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R134a Refrigerant in Vapour Compression Cycle: A Review Paper

Rajeev Satsangi[1], A. Dheeraj [2], Sunil Kumar[3], Ajay Kumar[4], Himanshu Singh[5], Neeraj Satsangi[6]

[1,2,3,4,5] Department of Mechanical Engineering, Dayalbagh Educational Institute, Agra, UP, India
[6]Department of Chemistry, Dayalbagh Educational Institute, Agra, UP, India

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Abstract - *Refrigerant is a substance used in a heat cycle usually for enhancing efficiency, by a reversible phase transition from a liquid to a gas. Traditionally, fluorocarbons, especially chlorofluorocarbons, were used as refrigerants, but they are being phased out because of their ozone depletion effects. Other common refrigerants used in various applications are ammonia, sulfur dioxide, and non-halogenated hydrocarbons such as propane. R134a is an inert gas used primarily as a "high-temperature" refrigerant for domestic refrigeration and automobile air conditioners. Contact of R134a with flames or hot surfaces have toxic and hazardous effect on the humans and environment. In this paper, a review of available alternative refrigerants and their physical and chemical properties have been done. Selection of efficient, eco-friendly and safe refrigerant for future has been attempted in this paper through discussions.*

Key Words: ODP, GWP, toxicity, flammability

1.INTRODUCTION

The main challenge of Refrigeration is to remove heat from a low temperature source and dump it at a higher temperature sink. So to accomplish this, it takes the advantage of the idea that highly compressed fluids at one temperature will tend to get colder when they are allowed to expand. If the pressure change is high enough, then the compressed gas will be hotter than our source of cooling (outside air, for instance) and the expanded gas will be cooler than our desired cold temperature. In this case, we can use it to cool at a low temperature and reject the heat to a high temperature.

1.1 Vapour Compression Cycle

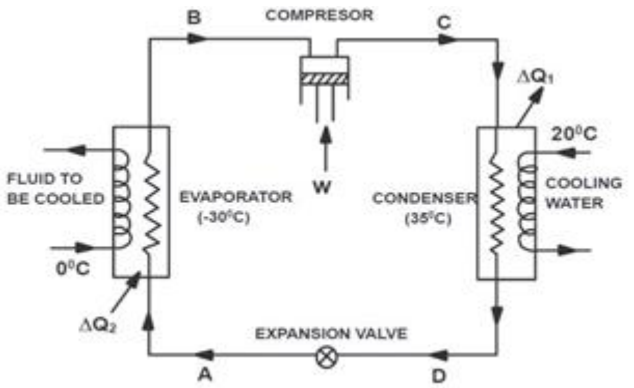

Fig -1: Vapour Compression Cycle

Figure 1 depicts the schematic view of vapor compression refrigeration cycle. The cycle operates between two pressure limits P_C and P_B and consists of four stages under which refrigerant circulates continuously .In the first stage the low temperature, low pressure vapor at state B is compressed by a compressor to high temperature and pressure vapor at state C, this is called the compression stage . In the next stage the compressed vapor is condensed into high pressure vapor at state D in the condenser and then passes through the expansion valve, this is stage is called the condensation stage. Here, in the expansion stage the vapor is throttled down through a throttle valve to a low pressure liquid and passed on to an evaporator, where it absorbs heat from the surroundings from the circulating fluid and vaporizes into low pressure vapor at state B. The fluid here is the refrigerant. The cycle then repeats in a similar fashion.

Each of the four stages will now be revisited in detail, explaining the physical changes that occur in the refrigerant and the devices used to accomplish these changes.

1.2 T-S diagram of vapour compression cycle

The T-s diagram for a vapor-compression refrigeration cycle is shown below with the explanation of each stage.

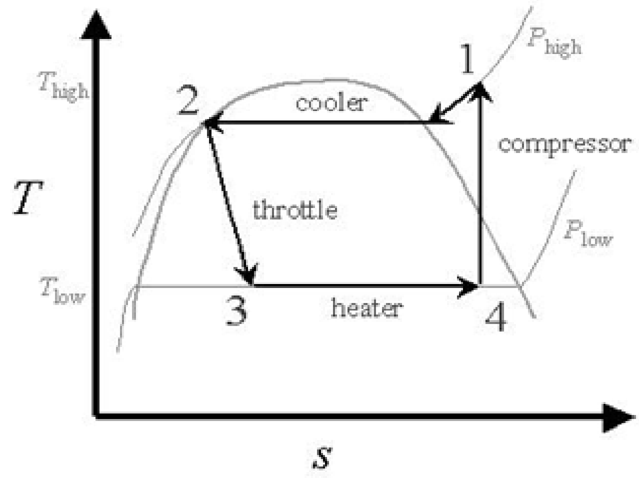

Fig -2: T-S diagram of vapour compression cycle

Compression (Process 4-1): Figure 2 depicts the T-s diagram of vapour compression cycle, the refrigerant is compressed by using a compressor and the pressure is increased from P_{low} to P_{high} . And it also raises the temperature of the refrigerant above the atmospheric temperature. Finally it leaves the stage as a superheated vapor. Energy is needed to power the compressor that is why electricity is required to operate a refrigerator.

Condensation (Process 1-2): In this stage the coiled tubes with aluminum fins dissipate the heat of the refrigerant to the surrounding. This device is very much similar to the evaporator, but may have different dimensions. As the hot vapor flows through the condenser, the outside air removes energy and the refrigerant becomes a saturated liquid. At this point the slightest drop in pressure will initiate evaporation, which is the basis for the third stage of the process.

Expansion (Process 2-3): This process is the key to the entire cycle, because this was the problem that we started with. Here the condensed vapor is throttled through a throttle or expansion valve resulting in a sudden drop in pressure which ultimately causes the lowering of temperature. This is achieved by utilizing the auto-refrigeration effect. This cold liquid-vapor mixture now enters into the final stage of the cycle.

Evaporation (Process 3-4): During this stage, the refrigerant travels through a device called an evaporator that has a large surface area and typically consists of a coiled tube surrounded by aluminium fins. The cold fluid is a mixture of liquid and vapor refrigerant .the refrigerant while flowing through the evaporator absorbs heat from the enclosed space (low temperature region) and all the liquid get evaporated the energy absorbed is used to change the state of the refrigerant from liquid to vapor. The energy absorbed by the refrigerant is the measure of its refrigeration effect. This lowers the temperature of the space, along with whatever food or beverages are stored in it. The refrigerant exits this stage as a saturated vapor and enters into the compressor stage to repeat the cycle again.

2. LITERATURE REVIEW

B.O. Bolaji et al [1] investigated experimentally the performances of three ozone friendly Hydrofluorocarbon (HFC) refrigerants R12, R152a and R134a. R152a refrigerant found as a drop in replacement for R134a in vapour compression system. B.O. Bolaji [2] discussed the process of selecting environmental-friendly refrigerants that have zero ozone depletion potential and low global warming potential. R23 and R32 from methane derivatives and R152a, R143a, R134a and R125 from ethane derivatives are the emerging refrigerants that are nontoxic, have low flammability and environmental-friendly. These refrigerants need theoretical and experimental analysis to investigate their performance in the system. S. Wongwises et al [3] found that 6/4 mixture of R290 and R600 is the most appropriate refrigerant to replace HFC134a in a domestic refrigerator. Bukola O. Balaji et al [4] investigated the exergetic performance of R12 and its substitute (R134a and R 152a) in the domestic refrigerator. R152a performed better than R134a in terms of COP, exergetic efficiency and efficiency defect as R12 substitute in domestic refrigeration system. Miguel Padilla et al [5] found that R413A (mixture of 88% R134a, 9%R218, 3%R600a) can replace R12 and R134a in domestic refrigerator. Molina and Rowlands (1974) have been expanded into a comprehensive and very complex theory emphasis about 200 reactions that CFCs are significantly destroyed by UV radiation in the stratosphere. In the year 1987 Hoffman predicted 3 % global ozone depletion with contact of CFCs emissions of 700 thousand tone /year [4, 5,]. A.S. Dalkilic et al [6] studied the performance analysis of alternative new refrigerant mixtures as substitute for R12, R134a and R 22. Refrigerant blend of R290/R 600a (40/60 by wt. %) and R 290/R1270 (20/80 by wt. %) are found to be the most suitable alternative among refrigerants tested for R12 and R22. Abhishek Tiwari et al [7] published a review paper on recent development on domestic refrigeration. Alka Bani Agrawal et al (8) worked on eco-friendly refrigerant as a substitute for CFC (Chlorofluorocarbon). The binary mixture in the ration of 64% and 36% of R290 and R600a found to be a retrofit or drop in substitute of R12 for use in the vapour compression refrigeration trainer. A. S. Dalkilic S. Wongwises[9] A performance comparison of vapour-compression refrigeration system using various alternative refrigerants A theoretical performance study on a traditional vapour-compression refrigeration system with refrigerant mixtures based on HFC134a, HFC152a, HFC32, HC290, HC1270, HC600, and HC600a was done for various ratios and their results are compared with CFC12, CFC22, and HFC134a as possible alternative replacements. K. Senthil Kumar et al [10] studied the behavior of HCFC (Hydrochloroflurocarbon)-123/ HC-290 refrigerant mixture computationally as well as experimentally and found that refrigerant mixture 7/3 as a promising alternative to R12 system. R. Cabello et al [11] studied the influence of the evaporating pressure, condensing pressure and superheating degree of the vapour on the exergetic performance of a refrigeration plant using three different working fluids R134a, R407c, R22.

1. NEED FOR ALTERNATIVES OF R134A

1.1 Refrigerant Generation

Since 1830-1930 was the first generation of refrigerants. It was based on the availability. These refrigerants were more highly toxic, flammable and some very highly reactive in nature. Examples include Ethers, CO etc. [21]. Since 1930-1990 was the second generation of refrigerants, was focused on reducing toxicity and flammability. Example: CFCs, HCFCs, HFCs, NH_3, HO etc. Since 1990-2010 was the third generation of refrigerants, was focused on protecting the ozone layer. Example - HCFCs, HFCs, HCs, NH_3, H_2O, CO_2 etc [21].

Since 2010 to onwards be the fourth generation is being focusing on refrigerants that do not contribute to global warming, ozone layer depletion, efficient, non-flammable and non-toxic with good stability. But the outlook for discovery or synthesis of these ideal refrigerants is extremely unlikely.

Therefore, trade-off among desired objectives is necessary to achieve the balanced solution [21].

1.1 Montreal Protocol

The United Nations environment programme conference held in Montreal in September 1987 the decision taken to phase out ozone depleting substances (ODS) within a fixed time period is known as Montreal Protocol. Some of the feature of MP is as follows.

1) Developed countries will phase out CFCs by 1996.

2) Developing countries will phase out CFCs by 2010 with freeze in 1999 and gradual reduction thereafter. Developed countries will phase out HCFCs by 2030 while developing countries have been provided a grace period of ten years i.e. phase out by 2040.

3) Global warming is another serious issue. Some naturally occurring substances mainly cause this but CFCs have very large global warming potential. [19, 20].

1.1 Kyoto Protocol

Main cause of global warming is due to the substance which is emerged from Kyoto protocol. Now a days R134a is being use in freezer and other vapour compression cycle instead of CFC-12 because it is low ozone depilation potential (ODP), another view is that its R134a contains 1300 global warming potential (GWP) per 100 year, which GWP rate is very high. The AFEAS 1970-2003 [21] reported of R134a is significantly increased during the last two decades. The emission of R134a in the atmosphere are rapidly increasing the concentration of greenhouse gases through some kind of leaks and mostly, as an indirect way, through energetic performance of refrigeration plant. So that it will be lead to the climatic problem. So in future R-134a must be remove under the Kyoto protocol.

1.1 Environmental concern

There are two major concern related to environment:

1) The first major concern is depletion of ozone layer. Ozone layer is a layer which protects the earth from ultraviolet rays. Ozone depletion potential is evaluated on a scale that uses CFC-11 as a benchmark. All the other components are based on how damaging to the ozone they are in relation to CFC-11.

2) The second major concern is global warming. Global warming is the increase in global earth surface temperature due to the absorption of infrared emission from earth surface. Global warming potential is evaluated on a scale that uses CO_2 as the bench mark i.e. CO2 is assigned a value and other components are compared to CO_2.

2. ALTERNATIVE TO R134$_A$

In CFCs and HCHCs present the chlorine content which contribute to the depletion of ozone layer. But the alternative refrigerant of CFCs and HCFCs is Hydroflrocarbon HFCs (R134a, R152a, and R32) as there are no content of chlorine. R134a is the leading replacement for domestic refrigerators. Although the ODP of R134a is zero, the GWP is relatively high which is shown in the table 1.

Table -1: Some Properties Of Selected Alternative Refrigerants

Refrigerant	Chemical Formula	Molecular Weight	Boiling Point (C)	Ozone Depletion Potential (ODP)	Global Warming Potential (GWP)
R32	CH_2F_2	52	-51.7	0	650
R134a	$C2H_2F_4$	102	-26.1	0	1300
R152a	$C2H_4F_2$	66	-24.0	0	140

It has been found through the research in R134a has fluorine content so it has high global warming potential or zero or low ozone depletion potential (ODP) [17, 18]. Although Global warming is a good thing in itself and allows life to exist in all its variety but the concern is that man's activities are increasing the concentration of carbon dioxide and other green gases in the atmosphere, causing the amount of absorbed infrared radiation to increase, and leading to atmospheric temperatures and consequent long term climate changes[15,16]. Hence, Kyoto protocol established the phased out of HFCs in the near future. Montreal and Kyoto protocols are interconnected, total climate change and ozone depletion depends on both the global warming potential and ozone depletion potential of the substances [20].

4.1 Alternative Refrigerant: CO2

CO_2's main attribute is that it has virtually no impact on global warming or ozone depletion. CO_2 is also nontoxic in small doses but concentrations over 5% can be lethal. It is also cheap and nonflammable, but when used as a refrigerant, CO_2 (which is called R-744) requires extremely high operating pressures compared to R-134a.

4.1 Alternative Refrigerant: HFC-152a

HFC-152a is almost a straight drop-in substitute for R-134a. The molecule is similar to R-134a except that two hydrogen atoms are substituted for two fluorine atoms. It has similar operating characteristics to R-134a but cools even better. An environmental benefit of HFC-152a is that it has a global warming rating of 120, which is 10 times less than R-134a, but still a lot higher than CO_2. That is why HFC-152a is currently used in many aerosol products as a propellant. Its main drawback is that it is slightly flammable.

4.1 Alternative Refrigerant: HFO-1234yf

Another new refrigerant that is being considered is HFO-1234yf. Developed jointly by Honeywell and DuPont, it is being promoted as a possible drop-in replacement for R-134a in both new vehicles and older vehicles, should that become necessary in the future. HFO-1234yf has thermal characteristics that are very similar to R-134a, so no major modifications to the A/C system are necessary. Better yet, HFO-1234yf has a global warming potential of only 4, compared to 1200 for R-134a, allowing it to meet the European requirements for a GWP of less than 150.

4.1 Alternative Refrigerant: Ammonia

Ammonia is produced in a natural way by human beings and animals; 17 grams/day for humans. Its ODP and GWP both are zero and possess excellent thermodynamic characteristics: small molecular mass, large latent heat, large vapour density and excellent heat transfer characteristics .Its smell causes leaks to be detected and fixed before reaching dangerous concentration also available at relatively low price. The only drawback of NH_3 is that it is toxic, flammable and not compatible with copper.

4.1 Alternative Refrigerant: Superfreeze 134a

Super-Freeze 134a a HC-based refrigerant from is a blend of environmentally safe hydrocarbon fluids designed as a direct replacement and retrofit refrigerant option for replacing R123a and R12 refrigerants in automotive air conditioning and refrigeration systems outside of the United States. Super-freeze 134a operates at lower head pressures and offers improved cooling properties and performance versus R134a and R12.

3. CONCLUSIONS

In the aftermath of the Montreal protocol HFC's have predominantly replaced CFC's and HCFC's in RAC equipment. Due to their high GWP, HFC's are not a good replacement solution. Kyoto protocol aims at the phasing out of HFCs in the near future the solution are the natural refrigerants: Ammonia, Hydrocarbons and Carbon dioxide that may lead to zero ODP and minimal GWP. For making the refrigerant more efficient system need to have low TEWI factor. In the future, the development agents will further develop more refrigerants which will not only be making the work system more efficient but also having the eco-friendly nature, leading to the attainment of the refrigeration goals and enhancing the well-being and safety of the worker.

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