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EXERGY ANALYSIS OF VCR -SYSTEM WITH MINT GAS, R-12, AND R-134A

Vikash Kumar[1], Amit Kumar Dubey[2], Chandra Bhan[3]
[1]Assistant Professor, Shekhawati Institute of Engineering and Technology Sikar(RJ)

ABSTRACT: A domestic refrigerator designed to work with R-134a was investigated to assess the possibility of using a mixture of propane and iso- butane (Mint Gas). The performance of the refrigerator using azotropic mixture as refrigerants was investigated and compared with the performance of refrigerator when R-134a, R12, is used as a refrigerant. The effect of Condenser Temperature and Evaporation Temperature on Coefficient of Performance, refrigerant effect, work of compressor and heat rejection ratio where investigated. The energy consumption and C.O.P of hydrocarbons and there blends shows that hydrocarbons can be used as refrigerants in the domestic refrigerator. The exergy analysis of mixture of propane and isobutene (mint gas) with R-12 and R-134a. The cycle considered for study is having super heated vapour after compression. Efforts have been made to consider sub cooling also.
Keywords: Exergy, subcooling superheating of mint gas, R134a, R-12

I. INTRODUCTION

A home refrigerator is a home appliance, usually a container with doors used to store food and reduce food bacterial growth by using Vapor Compression cooling. Vapour Compression Cooling is the method of removing heat from the inside and releasing it to the surrounding with the evaporation of refrigerant. An example of home refrigerator can be seen in figure 1.

A typical home refrigerator consists of these five basic parts:

- Compressor
- Condenser
- Expansion valve
- Evaporator
- Refrigerant

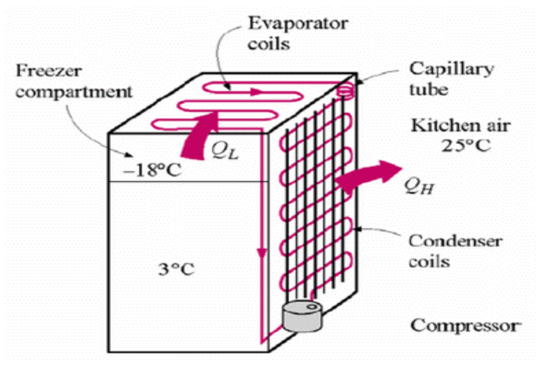

Fig 1
THE REFRIGERATION CYCLE.

The physic provides fundamental support to the idea of refrigeration cycle. A refrigeration cycle is the circulating process in which heat is taken from one region and released into the surroundings. Every home refrigerator is a live application of this concept. The operating principal of a refrigerator is that the energy is drawn from outside, particularly electricity. Every refrigerator requires electricity to operate. While plugged in the refrigeration cycle is able to circulate. A refrigeration cycle consists of four steps: compression, condensation, expansion and evaporation. In this section, these steps will be explained in detail.

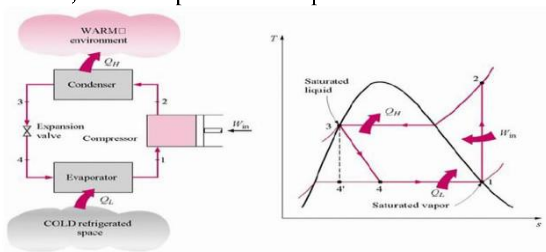

Fig 2: Global warming and ozone depletion potential

The refrigerant R-12 and R-134 has been widely used as a refrigerant in refrigeration and air conditioning due to their performance parameters and availability. But R-134 and R-12 have higher global warming. Global warming is increasing temperature of the earth which results an increase of water level in the oceans affecting the marine life and the coastal regions. In 1974 Sherwood Rowald and Mario Molina predicted that chlorofluorocarbon refrigerant gases reach the high stratosphere and there damage the protective mantle of the oxygen allotrope, ozone. In 1985, with discovery of the “ozone hole” over the Antarctic, the prediction of Rowald and Molina’s was proved correct. Worldwide attempts are being made to phase out the production and consumption of chloro fluorocarbons, as these chemicals are responsible for depletion of stratospheric ozone layer. During the last decade, the number of refrigerants likely to be used has dramatically increased as a consequence of the elimination of CFC’S and HCFC’S. Even the measure taken so far, as late 2008, a 2.7 million square kilometers ozone layer hole was detected above Antarctic. CFC’S are very stable, have a long life in the lower atmosphere and in spite of CFC’s being heavier than N2 and O2 , these slowly migrate in to the upper atmosphere by molecular diffusion caused by partial pressure difference. It was hypothesized that the chlorine atoms from the molecule would be split off by the action of sun light, and the free chorine will react with the ozone in the atmosphere,

MINT GAS

Mint gas is an azeotropic mixture of propane (R290) & isobutane (R600a).It has property very similar to R12 & R 134 which is commonly used refrigerant now a days. This blend of hydrocarbons is used in most of the ac of European cars. It contains 60% propane+40%iso butane. It is named as mint gas because it has cooling property like mint. Moreover it has zero ozone depletion potential and a negligible global warming potential (the two property due to which we need to replace the CFC's).

This blend is used for domestic refrigerators because of its following reasons-

- Operates at similar pressure to R-12 & R-134.
- Posse's similar volumetric refrigerating effect to R-12 and R-134a.
- Can be used in a R-12 or R-134a compressor.
- Can be used with R-12 or R-134a heat exchangers and expansion devices.
- Compatible with most common refrigeration materials and lubricants.

II. LITERATURE REVIEW

Remi Revellin, Jocelyn Bonjour [1] the authors have made the exergy analysis of direct replacement of R12 with the zeotropic mixture R413A on the performance of a domestic vapour compression refrigeration system originally designed to work with R12. Parameters and factor affecting the performance of both refrigerants are evaluated using an exergy analysis. In the literature no experimental data for exergy efficiency were reported. The working temperature is kept in between -100c to 150c. The evaporator and condenser air-flows are modified to simulate different evaporator cooling loads and condenser ventilation load. The overall energy and exergy performance of the system working with R413A is continuously better than that of R12.

B.O.Bolaji, M.A.Akintude [2] the authors have evaluated the performance of three ozone friendly hydrocarbons refrigerants in a vapour compression refrigeration cycle. The result obtained showed that R32 yielding undesirable characteristics such as high pressure and low coefficient of performance. Compression among investigated refrigerants confirmed that R152a and R134a could be used as a drop in replacement of R134a in vapour compression refrigeration system. The C.O.P of R152 was higher than that of other refrigerants.

M. Boumaza [3] the author found that due to the environmental concerns ozone depletion potential (ODP) and global warming potential (GWP) of the existing refrigerants, industry and researchers have to look in this field and investigating long-term solutions. With extensive work on alternatives to chlorofluorocarbons (CFCs) and hydro chlorofluorocarbons (HCFCs), initially hydro fluorocarbons were considered to be long-term solutions. The global warming of HFCs has become a hurdle to accept them as long-term solutions. Now, the focus is on the use of natural refrigerants like hydrocarbons (HCs) such R290, R600, ammonia, carbon dioxide and water. These natural substances have very low GWP, and a zero ODP. This paper presents simulation results through a thermodynamic analysis of R22 and three of its alternatives natural refrigerants (R290, R600a and R717) for A/C and refrigeration purposes operating under various outdoor temperatures, represented by the condenser temperatures. The examined new refrigerants show varying performance, depending on the evaporator temperatures, but in every case, the condenser temperature seems to have an important impact on the performance of the cycle.

PiotrA.Domanski,David Yashar,Minsung kim [4] the author has presented a comparable evaluation of R600A, R290, R134A in a finned tube evaporator model derived from NIST's EVAP-COND simulation package and used the circuitry designs were generated and evaluated for each refrigerant. The obtained results were evaporation effects the C.O.P spread for the studied refrigerants

Camelia, Adina [5] there study deals with a comparative analysis of the refrigerant impact on the operation and performances of a one stage vapor compression refrigeration system. Parameters and factors affecting the performances (in terms of refrigeration power, coefficient of performance, mechanical work consumption, etc) are evaluated on the basis of an exergy analysis. Different sensitivity studies are presented in a comparative manner for some refrigerants (R22, R134a, R717, R507a, and R404a). Graphical and numerical results are included. The effect of compression ratio is emphasized for the system operation working with these refrigerants, affecting the operation regime (maximum accepted temperature), respectively the performances of the system. Also the effects of sub cooling and superheating are shown. As conclusion, a comparative analysis between energetic base COP and exergetic efficiency is presented

kim,park [6] the author has studied several emerging refrigerants as a substitute of R134a the most widely used refrigerant in the world. In his study a thermodynamic model of refrigeration cycle was prepared and the study is made on it. In his study he has found that R407A can be a potential replacement of HFC refrigerants.

B.O.Bolaji [7] according to the author the production and use of R12 and other chlorofluorocarbon refrigerants will be prohibited completely all over the world in the year 2010 due to their harmful effects on the earth's protective ozone layer. Therefore, in this study, the exergetic performance of a domestic refrigerator using two environment- friendly refrigerants (R134a and R152a) was investigated and compared with the performance of the system when R12 (an ozone depleting refrigerant) was used. The effects of evaporator temperature on the coefficient of performance (COP), exergy flow destruction, exergetic efficiency and efficiency defect in the four major components of the cycle for R12, R134a and R152a were experimentally investigated. The results obtained showed that the average COP of R152a was very close to that of R12 with only 1.4% reduction, while 18.2% reduction was obtained for R134a in comparison with that of R12.

B.O.BOLAJI [8] the authors study presents experimental results of investigation of effects of sub-cooling on the performance of four ozone-friendly alternative refrigerants (R32, R152a, R143a, and R134a) in a domestic refrigeration system. The study was performed using a system designed for R12 with the aim of finding a drop-in replacement for the refrigerant. The results obtained showed that the sub-cooler in the refrigeration system positively affected the system performance and all the investigated refrigerants benefited from the performance improvement. An increase in sub-cooling effectiveness reduces the compressors work input and increases the system refrigeration capacity. Also, an increase in the degree of sub-cooling, reduces the pressure ratio, and increases both the refrigerant mass flow rate and coefficient of performance (COP) of the system. The comparison of the performance of R12 and the investigated alternative refrigerants showed that R152a and R134a have the most similar performance characteristics to R12, with R152a having a slightly better performance. These two refrigerants are the best replacements for R12 in a domestic refrigeration system. The performances of R32 and R143a were significantly lower than that of R12.

In this paper, the performances of three ozone-friendly Hydrofluorocarbon (HFC) refrigerants (R32, R134a and R152a) in a vapour compression refrigeration system were investigated experimentally and compared. The results obtained showed that R32 yielded undesirable characteristics, such as high pressure and low Coefficient of Performance (COP). Comparison among the investigated refrigerants confirmed that R152a and R134a have approximately the same performance, but the best performance was obtained from the used of R152a in the system. As a result, R152a could be used as a drop-in replacement for R134a in vapour compression refrigeration system. The COP of R152a obtained was higher than those of R134a and R32 by 2.5% and 14.7% respectively. Also, R152a offers the best desirable environmental requirements; zero Ozone Depleting Potential (ODP) and very low Global Warming Potential (GWP).

This work presents an experimental study on the application of hydrocarbon mixtures to replace HFC-134a in a domestic refrigerator. The hydrocarbons investigated are propane (R290), butane (R600) and isobutane (R600a). A refrigerator designed to work with HFC-134a with a gross capacity of 239 l is used in the experiment.

III. SYSTEM DESCRIPTION

The typical lay out of the Vapour compression system

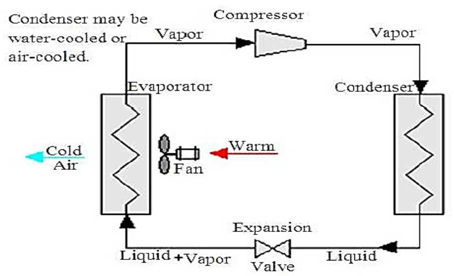

Fig. 3: Schematic Diagram of System Layout

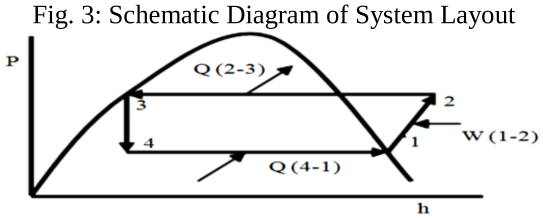

Fig. 4. Pressure Enthalpy Diagram of Vapour Compression System

The typical lay out of the Vapour compression system in shown in Fig.3. Refrigerant leaves the evaporator, now fully vaporized and slightly heated and returns to the compressor inlet to continue the cycle

The above Fig. 4 represents the pressure-enthalpy (p-h) diagram of a theoretical vapour compression refrigeration cycle. In this cycle, the refrigerant enters the compressor at state 1 at low pressure, low temperature and is compressed isentropically to dry saturated vapour state. The compressed dry saturated refrigerant is discharged at state 2 as a high pressure, high temperature and superheated vapour. The superheated vapour enters the condenser where it gives out the latent heat to the surrounding condensing medium.

The refrigerant enters the expansion devise where it experiences a sudden drop in the pressure and superheated vapour refrigerant is converted into partial wet vapour. The liquid vapour mixture of the refrigerant enters the evaporator at state 4 where it absorbs latent heat of vaporization from the medium which is to be cooled. The heat that is absorbed by the refrigerant at this stage is called the refrigeration effect. The refrigerant leaves the evaporator at low pressure, low temperature and saturated vapour at point 1 and the cycle is completed. The main characteristics of the tested refrigerants as shown in Table 1.

IV. PERFORMANCE ANALYSIS

For analysis the performance of vapour compression refrigeration system, following assumption are made:

- ✓ Degree of subcooling of liquid refrigerant in liquid-vapour heat exchanger (□ Tsub) = 5K.
- ✓ Mechanical efficiency of compressor ( ) = 80%.
- ✓ Difference between evaporator and space temperature (Tr – Te) = 20 °C.
- ✓ Evaporator temperature Tevap (in °C) ranging from –40 °C to -10 °C.
- ✓ Condenser temperature Tcond = 40 °C.
- ✓ Dead state temperature (To) = 27 °C.
- ✓ There is no pressure loss in pipelines.
- ✓ In all components steady state operations are considered.

The energy analysis based on first law of thermodynamic, the performance of vapour compression refrigeration system can be predicted in terms of Coefficient of Performance (COP), which is defined as the ratio of net refrigerating effect produced by the refrigerator to the work done by the compressor. It is expressed as:

CALCULATION AND FORMULATION

$T_{1=}$ Temperature of evaporator
$T_{2=}$Temperature of compressor suction
$T_{3=}$Temperature of compressor discharge
$T_{4=}$ Temperature of condenser discharge
$h_1, h_2, h_3, h_4,$ enthalpies of respective temperatures and s_1, s_2, s_3, s_4 entropies of respective temperatures

1. Mass flow rate (m) = kg/m
2. Refrigeration effect = h_2-h_1 kj/kg
3. Compressor power = $\frac{m(h_3-h_2)}{60}$ KJ/KG
4. Condenser heat rejected = $m(h_3-h_1)$ kj/kg
5. **C.O.P.** = <u>Refrigeration effect</u>

Compressor power
Exergy flow destruction in individual component

1. EXERGY OF COMPRESSOR

The irreversibility or exery loss in compressor

$I_{compressor} = mT_{\circ}[s_3 \text{-} s_2]$ kw

Whereas m is the mass flow rate of refrigerants(kg/s); T_0 is the ambient temperature(K);S is the specific entropy(KJ/Kgk)

2. EXERGY OF CONDENSER

The exergy loss in condenser is presented as;

$I_{condensr} = [m(h_3 \text{-} h_4) - T_{\circ}(s_3 \text{-} s_4)] - Q_c(1-\frac{T0}{T4})$

Where Q_C heat transferate in condenser(KW); T_4 Condenser outlet temperature(K) ; $I_{condenser}$ is the exergy destruction of condenser(KW)

3. EXERGY OF EXPANSION VALVE

The exergy destruction in expansion valve is given by;

$$I\ des\_exp = m[(h4 - h1) - T0(S4 - S1)]$$

Where $I_{des\_}$ exp is the exergy destruction in expansion valve(KW)

4. EXERGY DESTRUCTION IN EVAPORATOR

The exergy destruction in evaporator is given by $I_{des\_eva} = m[(h_2 \text{-} h_1) - T_0(S_2 \text{-} S_1)] - Qe(1-\frac{T0}{T1})$

Where Qe heat transfer rate in evaporator (KW):$T_1$is the exit of expansion valae(K);I_{des_eva} is the exergy destruction in evaporator (KW)

5. EXERGY EFFICIENCY OF THE SYSTEM

The exergy destruction rate (X_t) is given by;

$X_t = I_{des\_c} + I_{des\_con} + I_{des\_exp} + I_{des\_eva}$

The overall system exergetic efficiency is the ratio of exergy output (X_{out}) to
Exergy input (X_{in});

$\acute{\eta}_{exergetic} = \frac{Exergy\ \ output}{Exergy\ \ input}$

$\acute{\eta}_{exergetic} = \frac{Xout}{Xin} X100\%$

$X_{out} = X_{in} - X_t$

Exergy input to the system is supplied through the compressor work. Therefore

$X_{in} = W_c$

$\acute{\eta}_{exergtic} = (1-\frac{Xt}{Wc})x100\%$

V. RESULTS AND DISUSSION

The refrigerant enters the expansion devise where it experiences a sudden drop in the pressure and superheated vapour refrigerant is converted into partial wet vapour. The liquid vapour mixture of the refrigerant enters the evaporator at state 4 where it absorbs latent heat of vaporization from the medium which is to be cooled. The heat that is absorbed by the refrigerant at this stage is called the refrigeration effect. The refrigerant leaves the evaporator at low pressure, low temperature and saturated vapour at point 1 and the cycle is completed. The main characteristics of the tested refrigerants.

1. VARIATION OF EXERGY PERCENT WITH EVAPORATIVE TEMPERATURE

Shown in the graph and table the compared of exergy percent three different refrigerants mint gas, R-12 ,R134a when the evaporator temperature decreasing the exergy percent also increasing but the mint gas exergy more than R-12.and R-134a.

EVAP-TEMP	MINT GAS	R-134a	R-12
-4	57.92	53.11	50.40
-8	59.16	56.61	53.38
-12	61.2	59.4	58.32
-16	63.12	61.12	59.26

Table 5.1 : Exergy percent with Evaporative Temperature

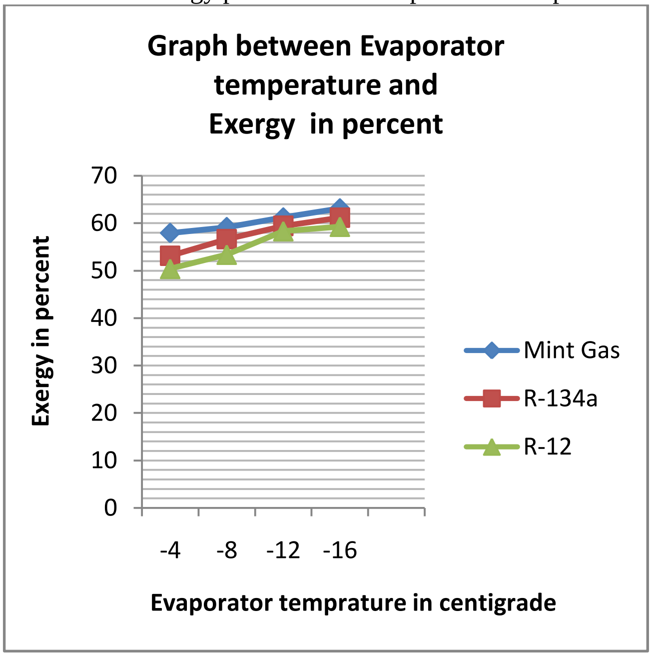

Figure No 5.1 Graph between Exergy percent with Evaporative Temperature

2. VARIATION OF EXERGY DEFECT IN COMPRESSOR WITH EVAPORATIVE TEMPERATURE

This is the comparison of exergy defect in the compressor. There are three refrigerant R-12, R-134a, and mint gas and when the evaporator temperature decreasing the defect also decreasing and mint gas defect is minimum as compared to R-12,R134a..

EVAP-TEMP	MINT GAS	R-12	R-134a
-4	0.013	0.041	0.054
-8	0.013	0.037	0.053
-12	0.017	0.027	0.042
-16	0.011	0.018	0.038

Table 5.2 Exergy defect in compressor with Evaporative Temperature

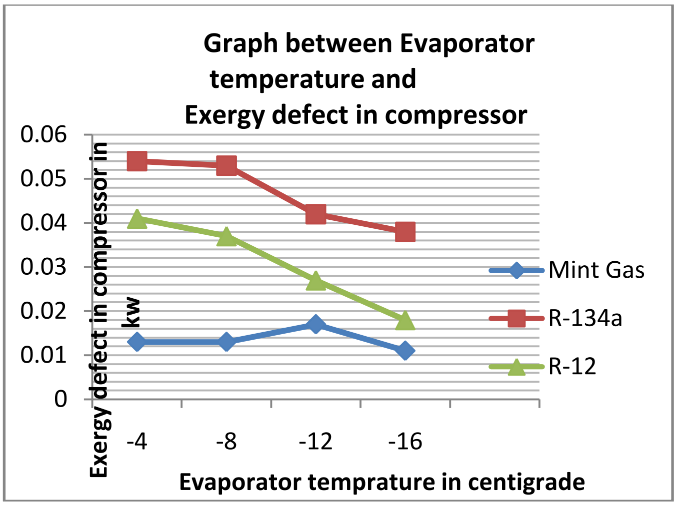

Figure No 5.2Graph between Exergy defect in compressor with Evaporative Temperature

3. VARIATION OF EXERGY DEFECT IN CONDENSER VARIOUS REFRIGERANTS WITH EVAPORATIVE TEMPERATURE

In condenser when the evaporator temperature decreasing the exergy defect also decreasing and exergy defect of mint gas is minimum as compare to R-12 and R134a

EVAP-TEMP	MINT GAS	R-134a	R-12
-4	0.020	.065	0.041
-8	0.017	0.053	0.0377
-12	0.0135	0.042	0.027
-16	0.0130	0.038	0.018

Table 5.3 : Exergy defect in condenser with Evaporative Temperature

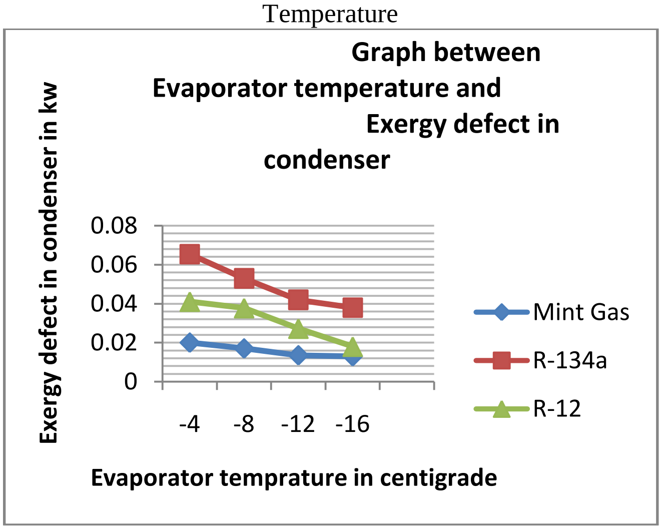

Figure No 5.3 Graph between Exergy defect in condenser with Evaporative Temperature

4. VARIATION OF EXERGY DEFECT IN EXPANSION VALVE VARIOUS WITH EVAPORATIVE TEMPERATURE

Exergy defect in expansion valve shown in the table and graph when the evaporator temperature decreasing the exergy defect also increasing with respect to the evaporative temperature and expansion defect is minimum in mint gas as compared to other refrigerant (R-12,R-134a)

EVAP-TEMP	MINT GAS	R-134a	R-12
-4	0.434	0.511	0.462
-8	0.552	0.685	0.575
-12	0.646	0.760	0.683
-16	0.769	1.07	0.843

Table 5.9: Exergy defect in expansion valve with Evaporative Temperature

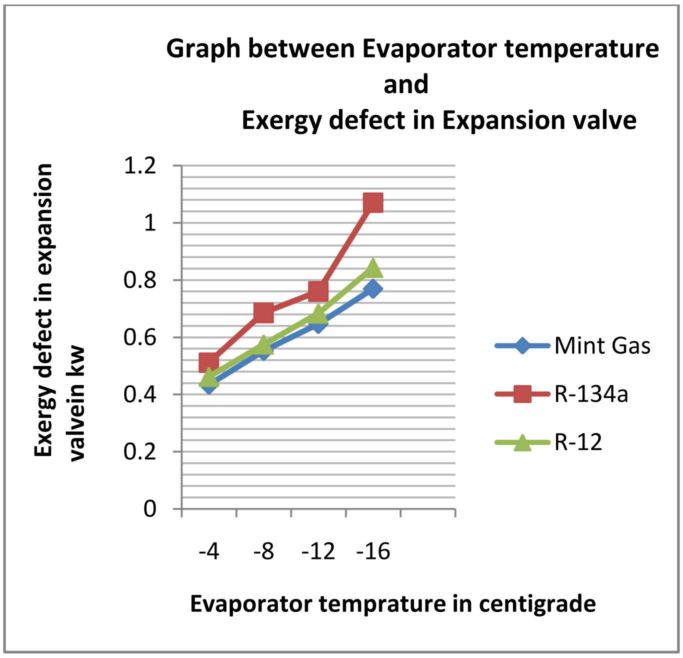

Figure No5.4: Graph between Exergy defect in expansion valve with Evaporative Temperature

5. VARIATION OF EXERGY DEFECT IN EVAPORATOR WITH EVAPORATIVE TEMPERATURE

Exergy defect in evaporator when the evaporator temperature decreasing defect increasing with respect to evaporator temperature but as compare to R-12,R-134a mint gas defect is minimum.

EVAP-TEMP	MINT GAS	R-134a	R-12
-4	0.990	0.807	0.785
-8	0.975	0.999	0.927
-12	1.087	1.183	1.183
-16	1.155	1.221	1.221

Table 5.5: Exergy defect in evaporator with Evaporative Temperature

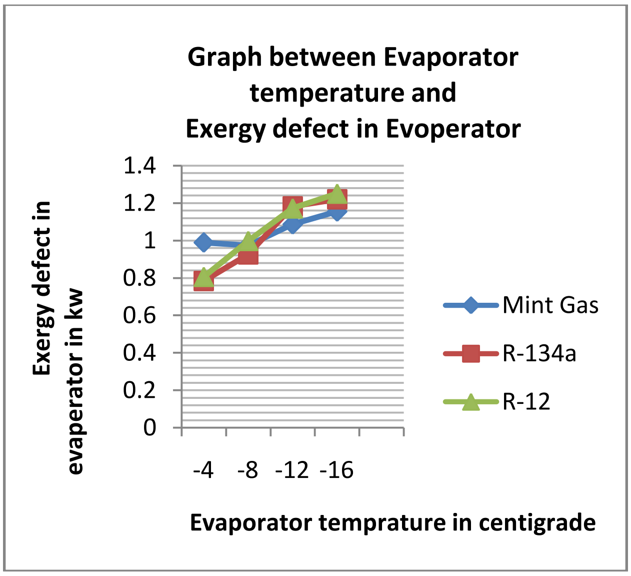

Figure No 5.5 Graph between Exergy defect in evaporator with Evaporative Temperature

VI. CONCLUSION

In the present study different refrigerants has been examined and compared with the mint gas. Mint Gas is presently used in the air-conditioner of European cars. In the present study we have examined the mint gas for the refrigerating purpose. The gas has been tested under the working condition of the refrigerator. The freezing point and the critical temperature of the gas is found satisfactory for the purpose of refrigeration. For checking the performance of the gas the working condition of the refrigerator has been varied. The evaporation and condenser temperature has been varied several times. For checking the available energy of the system exergy analysis has been performed and the results are more satisfactory in compression with the other commonly used refrigerants. Exergy defect in each component has been examined in order to calculate the loss of energy in each component but the results produced by mint gas are more satisfactory then other refrigerants.

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