Performance Evaluation of Refrigeration using Alternative Refrigerant

[1]Anup Kumar Dubey, [2]Rakesh Kumar, [3]Rohit Saxena
[1]Student, [2]Asst. Professor, [3]Asst, Professor
[1]Department of Mechanical Engineering,
[1]Jagannath University, Jaipur, Rajasthan, India

Abstract: Human from prehistoric times has been using refrigeration for a wide range of applications in his daily life. Having commenced with the use of naturally occurring ice and sailed through the use of a variety of compounds such as ammonia, hydrocarbons etc. and finally arrived at the use of CFCs and HCFCs. However, the use of CFCs and HCFCs results in the impending dangers of ozone depletion and global warming. At the advent of the Montreal protocol, R134a has been recommended as an alternate refrigerant to R12. R134a is not miscible in mineral oil. Polyol ester (POE) based synthetic oils are recommended. Due to the above factors, safe conversion of existing R134a refrigerators with environmental friendly refrigerants would be critical for the Refrigeration and Air-conditioning sector. In India, more than 80% of the domestic refrigerators utilize R134a as a refrigerant due to its excellent thermophysical properties. R134a is a high global warming potential gas and needs to be controlled as per the Kyoto protocol. In the present work endeavored to find the performance of both R600a and R134a and comparing both results which could be a drop-in replacement for R134a.

***Index Terms* - Refrigerants, COP, Refrigeration cycle**

1. INTRODUCTION

Refrigeration is a process of moving heat from one location to another in controlled conditions. The work of heat transport is traditionally driven by mechanical work but can also be driven by heat, magnetism, electricity, laser, or other means. Refrigeration has many applications, including, but not limited to household refrigerators, industrial freezers, cryogenics, and air conditioning. Heat pumps may use the heat output of the refrigeration process, and also, may be designed to be reversible, but are otherwise similar to refrigeration units.

In India, more than 80% of the refrigerators are working with R-134a, which is the best proposed alternative refrigerant to R-12. R-134a is a high GWP gas and needs to be controlled as per the Kyoto Protocol. In India, some of the refrigerant manufacturers are using R600a as a replacement for R-134a as R-600a is having zero ODP and negligible Global Warming Potential (GWP). With the phasing out of CFC12 and HFC134a, existing refrigeration and air-conditioning appliances will have to be replaced with new appliances or retrofitted with alternative refrigerants. Current research focuses on the development of new refrigerants to retrofit the existing R-12 and R-134a systems and R-134a to R-600a. Various alternative refrigerants are available to retrofit the conventional systems, but each one has its own merits and demerits.

In this study, the performance of eco-friendly refrigerant R-600a which is having low GWP and negligible ODP was investigated theoretically as an alternative to R-134a in a refrigeration system.

2. LITERATURE REVIEW

In this chapter, a comprehensive survey of the previous study on the performance of alternative refrigerants and their mixtures in refrigeration and air conditioning system is presented. The need for and the scope of the present research work have been outlined at the end of the chapter.

Qureshi and Bhatt [1] comparatively analyzed the COP using R-134a & R600a Refrigerant in the Domestic refrigerator at steady state condition. In domestic refrigerator, refrigerant was selected by the obtained result from R-134a and an experiment using 50 g of R-600a which indicates the similar result as R-134a.Based on outcomes R-600a charge amount, condenser-evaporator and compressor coefficient of performance were selected for the design. The analysis of variance result is indicated that R-600a charge amount was the most effective parameter. At optimum condition the amount of charge is required for R-600a was 50 g, 66% lower than R-134a one, which not only bring economic advantages but also significantly reduces the of flammability of the hydrocarbon refrigerant. Thus, in that work comparatively analyzed the of COP using R-134a & R-600a Refrigerant in the Domestic refrigerator at steady state condition. All the results were compared. Comparison of performance domestic refrigerator at steady state condition of the system was also studied. The result indicates that R-600a COP is mere than R-134a.

Bhargav and Jaiswal [2] worked with R-134a and was investigated to assess the possibility of using a mixture of propane and isobutane. The performance of the refrigerator using the azeotropic mixture as a refrigerant was investigated and compared with the performance of refrigerator when R-134a, R-12, R-22, R-290, R-600a is used as a refrigerant. The effect of condenser temperature and evaporation temperature on COP, refrigerating effect, condenser duty, work of compression and Heat Rejection Ratio were investigated.

Colbourne and Suen [3] worked on the use of flammable refrigerants, such as R-290 (propane), as an alternative to HCFC R22 in room split air conditioners (SACs) is being pursued. This study uses established quantitative risk assessment methods to estimate frequency and severity of ignition of R-600a domestic refrigerators, which corresponds to current experience. The methodologies are also applied to R-290 SACs based on their particular characteristics to estimate the associated risk. Results show the frequency and severity of ignition of SACs are significantly lower than domestic refrigerators due to the SAC installation characteristics being more conducive for dispersion of leaked refrigerant and less potential for the confinement of a flammable mixture in the event of ignition.

Rocca and Panini [4] worked on the results of an experimental analysis comparing the performance of a vapour compression refrigerating unit operating with R-22, and its performance in comparison to a new HFC fluid, substituting the former according to Regulation No 2037 / 2000.

Hussain [5] worked with the phasing out of ozone-depleting refrigerants under the Montreal protocol 1987 researchers on alternatives to new refrigerants (HFC's) and (HC's) are made to replace refrigerants (CFC) and (HCFC) in air-conditioning and cooling systems that destroy the ozone layer. Most of the refrigerating systems especially the domestic units replace R-12 by R-134a, this study makes a comparison of performance between the two cycles especially in the condenser where the main difference between R-12 and R-134a. A correlation has been developed from the data obtained, the refrigerant side heat transfer coefficients obtained from the experimental study is different by 5%-12% from that computed from the correlations developed by ref. [6].

Boorneni and Satyanarayana [7] have been focused on alternative refrigerant to conventional CFC refrigerant, CFC like R-12, R-22, R-134a are not eco-friendly. The emission of these refrigerants causes the depletion of ozone layer. Hence to avoid above difficulty the alternative of refrigerant in the form of R600a has been choosing. R-600a refrigerant is natural refrigerant consist of hydrocarbon. In the present work, the performance of the domestic refrigerator is determined using R-600a (Isobutane) and comparison with R-134a (TetraFluro-ethane) as the part of project work the refrigerator setup consists of an evaporator, compressor, condenser and expansion valve are chosen with the suitable specification.

Mahajan and Borikar [8] presented a study of different environment-friendly refrigerants with zero ozone depletion potential (ODP) and negligible global warming potential (GWP), to replace R-134a in a domestic refrigerator.

Dalkilic and Wongwises [9] analyzed theoretical performance study on a traditional vapour compression refrigeration system with refrigerant mixtures based on HFC134a, HFC152a, HFC32, HC290, HC 1270, HC 600, and HC 600a was done for various ratios and their results are compared with CFC 12, CFC 22, and HFC134a as possible alternative replacements. In spite of the HC refrigerants' highly flammable characteristics, they are used in many applications, with attention being paid to the safety of the leakage from the system, as other refrigerants in recent years are not related with any effect on the depletion of the ozone layer and increase in global warming.

Mohanraj et al. [10] worked on the experimental investigation on hydrocarbon refrigerant mixture (composed of R-290 and R-600a in the ratio of 45.2:54.8 by weight) as an alternative to R-134a in a 200 L single evaporator domestic refrigerator. The discharge temperature of hydrocarbon mixture was found to be 8.5 to 13.4 K lower than that of R-134a. The overall performance has proved that the above hydrocarbon refrigerant mixture could be the best long-term alternative to phase out R-134a.

Joybari et al. [11] investigated the performance of a domestic refrigerator originally manufactured to use 145 g of R-134a. It was found that the highest energy destruction occurred in the compressor followed by the condenser, capillary tube, evaporator, and superheating coil.

Rasti et al. [12] did a study of substitution of two hydrocarbon refrigerants instead of R-134a in a domestic refrigerator. Experiments are designed on a refrigerator manufactured for 105 g R-134a charge.

3. EXPERIMENTAL SETUP

3.1 SELECTION OF REFRIGERANTS

In order to attain experimental results, we choose R600a and R134a refrigerants to find actual COP and to compare both refrigerants.

3.2 EXPERIMENTAL SETUP

In this chapter, an experimental set up is designed to find the COP of the domestic vapor compression system. The system will be of the size of a 165 L domestic refrigerator and properties are shown in Table 3.1. The main objectives of the set up will be to keep the evaporator temperature constant during the experiment on explaining in the aim of the present work. In this experimental R-600a is compared with the R-134a in a domestic refrigeration system. The hermit sealed compressor, the air cool natural convection condenser and the capillary tube used for the setup are the same as for domestic refrigerator. The evaporator is placed in an insulated box which may be the use itself. In the experimental setup. The cooling load may be provided by lamp bank. The load can be varied by with 0 Watts, 30 Watts, 60-Watt lamp. The vapor compression refrigeration system, so that the experimental can be carried out at different load. The watt of the lamp is calculated the experiment set up as shown in the figure. The experiment setup consists of the following component.

1. The compressor usually sealed. The power to the compressor (watt) is measured by an energy meter disc type. And stopwatches. The thermostat is disconnected.
2. The condenser
3. The expansion device (capillary tube)
4. The evaporator.

Table 3.1 Properties of the refrigerator

Cabinet volume	165 liters
Compressor	Hermetically sealed, Reciprocating type Rated power: 120 W 1.1 A, 50 Hz, 230 V AC
Condenser	Serpentine type, Externally fitted and air cooled
Evaporator	Single evaporator, clinching type
Capillary	Bore 0.7874 mm Length 3.35 m
Refrigerants	R600a (Isobutane) R134a (Tetrafluoroethane)
Cooling Capacity	85 W

Six sensors are placed at evaporator inlet and outlet, condenser inlet and outlet, Cabin 1 and Cabin 2 to measure temperatures. The evaporator lamp bank is to be placed in an insulated chamber the instrument.

- The pressure gauge has fit the suction and discharge of the compressor.
- Sensors are used to measure the temperature at various points.

For finding the coefficient of performance of any refrigerant, the compressor should have specifications of that refrigerant that can withstand from leakages. For this experiment, totally six times the coefficient of performance is calculated at 0, 30 and 60 W for both R600a and R134a and the properties of refrigerant are given in Table 3.2. For every 30 minutes, the readings are taken at 0, 30 and 60 W load until the Steady state comes. Then the results are noted at Steady state time.

Table 3.2 Properties of the refrigerants R-134a & R-600a

Properties	**R-134a**	**R-600a**
Name	Tetra Fluro Ethane	Isobutene
Chemical Formula	CH3CH2F	C4H10
Critical temperature in °C	101	135
Molecular W in kg/k mole	102	58.1
Normal Boil point in °C	-26.5	-11.6
Pressure at -25 °C in bar (absolute)	1.07	0.58
Global warming potential	1432	3
Ozone depletion potential	0	0
Liquid density kg/lit	1.37	0.60
Vapour density kg/m3	4.4	1.3
Volumetric capacity k J/m3	658	373

3.3 EXPERIMENTAL PROCEDURE

A domestic refrigerator works on vapor compression refrigeration system. The compressor, usually Hermit sealed. The power to the compressor (Kilowatt) is measured by an energy meter disc type. The process is comprised of a compressor, condenser, expansion, and evaporator. In these processes of vapor compression refrigeration system, we have utilized lamp banks placed in parallel connection Lamp bank is represented as a Refrigerant effect. The condenser is used the air cool natural convection condenser. According to the first law of thermodynamic “Heat and mechanical work are mutually converted” it means that when a system is undergoing thermodynamic cycles then the net heat supplied to system from the surrounding is equal to network done by the system on its surrounding. The function of the evaporator to evaporate the refrigerant gains to heat bulbs at no load,30 W load and Power board has to Switch ON, Domestic refrigerator compressor is start using the refrigerant R-600a (Isobutene). And then produced by cooling effect. In case, of compressor we have fixed energy to measure the power disc type energy meter at a constant temperature. Take down the energy meter reading no of seconds for 30revolutions of energy meter. Take down the reading of compressor pressure discharge inlet &condenser. The outlet from the pressure gauges. The thermocouple is measured by the temperature at the condenser. Calculate the coefficient of performance & energy consumption of vapors compression refrigeration system. And the experiment is repeated for refrigerant (R-134a) and the readings are measured.

4. RESULTS AND DISCUSSIONS

The experimental setup was done and readings are taken at regular intervals until steady state temperature. At steady state temperature, the readings are noted for calculations to find actual and theoretical COP for both R-134a and R-600a.

Here

T1 = Evaporator Outlet

T2 = Condenser Inlet

T3 = Condenser Outlet
T4 = Evaporator Inlet
T5 = Cabin 1
T6 = Cabin 2
P1 = Condenser Pressure
P2 = Evaporator Pressure

Table 4.1: At 0 W load condition performance for R-600a

Time (Hours)	Evaporator outlet (T1) ^{0}C	Condenser Inlet (T2) ^{0}C	Condenser outlet (T3) ^{0}C	Evaporator inlet (T4) ^{0}C	Cabin (1) (T5) ^{0}C	Cabin (2) (T6) ^{0}C
2:30	5.5	50.8	45.7	3.9	9.6	14.9
3:00	4.2	49.5	44.1	-0.1	7.3	11.6
3:30	2.8	49.5	44.6	-0.9	6.1	9.7
4:00	2.7	49.6	44.8	-1	5.4	8.8
4:30	2.7	49.6	45	-1.1	5.3	8.4
5:00	2.4	48.9	43.8	-1.4	4.9	8
5:30	2.3	48	43	-1.6	4	7.6
6:00	2.2	48.1	43	-1.8	3.3	7.2
6:30	2	47.6	42.8	-1.9	2.6	7
7:00	1.8	47	42.3	-2	2.5	7
7:30	1.3	47.1	42.4	-2	2.5	7
7:40	1.3	47.1	42.4	-2	2.5	7.1

Table 4.1 gives the six temperatures namely evaporator outlet condenser inlet, condenser outlet, evaporator inlet, cabin inlet & cabin outlet temperatures respectively marked as T1, T2, T3, T4, T5 and T6 for 0-Watt leading condition with refrigerated R-600a as working fluid.

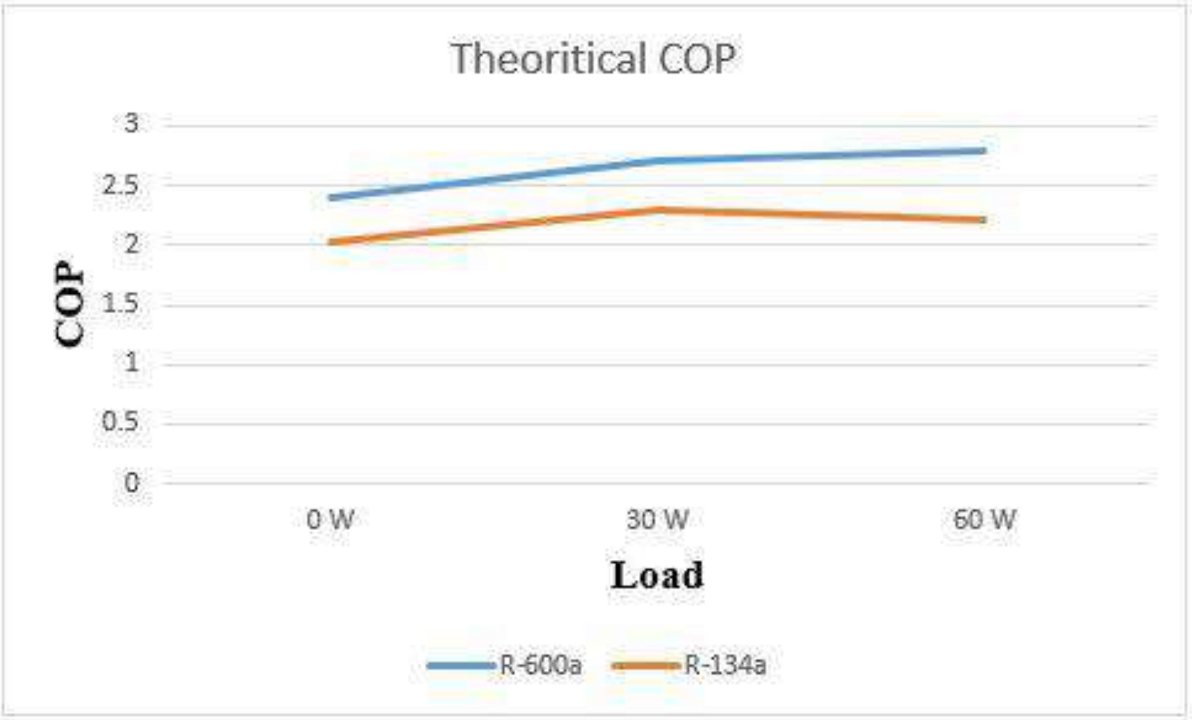

Figure 4.1 Comparison of Theoretical COP

Fig, 4.1 represents the theoretical COP of both refrigerants at different load conditions. At 0 W load condition, theoretical COP of R-134a is 15.8% lesser than theoretical COP of R-600a. At 30 W load condition, theoretical COP of R-134a is 15.1% lesser than theoretical COP of R-600a. At 60 W load condition, theoretical COP of R-134a is 21% lesser than theoretical COP of R-600a. At 0 and 30 load conditions, theoretical COP of R-600a is same when compared with theoretical COP of R-134a.At 60 W load condition, theoretical COP of R-600a is much higher than R-134a which is having lesser performance when compared with R-600a.

5. CONCLUSION

In this study, a vapor-compression refrigeration system is used for the performance analysis of alternative refrigerant R-600a as substitutes for R-12, R-134a. Considering the comparison of performance coefficients (COP) and also the main environmental impacts of ozone layer depletion and global warming, refrigerant R-600a is found to be the most suitable alternatives among refrigerants tested for R12 respectively. The experimental calculations are done by comparing the coefficient of performance using refrigerant R-600a (Isobutane) and R-134a (tetrafluoromethane) at steady state condition. The theoretical coefficient of performance of R-600a was higher when compared with R-134a at 0W, 30W, and 60W load conditions. Energy consumption by refrigerator gradually decreases when R-134a is replaced with R-600a as COP of R-600a is higher. Replacing R-134a with R-600a decreases GWP from 1432 to 3 and causes no harm to ozone as R-600a has negligible GWP. As R-600a has low GWP and zero ODP it causes no harm to environment. Thus, the reported results prove that the R-600a can be used as an alternative to phase out R-134a and R-12 in domestic refrigerators.

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