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Energy analysis of VCR -system with mint gas, R-12 and R-134a

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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 isotropic 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 energy analysis of mixture of propane and isobutene (mint gas) with R-12 and R-134a. The cycle considered for study is having super heated vapor after compression. Efforts have been made to consider sub cooling also.

Indexed Terms: sub cooling 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. Vapor 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

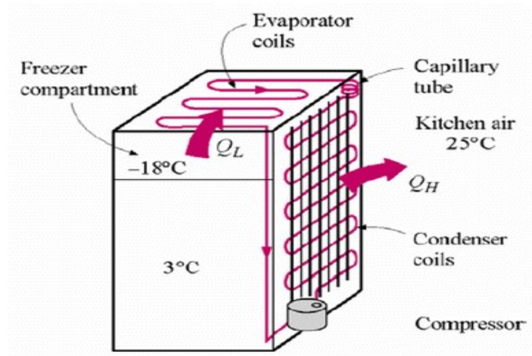

Fig. 1: The Refrigeration Cycle

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.

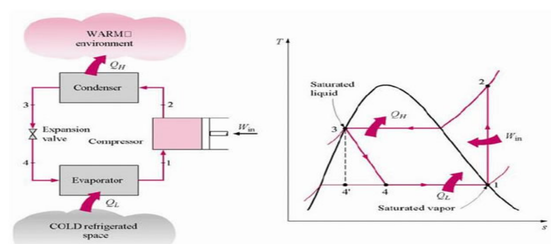

Fig. 2: Global warming and ozone depletion potential

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 N_2 and O_2 , 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) & iso- butane (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

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- 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 -10^0c to 15^0c. 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.

- Piotr A. 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

III. SYSTEM DESCRIPTION

The typical lay out of the Vapor compression system.

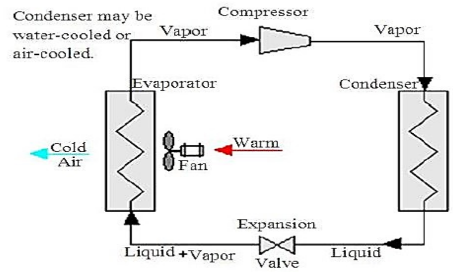

Fig. 3: Schematic Diagram of System Layout

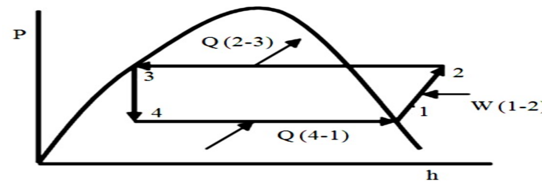

Fig. 4: Pressure Enthalpy Diagram of Vapor Compression System

The typical lay out of the Vapor 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 vapor compression refrigeration cycle. In this cycle, the refrigerant enters the compressor at state 1 at low pressure, low temperature and is compressed isentropic ally to dry saturated vapor state. The compressed dry saturated refrigerant is discharged at state 2 as a high pressure, high temperature and superheated vapor. The superheated vapor 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 vapors refrigerant is converted into partial wet vapor. The liquid vapor 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 vapor 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 vapor 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. = $\frac{\text{Refrigeration effect}}{\text{Compressor power}}$

V. RESULTS AND DISUSSION

1. VARIATION OF C.O.P OF WITH EVAPORATIVE TEMPERATURE:

Shown in the table and graph there are five refrigerant comparison mint gas, R-134a, R-12,R-22, and R-290 when the evaporator temperature decreasing continuously. The C.O.P. also decreasing with respect to the evaporative temperature. Then find out that mint gas C.O.P. is better than other refrigerants .the gases of the decreasing order show below.

Mint gas > R-134a >R-290 > R-22 > R-12

EVAP-TEMP	MINT GAS	R-134a	R-12	R-22	R-290
-4	3.68	2.9	1.39	2.32	2.85
-8	3.48	2.4	1.21	1.44	2.36
-12	2.67	2.15	1.18	1.21	1.97
-16	1.59	1.76	1.10	1.16	1.64
-20	1.73	1.72	1.01	1.02	1.34

Table 1: Variation of C.O.P. with Evaporative Temperature

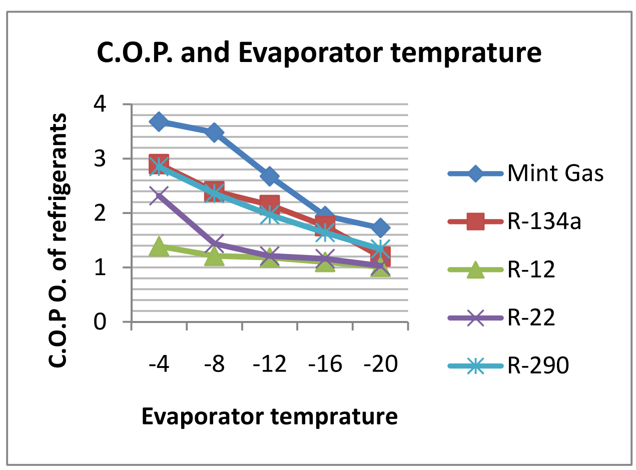

Fig. 5

2. VARIATION OF REFRIGERATION EFFECT WITH EVAPORATIVE TEMPERATURE:

This is the comparison of refrigeration effect with respect to the evaporator temperature when the cycle running and evaporator temperature decreasing the refrigeration effect also decreasing with respect to the evaporator temperature .when compare the other refrigerants then find mint gas refrigerant effect is better than other refrigerants'. The decreasing order of refrigerants shown in below.

Mint gas > R-290 > R-22 > R134a > R12

EVAP-TEMP	MINT GAS	R-134a	R-12	R-22	R-290
-4	193	95.49	80.99	114.04	176.76
-8	215.93	89.66	72.99	109.34	161.92
-12	205.33	83.76	71.23	105.73	147.04
-16	191.42	70.46	64.37	97.74	133.25
-20	175.32	68.01	62.07	95.23	117.64

Table 2

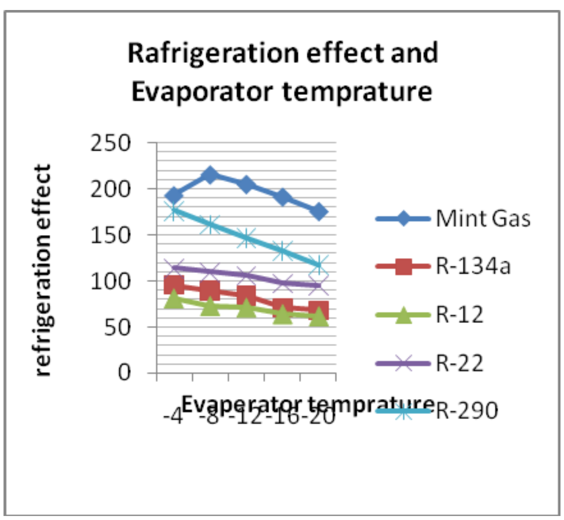

Fig. 6: Graph between Variations of refrigeration effect with evaporator temperature

3. VARIATION OF HEAT TRANSFER RATE WITH CONDENSER TEMPERATURE:

There are five refrigerants comparison with the condenser temperature and heat rejected by the refrigerants in the condensation process. In this process when the condenser temperature increase continuously the heat rejection rate also increasing with respect to the condenser temperature and find out mint gas heat rejection rate minimum as compare to other refrigerant.

Mint gas < R134a < R290 < R22 < R12

COND-TEMP	MINT GAS	R-134a	R-12	R-22	R-290
68	140.74	155.36	199.06	165.41	157.76
70	150.09	163.71	211.43	196.1	165.97
72	160.52	168.84	229.32	205.73	174.89
75	176.16	182.11	240.81	212.85	186.31
78	180.85	183.56	252.44	232.81	203.39

Table 3

4. VARIATION OF MASS FLOW RATE WITH EVAPORATIVE TEMPERATURE:

It is the comparison of the mass flow rate various refrigerants and evaporator temperature when the evaporator temperature decreasing the mass flow rate increasing but as compare the other refrigerant mint gas minimum mass flow rate increase same evaporator temperature. Shown in minimum to maximum mass flow rate refrigerants order.

Mint gas < R290 < R22 gas < R134a< R12

EVAP-TEMP	MINT GAS	R-134a	R-12	R-22	R-290
-4	0.50	1.20	1.44	1.02	0.66
-8	0.54	1.30	1.59	1.06	0.72
-12	0.56	1.39	1.68	1.10	0.79
-15	0.60	1.65	1.81	1.19	0.87
-20	0.66	1.70	1.88	1.26	0.99

Table 4

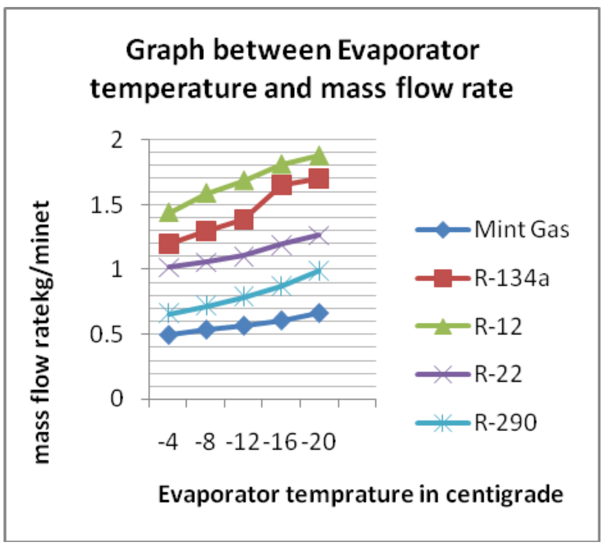

Fig. 7: Graph between mass flow rates with Evaporative Temperature

5. VARIATION OF COMPRESSOR POWER WITH EVAPORATIVE TEMPERATURE:

In the above table shown when the evaporator temperature slowly decreasing the compressor power increasing. When compare with other refrigerants then find out mint gas require minimum power to drive the compressor compare the other refrigerant.

Mint gas < R-134a < R-290 < R22 < R12

EVAP-TEMP	MINT GAS	R-134a	R-12	R-22	R-290
-4	0.43	0.68	1.37	0.81	0.68
-8	0.55	0.78	1.49	1.18	0.82
-12	0.74	0.89	1.82	1.60	0.97
-16	0.99	1.09	2.06	1.75	1.17
-20	1.02	1.12	2.30	1.90	1.44

Table 5: Variation of compressor power with Evaporative Temperature

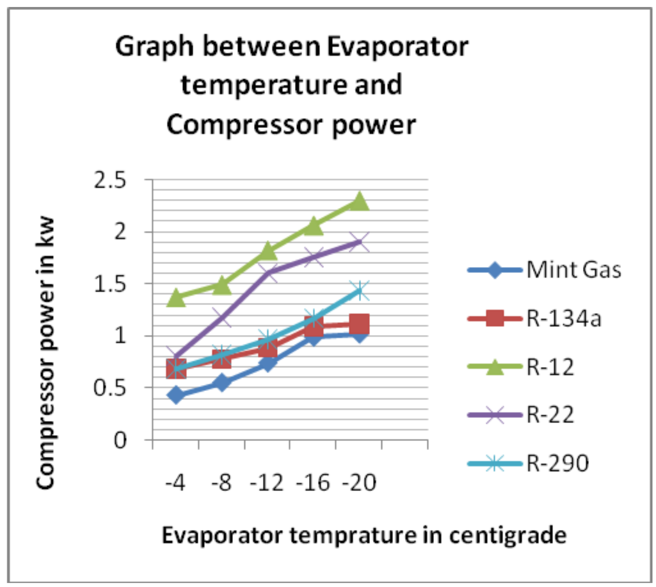

Fig. 8: Graph between Variations of compressor power with Evaporative Temperature

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 energy analysis has been performed and the results are more satisfactory in compression with the other commonly used refrigerants. Energy 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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