International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Performance Analysis of Eco-Friendly Alternative Refrigerant for Vapour Compression Refrigeration System

[a] Jagan Mohan D, [b] Periyasamy M

[a] PG Scholar of Thermal Engineering, Department of Mechanical Engineering, Government College of Engineering , Salem- 11
[b] Assistant Professor, Department of Mechanical Engineering, Government College of Engineering , Salem- 11

A B S T R A C T

As we enter the fourth generation of refrigerants, we consider the evolution of refrigerant molecules, the ever-changing constraints and regulations that have driven the need to consider new molecules. The advancements in the tools and property models used to identify new molecules and design equipment using them. These separate aspects are intimately intertwined and have been in more-or-less continuous development since the earliest days of mechanical refrigeration, even if sometimes out-of-sight of the mainstream refrigeration industry. We highlight three separate, comprehensive searches for new refrigerants in the 1920s, the 1980s, and the 2010s-that sometimes identified. New molecules, but more often, validated alternatives already under consideration. A recurrent theme is that there is little that is truly new. Most of the new refrigerants, from R-12 in the 1930s to R-1234yf in the early 2000 were reported in the chemical literature decades before they were considered as refrigerants. The search for new refrigerants continued through the 1990s even as the hydro fluorocarbons (HFCS) were becoming the dominant refrigerants in commercial use. This included a return to several long-known natural refrigerants. Finally, we review the evolution of the NIST REFPROP database for the calculation of refrigerant properties.

Keywords: *Refrigerant, hydro fluorocarbons, NIST REFPROP*

1. INTRODUCTION

As per Montreal protocol 1987, the use of chlorofluorocarbons (CFCs) was completely stopped in most of the nations. However, hydro chlorofluorocarbons (HCFCs) refrigerants using in developing nations and developed nations should phase out by 2030.Most of the developed nations reduced the consumption of HCFC refrigerants. The Kyoto Protocol of United Nations Framework Convention on Climate Change (UNFCCC) calls for reduction in emission of six categories of greenhouse gases, which includes hydro fluorocarbons (HFCs) used as refrigerants. To meet the global demand in refrigeration and air-conditioning sector, it is necessary to look for long term alternatives to satisfy the objectives of international protocol. Only a few pure fluids are having properties closer to the existing halogenated refrigerants. The refrigerant mixtures provide much flexibility in searching new environment friendly alternatives to match the desirable properties with the existing halogenated refrigerants.

The two alternative options are HC and HFC mixtures with lower GWP.HC based mixtures are environment friendly, which can be used as alternative refrigerants. In agreement with the Montreal protocol many refrigerants containing CFCs and HCFCs were increasingly replaced with hydro-fluorocarbons (HFCs) which have zero ozone depletion potential (ODP) and negligible global warming potential (GWP). The main components of a vapour compression refrigeration system are compressor, condenser, expansion devices, evaporator etc. A refrigerant compressor is a machine used to compress the refrigerant from the evaporator and to raise its pressure so that the corresponding temperature is higher than that of the cooling medium. The condenser is an important device used in the 4 high-pressure side of a refrigeration system. Its function is to remove heat the hot vapour refrigerant discharged from the compressor. The expansion device used here is a capillary tube from which the liquid refrigerant from the condenser is expanded and pressure reduced. The evaporator is used in the low pressure side of a refrigeration system. The liquid refrigerant from the expansion device enters into the evaporator where it boils and changes into vapour. The function of an evaporator is to absorb heat from the space or medium which is to be cooled, by means of a refrigerant. The temperature of the boiling refrigerant in the evaporator must always be less than that of the surrounding medium so that the heat flows to the refrigerant. It is connected between the receiver and the evaporator. Many efforts have to be done to improve the performance of vapour compression refrigeration system.

2. LITERATURE REVIEW

[1] Wong wises et al. [2007] performed the theoretical study on traditional vapour compression refrigeration system with refrigerant mixtures based on HFC134a, HFC152a, HFC32, HC290, HC1270, HC600 and HC600a for various ratios and their results are compared with CFC12, CFC22 and CFC134a as possible alternative replacement. Considering the comparison of coefficient of performance (COP) and pressure ratio of tested refrigerants and also the main environmental impacts of ozone layer depletion and global warming, Refrigerant blends of HC290 (40%) + HC600a (60%) and HC290 (20%)+HC1270 (80%) are found to be the most suitable alternatives among refrigerants tested for R12 and R22 respectively. The refrigeration efficiency, coefficient of performance (COP) of the system increases with increasing evaporating temperature for a constant condensing temperature. Similarly Hc22a can be tested for R-134a.

[2] Kamlesh Jain [2008] also carried experimental investigation to find out a drop-in replacement for R134a with the binary mixture of 45.2 % R290/ 54.8 % R600a in a 200 liter single evaporator domestic refrigerator. Tests were carried out at different ambient temperatures (24, 28, 32, 38 and 430C); cycles ON/OFF tests were carried out at 32 0C ambient temperature. The results showed that the HC mixture has lower energy consumption; pull down time and ON time ratio by about 11.1%, 11.6% and 13.2% respectively, with 3.25 to 3.6% higher COP. The discharge temperature of HC mixture was found to be 8.5 to 13.4 K lower than that of R134a. The overall result has proved that the above hydrocarbon refrigerant mixture could be the best long-term alternative to R134a.

[3] Ahmed Quasim Singh [2010] has studied the performance of a small capacity directly cooled refrigerator by using the alternative to R-134a. The compressor displacement volume of the alternative system with R600a/R290 6 (45/55) has modified from that of the original system with R-134a to the optimized R600a/R290 system was approximately 50% of that of the optimized R-134a system. The capillary tube lengths for each evaporator in the optimized R600a/R290 system were 500mm longer than those in the optimized R-134a system. The power consumption of the optimized R-134a system was 12.3% higher than that of the optimized R600a/R290 system. The cooling speed of the optimized R600a/R290 (45/55) system at evaporator 0C was improved temperature by 28.8% over that of the optimized R-134a system.

[4] Rishabhverma, Ravi Sastri [2011] improved coefficient of performance of system. To improve the coefficient of performance, it should be noted that compressor work should decrease and refrigerating effect should increase. Modifications in condenser are meant to increase degree of sub-cooling of refrigerant which increased refrigerating effect or more cooling water is required in condenser. The purpose of a compressor in vapour compression system is to elevate the pressure of the refrigerant, but refrigerant leaves the compressor with comparatively high velocity which may cause splashing of liquid refrigerant in the condenser tube, liquid hump and damage to condenser by erosion. It is needed to convert this kinetic energy to pressure energy by using diffuser. By using diffuser power consumption is less for same refrigerating effect improve.

[5] Sattar et al. [2013] designed a domestic refrigerator to work with R134a and was used as test unit to determine the possibility of using hydrocarbons and their blends as refrigerants. Pure butane, isobutene and mixture of propane, butane and isobutene were used as refrigerants. In this experiment, effect of condenser temperature and evaporator temperature on COP, refrigerating effect, Condenser work, work of compression and heat rejection ratio were investigated. After successful investigation on the performance of hydrocarbon and blends of hydrocarbon refrigerants it is found that COP of the system is comparable to R-134a and also energy consumption is similar to R- 134a.

3. METHODOLOGY

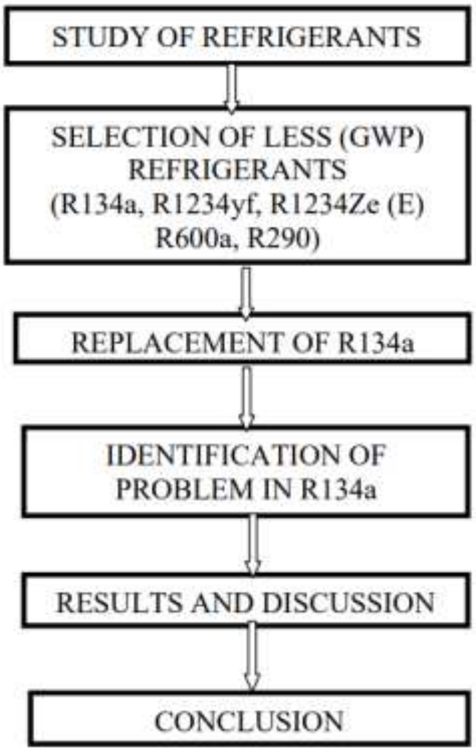

Fig.3.1 Methodology

4. ENVIRONMENTAL IMPACTS

The first major environmental impact that struck the refrigeration-based industries is ozone depletion potential (ODP) due to manmade chemicals into the atmosphere. About 90% of the ozone exists in the stratosphere between 10 and 50 km above the earth surface. Molena and Rowland (1974) give in detail that chlorine based refrigerants are stable enough to reach the stratosphere, where the chlorine atoms act as catalyst to destroy the stratospheric ozone layer which protects the earth surface from direct ultra violet rays. As per the Montreal Protocol 1987, developing countries like India, with a per capita consumption less than 0.3 kg of ozone depletion substance have been categorized as Article-5 countries. These countries are required to phase out all chlorofluro Carbons (CFCs) by 2010 and all hydro chlorofluro carbons (HCFCs) by 2040.

5. VAPOUR COMPRESSION REFRIGERATION SYSTEM

The vapour compression uses a circulating refrigerant which absorbs and removes heat from the space to be cooled and subsequently rejects that heat. The typical vapor-compression system consists of four components.

- Compressor
- Condenser
- Capillary tube
- Evaporator

In an ideal vapor-compression cycle, the system executing the cycle undergoes a series of four processes one isentropic (reversible adiabatic) process, one expansion process alternated with two isobaric processes.

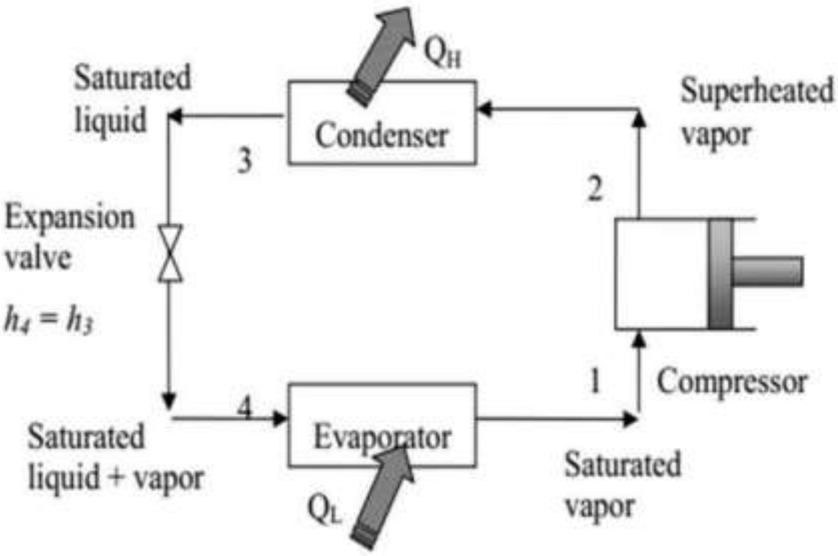

Fig.5.1 Vapour Compression Refrigeration System

6. COEFFICIENT OF PERFORMANCE

A comparison of the coefficient of performance of domestic refrigerators working with various refrigerants namely R12, R134a, propane (R290), isobutene (R600a) and the HFO (R1234yf) can be concluded. The COP of R600a are closer to that of R12.The lowest COP was when to use R1234yf, at same standard operating conditions. The COP of isobutane among substitutes refrigerants is the best. This means that the isobutene is a suitable replacement for R12 and R134a over the considered range of operating conditions. This means that the R1234yf is the best alternative refrigerant for R12 and R134a although, that is lower COP. The COP is drawn to different refrigerants on the same graph. Results which exhibits a gradual increase in the COP of various refrigerants, which indicates that pure commercial isobutene as an alternative refrigerant give the highest COP about (3%) comparison to R134a, but it was slightly lower than R12, while, pure R1234yf and propane R290 give lowest COP about (9.38%,6.5%) and (4.94%,1.93%) comparison with R12 and R134a, respectively.

Fig.6.1 Coefficient of Performance

7. REFRIGERANT AND PROPERTIES

Table.7.1 Refrigerant and Properties

Refrigerant Name	Normal Boiling Point(°C)	Critical Temperature (°C)	Critical Pressure (Mpa)	GWP	Flammability	Safety Class
R32	-51.7	78.1	5.784	650	Slightly	A2L
R134a	-26.1	101	4.059	1300	Inflammable	A1
R290	-42.1	96.1	4.247	20	Flammable	A3
R600a	-11.7	134.7	3.604	3	Flammable	A3
R600	-0.53	152	3.796	20	Flammable	A3
R1234yf	-29.5	99.7	3.382	4	Slightly	A2L

8. CONCLUSION

In this paper, an experimental analysis of a vapor compression system using R1234yf as a drop-in replacement for R134a has been presented. In order to obtain a wide range of working conditions a total of 104 steady state tests have been carried out. The tests have been performed varying the condensing pressure, evaporating pressure, superheating degree, the compressor speed and the IHX use. The energetic comparison is performed on the basis of the cooling capacity, the volumetric efficiency, the compressor power consumption, and the COP. The main conclusions of this paper can be summarized as follows

➢ Facility is about 9% lower than that presented by R134a in the test range. This difference in the values of cooling capacity obtained with both refrigerants decreases when the condensing. The cooling capacity of R1234yf used as a dropin replacement in a R134a refrigerant temperature increases and when an IHX is used.

➢ The volumetric efficiency using R1234yf is about 5% lower in comparison with that obtained with R134a. Furthermore, the compressor volumetric efficiency using R1234yfshows a greater dependence on the compressor speed.

➢ The values of the COP obtained using R1234yf are between 5% and 30% lower than those obtained with R134a. Here, it is observed that when the condensing temperature.

➢ Rises from 313.15 K to 333.15 K this difference decreases from 25% until 8%, even more in the case of using an IHX.

➢ Finally, it can be concluded, from the experimental results, that the energy performance parameters of R1234yf in a drop-in replacement are close to those obtained with R134a at high condensing temperatures and making use of an IHX.

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