Energy & Exergy Analysis in Vapour Compression Refrigeration System

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Abstract — Simple vapour compression refrigeration system consists of compressor, condenser, evaporator and expansion valve. The steady flow energy and exergy equation is applied to different components of the simple vapour compression system. A comparative analysis of vapour compression refrigeration system is studied by using two different refrigerants viz. R12 and R134a. Two different conditions are taken for the study; by keeping evaporator temperature constant and varying condenser temperature and vice versa. By applying first law of thermodynamics upon the system only the coefficient of performance can be determined but it doesn't give any ideas regarding the loss of energy incurred the system, and this can be overcome by exergy analysis. By applying exergy analysis upon every components of the system, the exergy destruction, COP, Exergetic efficiency, First and Second law of efficiency are calculated. The results obtained are plotted in the form of graphs. It is observed that the coefficients of performance and exergy efficiency are better in case of R12 than R134a. It is also observed that the first and second law of efficiency is higher in R12 than R134a. The COP decreases with decrease of first and second law efficiency. The COP increases with increase of degree of sub-cooling for both the refrigerants.

Index Terms-- COP, Exergy, First law efficiency, Second law efficiency

1 Introduction

From the last eight decades chlorofluorocarbon (CFCs) have been used widely used over air-conditioning and refrigeration system due to its suitable characteristics such as non-toxic, non-flamable, low freezing point and easy to detects licks, but in recent years it recognized that it produced chlorine This destroys the earth's ozone layer through stratosphere, which is causing for serious health problems. That's why CFCs is prohibited completely in 2010.So hydrofluorocarbons are presently replacing chlorofluorocarbons only due to it don't contains any chlorine atoms and their ozone depletion potential is zero. Therefore the choice of vapour compression refrigeration system operating fluids must be governed by both the absence of chlorine and bromine atoms in the molecule and a low direct and indirect contribution to the green house effect.

Thermodynamics first law states that "The energy cant created not be destroyed its only transfer it states from one to another" by concerned this law up on refrigeration system it can't gives information on how ,where, and how much system performance is degraded .It only gives information about the coefficient of performances. That's why for knowing the loss of energy by applying the exergy analysis up on the system. It is defined as the exergy is the energy that is available to be use. When the system and the surrounding in equilibrium the exergy is consider as zero. By applying exergy analysis upon every parts of the refrigeration system it is easy to find out loss of energy and in which components, and also identifying main sites of exergy destruction shows the direction for potential improvement.

The only reason for calculating by using exergy analysis by considering one by one components because it is the complex system.There have been several studies by taking the eco-friendly refrigerants on the basis of energy and exergy analysis over vapour compression refrigeration system. The studies are:-

In the year of 2002 Aprea & Greco by taking refrigerants R22 and R407c (azeotropic blend) experimented on the Vapour compression plant with a reciprocating compressor to evaluated the compressor performance using R407c in comparison to R22. They got that over all exergetic performance of R22 is consistently better that of its candidate substitute R407c, and also suggests that R407c is a promising drop in substitute for R22.

Said & Ismail by taking refrigerant R123 & R 134a ,R11 and R12 as coolants by theoretical analysis and got that for a specific amount of exergy, more compression work is required for R123 & R134a than R11 & R12.And also the differences not very high in evaporator temperature by alternating the refrigerants. Also found that evaporation temperature for each condensation temperature, which yields the highest exergetic efficiency.

Aprea & Renno studied experimentally in a commercial vapour compression refrigeration plant which is generally used for preservation of foodstuff by taking R22 and candidate substitute R417A as working fluids, considering nominal frequency of 50Hz.The experiment indicated that R417A is a long term replacement for R22, and also best exergetic performance of R22 than R417A, also calculating exergy destroyed in the plant components.

In the year of 2006 Khalid by applying first law of thermodynamics by taking R22 and its substitute refrigerant mixtures R407C,R410A & R417A.He gives that COP of R417A is 12%

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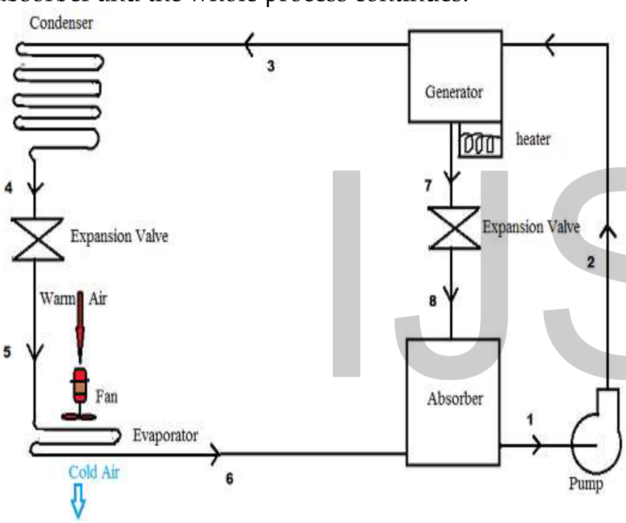
higher than R22 but, R407 and R410A COP is 5% lower thn R22 and R417A.

2 SYSTEM DESCRIPTION

2.1 PROCESS

Vapour compression refrigeration system (VCRS) in which the refrigerant undergoes phase changes in one of the many refrigeration cycles and is the most widely used method for air-conditioning of building and automobiles. It is also used in domestic and commercial refrigeration for chilled or frozen storage for food. All such system have four components a compressor, a condenser thermal expansion valve and an evaporator.

Refrigerant solution is pumped to generator with help of pump. Then it is heated for separating vapour from the solution, then it will go to the condenser where it will condenses. Then the sub cooled liquid go to the expansion valve where it will expand and produced liquid vapour mixture, which go to the evaporator and produced saturated sub cooled vapour only for cooling purposes. Finally the solution is transferred to absorber and the whole process continues.



2.2 ADVANTAGE

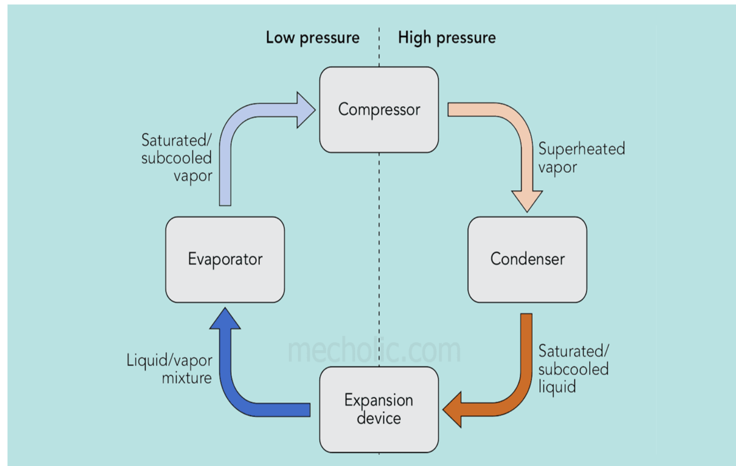
1. Size is small compared to an air refrigeration system.
2. Running cost is low due to volume of refrigerant circulated is low.
3. High coefficient of performance.
4. The operating temperature range is huge.
5. Temperature at the evaporation easily controlled by regulating expansion valve.
6. It requires smaller evaporator.

2.3 DISADVANTAGE

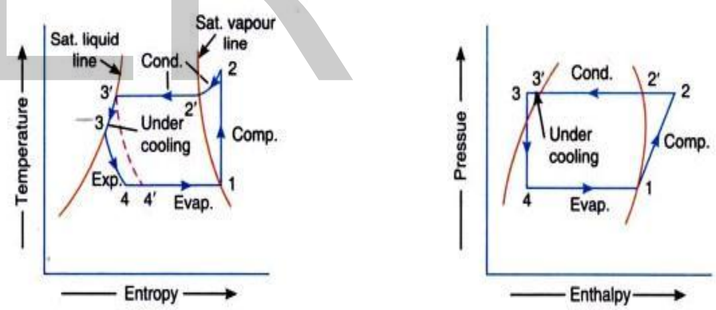
1. High initial cost, costly refrigerants.
2. Environmental hazardous refrigerant involved.
3. Must ensure the prevention of leakage of refrigerants.

2.4 APPLICATION

1. Domestic refrigeration-Keeping food in dwelling units.
2. Commercial refrigeration-Holding and displaying frozen and fresh food in retail outlets.
3. Food processing and Cold storage-Wholesale distribution point.
4. Industrial refrigeration (25KW to 30KW)-Chemical processing cold storage, building and district heating and cooling.
5. Transport refrigeration-Foodstuffs during transport by road, rail, air and sea.
6. Electronics cooling-Low temperature cooling of CMOS circuitry and other components in large computer and servers.
7. Medical refrigeration.
8. Cryogenic refrigeration.



2.5 DIAGRAM



(a) T-s diagram. (b) p-h diagram.

3 MATHEMATICAL MODEL

The system is analysed both from energetic and exergetic point of view.

3.1 ENERGETIC APPROACH

The change in internal energy of a system is equal to the heat added to the system minus the done by the system.

Du =Q-W

Change in internal = Heat added to the system – Work done by the system

By applying above statement (First law of thermodynamics) upon the control volume. Whose mathematical expression is

$$\frac{dE_{cv}}{dt} = \sum_i \dot{m}\left(h + \frac{v^2}{2} + gz\right) - \sum_0 \dot{m}\left(h + \frac{v^2}{2} + gz\right) + \dot{Q}_{cv} - \dot{W}_{cv} \ldots\ldots\ldots\ldots 1$$

Where

E= System energy (J)
t = Time(S)
m = Mass flow rate of refrigerants (kg/s)
h = Specific enthalpy of refrigerants (j/kg)
V2/2 = Specific kinetic energy (j/kg)
gz = Specific potential energy (j/kg)
Qcv & Wcv = Energetic exchange of the control volume with its surrounding in form of heat flux and work rate (power)
i and o = input and out late states respectively

Applying steady state upon equation (1)

$$\dot{Q}_{cv} = \sum_0 \dot{m}\left(h + \frac{v^2}{2} + gz\right) - \sum_i \dot{m}\left(h + \frac{v^2}{2} + gz\right) + \dot{W}_{cv} \ldots\ldots\ldots\ldots 2$$

Taking equation (2) for applying in vapour compression refrigeration system.Kinetic energy and potential energy are negligible, so equation (3)

$$\dot{Q}_{cv} - \dot{W}_{cv} = \sum_0 (\dot{m}h) - \sum_i (\dot{m}h) \ldots\ldots\ldots\ldots 3$$

Applying equation (3) in each components of the vapour compression refrigeration system.

(a) Evaporator

$$\dot{Q}_E = \dot{m}(h_1 - h_4)$$

QE = Refrigeration load

(b) Condenser

$$\dot{Q}_c = \dot{m}(h_3 - h_2)$$

Qc = Heat rejected at the condenser

(c) Compressor

$$\dot{W}_c = \dot{m}(h_1 - h_2)$$

Wc = Rate of work input to the compressor

(a) (d) Throttling Valve

$$\dot{m}h_3 = \dot{m}h_4$$

The energetic efficiency of the system is measured by the coefficient of performance.

(b) COP = Refrigeration load / Work input

$$\frac{\dot{Q}_E}{\dot{W}_E}$$

3.2 EXERGECTIC APPORACH

In thermodynamics the exergy of a system is the maximum useful work possible during a process that brings the system in to equilibrium with a heat reservoir.
The exergetic balance equation for a control volume is

$$\frac{dx_{cv}}{dt} = \sum_o \left(1 - \frac{T_o}{T_r}\right)\dot{Q}_r - \left(w^{\cdot} - P_o\frac{dv_{cv}}{dt}\right) + \sum_i \dot{m}\varphi - \sum_o \dot{m}\varphi - X_{destroyed} \ldots\ldots\ldots 4$$

Where

To = Temperature of the surrounding (Ambient temperature)
Tr = Temperature of the heat source (Highest temperature)
Qr = Heat energy rejected by condenser
W = Work done in compressor
Po = Energy absorbed by evaporator
V = Velocity
Y = Availability function of closed system depends upon both system properties and environment properties.

For applying steady operation equation (4)

$$X_{destroyed} = \sum_o \left(1 - \frac{T_o}{T_r}\right)\dot{Q}_r - W + \sum_i \dot{m}\varphi - \sum_o \dot{m}\varphi \ldots\ldots\ldots 5$$

Applying the exergetic balance equation to each component of the vapour compression refrigeration system.

(a) (a)Evaporator

$$\dot{X}_E = \left(1 - \frac{T_o}{T_r}\right)\dot{Q}_E + \dot{m}(h_4 - T_oS_4) - \dot{m}(h_1 - T_0S_1) \ldots\ldots\ldots 6$$

(b) (b)Compressor

$$\dot{X}_c = \dot{m}(h_1 - T_oS_1) + \dot{W}_c - \dot{m}(h_2 - T_0S_2) \ldots\ldots\ldots 7$$

(c)Condenser

$$\dot{X}_{cond} = \dot{m}(h_2 - T_oS_2) - \dot{m}(h_3 - T_0S_3) \ldots\ldots\ldots 8$$

(d)Throttling valve

$$\dot{X}_{exp} = \dot{m}(h_3 - T_oS_3) - \dot{m}(h_4 - T_0S_4) \ldots\ldots\ldots 9$$

Here throttling process is isenthalpic process

h3 = h4

Therefore equation (10) can be expressed as

$$\dot{X}_{exp} = \dot{m}T_o(S_4 - S_3) \ldots\ldots\ldots 10$$

The total exergy destruction rate

$$\dot{X}_T = \dot{X}_E + X_C + \dot{X}_{cond} + X_{exp} \ldots\ldots\ldots 11$$

The overall system exergetic efficiency is the ratio of the exergy output (Xout) to exergy input (Xin)

$$\Re_x = \left(\frac{\dot{X}_{out}}{\dot{X}_{in}}\right) \times 100\% \ldots\ldots\ldots\ldots 12$$

The only source of exergy input to the system is through the electrical power supplied to the compressor that is Xin = Wc, can be expressed as

$$\Re_x = \left(\frac{W_c - \dot{X}_T}{W_c}\right) \times 100\% \ldots\ldots\ldots\ldots 13$$

3.3 FIRST LAW OF EFFICIENCY

First law efficiency is identical to the popular meaning of efficiency - recognizing explicitly the first law of thermodynamics - i.e., the useful output of an energy converter divided by the input energy.

¶1=Qc/Wc…..………………………….14

3.4 SECOND LAW OF EFFICIENCY

Second law o efficiency is defined as the ratio minimum exergy which must be consumed to do a task divided by the actual amount of exergy consumed in performing the task.
It is defined as minimum exergy intake to actual exergy intake.

¶2=¶1*(1-To/Tc)……………………………….15

4 RESULTS & DISCUSSION

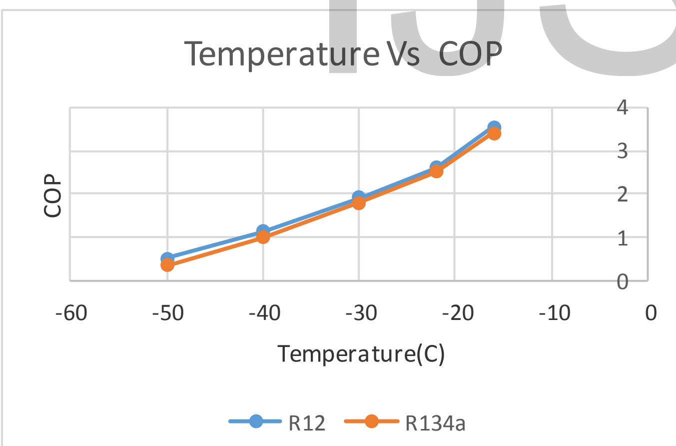


Fig-1

It shows that COP increases with increase of temperature. COP of R12 is higher than R134a.Variation of COP with varying evaporator temperature of both the refrigerants.

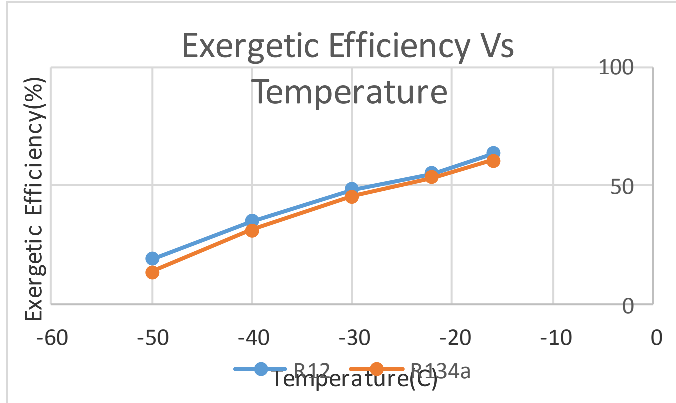


Fig-2

Exergetic efficiency of both the refrigerants decreases with increase in temperature.The exergetic efficiency of R12 is high thanR134a.

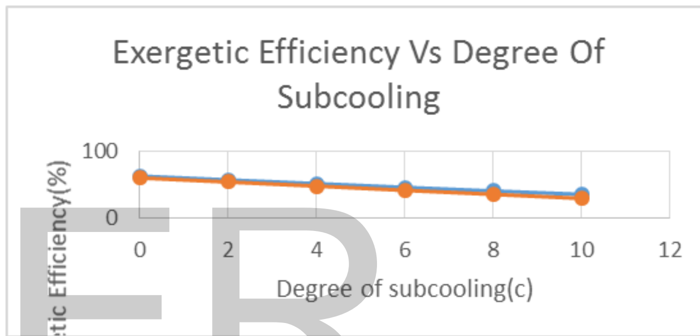


Fig-3

The variation of exergetic efficiency with degree of sub cooling. The exergetic efficiency is more when the degree
Of sub cooling is less.

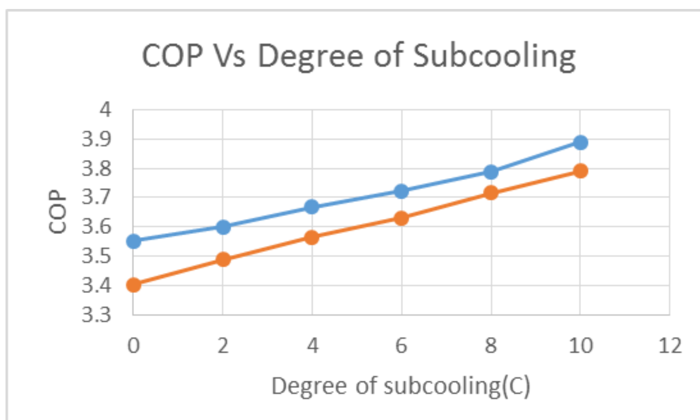


Fig-4

Variation of COP with degree of sub cooling.COP increases with increases in degree of sub cooling for both the refriger nt.

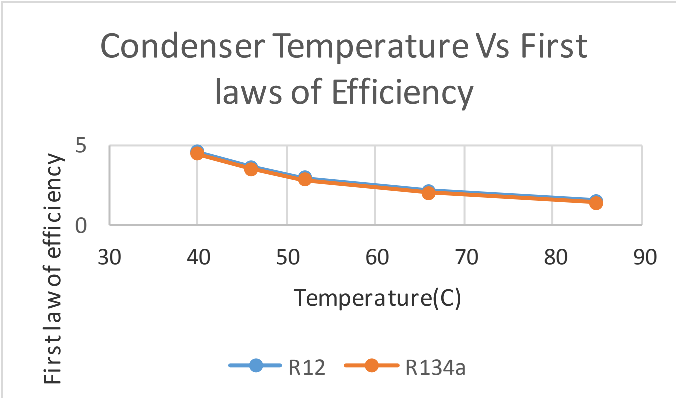


Fig-5

Condenser temperature increases with decreases of First law of efficiency of both the refrigerants.First law of efficiency of R12 is higher than R134a.

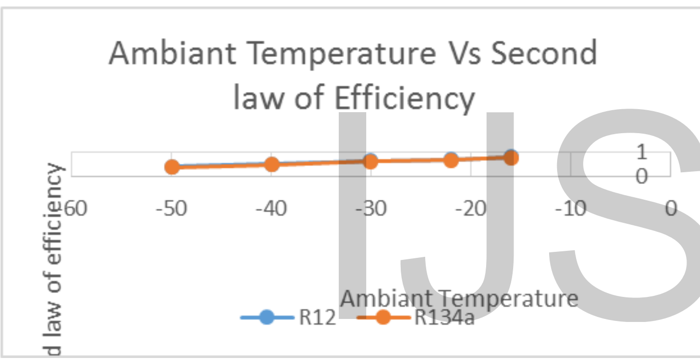


Fig-6

Second law of efficiency of R12 is higher than R134a as corresponding ambient temperature.

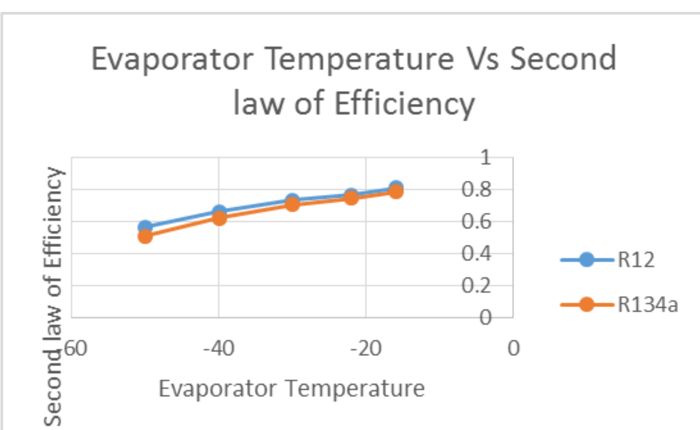


Fig-7

Evaporator temperature decreases with decreases of Second law of efficiency.Evaporator temperature is high with high of Second law of efficiency.

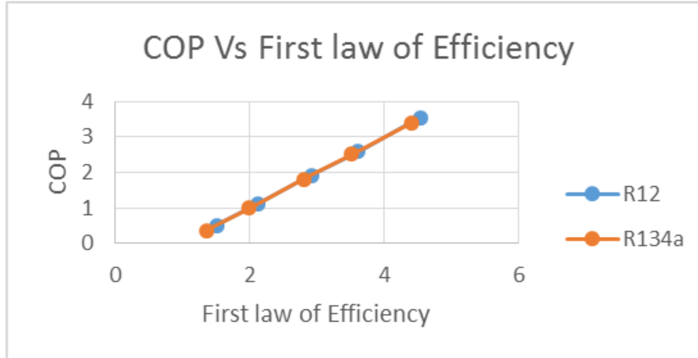


Fig-8

COP decreases with decreases of First law of efficiency.COP is high with high of First law of efficiency.

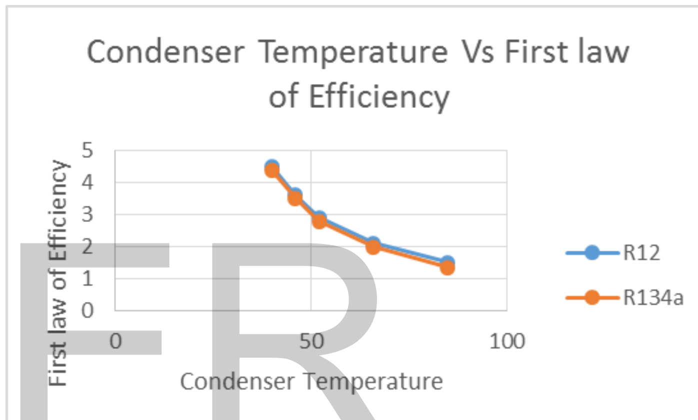


Fig-9

Condenser temperature increases with decreases of First law of efficiency of both the refrigerants.At low condenser temperature high first law of efficiency.At high condenser temperature low first law of efficiency.

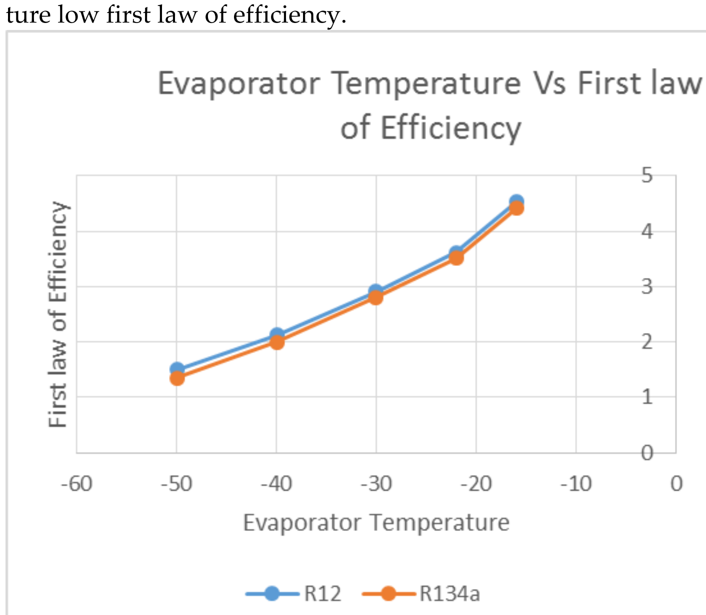


Fig-10

Evaporator temperature decreases with decreases of first law of efficiency of both the refrigerants.At high temperature the first law of efficiency is high.

5 CONCLUSIONS

In one stage vapour compression refrigeration system by taking two refrigerants that is R12 and R134a are calculating coefficient of performance, exergetic efficiency, first and second law of efficiency. The effects of evaporator temperature and sub-cooling were studied on the system operation and performances. Exergy destruction is applied in each components of vapour compression refrigeration system. By taking all values comparing among them and plotted graphs, finally concluded that the COP, Exergetic efficiency, First and Second law of efficiency of R12 is better than R134a.

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