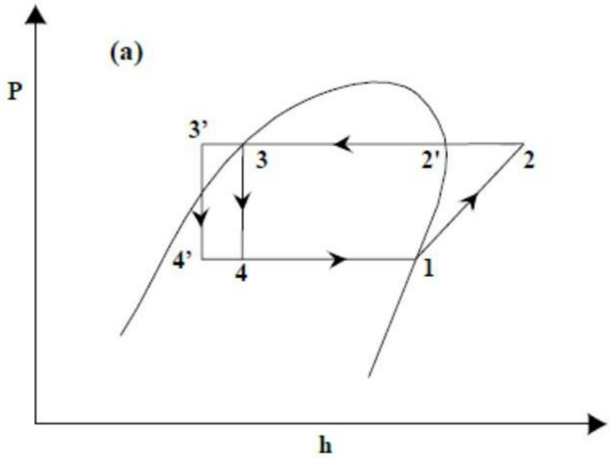

Figure 2 Effect of sub- cooling from 3-3'

HEAT EXCHANGER

Heat exchangers are the devices that are used to transfer the heat from one to another. These are widely used in space heating, refrigeration, air conditioning, chemical plants etc. parallel flow and counter flow are the two flow types used in heat exchanger. In parallel flow arrangement the 2 fluids flow in same direction, they move in opposite direction in counter flow arrangement.

ETHYLENE GLYCOL

Ethylene glycol is a colourless, practically odourless, low volatile, low viscous, hygroscopic liquid. It is completely miscible water and many organic liquids. Ethylene glycol is significantly used as all weather automotive antifreeze based on its ability to lower the freezing point when mixed with water. It is used as stabilizer against gel formation, Applications include De-icing fluids (air craft, runway), latex paints, adhesives, glues. It is used in as humectants in paper and leather industry.

Table1. Properties of Ethylene glycol

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Chemical formula	$HOCH_2\,CH_2OH$
Solubility	Soluble in water, Acetone, pine oil and organic liquids.
Normal freezing point	-13^0 c
Vapour pressure	0.0075kpa
Specific gravity	1.1153
Molar mass	62.07g/mol

PROPOSED METHOD FOR IMPROVING THE CO-EFFICIENT OF PERFROMANCE OF THE VCRS SYSTEM

Refrigerant in the refrigeration cycle along the capillary tube has high temperature than that of evaporator outlet pipe temperature. The capillary tube is rotated along the length of the evaporator outlet pipe and then connected to evaporator inlet. A heat exchanger like set up takes place in the cycle. Heat exchange takes place between the capillary tube and evaporator outlet pipe. The refrigerant coming from the capillary tube undergoes sub-cooling and increases the refrigeration effect in the evaporator. Similarly the refrigerant in evaporator outlet pipe gains heat and enters into compressor. By the effect of sub-cooling the co-efficient of performance of the refrigeration system is improved. The system with and without heat exchanger was analysed using two refrigerants R-134a and R-600a and it was found that the system with heat exchanger and R-600a refrigerant was more efficient than the other combinations.

In evaporator phase change material named ethylene glycol was mixed with water. The Ethylene glycol is mixed with water in order to lower its freezing point. Ethylene glycol and the water mixture freezes in the evaporator when the temperature in the evaporator reaches less than -3.5 degree When there is a power loss or when the system is turned off this PCM which is already freeze, helps in protecting the temperature rise in evaporator.

ADVANTAGES OF USING R-600a OVER R-134a

- Specific heat at constant pressure is much higher
- Latent heat of vaporisation of R-600a is much higher over R-134a
- With small change in pressure the temperature of R-600a can be brought to the required cold conditions
- It is non toxic with zero Ozone Depletion Potential (ODP)
- It has very low Global Warming Potential (GWP)

II. EXPERIMENTAL WORK

In this work a simple heat exchanger setup is made in the VCRS system as shown in below figure without adding any external devices.

Figure 3 Heat Exchanger like set up

From figure 3 along the capillary tube the refrigerant has high temperature than evaporator outlet pipe temperature. So the capillary tube is rotated along the evaporator outlet pipe with a length of 24cm to make the heat exchanger. Thus the capillary tube temperature is reduced (sub cooled) and the same manner the refrigerant temperature entering into the compressor can be increased.

Figure 4 Complete set up with Heat Exchanger

The above figure shows the complete VCRS system with heat exchanger containing compressor, condenser, capillary tube and evaporator. The refrigerant used in this system is R-134a. Today almost all the domestic refrigerants are using R-134a, so the same refrigerant is used here.

Table2. Specifications of Heat Exchanger

Evaporator outlet pipe diameter	1 cm
Length of heat exchanger	24 cm
Material	Copper

Table3. Readings for the VCRS system using R134a and with heat exchanger

Compressor inlet temperature	14.7
Compressor outlet temperature	72
Condenser temperature	37.2
Evaporator temperature	-3
Low pressure (P1)	3 bar
High pressure (P2)	13bar

Time in Mns	Compressor inlet Temperature (T_1)	Compressor outlet Temperature (T_2)	Condenser Temperature (T_3)	Evaporator Temperature (T_4)	Pressure in bars (p_1)	Pressure in bars (p_2)	COP
10	15.7	54	34	-4	1.2	2.7	5.23
20	15.5	56	34.2	-4.5	1.2	2.7	5.27
30	15.6	56	34.8	-5.2	1.2	2.7	5.28
40	15.7	56.5	35	-5.7	1.2	2.7	5.26
50	15.5	57	35.8	-6.2	1.2	2.7	5.28
60	15.2	57	36	-6.8	1.2	2.7	5.28

SAMPLE CALCULATIONS

From P-H chart of R-600 at pressure (P1) and temperature (T1) the enthalpy value is

H_1=670kj/kg

From P-H chart of R-600 at pressure (P2) and temperature (T2) the enthalpy value is

H2=740kj/kg

From P-H chart of R-600 at pressure (P1) and temperature (T4) the enthalpy value is

h4=300kj/kg

Refrigerating effect=h1-h4=670-300=370Kj/kg

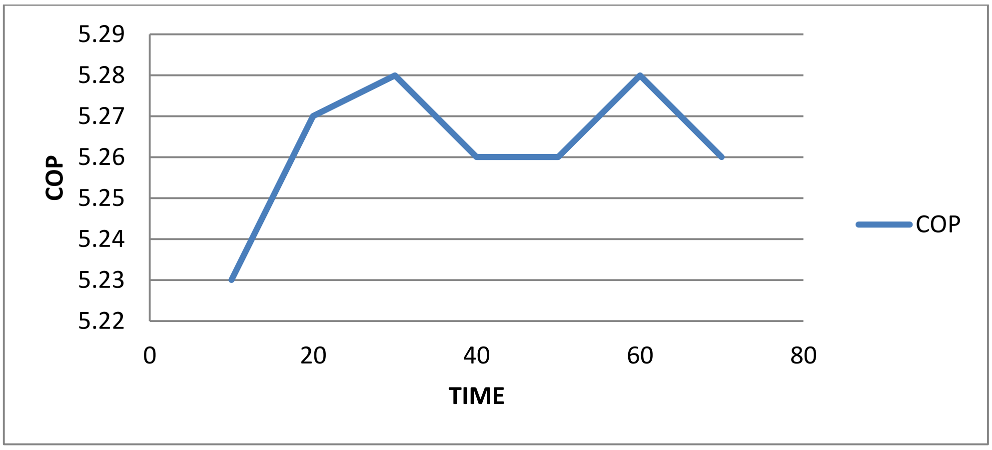
Compressor work =h2-h1=740-670=70Kj/kg

Coefficient of performance (COP) = Refrigerating effect/ Compressor work

= 370/70 = 5.285

Table3. Co-efficient of Performance for different time period

Time in Mins	Compressor Inlet Temp (T1) in degrees	Compressor Outlet Temp (T2)	Condenser Temp (T3)	Evaporator Temp (T4)	Pressure (P1) in bar	Pressure (P2) in bar	COP
10	14.7	72	37.2	-3	3	13	4.77
20	14.7	72.4	37	-3.1	3	13	4.77
30	14.5	73	37	-3.1	3	13	4.67
40	14.6	74.2	36.8	-3.2	3	13	4.57
50	14.7	74.8	36.8	-3.2	3	13	4.56
60	14.6	75.1	36.5	-3.2	3	13	4.3



Graph 1 Time vs COP

Graph 1 shows the relationship between time and cop. Readings are taken for every 10 minutes up to more than an hour to understand the co- efficient of performance. There is only a slight variation in cop which shows the effective performance of the system.

Table 4. Readings for the VCRS system using R134a without Heat Exchanger set up

Compressor inlet(t_1) in degrees	14
Compressor outlet(t_2)	75
Condenser temperature(t_3)	40
Evaporator temperature(t_4)	2.5
Low pressure (p_1)	3.2 bar
High pressure(p_2)	12.8 bar

From P-H chart of R-134a at pressure (p_1) and temperature (t), the enthalpy is given as

h_1= 610kj/kg

From P-H chart of R-134a at pressure (p_2) and temperature (t_2), the enthalpy is given as

h_2= 665kj/kg

From P-H chart of R-134a at pressure (p_2) and temperature (t_3), the enthalpy is given as

h_3= 460kj/kg

From P-H chart of R-134a at pressure (p_4) and temperature (t_4), the enthalpy is given as

h_4= 410kj/kg

Refrigeration effect = h_1-h_4 = 610 – 410 = 200kj/kg

Compressor work = h_2-h_1 = 665 – 610 = 55kj/kg

Co-efficient of performance (COP) = refrigeration effect / compressor work

= 200 / 55

= 3.63

By this we can conclude that by incorporating heat exchanger like set up in VCRS system we can improve the co-efficient of performance of the system.

PEFRRFORMANCE ENHANCED BY USING R-600a OVER R-134a

Cop by using R-134a as refrigerant=4.73
Cop by using R-600a as refrigerant=5.28
Cop enhanced = 5.28-4.73/4.73=0.116
When calculated in terms of percentage it is 11.6%

III. WORKING OF PHASE CHANGE MATERIAL IN EVAPORATOR

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As we all know that there is a temperature rise in evaporator when the VCRS system is turned off or when there is power loss. To protect the temperature rise for a certain period, this phase change material is used. Here the phase change material used is Ethylene glycol. Basically the availability of Ethylene glycol in market is in liquid form. We can't use the Ethylene glycol directly into the evaporator. So a solution is prepared by mixing it with water in the ratio of 1:5. 1250 ml of water is used to prepare solution for 250 ml of Ethylene glycol.

Figure 5 Magnetic Stirrer

Figure 6 Solution in evaporator

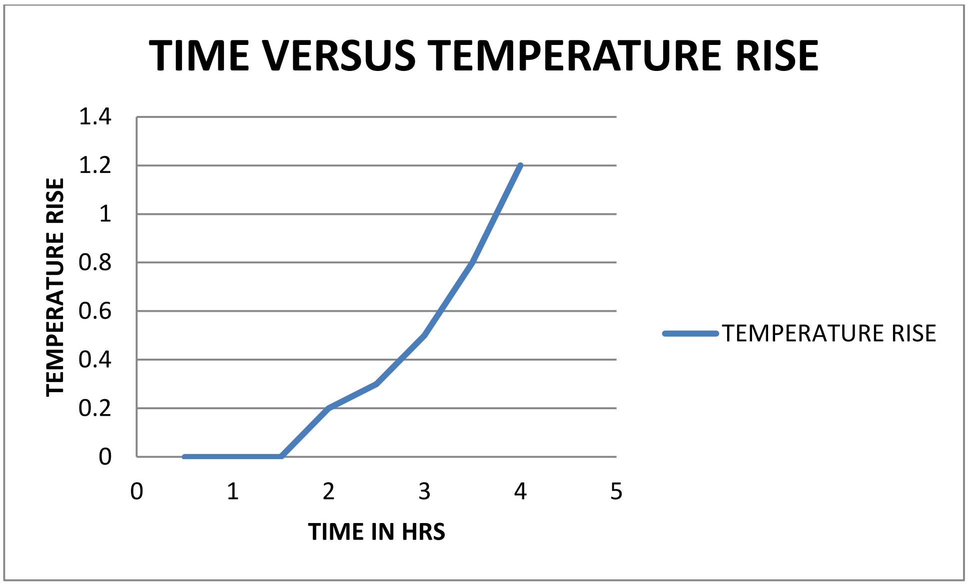
From **figure 6,** once after the solution is prepared it is poured into the evaporator. Make sure that the evaporator coils are completely immersed in the PCM for the better results. As the solution is mixed with 1:5 ratio the freezing point of the solution reduces. So when evaporator temperature is less than -2 degree, the solution undergoes partial freezing. The solution freezes and cools because of low evaporator temperature. Once the solution freezes the VCRS system is turned off. When the system is turned off the solution which is already freezed in the evaporator slows down the temperature rise in evaporator for a period of 4 to 5 hrs.

Figure 7 Freezing of pcm in evaporator

Table3. Temperature rise in evaporator when the system is turned off

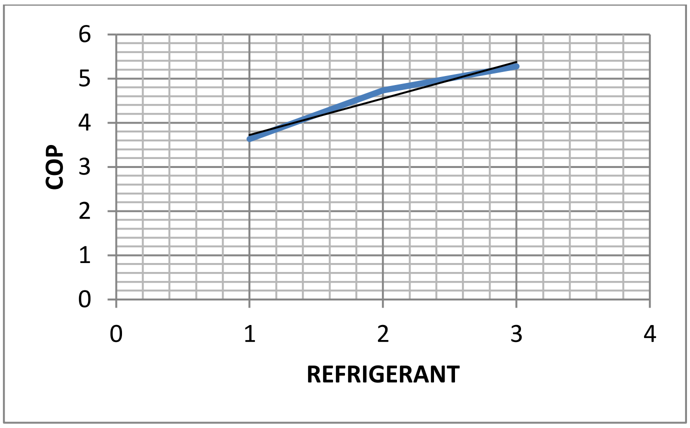
Time in hrs	Temperature rise in degrees
0.5 hr	0
1 hr	0
1.5 hr	0
2 hrs	0.2
2.5 hrs	0.3
3 hrs	0.5
3.5 hrs	0.8
4 hrs	1.2

If we observe the table 3 readings the temperature rise in first one hour is almost zero that indicates the importance of pcm. After some time period 4 to 5 hrs, the evaporator temperature starts to increase. However these readings were taken under no load conditions. If there is a load in evaporator may be values differ slightly.



Graph 2 Time vs Temperature rise

Graph 2 shows the relationship between the time and temperature rise in evaporator. It clearly indicates that there is only 2.5 degrees increase in temperature for 4 hrs which is very much useful for domestic and medical applications.



Graph 3 Refrigerant vs COP

Above graph indicates the variation in cop when refrigerants R-134a and R-600a are used (with and without heat exchanger) . The graph indicates that refrigerant R-600a when used in VCRS system with heat exchanger has the greater cop when compared to the other combinations.

Iv. RESULTS

By incorporating this heat exchanger like set up in refrigeration system the co-efficient performance can be increased more than the systems that have not this set up. Phase change material (Ethylene glycol) is very effective in protecting the temperature rise in evaporator when there is power loss. For 4 hours there is only 2.5 degree rise in temperature.

V. CONCLUSION

Now we can conclude that by using VCRS system, with the heat exchanger of this type improves the co-efficient of performance of the refrigeration system with the effect of sub-cooling. Many projects have done on this work but in this work heat exchanger is designed without adding any external devices. Another advantage added in this work is a phase change material called Ethylene glycol helps in protecting the temperature rise in the evaporator when there is a power loss or when the system is turned off, along with this we are simultaneously reducing the Ozone Depletion Potential using R-600a.

VI. SCOPE FOR FUTURE WORK

The VCRS system with heat exchanger could be analysed using different kinds of eco-friendly refrigerants such as R -11, R-12, R13, R-404a etc. The simple VCRS system when turned into a cascaded system might keep the refrigerant effect for about 10 hours when the PCM is freezed in it. Different combinations of refrigerants and PCMs materials could be worked out.

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