Experimental Investigation of COP Using Hydro Carbon Refrigerant in a Domestic Refrigerator

Anusha Peyyala¹, Dr N V V S Sudheer²
¹Assistant Professor, Mechanical Engineering Department, P V P Siddhartha Institute of Technology, Vijayawada.
²Associate Professor, Mechanical Engineering Department, R V R & J C College of Engineering, Guntur.

Abstract: Under the Montreal protocol 1987 researchers worked on the possibility of alternative refrigerants like Hydrofluorocarbon’s [HFC’s] and Hydrocarbon’s[HC’s] to replace refrigerants Chlorofluorocarbon’s [CFC’s] and Hydrochlorofluorocarbons [HCFC’s] in air-conditioning and cooling systems that are destroying the ozone layer. On October 15, 2016 one hundred and ninety plus countries including India came to an agreement called Kigali Amendment to phase out potent green house gases by 2045 there by preventing 0.5 C rise in global temperature by 2050. Under this agreement India agreed to a timeline to reduce the use of HFC’s by 85% of their baseline by 2045. HFC’s are a family of greenhouse gases that are largely used in refrigerators and air conditioners which have reduced the Ozone Depleting Potential [ODP] but increased the Global Warming Potential [GWP]. Refrigeration and its applications are important in almost all branches of industry, so engineers have to become aware of its principles, uses and limitations. Since the decade there are major changes in the choice of refrigerants due to environmental factors. This issue is on-going and new developments should be developed to decrease the environmental problems. So the aim of this paper is to present the experimental analysis of Coefficient of performance [COP] values using R134a [HFC] & R600a [HC] as Refrigerants in Domestic refrigerator using conventional and nonconventional energy sources. Based on the results, usage of R600a in domestic refrigerators will reduce the ODP and also GWP problems which fulfills the nominal requirements of human beings without any effects.

Keywords: COP, Domestic Refrigerator, Eco Friendly Refrigerant, Solar Refrigerator.
1. INTRODUCTION

The term refrigeration means the use of mechanical devices for producing and maintaining the temperatures of the system less than that of surroundings. American Society of Refrigerating Engineers defines refrigeration as “the science of providing and maintaining temperature below that of the surrounding atmosphere”. Equipment used for removing the heat continuously for maintaining low temperature in a space is called ‘refrigerator’ and cycles on which it operates are called ‘refrigeration cycles’. The working fluids used for carrying away heat are called ‘refrigerants’ which are used in both refrigeration and air conditioning equipments. The refrigerants Chlorofluorocarbon [CFC’s] and hydro chlorofluorocarbon [HCFC’s] have high ozone depleting potential [ODP] and global warming potential [GWP]. Because of this reason these refrigerants needs to be replaced with new eco friendly refrigerants to protect the environment and the hydro fluorocarbon [HC] refrigerants with zero ozone depletion potential have been recommended as alternatives.

Refrigeration is extensively used for increasing the storage life of perishable items specially food products, vegetables, fruits, milk, beverages, chilling of water, ice formation etc. along with industrial applications in chemical manufacturing, petroleum refinery, petrochemical plants, paper and pulp industry etc. In most household refrigerators as well as in many large commercial and industrial refrigeration systems the vapor-compression cycle is used.

An Evaporator turns the liquid form of a chemical into its gaseous form and the purpose of the evaporator is to receive low-pressure, low temperature fluid from the expansion valve and to bring it in close thermal contact with the load. Latent heat from the load will be taken up by the refrigerant which leaves the evaporator as a dry gas. Compressor is a device used to compress the liquid (or) gas from low pressure to higher. In VCR system the compressor is placed between the evaporator and condenser. Condenser is a device that is used to condense a fluid from its gaseous state to liquid. The function of condenser is that the hot, high-pressure gas from the compressor is cooled to remove first the superheat and then the latent heat, so that the refrigerant will condense back to a liquid. In nearly all cases, the cooling medium will be air or water Expansion valve is a device used to convert the high pressure liquid coming from the condenser to the low pressure liquid which then goes to the evaporator. The working fluid (or) working substance that is used to absorb the heat from the cold system, in order to provide and maintain lower temperature than that of surroundings in known as “Refrigerant”. The refrigerant is a heat carrying medium which during their cycle (i.e. compression, condensation, expansion and evaporation) in the refrigeration system absorbs heat from a low temperature system and discards the heat so absorbed to a higher temperature system.

The natural ice and a mixture of ice and salt were the first refrigerants. In 1834, ether, ammonia, Sulphur dioxide, methyl chloride and carbons dioxide came into use as refrigerants in compression cycle refrigeration machines. In the present days, many new refrigerants including halo-carbon compounds, hydro- carbon compounds are used for air conditioning and refrigeration applications. The suitability of a refrigerant will be determined by its physical, thermodynamical, chemical properties and various factors. There is no one refrigerant which can be used for all types of applications.

The Vision of this work is to model an eco friendly domestic refrigerator, Mission is to know the Best possible eco friendly refrigerant and Objective is to prepare an experimental set up to calculate COP values for test refrigerant using both renewable and non-renewable energy
sources under steady state conditions. The Ozone Depletion Potential ODP of R134a is zero, but it has a relatively high global warming potential GWP. Many researchers are concentrating on the development of best possible environmentally friendly refrigerants. The Isobutane has been in use in the past, in refrigerators up to the 40’es, and has now again found a wide use in domestic refrigerators and freezers in Europe, especially in Germany, where more than 90% of refrigerators are manufactured using R-600a as refrigerant because of zero ODP and a negligible GWP.

Chlorofluorocarbons [CFC’s] and hydro chlorofluorocarbons [HCFC’s] have less toxicity, material compatibility and non flammability that have led to their widespread use by both consumers and industries around the world as refrigerants in refrigeration and air conditioning systems. This presence of chlorine atoms removes zone in the atmosphere and later these chlorine atoms continues to convert ozone to oxygen. Hydro fluorocarbons [HFC’s] and Hydrocarbons [HC’s] are an alternate for CFC’s and HCFC’s in which there are no chlorine atoms which will not participate in destroying ozone layer. R134a and R152a belongs to the family of HFC’s and R290, R600, R600a belongs to the family of HC’s. Scientists and Researchers are searching for a new ozone friendly refrigerant for the domestic refrigerator and freezer. So it is highly important to prepare an environment friendly refrigerant without compromising international standards and commitments to protect the environment.

A.S. Dalkilic et al. [1] did a theoretical performance study with refrigerant mixtures based on HFC134a, HFC152a, HFC32, HC290, HC1270, HC600, and HC600a on a traditional vapor-compression refrigeration system. Their results are compared with CFC12, CFC22, and HFC134a as possible alternative replacements. In spite of the HC refrigerants' which are flammable can be used in many applications. For the condensation temperature of 50 °C and evaporating temperatures ranging between − 30 °C and 10 °C their theoretical results showed that all of the alternative refrigerants investigated in this analysis have lower performance coefficient (COP) than CFC12, CFC22, and HFC134a. Refrigerant blends of 40 percent HC290 and 60% HC600a by weight instead of CFC12, and 20 % HC290 and 80% HC1270 by weight instead of CFC22 are found to be the best replacement refrigerants among other alternatives.

K. Mani et al. [2] conducted an experiment on vapor compression refrigeration system with the new R290/R600a refrigerant mixture and compared with CFC12 and HFC134a. The vapor compression refrigeration system was initially designed to operate with R12. Experimental results showed that the refrigerant R290/R600a had 19.9 to 50.1 percent higher refrigerating capacity than R12 and 28.6 to 87.2 percent than R134a. The refrigerant R134a showed slightly lower refrigerating capacity than R12. The mixture R290/R600a consumed 6.8 to 17.4 percent more energy than R12. The refrigerant R12 consumed slightly more energy than R134a at higher evaporating temperatures. The coefficient performance of R290/R600a mixture increases from 3.9 to 25.1 percent than R12 at lower evaporating temperatures and 11.8 to 17.6 percent at higher evaporating temperatures. The refrigerant R134a showed slightly lower coefficient of performance 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 percent] mixture can be considered as a drop-in replacement refrigerant for CFC12 and HFC134a. M.A. Akhavan-Behabadi et al. [3] carried out an experimental study on heat transfer characteristics of a nano-refrigerant flow during condensation inside a horizontal smooth tube.

Experiments are conducted for three different working fluid types including pure refrigerant[R600a],refrigerant/lubricant[R600a/oil]and nano-refrigerant-refrigerant/lubricant/nanoparticles [R600a/oil/CuO]. Akintunde M.A et al.[4] conducted an Experimental study of
R134a, R406A and R600a as alternative to Freon 12 where research is focused on refrigerant blends as alternatives to R12 only. M.A. Sattar et al. [5] conducted Performance investigation of domestic refrigerator using pure hydrocarbons and blends of hydrocarbons as refrigerants. The COP for the HC’s and blends of HC’s are compared with the COP of HFC134a. Neil A Roberts et al. [6] Presented laboratory results of energy saving refrigerant blends comprising R125, R134a, R600 or R600a. Blends R417A and 79 are suitable as replacements for R22, R402B, R408A, R502.

Khalid A. Joudi et al. [7] did a computational model with the objective of simulating the performance of an ideal automotive air conditioning system, working with several refrigerants. The main function of this model was to determine the most suitable alternative refrigerant for R-12. The effects of several parameters on system performance and compatibility were investigated, including evaporating temperature, condensing temperature and compressor rotational speed. Five refrigerants were studied by this model, including R-12, R-134a, R-290, R-600a and a mixture of propane and isobutane R290/R600a (62/38, molar percentage). The model predicted that the mixture (R290/R600a) was the most suitable alternative for R-12 and that several modifications should be performed when the other alternative refrigerants are used in the R-12 system. The major part of this work was an experimental investigation for the use of R290/R600a as a drop-in alternative for R-12 in a prototype automotive air conditioning system.

2. ECO FRIENDLY REFRIGERANTS

We have discussed above that there is no ideal refrigerant. A refrigerant is said to be ideal if it has all of the following properties: Low boiling point, High critical temperature, Low specific heat of vaporization, Low specific heat of liquid, Low specific volume of vapor, Non corrosive to metal, Non flammable and non explosive, Non toxic, Low cost, Easy to liquefy at moderates pressure and temperature, Easy of locating leaks by odor or suitable indicator, and Mixes well with oil.

Hydrocarbon Refrigerants [HC’s]:

Most of the hydrocarbon refrigerants are successfully used in industrial and commercial installation. They posses satisfactory thermodynamic properties but are flammable and some of the various hydro carbon refrigerants are given in the following table.

| Refrigerant number | Chemical name | Chemical formula |
|--------------------|---------------|-----------------|
| R-170              | Ethane        | C2H6            |
| R-290              | Propane       | C3H8            |
| R-600              | Butane        | C4H10           |
| R-600a             | Iso-butane    | C4H10           |

Nowadays R-134a refrigerant is the most commonly used refrigerant in domestic refrigerator which is causing serious environmental effects. So to overcome this problem there is a need to change the refrigerant, where we have used R-600a as a refrigerant which is examined for the comparison of C.O.P of R-600a and R-134a.
In earlier days mechanical refrigeration systems employed sulfur dioxide, methyl chloride and ammonia. Being toxic, sulfur dioxide and methyl chloride rapidly disappeared from the market with the introduction of CFC’s. Occasionally, one may encounter older machines with methyl formate, chloromethane, or dichloromethane [called carrene in the trade]. Chlorofluorocarbons were little used for refrigeration until better synthesis methods, developed in the 1950s, reduced their cost. Their domination of the market was called into question in the 1980s by concerns about depletion of the ozone layer. Following legislative regulations on ozone depleting chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs), substances used as substitute refrigerants such as per fluorocarbons (FCs) and hydro fluorocarbons (HFCs) have also come under criticism. They are currently subject to prohibition discussions on account of their harmful effect on the climate. In 1997, FCs and HFCs were included in the Kyoto Protocol to the Framework Convention on Climate Change.

In 2006, the EU adopted a Regulation on fluorinated greenhouse gases, which makes stipulations regarding the use of FCs and HFCs with the intention of reducing their emissions. The provisions do not affect climate-neutral refrigerants. But these refrigerants also responsible for global warming, and now it emerges the world to move towards the Hydrocarbons(HC’s)

Concerns with depletion of the ozone layer by Freon gases have led to increased use of isobutane as a gas for refrigeration systems, especially in domestic refrigerators and freezers, and as a propellant in aerosol sprays.

2.1 Iso-Butane as a Refrigerant: In this project we examined isobutene[R-600a] as a refrigerant which is hydrocarbon in nature, R134a is the long-term replacement refrigerant for R12 because of having favorable characteristics such as zero ODP, non-flammability, stability and similar vapors pressure as that of R12. The ODP of R134a is zero, but it has a relatively high GWP [global warming potential]. Many studies are being carried out which are concentrating on the application of environmentally friendly refrigerants in refrigeration systems. The issues of ozone layer depletion and global warming have led to consideration of hydrocarbon refrigerants such as propane, isobutene, n-butane or hydrocarbon blends as working fluids in refrigeration and air-conditioning systems. Hydrocarbons are designated as A3 (highly flammable) refrigerants.

The hydrocarbon (HC) as refrigerant has several positive characteristics such as zero ozone depletion potential, very low global warming, non-toxicity, high miscibility with mineral oil, good compatibility with the materials usually employed in refrigerating systems. Isobutane [i-butane], also known as methyl propane, is a chemical compound with molecular formula C₄H₁₀ and is an isomer of butane. It is the simplest alkane with a tertiary carbon. When used as a refrigerant or a propellant, isobutane is also known as R-600a. Some portable camp stoves uses a mixture of isobutane with propane, usually in the ratio of 80:20. Isobutane is also used as a feedstock in the petrochemical industry, for example in the synthesis of isooctane. It has zero ozone depletion potential ODP and a negligible global warming potential GWP. Furthermore it is a substance which is a part of petrol gases from natural sources.

The refrigerant R 600a has been in use in the past, in refrigerators up to the forties, and has now again found a wide use in domestic refrigerators and freezers in Europe, especially in Germany.
where more than 90 percent of refrigerators are manufactured using Isobutane as a refrigerant. Due to the abundant availability of isobutane it has been recommended as a possible refrigerant for this application which is having good energy efficiency.

3. EXPERIMENTAL PROCEDURE

3.1 Conventional Source of Energy:
An experimental facility was designed and fabricated to calculate the COP of this system. For the experimental setup [Hermetically sealed single cylinder reciprocating compressor having a stroke volume of 6.64 cubic centimeter], [0.78 ± 0.02 mm Inner diameter and 2.0 ± 0.05 mm Outer diameter and 2.75 ± 0.03 m Length copper capillary tube having a charge capacity of 40-90 grams], [steel wire on tube air cooled condenser having a 4.76/6.18 mm Tube diameter (inner/outer) and 0.724square meter Outer surface area with a Maximum working pressure of 40 bar], [Roll bond-type Aluminum Evaporator with 1184 ± 1 mm Length, 1.2 ± 1 mm Thickness of evaporator panel with 0.35squaremeter Passage way surface of panel , 0.024 cubic meter Volume capacity of panel, 6.5 mm Outlet tube diameter, 20 bar Maximum working pressure] were selected. After making the connections properly 70g of R600a [HC] refrigerant is filled in the system with a pressure of 5psi and properly sealed. The compressor is turned on for the for the readings, where room temperature as well as all the component temperatures are noted at equal intervals of time until steady state with the help of digital thermometer.

Graph1. shows the change in evaporator, compressor, condenser and expansion valve components temperatures of a refrigerator with respect to the time.

3.2 Non Conventional Source Of Energy:
Refrigerator which runs on electricity provided by solar energy is known as solar refrigerator. There are so many areas in India where electricity is not available. So to preserve food, medicine in those areas refrigerator is required. Solar energy is one of the promising energy sources that can replace conventional energy sources at no or low cost. Solar-Powered refrigerators may be most commonly
used in future generation. Need of solar refrigeration is to minimize environmental impact and fuel cost, to help mitigate poverty and climate change, Food preservation and to avoid medicines from spoiling. This section explains solar refrigerator designed and developed for monitoring its performance in Indian climatic conditions. Solar panel consists of photovoltaic cells to collect the sunlight which converts the solar power into thermal energy and then to electric power. In this setup 155 watts solar panel is used to collect the sunlight and converted to 12 V DC Electric power, but the refrigerator compressor runs on AC current. Solar charge controller monitors the charge of the battery when battery is fully charged, controller will stop electric power from solar panel which gives an alert). Energy demand doesn’t always coincide with energy production. Inverter is a device which is used to convert the Direct current into Alternating current or vice-versa. As mentioned above the power generated from the solar panel is in DC current form so it should be changed to AC form for the usage. Energy will be stored by battery when by solar panel which supplies electricity to the compressor when it is needed. In other words it can be charged in daytime and can be used in night time. It is charged by the battery charger. Battery charger can also operate the unit when 120V AC Current is available. These are the basic components of the solar refrigerator, when the connections are made properly the compressor is turned on for the inspection. The solar refrigerator is shown below with the connections where all the component temperatures are noted at equal intervals of time.

When we compared the COP values of the refrigerator when worked with conventional and non conventional energy sources the COP values are almost same. But a domestic refrigerator equipped with environment friendly refrigerant working with the help of solar energy will be the best possible system and can be called as a Green Refrigerator.

![Experimental Set up](image1.png)  
![Graph 2. Variation of evaporator temperature](image2.png)

Advantages are Eco-Friendly, More abundant in nature, Cost of refrigeration is less, and Refrigeration can be done in remote areas. Applications are it can be used in army for vaccine preservations, Food preservation in remote areas, Can be used to offset or eliminate the diesel fuel powered refrigeration systems currently used in transport applications.
4. Conclusion

In this project R-600a (ISO BUTENE) was used as refrigerant in domestic refrigerator, basically designed for R-134a as refrigerant. We tested the performance of refrigerator by charging 70g of R-600a and checked its performance. Experiment has been performed under different loads where Readings of various component temperatures are taken with the help of the digital thermometer at an interval of five minutes each. The pressure of refrigerant is initially 5psi and changes are not considerable. We found that Ammeter reading fluctuates between 0.5A to 1A and voltmeter reading fluctuated in the range of 210V to 220V. For further calculation we took these values as 0.5A and 215V as these values were more consistent. However from the view of C.O.P it slightly differed with R-134a but the C.O.P of R600a can be increased by using some more techniques. Except from the economical point of view it is more and more important to use the eco-friendly refrigerants for our safety i.e. using R-600a as the refrigerant reduces the GWP and ODP problems which fulfills the nominal requirements of the human beings. From this project our conclusion is that the environmental problems should be decreased at any cost and this can be achieved by employing R-600a [HC’s] as the refrigerant. More research needs to be done on this aspect as hydrocarbons are flammable in nature.

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Anusha Peyyala
Assistant Professor,
Department of mechanical engineering,
P V P Siddhartha Institute of Technology,
Vijayawada, India.

Dr NVV S Sudheer
Associate professor
Department of Mechanical Engineering,
R V R & J C College of engineering, Guntur, India.