ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 6, Issue 4, July 2017

Experimental study of eco-friendly refrigerants in a vapour compression refrigeration system

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Abstract : Refrigeration means "the science of providing and maintaining temperatures below that of the surrounding temperature". Refrigeration has its wide applications in industries, domestic purpose and cold storage plants. The refrigerants R12and R22 has wide spread usage in refrigeration system because of their superior performance in comparison with other refrigerants. The main drawback of these refrigerants is, these refrigerants have significant effect on the environmental imbalance and causes depletion of ozone layer as a side effect. In search of new eco-friendly refrigerants, two new eco-friendly refrigerants R134a and R407c were tested for their performance. The refrigerants R12 and R22 were replaced with R134a and R407c refrigerants and experiments were conducted on a vapor compression refrigeration system using a reciprocating compressor. The coefficient of performance (COP) of R134a and R407c refrigerant were calculated from the results. The R407c refrigerant has shown a improvement in COP when compared with COP of R22 refrigerant. The results were shown a considerable increment in the coefficient of performance of the refrigeration system with the new eco-friendly refrigerants.

I. INTRODUCTION

Vapor compression refrigeration systems are the most commonly used among all refrigeration systems. In a vapor compression refrigeration system, refrigeration is obtained as an effect of evaporation of refrigerant at low temperatures. A compression refrigeration cycle has four components namely evaporator, compressor, condenser and expansion valve.

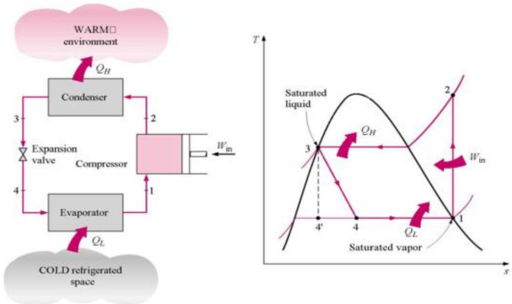

Fig 1: Ideal vapor compression refrigeration system.

In an ideal vapor compression cycle the refrigerant enters the compressor as a saturated vapor and is cooled to a saturated liquid state in the condenser. It is then throttled to a evaporator pressure and vaporizes as it absorbs the heat from the refrigerated space. The ideal vapor-compression cycle consists of four processes. i) 1-2 isentropic compression, ii) 2-3 constant pressure heat rejection in the condenser, iii) 3-4 throttling in an expansion valve, iv) 4-1 constant pressure heat addition in the evaporator. In the vapor compression refrigeration system a wide variety of refrigerants can be used in these systems to suit different applications. Common refrigerants in usage are: i) Hydrogen, fluorine, carbon (HFC), ii) Hydrogen, chlorine, fluorine, carbon (HCFC), iii) Hydrogen, carbon (Hydrocarbon), iv) Chlorine, fluorine, carbon (CFC). Among those refrigerants Halocarbon refrigerants are all synthetically produced and was developed as the Freon family of refrigerants here HCFC, HFC. The widely used among the all refrigerants are CFCs, because of their superior performance than the other refrigerants. The main drawback in using these CFC refrigerants is these are hazardous to the environment and causes eco imbalance in nature. These refrigerants take a major part in the depletion of ozone layer. Constants efforts were put in research to find the new kind of eco friendly refrigerants that gives better or more performance than CFCs.

Table 1: Properties of different refrigerants

Refrigerant	Boling point at 760 mm of Hg, °C	Freezing point in °C	Critical temperature in °C	Critical pressure in bar	Latent heat of vaporization kJ/kg	Specific volume (m^3/kg)	Cost per kg in Rs
R12	-29.8	-157.8	111.97	41.36	157.26	0.0910	800
R134a	-26.2	-77	100.95	40.6	203.12	0.0604	650
R22	-41.3	-160	96.15	49.9	210.11	0.0416	550
R407c	-46.3	-160	86.024	46.29	268.3	0.0304	600

II. EXPERIMENTATION

Figure-1 shows the components of a vapor-compression refrigeration cycle: a compressor, condenser, expansion valve, and evaporator. A low pressure, low temperature liquid is converted to vapor in the evaporator, thus absorbing heat from the refrigerated space and keeping that space cool. The fluid is driven around the cycle by the compressor, which compresses the low temperature, low pressure vapor leaving the evaporator to high pressure, high temperature vapor. That vapor is condensed to liquid in the condenser, thus giving off heat at a high temperature to the surrounding environment. Finally, the high pressure, high temperature liquid leaving the condenser is cooled and reduced in pressure by passing it through an expansion valve. This provides the input to the evaporator which was the first step of the cycle described above. The work and heat flows shown in the diagram are W_{in}, Q_H and Q_L. W_{in} is the work input to the compressor. The rate of work input to the compressor is most of the power requirement to run the refrigeration system. Power will probably be needed to drive one or more fans, but their power requirement will be small in comparison with that needed to drive the compressor. Q_H is the high temperature heat rejected to the surroundings by the condenser. Q_L is the low temperature heat absorbed from the cooled space by the evaporator.

A vapor compression refrigeration system was taken to carry out the experiments. Before starting the test, refrigerant left in the system was collected by using refrigerant evacuation pump. Nitrogen gas has been used for fleshing out of compressed old oil through condenser evaporator pipe line, replacement of filter drier, cleaning of oil filter has been done. Later pressure test and vacuum tests were conducted on the test rig. Primarily Experimentation was done with R12 refrigerant. R12 Refrigerant was used to fill the system. After filling 50% of the refrigerant, the refrigeration system has to be started then complete the process of filling the refrigerant. After collecting compressor inlet pressure and outlet pressure, refrigerant circulated and all reaming necessary data, the same procedure was carried out with the reaming three refrigerants also.

Table 2:- Pressure and specific Enthalpy values at different stages during the vapor compression refrigeration cycle that works Brayton cycle.

R12	Pressure (bar)	Specific Enthalpy (kJ/kg)		R134a	Pressure (bar)	Specific Enthalpy (kJ/kg)		R22	Pressure (bar)	Specific enthalpy (kJ/kg)		R407c	Pressure, bar	Specific Enthalpy (kJ/kg)
1	2.415	184.94		1	2.549	396.33		1	4.4785	250.3		1	4.547	413.9
2	8.957	225.2		2	9.301	422.988		2	15.158	280.77		2	14.813	442.95
3	8.957	71.55		3	9.301	250.41		3	15.158	97.03		3	14.813	261.6
4	2.415	71.55		4	2.549	250.41		4	4.4785	97.03		4	4.547	261.6

The pressure, temperature at every stage in the cycle was measured and the necessary calculations were performed to find out the COP, power and compression displacement of the vapor compression refrigeration n system.

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III. CALCULATIONS

R134a Refrigerant:

Compressor inlet pressure = 37 psi = 37 $\times$ 0.0689 = 2.5493 bar

Compressor outlet pressure = 135 psi = 135 $\times$ 0.0689 = 9.3015 bar

At p_1 = 2.5493 bar, h_f = 194.68 kJ/kg; h_g = 396.33 kJ/kg; s_g = 1.7297 kJ/kg-K ; T_{sat} = -4 ^oC

At p_2 = 9.3015 bar, h_f = 250.41 kJ/kg; h_g = 417.78 kJ/kg; s_g = 1.7129 kJ/kg-K ; T_{sat} = 36 ^oC

During reversible adiabatic compression 1-2: $s_1 = s_2$

$s_{g1} = s_{g2} + C_p.\log [T_{sup}/T_{sat}]$

$1.7297 = 1.7129 + 2.1 \times \log [T_{sup}/(36+273)]$ (T_{sup}=311.48 K =38.48 ^oC)

$h_2 = h_g + C_p (T_{sup} - T_{sat}) = 417.78 + 2.1 (38.48-36) = 422.988$ kJ/kg

Enthalpy of vapor entering compressor h_1 = 396.33 kJ/kg

Enthalpy of vapor leaving compressor h_2 = 422.988 kJ/kg

Evaporator pressure = 2.549 bar

Enthalpy of liquid entering evaporator h_f = 194.68 kJ/kg

Enthalpy of vapor leaving evaporator h_g = 396.33 kJ/kg

Heat of compression = $h_2 - h_1$ = 422.98-396.33 = 26.65 KJ/Kg

Net refrigerant effect (NRE) = $h_1 - h_f$ = 396.33 – 194.68 = 201.65 KJ/Kg

COP = 201.65/26.65 = 7.566

Refrigerant circulated = 200/Refrigeration effect = 3.1566/201.65 = 0.01743 Kg/S

Compression work= Heat of compression $\times$ refrigerant circulated = 26.65 $\times$ 0.01743 = 0.4645 KJ/S

Power (watts) = 0.6226 Hp $\times$ 746 = 46.45 W

Capacity = Ref. circulated $\times$ Net refrigerant effect = 0.01743 $\times$ 201.65 = 3.5147 KJ/S

$$\text{Compression displacement} = \frac{\text{Capacity} \times \text{Volume of gas entering compressor}}{\text{NRE}} = 1.0531 \times 10^{-3}\ m^3/S$$

IV. RESULTS AND DISCUSSIONS

The thermodynamic efficiency of a refrigeration system depends mainly on its operating temperatures. Along with the temperature other operating conditions such as suction pressure, discharge pressure, pressure ratio and isentropic index of compression are also having their significant effect on the coefficient of performance o the refrigeration system. At a given evaporator temperature, the saturation pressure should be above atmospheric for prevention of air or moisture ingress into the system and ease of leak detection. Higher suction pressure is better as it leads to smaller compressor displacement. At a given condenser temperature, the discharge pressure should be as small as possible to allow light-weight construction of compressor, condenser etc. Pressure ratio should be as small as possible for high volumetric efficiency and low power consumption. Apart from the operating conditions of the system, the properties of refrigerant have their major effect on the coefficient of performance of the refrigeration system. Some properties of refrigerants and their effect are illustrated in this work. Latent heat of vaporization should be as large as possible so that the required mass flow rate per unit cooling capacity will be small. Isentropic index of compression should be as small as possible so that the temperature rise during compression will be small. Liquid specific heat should be small so that degree of sub cooling will be large leading to smaller amount of flash gas at evaporator inlet. Vapor specific heat should be large so that the degree of superheating will be small. Thermal conductivity in both liquid as well as vapor phase should be high for higher heat transfer coefficients. Viscosity should be small in both liquid and vapor phases for smaller frictional pressure drops. The thermodynamic properties are interrelated and mainly depend on normal boiling point, critical temperature, molecular weight and structure.

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Table 3: C.O.P. and power of the refrigerants tested.

Refrigerants	R12	R134a	R22	R407c
C.O.P	3.83	7.56	6.86	7.36
Power(Watt)	91.39	46.45	51.22	47.75

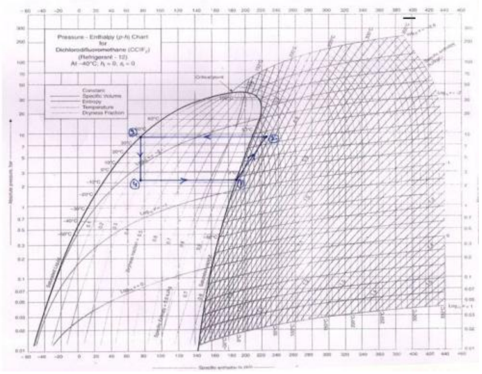

Fig 2: R12 P-h Chart

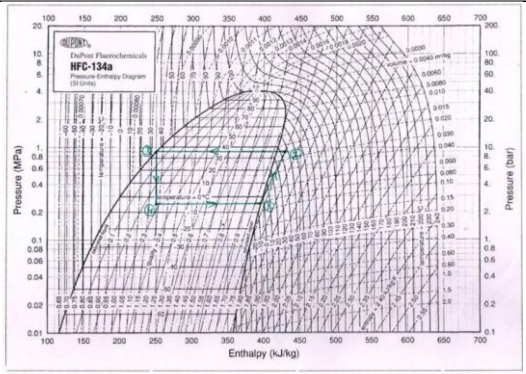

Fig 3: R134a P-h Chart

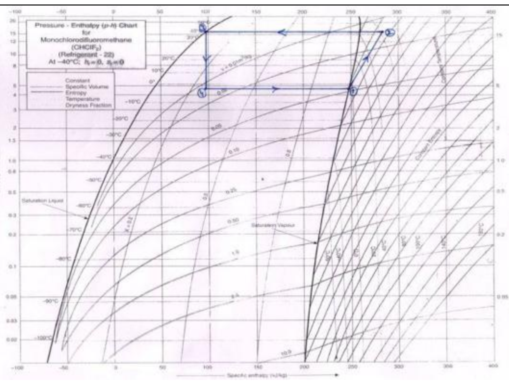

Fig 4: R22 P-h Chart

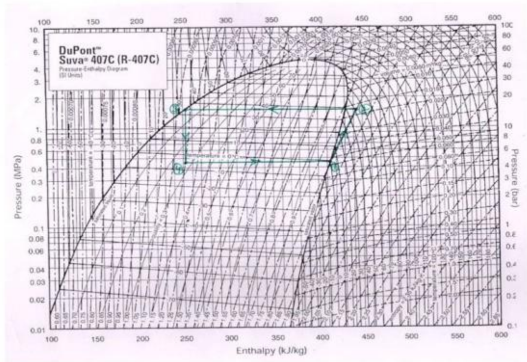

Fig 5: R407c P-h Chart

The COP of R134a is higher than the COP of refrigerant R12. This effect is because the refrigerant R134a is having low boiling point and less critical temperature than the refrigerant R12. Because the less pressure ratio in the operating time the R134a consumes less power than the refrigerant R12. In the view of economic operating of refrigerating the R134a is cheaper than the R12. Apart from all the R12 causes depletion of ozone layer and cause global warming, whereas the R134a is eco friendly refrigerant. The refrigerant R407c got a slight increment in the COP than the refrigerant R22. There is no much difference in the pressure ratios of the two refrigerants R407c and R22 in the operation. Because of these reasons the COP and power consumption of the two refrigerants R407c and R22 are same with a slight variation. But the eco friendly nature of the refrigerant R407c finds more applications than R22. The coefficient of performance of R134a is compared with R12 and the coefficient of performance of R407c is compared with R22. By using the refrigerants R134a and R407c the coefficient of performance is increased power consumption decreased for the same refrigeration system. The eco friendly nature of the new refrigerants leads to replacement of the refrigerants R12 and R22 with R134a and R407c. The properties of refrigerants, it is observed that the specific volume of saturated vapour at -15 °C for the four refrigerants is almost same with slight variation and the amount of refrigerant circulated in the refrigeration system is also equal.

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V. CONCLUSION

1. The refrigerant R134a resulting a higher COP value than the COP of refrigerant R12, and the COP of R407c refrigerant is a little bit higher than COP of R22. This shows that replacing the refrigerants R12 and R22 with R134a and R407c refrigerants results the better performance.
2. The specific volume of saturated vapour at -15 C for the four refrigerants is almost same with slight variation. As an affect of that changing of the refrigerants does not affect the functioning of the refrigeration system.
3. The amount of refrigerant circulated in the refrigeration system is almost equal, so replacing the R12, R22 with R134a and R407c does not effect the cost of the system.
4. For the same operating conditions the enthalpy and entropies of R134a and R407c are higher than R12 and R22 respectively.
5. Finally it is justifiable to replace the R12 with R134a and R22 with R407c refrigerants which eco friendly in nature and does not cause global warming.

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