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Effect of different refrigerants on vapor compression refrigeration system-A review

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***Abstract* - The refrigeration technology has quickly become popular in society, because of its wide range of applications. The term refrigeration refers to cooling of particular space or substance below the atmospheric temperature. Refrigeration system basically involves evaporation of liquid refrigerant by absorption of latent heat from its surrounding in order to produce the required cooling effect. One of the most important applications of refrigeration has been the preservation of perishable food products by storing them at low temperature. Different refrigeration systems are; vapor compression, steam-jet or steam-ejector, vapor absorption and air refrigeration system. The most commonly used method of cooling is with vapor compression cycle(VCC) because it is fairly easy to construct a cooling device employing this method and the cost is low. A VCC consist of a liquid refrigerant as a working medium which undergoes phase changes. There are different refrigerants used from last few decades depending upon their requirements. This paper epitomizes effects of different refrigerants on VCC and their performance and analysis have been reviewed. the main purpose is not only to provide an equivalent for any refrigerant but it has to be considered that it also abate the rate of harmful emissions due to leakages in refrigerating components. Some refrigerant mixtures can be blended with conventionally used refrigerants like R12 and R22 as possible alternative replacements. with the use of some refrigerants environmental impact of ozone layer depletion and global warming can be reduced to great extend.**

***Keywords* - refrigeration, evaporation, refrigerant, cooling, compression, absorption, emission**

I. INTRODUCTION

Refrigeration: Refrigeration is a process of extracting heat from a space to be cooled in controlled conditions. The work supplied to remove the heat is mechanical work, but also the system can be driven by heat, magnetism, electricity, laser or other means.

The idea of preserving food began at a particular time in past from the ancient Roman and Chinese empires. The use of natural refrigeration (refrigeration without using refrigeration equipments) began in the distant past, early in the 20th century natural production of ice was much bigger than man-made ice. Natural ice was originated in cold regions and was transported over a large distances. Once, harvested, the ice had to be stored in ice storage equipments with thermally insulated walls. the chilling effect of addition of certain salts to water was discovered further. It has wide range of applications, some of them are as follows:

A. Commercial refrigeration
B. Domestic refrigeration
C. Food processing and cold storage
D. Transport refrigeration
E. Cooling of electronics
F. Magnetic cooling and air conditioning in buildings houses

1.1 Refrigeration effect: the cooling effect that would be produced due to circulation of the refrigerant throughout the cycle is called as refrigeration effect.

1.2 Coefficient of performance of refrigerator (C.O.P): it is the ratio of amount of heat energy extracted in the refrigerator at the low temperature to the work supplied to operate the cycle.

$$\mathbf{C.O.P = \frac{Q}{W}}$$

Where,
Q = amount of heat extracted in the refrigerator (or amount of refrigeration produced, or the capacity of a refrigerator).
W = work supplied to operate the cycle.

II. REFRIGERANT

It is the working medium which carries the heat and undergoes phase change throughout the refrigeration cycle. An ideal refrigerant should liberate all the heat which it is capable of absorbing. There are basically two types of refrigerants,

- **Primary refrigerants:** those refrigerants which cools the space by absorption of its latent heat. Such as, carbon dioxide, fluorinated hydrocarbons, ammonia, methylene chloride, sulphur dioxide and mythyl chloride.

- **Secondary refrigerants:** those refrigerants which cools the space by absorbing their sensible heat. Such as water, air, calcium chloride brine solution, sodium chloride, brine, glycol, etc.

2.1 Refrigerants are also classified as:
CFC: They are molecules composed of carbon, fluorine and chlorine. They are stable and reach the stratosphere without too many problems and hence, contributes to the destruction of the ozone layer. These are R11, R12, R113, R500, R502 etc.
HCFC: They are molecule composed of carbon, chlorine, fluorine and hydrogen. They are less stable than CFCs, destroy ozone to a lesser extent. Such as R22, R123, R124, R401a etc.
HFC: They are molecules composed of carbon, hydrogen and fluorine .They do not contain chlorine and therefore do not participate in the destruction of the ozone layer.
Ammonia: (NH3) or R717 thermodynamically it is an excellent refrigerant for evaporation temperatures between -35 °C to 2 °C. But it is toxic and flammable in nature, so it is generally used in industrial refrigeration.
Hydrocarbons (HC): As R290, R600a this is primarily butane (R600), propane (R290) and isobutene (R600a). These fluids have good thermodynamic properties, but are quite dangerous because of their flammability.
Carbon dioxide (CO2) or R744: This is inorganic, non-toxic, non flammable, but inefficient in thermodynamics.

2.2 Thermo physical properties of some refrigerants

Sr No	Type	Number	Molecular name	Molecular mass	Normal boiling point (℃)	Critical temperature (℃)	Critical pressure (kPa)	Net (GWP)	ODP
1	CFC	R12	CCl_2F_2	120.9	-29.8	111.97	4136	10900	1
2	HCFC	R22	$CHClF_2$	86.5	-40.7	96.14	4990	1810	0.05
3	HFC	R32	CH_2F_2	52	-52	78.11	5782	675	0
4	HFC	R134a	$C_2H_2F_4$	102	-26.3	101.06	4059	1430	0
5	HFC	R152a	$C_2H_4F_2$	66	-25	113.26	4517	124	0
6	HC	R290	C_3H_8	44.1	-42.1	96.7	4248	3.3	<0
7	HC	R600a	C_4H_{10}	58.1	-11.7	134.7	3640	3	0
8	HO	R1270	C_3H_6	42.1	-47.6	92.42	4665	1.8	<0

Table: 1

III. PARTS OF VAPOR COMPRESSION CYCLE

1. **Compressor:** Refrigerant enters the compressor as a gas under low pressure and low temperature. Then, the refrigerant compressed adiabatically, so the fluid leaves the compressor under high pressure with high temperature.
2. **Condenser coil:** The high pressure, high temperature gas releases heat energy and condenses inside the 'condenser'. The condenser is in contact with the hot reservoir of the refrigeration system(the gas releases heat into the reservoir because of the external work added to the gas.) the refrigerant leaves as a high pressure liquid at the end of condenser.
3. **Expansion device:** The liquid refrigerant is pushed through a expansion device (capillary tube) which causes it to expand. As a result, the refrigerant is at low pressure and low temperature. While still in liquid phase (when the refrigerant forced through expansion valve, its pressure is reduced causing the liquid to expand.)
4. **Evaporator coil:** The low pressure, low temperature liquid refrigerant enters the evaporator coil. Because a low pressure is maintained, the refrigerant is able to boil at a low temperature. So the liquid absorbs the heat from surrounding and evaporates. The refrigerant leaves the evaporator as a low temperature low pressure gas and is taken into compressor again, back at the beginning of the cycle.

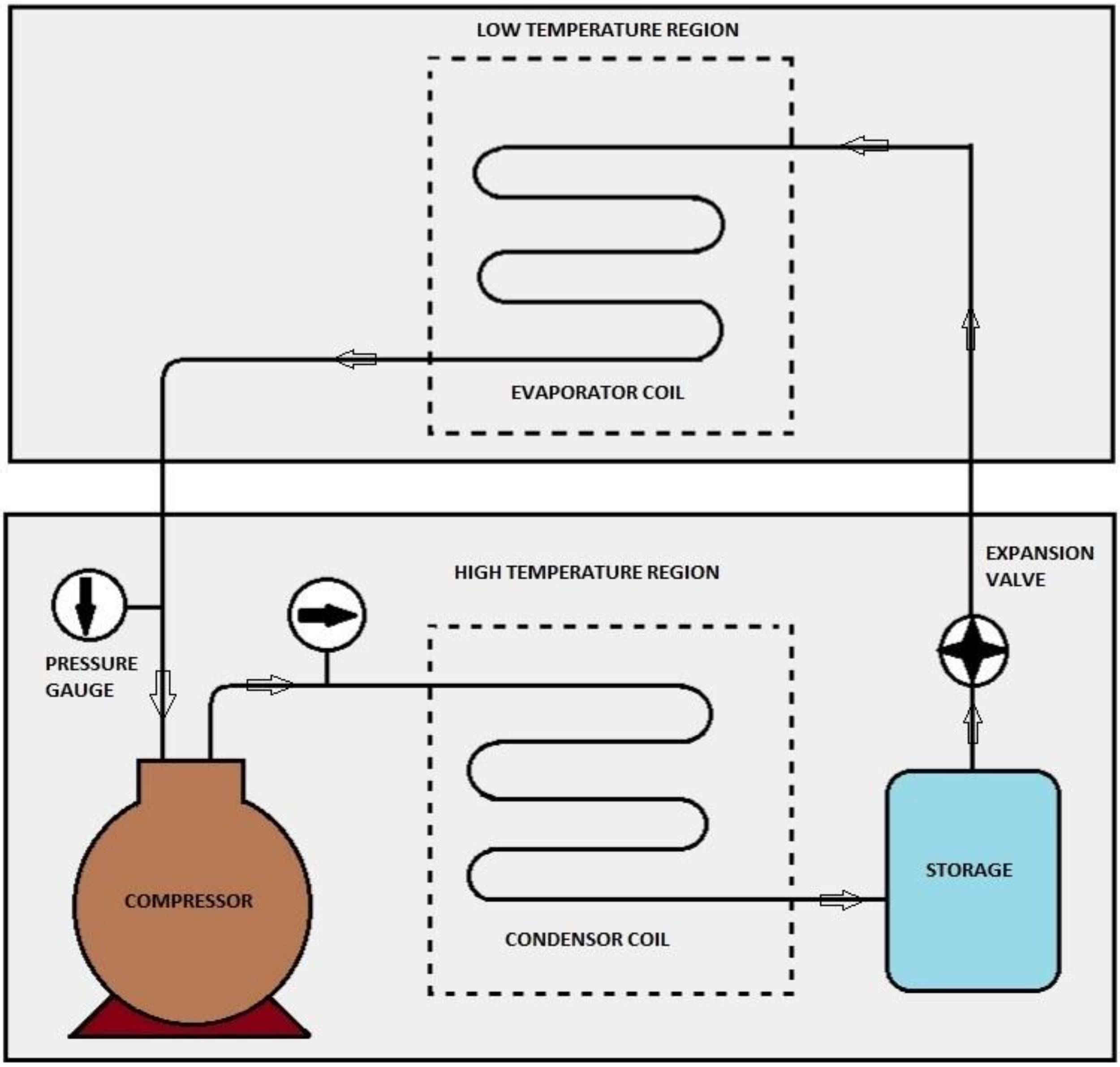
LOW TEMPERATURE REGION
EVAPORATOR COIL
HIGH TEMPERATURE REGION
EXPANSION VALVE
PRESSURE GAUGE
COMPRESSOR
CONDENSOR COIL
STORAGE

Figure: 1

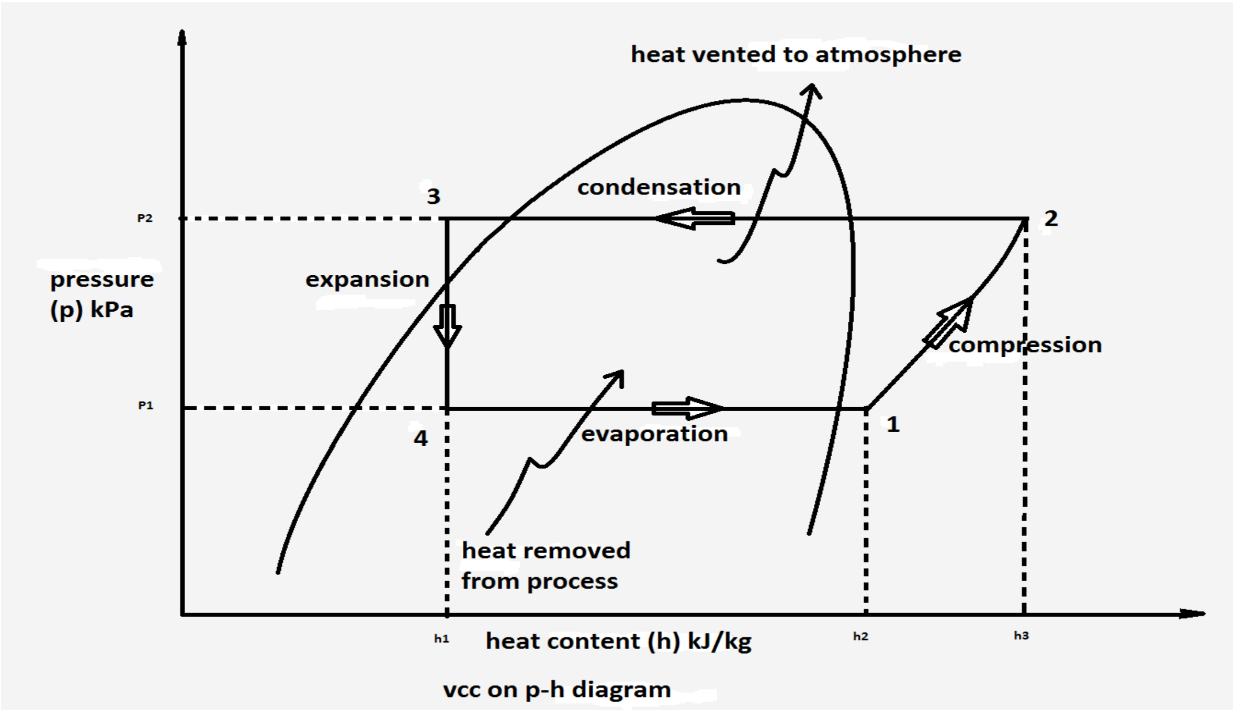

Figure: 2

3.1 Processes involved in cycle are as follows:

Process 1–2: Isentropic compression in compressor.
Process 2-3: Heat rejection at Constant pressure in condenser.
Process 3–4: Isenthalpic expansion in expansion device.
Process 4–1: Heat absorption at constant pressure in evaporator.

$$\textbf{Refrigerating effect} = (h_2 - h_1)$$

$$\textbf{Coefficient of performance} = \frac{(h_2 - h_1)}{(h_3 - h_2)}$$

IV. LITERATURE SURVEY

4.1 R. Cabello et al [1]

Researchers have presented an experimental comparison between refrigerants R134a and R152a and results were concluded. For this experiment the same refrigeration plant with hermetic compressor was used with both refrigerants. The refrigerant was replaced by conventional "drop-in" process in order to carry out an energy comparison. generally fluorinated gases are used as refrigerants in plants but they are having high global warming potential(GWP) values in case of leakages, in such situations a small number of current HFC refrigerants could be used without contradicting, the future regulations. Among those refrigerants with a GWP lower than the value set by the regulations, HFC152a with (GWP-138) can be considered as good one.

4.1.1 Material specification

1. Single stage reciprocating hermetic compressor: cubic capacity (CC) - 12.11 cm^3 and speed – 2900 rpm.
2. Lubricating oil: 350 ml of (POE) polyolester oil.
3. Heat exchanger: area- 0.576 m^2 (as condenser) and 0.216 m^2(as evaporator).
4. Electronic expansion valve
5. Coalescing oil separator.

4.1.2 Experimental procedure:

To evaluate energy performance of the system, 36 steady state tests were carried out for each refrigerant (R-152a and R-134a) under wide range of operating conditions. Each trial had minimum steady-state period of 20 minutes with a sampling rate of 10 s .after each test oil separator connected to the compressor crankcase for an oil return evaporating and condensing pressure were obtained as an average value between the inlet and outlet pressure for each element. The system was first tested at R-134a and without internal heat exchanger (IHX) afterwards the same procedure were carried out for R152a.

4.1.3 Result and conclusion

a. Refrigerant mass flow rate: specific volume of R152a is upto 73.59% higher than that of R134a thereby reducing the mass flow rate. Mass flow rate of R152a was found to be upto 41.5% lower than R134a.

b. Compressor power consumption: at same working conditions R512a yields lower compressor power consumption than R134a.
c. Discharge temperature: R152a has discharge temperature higher than R134a.
d. Cooling capacity: specific cooling capacity depends on the refrigerant latent heat. The latent heat for R152a is approximately 52.1% higher than R134a at same pressure level. Hence, R152a has cooling capacity than R134a.
e. Coefficient of performance: COP obtained with R152 a was upto 11.70 more than R134a working without and upto 13.20 working with (IHX).COP using R152a is found to be more than that of R134a.

4.2 Shubham R. Yennawar1 et al [2]

In this paper researchers have carried out performance analysis of vapor compression refrigeration system using refrigerants, R134a and R600a (Isobutane). Various performance measures like pressure ratio, volumetric cooling capacity, volumetric efficiency ,compressor discharge temperature and mass flow rate of refrigerants were analyzed. At various evaporating and condensing temperatures the performance of cycle in the form of COP ,refrigerating capacity, and compressor work were evaluated for investigated refrigerants. In this study refrigerant R6001 is used as the working fluid for the comparison with conventional refrigerant R134a.

4.2.1 Material specification

Compressor: hermatically sealed
Heat exchangers (condenser and evaporating system)
Expansion device

4.2.2Result and conclusion

variable factor / refrigerant	power (p) J/Sec	refrigerating effect(RE) J/Sec	workdone (WD) J/Sec	coefficient of performance (CPO)
R134a	171.81	686.32	171.80	3.99
R600a	136.85	614.98	136.82	4.53

Table: 2

From result table it is seen that environmental impact of ozone layer depletion and global warming can be reduced to great extend with the use of refrigerant R600a, it is a refrigerant having comparatively high COP with lesser environmental impact hence it is necessary to make use of refrigerant R600a with low GWP and ODP.

4.3 B.O. Bolaji1 et al [3]:

The researchers have investigated the performances of three ozone-friendly Hydrofluorocarbon (HFC) refrigerants (R32, R134a and R152a) in a vapour compression refrigeration system experimentally and compared with each other in order to get required possible replacement for future use.

A single-fluid Hydrofluorocarbon (HFC) refrigerant, R134a, is commonly preferred for domestic refrigerators. Although the ODP of R134a is having zero value and the GWP is having relatively higher value as compared with other two refrigerants. Because of this reasons there is a need of replacement of such refrigerant in domestic refrigeration system and it has been seen that the production and use of R134a will be terminated soon. Therefore, other replacements will be needed that are thermodynamically efficient as R134a. This study compares the performance of R134a and other two low GWP HFC refrigerants (R32 and R152a) in vapor compression refrigeration system. The performance parameters of the refrigerants were analysed and determined by means of theoretical cycle calculation using experimental data.

4.3.1 Material specification:

Compressor: reciprocating compressor (hermetically sealed)
Evaporator
Condenser
Expansion device: capillary tube.
Two Pressure gauges: accuracy of $\pm$0.5Kpa
Thermocouple: accuracy of $\pm$0.1℃

4.3.2 Experimental procedure:

A vapor compression refrigeration system was used for analysis, consist of a hermetic reciprocating compressor, evaporator, condenser and capillary tube (expansion device). These components are connected by pipelines in which a refrigerant with suitable thermodynamic properties circulates. The system was instrumented with two pressure gauges at the inlet and outlet of the compressor for measuring the suction and discharge pressures. The temperature of the refrigerant at four different points indicated with copper-constantan thermocouples. The energy consumption of the refrigeration system was measured with energy meter. The mass flow rate of the refrigerant was measured using a flow meter installed in the liquid line between the condenser and the capillary tube. The system was charged with the help of charging system and evacuated with help of vacuum pump in order to remove the moisture. After charging each refrigerant, required data were collected at different evaporator temperatures and the results were obtained for each refrigerant.

4.3.4 Result and conclusion:

Out of the three refrigerants investigated, R152a has shown the desirable environmental requirements with zero Ozone Depletion Potential (ODP) and very low Global Warming Potential (GWP). R32 yields undesirable characteristics, such as high operating temperature and pressure, low Volumetric Cooling Capacity and low Coefficient of Performance (COP). R152a refrigerant has shown approximately the same performance with R134a, therefore, R152a is considered as a good substitute for R134a in vapor compression refrigeration system. The best performance was obtained with the use of R152a in the system.

4.4 A.S. Dalkilic et al [4]:

Analysis of alternative new refrigerant mixtures as substitute for CFC12, HFC134a, HFC and CFC22 is carried out and also the variation of physical properties of pure and mixed refrigerants such as, evaporating pressure, pressure ratio, isentropic compression work, volumetric refrigeration capacity (VRC), suction vapor flow rate and COP were investigated in this theoretical study and they are plotted against the evaporating temperature for the ideal refrigeration cycle.

4.4.1 Result and conclusion:

As a result of the analysis, HC290/HC600a(40/60 by wt %) instead of R12 and HC1270(20/80 by wt%) instead of R22 are found to be the best alternative refrigerants in terms of the factors in choosing the refrigerants. Theoretical results showed that all of the alternative refrigerants (mixtures of refrigerants) investigated in the paper have slightly lower COP than CFC12, FC234a and HFC134a.

V. **CONCLUSION**

After overall study of vapor compression refrigeration system with the use of different refrigerants it can be concluded that, there is need for detailed research into this sector. Among those refrigerants with a GWP lower than the value set by the regulations, HFC152a with (GWP-138) can be considered as good one. Environmental impact of ozone layer depletion and global warming can be reduced to great extend with the use of refrigerant R600a, it is a refrigerant having comparatively high COP with lesser environmental impact.R32 yields undesirable characteristics, such as high operating temperature and pressure, low Volumetric Cooling Capacity and low Coefficient of Performance (COP). R152a refrigerant has shown approximately the same performance with R134a, therefore, R152a is considered as a good substitute for R134a in vapor compression refrigeration system. Some refrigerant mixtures based on HFC134a, HFC152a, HFC32, HC290, HC1270, HC600 can be blended with conventionally used refrigerants like R12 and R22 as possible alternative replacements.

VI. NOMENCLATURE

SR NO	SYMBOL	MEANING
1	COP	Coefficient of performance
2	GWP	Global warming potential
3	ODP	Ozone depletion potential
4	CFC	Chlorofluorocarbon
5	HCFC	Hydro Chlorofluorocarbon
6	HFC	Hydrofluorocarbon
7	R600a	Isobutane
8	R134a	Tetrafluoroethane
9	R12	Dichlorodifluoromethane
10	R22	Monochlorodifluoromethane
11	R32	Difluoromethane
12	R152a	Difluoroethane
13	R290	Propane
14	R1270	Propane(propylene)
15	IHX	Internal heat exchanger
16	VRC	Volumetric refrigeration capacity

Table: 3

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