

# Evaluation of Vapour Compression Refrigeration System Using Different Refrigerants-A Review

Ramesh Nayak roll no 14tq1d2120  
Siddhartha Institute of Technology and Sciences  
Ghatkesar, Rangareddy, Telangana,

G. Naresh Babu,  
Assistant Professor,  
Siddhartha Institute of Technology and Sciences,

**Abstract-** The performance of heat transfer is one of the most important research areas in the field of thermal engineering. There are a large number of refrigerants, which are used to transfer heat from low temperature reservoir to high temperature reservoir by using vapour compression refrigeration system. There are various obstacles faced in working of different refrigerants due to their environmental impact (R11, R12), toxicity ( $NH_3$ ), flammability (HC) and high pressure ( $CO_2$ ); which makes them more hazardous than other working fluids according to safety and environmental issues. Researchers observed the performance of different environmental friendly refrigerants and their mixtures in different proportions. They also observed the effect of working parameters like dimensions of capillary tube, working pressures and working temperatures, which affect the coefficient of performance (COP) of vapour compression refrigeration system. From the literature there seems to be need of new efficient, minimum global warming potential (GWP), minimum ozone depletion potential (ODP) and environmental friendly refrigerants.

**Index Terms**— Vapour Compression Refrigeration System, Refrigerant, COP, ODP, GWP.

## I. INTRODUCTION

Vapour compression refrigeration system is a system which is used to transfer heat from low temperature reservoir to high temperature reservoir with the help of working fluid, called refrigerant. There are different types of refrigerant, which were used as the working medium in vapour compression refrigeration system in the last few decades, but they cause of ozone layer depletion and green house effect.

### A. Refrigeration System: Working Principle and Construction

Refrigeration system is based upon the Clausius statement of second law of thermodynamics. This statement shows, "It is impossible to construct a device which, operating in a cycle, will produce no effect other than the transfer of heat from a cooler to a hotter body. The construction of vapour compression refrigeration system is illustrated in figure 1. This system consists of four basic components, i.e. a compressor, an evaporator, a condenser and capillary tubes. Here the compressor delivery head, discharge line, condenser and liquid line form the high pressure side of the system. The expansion line, evaporator, suction line and compressor suction head form the low pressure side of the system. In plants with a large amount of refrigerant charge, a receiver is installed in the liquid line. A drier is also installed in the

liquid line. The drier contains silica gel and absorb traces of moisture presented in the liquid refrigerants so that it does not enter the narrow cross section of the expansion device causing moisture chocking by freezing.

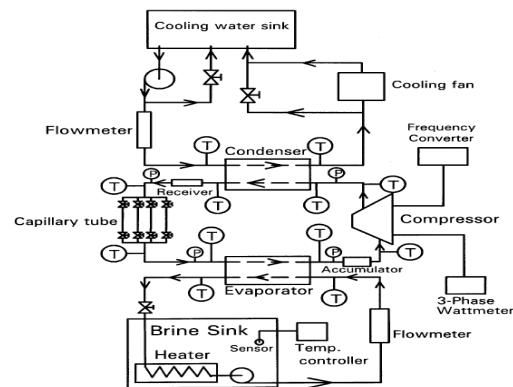


Fig 1: Schematic of the Vapour Compression Refrigeration System [5].

### B. Processes Involved in Vapour Compression Refrigeration System:

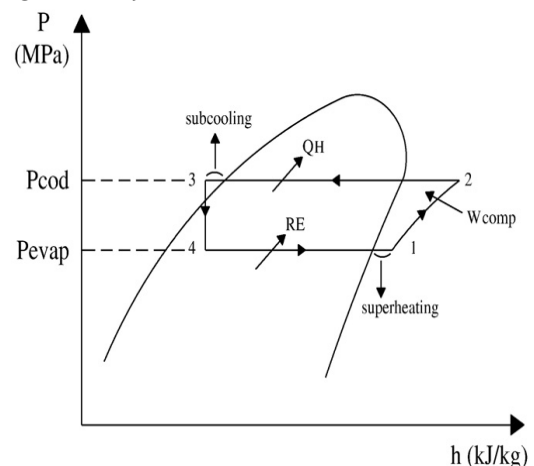


Fig 2: Pressure-Enthalpy Graph for Vapour Compression Refrigeration System [11].

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

### C. Refrigerant:

The working fluid used to transfer the heat from low temperature reservoir to high temperature reservoir is called refrigerant. There are different types of refrigerant which are described as followings. *CFC*: They are molecules composed of carbon, chlorine and fluorine. They are stable, allowing them to reach the stratosphere without too many problems. It contributes to the destruction of the ozone layer. These are R11, R12, R113, R500, R502 etc. *HCFC*: They are molecules composed of carbon, chlorine, fluorine and hydrogen. They are less stable than CFCs, destroy ozone and to a lesser extent. These are R22, R123, R124, R401a etc. *HFC*: They are molecules composed of carbon, fluorine and hydrogen. They do not contain chlorine and therefore do not participate in the destruction of the ozone layer. This is known as substitution substance. Restrictions on this family of gas are currently limited. Within the European Union, the HFC will be banned from air conditioners for cars from 2011. These are R134a.

#### 1. Mixture of refrigerants:

They can be classified according to the type of fluorinated components they contain. They are also distinguished by the fact that some mixtures are:

- Zeotropic: in a state change (condensation, evaporation), the temperature varies. These are R404a, R407a and R410a etc.
- Azeotropes: they behave like pure, with no change in temperature during the change of state. These are R500, R502 and R507a etc.

#### 2. Ammonia (NH<sub>3</sub>) or R717

Fluid inorganic thermodynamically is an excellent refrigerant for evaporation temperatures between -35 °C to 2 °C. But it is a fluid dangerous toxic and flammable, so it is generally used in industrial refrigeration.

#### 3. Hydrocarbons (HC) as R290, R600a

This is primarily propane (R290), butane (R600) and isobutene (R600a). These fluids have good thermodynamic properties, but are dangerous because of their flammability. The world of the cold has always been wary of these fluids, even if they have reappeared recently in refrigerators and insulating foams. Their future use in air conditioning seems unlikely, given the cost of setting both mechanical and electrical safety.

#### 4. Carbon dioxide (CO<sub>2</sub>) or R744

This is inorganic, non-toxic, non flammable, but inefficient in thermodynamics. Its use would involve high pressure and special compressors. Currently, specialists in air conditioning and refrigeration are interested again by:

- Its low environmental impact (ODP = 0, GWP = 1);
- The low specific volume resulting in facilities with low volume (small leak);
- It has the distinction of having a low critical temperature at 31 °C at a pressure of 73.6 bars.

### D. Mathematical Relations:

- a. Heat rejection in condenser -

$$Q_r = m_{cw} \times C_{pw} \times \Delta T_{cw}$$

- b. Heat abstraction in evaporator -

$$Q_a = m_{ew} \times C_{pw} \times \Delta T_{ew}$$

- c. Work input in compressor -

$$W_{in} = \text{Energy meter reading}$$

- d. Coefficient of performance

$$COP = \frac{Q_a}{W_{in}}$$

## II. LITERATURE REVIEW

James M. Calm [1], has studied the emission and environmental impacts of the different refrigerants (R11, R123, R134a) due to leakage from centrifugal chiller system. He also investigated the total impact in form of TEWI by analyzing the direct and indirect CO<sub>2</sub> emission equivalent due to leakage and energy consumption by the system. He studied the change in system efficiency or performance due to charge loss. He also summarized the methods to reduce the refrigerant losses by the system like design modifications, improvement in preventive maintenance techniques, use of purge system for refrigerant vapour recovery, servicing and lubricant changing in system. Samira Benhadid-Dib and Ahmed Benzaoui [2], have showed that the refrigerants are widely used in both industrial and domestic equipments. These fluids, which are banned due to their environmental toxicity, are expected to be replaced. Replacing them is a difficult task considering that the only solutions currently, called "natural" refrigerants, such as ammonia, hydrocarbons and CO<sub>2</sub>. The disadvantages of these products are mainly toxicity (NH<sub>3</sub>), flammability (HC) and high pressures (CO<sub>2</sub>). However, with least skills and observance with safety rules, they do not finally prove to be more dangerous than other fluids. They proposed as a contribution to the protection of our environment. Samira Benhadid-Dib and Ahmed Benzaoui [3], have showed that the uses of halogenated refrigerants are harmful for environment and the use of "natural" refrigerants become a possible solution. Here natural refrigerants are used as an alternative solution to replace halogenated refrigerants. The solution to the environmental impacts of refrigerant gases by a gas which contains no chlorine no fluorine and does not reject any CO<sub>2</sub> emissions in the atmosphere. The researchers showed that emissions have bad effects on our environment. They also concerned by a contribution to the reduction of greenhouse gases and by the replacement of the polluting cooling fluids (HCFC). Eric Granryd [4], has enlisted the different hydrocarbons as working medium in refrigeration system. He studied the different safety standards related to these refrigerants. He showed the properties of hydrocarbons (i.e. no ODP and negligible GWP) that make them interesting refrigerating alternatives for energy efficient and environmentally friendly. But safety precautions due to flammability must be seriously taken into account. Y. S. Lee and C. C. Su [5], have studied the performance of domestic

vapour compression refrigeration system with isobutene (R600a) as refrigerant and compare the results with R12 and R22. They used R600a about 150 g and set the refrigeration temperature about 4 °C and -10 °C to maintain the situation of cold storage and freezing applications. They used 0.7 mm internal diameter and 4 to 4.5 m length of capillary tube for cold storage applications and 0.6 mm internal diameter and 4.5 to 5 m length of capillary tube for freezing applications. They observed that the COP lies between 1.2 and 4.5 in cold storage applications and between 0.8 and 3.5 in freezing applications. They also observed that the system with two capillary tubes in parallel performs better in the cold storage and air conditioning applications, whereas that with a single tube is suitable in the freezing applications. R. Cabello, E. Torrella and J. Navarro-Esbri [6], have analyzed the performance of a vapour compression refrigeration system using three different working fluids (R134a, R407c and R22). The operating variables are the evaporating pressure, condensing pressure and degree of superheating at the compressor inlet. They analyzed that the power consumption decreases when compression ratio increases with R22 than using the other working fluids. Mao-Gang He, Tie-Chen Li, Zhi-Gang Liu and Ying Zhang [7], have analyzed that the R152a/R125 mixture in the composition of 0.85 mass fraction of R152a has a similar refrigeration performance with the existing refrigerant R12. Experimental research on the main refrigeration performances of domestic refrigerators was conducted, under the different proportions and charge amounts, when R152a/R125 is used to substitute R12 as a “drop-in” refrigerant. The experimental results indicate that R152a/R125 can be used to replace R12 as a new generation refrigerant of domestic refrigerators, because of its well environmentally acceptable properties and its favorable refrigeration performances. Ki-Jung Park, Taebeom Seo and Dongsoo Jung [8], have analyzed performances of two pure hydrocarbons and seven mixtures composed of propylene, propane, R152a, and dimethylether were measured to substitute for R22 in residential air-conditioners and heat pumps at the evaporation and condensation temperatures of 7 °C and 45 °C, respectively. Test results show that the coefficient of performance of these mixtures is up to 5.7% higher than that of R22. Whereas propane showed 11.5% reduction in capacity, most of the fluids had a similar capacity to that of R22. For these fluids, compressor-discharge temperatures were reduced by 11–17 °C. For all fluids tested, the amount of charge was reduced by up to 55% as compared to R22. Overall, these fluids provide good performances with reasonable energy savings without any environmental problem and thus can be used as long-term alternatives for residential air-conditioning and heat-pumping applications. Ki-Jung Park and Dongsoo Jung [9], have analyzed thermodynamic performance of two pure hydrocarbons and seven mixtures composed of propylene (R1270), propane (R290), R152a, and dimethylether (R170) was measured in an attempt to substitute R22 in residential air-conditioners. The pure and mixed refrigerants tested have GWP of 3–58 as compared to that of CO<sub>2</sub> at the evaporation

and condensation temperatures of 7 and 45 °C, respectively. Test results show that the COP of these mixtures is up to 5.7% higher than that of R22. Whereas propane showed 11.5% reduction in capacity, most of the fluids had the similar capacity to that of R22. Compressor discharge temperatures were reduced by 11–17 °C with these fluids. There was no problem found with mineral oil since the mixtures were mainly composed of hydrocarbons. The amount of charge was reduced up to 55% as compared to R22. K. Mani and V. Selladurai [10], have analyzed a vapour compression refrigeration system with the new R290/R600a refrigerant mixture as drop-in replacement was conducted and compared with R12 and R134a. The vapour compression refrigeration system was initially designed to operate with R12. The results showed that the refrigerant R134a showed slightly lower COP than R12. The discharge temperature and discharge pressure of the R290/R600a mixture was very close to R12. The R290/R600a (68/32 by wt %) mixture can be considered as a drop-in replacement refrigerant for R12 and R134a. A.S. Dalkilic and S. Wong wis [11], have studied the performance on a vapour compression refrigeration system with refrigerant mixtures based on R134a, R152a, R32, R290, R1270, R600 and R600a was done for various ratios and their results are compared with R12, R22 and R134a as possible alternative replacements. The results showed that all of the alternative refrigerants investigated in the analysis have a slightly lower COP than R12, R22, and R134a for the condensation temperature of 50 °C and evaporating temperatures ranging between -30 °C and 10 °C. Refrigerant blends of R290/R600a (40/60 by wt. %) instead of R12 and R290/R1270 (20/80 by wt. %) instead of R22 are found to be replacement refrigerants among other alternatives. Vincenzo La Rocca and Giuseppe Panno [12], have analyzed and compared the performance of a vapour compression refrigerating unit operating with R22, and with three new HFC fluids, substituting the former according to Regulation No 2037/2000. Here the plant working efficiency was first tested with R22 and then with three new HFC fluids: R417a, R422a and R422d. It is analyzed that the performance with the new tested fluids did not result as efficient as when using R22. Minxia Li, Chaobin Dang and Eiji Hihara [13], have investigated that Hfo1234yf has been proposed for mobile air-conditioners due to its low GWP and performance comparable to that of R134a. However, its performance is inferior to that of R410a. This makes it difficult to be applied to residential air-conditioners. In order to apply the low GWP refrigerant to residential air-conditioners, refrigerant mixtures of Hfo1234yf and R32 are proposed, and their flow boiling heat transfer performances were investigated at two mass fractions (80/20 and 50/50 by mass %) in a smooth horizontal tube with an inner diameter of 2 mm. The results showed that the heat transfer coefficients of the mixture with an R32 mass fraction of 20% were 10–30% less than those of pure Hfo1234yf for various mass and heat fluxes. When the mass fraction of R32 increased to 50%, the heat transfer coefficients of the mixture were 10–20% greater than those of

pure Hfo1234yf under conditions of large mass and heat fluxes.

### III. LIMITATIONS FOR USE OF REFRIGERANTS

Some refrigerants are expelled due to their environmental impact, are expected to be replaced. Replacing them is a difficult task considering that the only solutions currently available are the so-called "natural" refrigerants, such as ammonia, hydrocarbons and CO<sub>2</sub>. The disadvantages of these products are mainly toxicity (NH<sub>3</sub>), flammability (HC) and high pressures (CO<sub>2</sub>). Some refrigerants are banned due to their high ozone depletion potential (ODP) and global warming potential (GWP), these are followings.

- Production of R11 was halted by the clean air act on January 1, 1996.
- Production of R12 was halted by the clean air act on January 1, 1996.
- Production of R113 was halted by the clean air act on January 1, 1996.
- Production of R500 was halted by the clean air act on January 1, 1996.
- Refrigerant R134a is a commercially available hydro fluorocarbon (HFC) refrigerant long-term replacement for R12 in new equipment and for retrofitting medium temperature CFC.

### IV. FACTORS AFFECTING THE PERFORMANCE OF VAPOUR COMPRESSION REFRIGERATION SYSTEM

From the literature survey it is observed that following factors affect the performance of vapour compression refrigeration system.

- Properties of working fluid.
- Mixture proportions of different refrigerants.
- Suction pressure.
- Discharge pressure.
- Pressure ratio.
- Amount of charge filled.
- Dimensions of capillary tubes.

### V. CONCLUSION

Researchers have carried out experimental investigations to find out the various factors affecting the performance of vapour compression refrigeration system. The following results were observed.

- Working fluid properties, mixture proportions, suction and discharge pressure, dimensions of capillary tubes, amount of charge affect the performance of refrigeration system.
- Single capillary tube having smaller inner diameter is suitable for freezing applications, whereas parallel capillary tubes having more inner diameter are suitable for cold storage or air conditioning applications.
- For reducing the harmful effects on environment, it is necessary to use and research about the new refrigerants with low GWP and ODP.

### VI. FUTURE ENHANCEMENT

- To study the effect of new efficient, minimum GWP, minimum ODP and environmental friendly refrigerants.
- Innovation of new refrigerant mixture having high COP with less environmental impact.
- To develop a mathematical model by considering multiple factors so that experimental investigation can be minimized.

### VII. NOMENCLATURE

Symbol	Meaning
COP	Coefficient of performance
GWP	Global warming potential
ODP	Ozone depletion potential
GHG	Green house gas
TEWI	Total equivalent warming impact
CFC	Chlorofluorocarbon
HCFC	Hydro Chlorofluorocarbon
HFC	Hydrofluorocarbon
R11	Trichlorofluoromethane
R12	Dichlorodifluoromethane
R22	Monochlorodifluoromethane
R32	Methylene Fluoride
R125	Pentafluoroethane
R134a	Tetrafluoroethane
R152a	Difluoroethane
R290	Propane
R407c	23% of R32, 25% of R125 and 52% of R134a
R410a	50% of R32 and 50% of R125
R600	Butane
R600a	Isobutane
R717	Ammonia
R744	Carbon Dioxide
R1270	Propylene
Hfo1234yf	Tetrafluoropropene
$m_{cw}$	Mass flow rate of water in condenser (Kg/s)
$m_{ew}$	Mass flow rate of water in evaporator (Kg/s)
$\Delta T_{cw}$	Temperature difference in condenser water (K)
$\Delta T_{ew}$	Temperature difference in evaporator water (K)
$C_{pw}$	Specific heat of water (KJ/Kg.K)

### REFERENCES

- [1] James M. Calm, "Emissions and environmental impacts from air-conditioning and refrigeration systems," International Journal of Refrigeration 25, pp. 293–305, 2002.
- [2] Samira Benhadid-Dib, and Ahmed Benzaoui, "Refrigerants and their impact in the environment. Use of the solar energy as the source of energy," Energy Procedia 6, pp. 347–352, 2011.
- [3] Samira Benhadid-Dib, and Ahmed Benzaoui, "Refrigerants and their environmental impact Substitution of hydro chlorofluorocarbon HCFC and HFC hydro fluorocarbon. Search for an adequate refrigerant," Energy Procedia 18, pp. 807 – 816, 2012.

- [4] Eric Granryd, "Hydrocarbons as refrigerants - an overview," International Journal of Refrigeration 24, pp. 15-24, 2001.
- [5] Y.S. Lee, and C.C. Su, "Experimental studies of isobutene (R600a) as the refrigerant in domestic refrigeration system," Applied Thermal Engineering 22, pp. 507-519, 2002.
- [6] R. Cabello, E. Torrella, and J. Navarro-Esbri, "Experimental evaluation of a vapour compression plant performance using R134a, R407C and R22 as working fluids," Applied Thermal Engineering 24, pp. 1905-1917, 2004.
- [7] Mao-Gang He, Tie-Chen Li, Zhi-Gang Liu, and Ying Zhang, "Testing of the mixing refrigerants HFC152a/HFC125 in domestic refrigerator," Applied Thermal Engineering 25, pp. 1169-1181, 2005.
- [8] Ki-Jung Park, Taebeom Seo, and Dongsoo Jung, "Performance of alternative refrigerants for residential air-conditioning applications," Applied Energy 84, pp. 985-991, 2007.
- [9] Ki-Jung Park, and Dongsoo Jung, "Thermodynamic performance of HCFC22 alternative refrigerants for residential air-conditioning applications," Energy and Buildings 39, pp. 675-680, 2007.
- [10] K. Mani, and V. Selladurai, "Experimental analysis of a new refrigerant mixture as drop-in replacement for CFC12 and HFC134a," International Journal of Thermal Sciences 47, pp. 1490-1495, 2008.
- [11] A.S. Dalkilic, and S. Wong wisers, "A performance comparison of vapour-compression refrigeration system using various alternative refrigerants," International Communications in Heat and Mass Transfer 37, pp. 1340-1349, 2010.
- [12] Vincenzo La Rocca, and Giuseppe Panno, "Experimental performance evaluation of a vapour compression refrigerating plant when replacing R22 with alternative refrigerants," Applied Energy 88, pp. 2809-2815, 2011.
- [13] Minxia Li, Chaobin Dang, and Eiji Hihara, "Flow boiling heat transfer of HFO1234yf and R32 refrigerant mixtures in a smooth horizontal tube: Part I. Experimental investigation," International Journal of Heat and Mass Transfer 55, pp. 3437-3446, 2012.



Ramesh Nayak roll no 14tq1d2120  
Siddhartha Institute of Technology and Sciences  
Ghatkesar, Rangareddy, Telangana,



G. Naresh Babu,  
Assistant Professor,  
Siddhartha Institute of Technology and Sciences,