# PERFORMANCE TESTING ON A MINI REFRIGERATOR RETROFITTED WITH AN ECO-FRIENDLY REFRIGERANT USING HC BLEND

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## ABSTRACT

In the present investigation, an experimental study on the application of hydrocarbon to replace tetrafluoroethane (R134a) in a domestic refrigerator. The hydrocarbons (HCs) investigated are propane (R290) and isobutane (R600A). A refrigerator designed with a gross capacity of 80 liter is used in the experiment. This paper presents a study of different environment friendly refrigerants with zero ozone depletion potential (ODP) and negligible global warming potential (GWP), to replace R-134a in domestic refrigerator. This refrigerants are recommended for future generation in substitute for tetrafluoroethane (R134a) refrigerant. The effects of the main parameters of performance analysis such as coefficient of performance (COP) were investigated.

**Keywords:** Tetrafluoroethane, isobutene and refrigerants.

## INTRODUCTION

Refrigeration may be defined as the process of lowering the temperature of a substance less than that of its surroundings. One of the most important applications of refrigeration is to preserve food products by storing them at low temperature. Refrigeration system also used for providing thermal comfort to human beings by means of air conditioning (1-2). The Montreal Protocol regulates the production and trade of ozone-depleting substances. Since the refrigerants used in air conditioning and refrigeration units contain chlorine, which causes the ozone depletion, the industry and research institutes are challenged to find suitable alternates. Results from many researches show that ozone layer is being depleted due to the presence of chlorine in the stratosphere. The general consensus for the cause of this is that CFCs and HCFCs are large class of chlorine containing chemicals, which migrate to the stratosphere where they react with ozone.

Environmental concerns have always been the driven force in the developments of environmental friendly refrigerants. Active research in fields of system design optimization, energy efficiency increase, search of the new refrigerants and efficient use of the old systems is important for both heat pump and refrigeration systems (3-4). While human influence on the climate system is clear, it is important to have transparent and easy to use methods when designing an energy system with low environmental impact. In addition to the direct impact of the refrigerant (which is conveniently estimated by GWP), any system or process, which requires energy input, indirectly affects the environment. This impact is originated from CO2 emissions from the energy production processes.

CFC refrigerants such as R11, R12, R113, R114 and R115 have been used extensively in the refrigeration and air conditioning systems. CFCs were in popular use up to the mid-eighties. Production of CFCs was phased out by the Montreal Protocol in developed countries in 1st of January, 1996. Production in developing countries will be phased out in 2010. They are used in vapor compression processes with all types of compressors. The common CFCs are stable, safe, nonflammable and efficient, but they have also damaged the Earth’s ecology. Hydrocarbons are natural, non-toxic that have no ozone depleting properties and absolutely minimum global warming potential (Table 1).

**Table.1.** Formula and composition of refrigerant

| Refrigerant | Formula | Chemical name | Critical temperature | Molecular weight | Boiling point |
|---|---|---|---|---|---|
| R134a | CF3CH2F | Tetrafluoroethane | 101°C | 102 Kg / Kmol | -26.4°C |
| R290 | CH3CH2CH3 | Propane | 96.8°C | 44 Kg / Kmol | -42.1°C |
| R600a | CH(CH3)3 | Isobutane | 135°C | 58.1 Kg /Kmol | -11.6°C |

The refrigerants mentioned in this bulletin have similar values of TLV (Threshold Limit Values), which is a value that defines the maximum concentration of toxic gases in the workplace, without affecting those exposed to this environment. This way, the same care that should be taken when handling other fluids must also be taken when handling the R290 or R600a, such as: Avoid direct inhalation Avoid contact with skin Avoid contact with fire.

According to the chemical characteristics of each refrigerant, its compatibility with lubricating oils and other components of the refrigeration system, like the filter dryer, must be considered. The hydrocarbons are compatible with all common elastomers and plastic refrigeration materials used as valve seats, seals and gaskets. Materials such as natural rubber, silicone, PP, PVC, PVDF, EPDM and CSM are not suitable for use with the hydrocarbons:

**Objectives:**

To make effective refrigeration making use of hydrocarbon (HC) blends

HCFC and HFC free refrigeration system

Refrigeration system having "Low Maintenance Cost".

## EXPERIMENTAL DETAILS

The components used in this experimental details are Compressor , Condenser , Expansion valve, Evaporator , Thermocouple and Pressure gauge .

**Compressor:** The low pressure and temperature vapor refrigerant from evaporator is drawn into the compressor through the inlet or suction valve A, where it is compressed to a high pressure and temperature. This high pressure and temperature vapor refrigerant is discharged into the condenser through the delivery valve (5).

**Condenser:** The condenser or cooler consists of coils of pipe in which the high pressure and temperature vapor refrigerant is cooled and condensed. The refrigerant, while passing through the condenser, gives up its latent heat to the surrounding condensing medium which is normally air or water.

**Expansion Valve:** It is also called throttle valve or refrigerant control valve. The function of the expansion valve is to allow the liquid refrigerant under high pressure and temperature to pass at a controlled rate after reducing its pressure and temperature. Some of the liquid refrigerant evaporates as it passes through the expansion valve, but the greater portion is vaporized in the evaporator at the low pressure and temperature (7-8).

**Evaporator:** An evaporator consists of coils of pipe in which the liquid-vapor. Refrigerant at low pressure and temperature is evaporated and changed into vapor refrigerant at low pressure and temperature. In evaporating, the liquid vapor refrigerant absorbs its latent heat of vaporization from the medium (air, water or brine) which is to be cooled.

**Thermocouple:** Thermocouples are metal couples which work on the See beck effect. In this effect, any conductor is subjected to a thermal gradient, it will generate a voltage. Measuring this voltage necessarily involves connecting another conductor to the hot end. This additional conductor will then also experience the temperature gradient, and develop a voltage of its own which will oppose the original.

**Pressure gauge:** Instruments used to measure and display pressure in an integral units are called pressure gauges or vaccum gauges. A pressure gauge used to measure pressure lower than the ambient atmospheric pressure. Most gauges measure pressure relative to atmospheric pressure as the zero point, so this form of reading is simply referred as "gauge pressure".

## Experimental Methodology

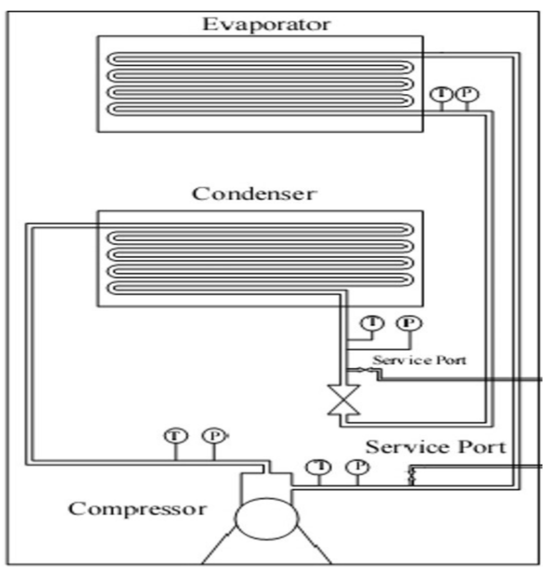


**Figure 1.** Schematic diagram of apparatus

Where T = Thermocouple, P = Pressure gauge

## Test unit and apparatus

**Figure 2.** Rear view of mini refrigerator

**Figure 3.** Rear view of mini refrigerator with high pressure and low pressure gauge

**Figure 4.** Rear view of mini refrigerator with copper capillary tube

**Figure 5.** Inner view of evaporator with 3/16 copper tube

**Figure 6.** Rear view of mini refrigerator with low pressure gauge and thermocouple

**Figure 7.** Inner view of mini refrigerator loaded with 10 kg of water

**Procedure:**

Switch the refrigerator and allow it to run for 30 minutes. Two high pressure gauge are connected, one at the compressor outlet and the other at condenser outlet. Two low pressure gauge are connected, one at the expansion outlet and the other at evaporator outlet. Four thermocouples are connected, two at compressor and condenser outlet and the other two at expansion and evaporator outlet (6).

## RESULTS AND DISCUSSION

Readings are noted down in different refrigerators values. Similar finding reported in earlier researcher (7)

**Tetra fluoro ethane (R-134a)**

**Condition:** No load

**Observation:**

1. Pressure of the refrigerant at compressor outlet ( P1 ) = 220 psi
2. Temperature of the refrigerant at compressor outlet ( T1 ) = 62°C
3. Pressure of the refrigerant at condenser outlet ( P2 ) = 220 psi
4. Temperature of the refrigerant at condenser outlet ( T2 ) = 51°C
5. Pressure of the refrigerant at evaporator inlet ( P3 ) = 6 psi
6. Temperature of the refrigerant at evaporator inlet ( T3 ) = -4.4°C
7. Pressure of the refrigerant at evaporator outlet ( P4 ) = 6 psi
8. Temperature of the refrigerant at evaporator outlet ( T4 ) = 15.4°C

**Calculation:**

-  Theoretical COP = T3 / T2 – T3 = 266.3 / 57.7 = 4.615
-  Actual COP = Refrigerant effect / work done = h2-h1 / h3- h2 = 104.67 / 69.78

From the PH chart of HFC – 134a

h1 = 151.19 kJ/kg

h2 = 255.86 kJ/kg

h3 = 325.64 kJ/kg

 Actual Coefficient of Performance = 2.2

### Propane (R-290)

**Condition:** No load

**Observation:**

1. Pressure of the refrigerant at compressor outlet ( P1 ) = 130 psi
2. Temperature of the refrigerant at compressor outlet ( T1 ) = 55.9°C
3. Pressure of the refrigerant at condenser outlet ( P2 ) = 130 psi
4. Temperature of the refrigerant at condenser outlet ( T2 ) = 38°C
5. Pressure of the refrigerant at evaporator inlet ( P3 ) = 29 psi
6. Temperature of the refrigerant at evaporator inlet ( T3 ) = -6°C
7. Pressure of the refrigerant at evaporator outlet ( P4 ) = 29 psi
8. Temperature of the refrigerant at evaporator outlet ( T4 ) = 26°C

**Calculation:**

 Theoretical COP = T3 / T2 – T3 = 267 / 44 = 6.06

 Actual COP = Refrigerant effect / work done = h2-h1 / h3- h2 = 230 / 40

From the PH chart of HC – 290

h1 = 580 kJ/kg

h2 = 620 kJ/kg

h3 = 350 kJ/kg

 Actual Coefficient of Performance = 5.7

### Isobutane (R-600a)

**Condition:** No load

**Observation:**

1. Pressure of the refrigerant at compressor outlet ( P1 ) = 140 psi
2. Temperature of the refrigerant at compressor outlet ( T1 ) = 61.9°C
3. Pressure of the refrigerant at condenser outlet ( P2 ) = 140 psi
4. Temperature of the refrigerant at condenser outlet ( T2 ) = 47.3°C

5. Pressure of the refrigerant at evaporator inlet ( P3 ) = 29 psi
6. Temperature of the refrigerant at evaporator inlet ( T3 ) = -0.8°C
7. Pressure of the refrigerant at evaporator outlet ( P4 ) = 29 psi
8. Temperature of the refrigerant at evaporator outlet ( T4 ) = 9.7°C

**Calluation:**

- Theoretical COP = T3 / T2 – T3 = 270.6 / 49.7 = 5.444
- Actual COP = Refrigerant effect / work done = h2-h1 / h3- h2 = 104.49 / 46.52

From the PH chart of HC – 600a

h1 = 163 kJ/kg

h2 = 314.01 kJ/kg

h3 = 267.49 kJ/kg

- Actual Coefficient of Performance = 2.246

### Tetra fluoro ethane (R-134a)

**Condition:** Load with 10 Kg

**Observation:**

1. Pressure of the refrigerant at compressor outlet ( P1 ) = 210 psi
2. Temperature of the refrigerant at compressor outlet ( T1 ) = 68.4°C
3. Pressure of the refrigerant at condenser outlet ( P2 ) = 210 psi
4. Temperature of the refrigerant at condenser outlet ( T2 ) = 52.2°C
5. Pressure of the refrigerant at evaporator inlet ( P3 ) = 6 psi
6. Temperature of the refrigerant at evaporator inlet ( T3 ) = -3.8°C
7. Pressure of the refrigerant at evaporator outlet ( P4 ) = 6 psi
8. Temperature of the refrigerant at evaporator outlet ( T4 ) = 16.6°C

**Calculation:**

- Theoretical COP = T3 / T2 – T3 = 266.9 / 58.3 = 4.578
- Actual COP = Refrigerant effect / work done = h2-h1 / h3- h2 = 93.04 / 69.78

From the PH chart of HFC – 134a

h1 = 162.82 kJ/kg

h2 = 255.86 kJ/kg

h3 = 325.64 kJ/kg

 Actual Coefficient of Performance = 1.333

## Propane (R-290)

**Condition:** Load with 10 Kg

**Observation:**

1. Pressure of the refrigerant at compressor outlet ( P1 ) = 130 psi
2. Temperature of the refrigerant at compressor outlet ( T1 ) = 51°C
3. Pressure of the refrigerant at condenser outlet ( P2 ) = 130 psi
4. Temperature of the refrigerant at condenser outlet ( T2 ) = 30°C
5. Pressure of the refrigerant at evaporator inlet ( P3 ) = 29 psi
6. Temperature of the refrigerant at evaporator inlet ( T3 ) = -1.6°C
7. Pressure of the refrigerant at evaporator outlet ( P4 ) = 29 psi
8. Temperature of the refrigerant at evaporator outlet ( T4 ) = 27.4°C

**Calculation:**

 Theoretical COP = T3 / T2 – T3 = 271.4 / 31.6 = 8.5

 Actual COP = Refrigerant effect / work done = h2-h1 / h3- h2 = 126 / 28

From the PH chart of HC – 290

h1 = 397 kJ/kg

h2 = 425 kJ/kg

h3 = 271 kJ/kg

 Actual Coefficient of Performance = 4.5

## Isobutane (R- 600a)

**Condition:** Load with 10 Kg

**Observation:**

1. Pressure of the refrigerant at compressor outlet ( P1 ) = 140 psi
2. Temperature of the refrigerant at compressor outlet ( T1 ) = 62.6°C
3. Pressure of the refrigerant at condenser outlet ( P2 ) = 140 psi
4. Temperature of the refrigerant at condenser outlet ( T2 ) = 46.6°C
5. Pressure of the refrigerant at evaporator inlet ( P3 ) = 29 psi
6. Temperature of the refrigerant at evaporator inlet ( T3 ) = 1.1°C
7. Pressure of the refrigerant at evaporator outlet ( P4 ) = 29 psi
8. Temperature of the refrigerant at evaporator outlet ( T4 ) = 11.9°C

**Calluation:**

 Theoretical COP = T3 / T2 – T3 = 274.1 / 45.5 = 6.024

 Actual COP = Refrigerant effect / work done = h2-h1 / h3- h2 = 116.3 / 58.15

From the PH chart of HC – 600a

h1 = 151.19 kJ/kg

h2 = 267.49 kJ/kg

h3 = 325.64 kJ/kg

 Actual Coefficient of Performance = 2.0

**Table 1.** Test conducted for the following refrigerants shown below with no load condition

| Refrigerant | P1 (psi) | T1 (°C) | P2 (psi) | T2 (°C) | P3 (psi) | T3 (°C) | P4 (psi) | T4 (°C) |
|---|---|---|---|---|---|---|---|---|
| R134a | 220 | 62 | 220 | 51 | 6 | -4.4 | 6 | 15.4 |
| R290 | 130 | 55.9 | 130 | 38 | 29 | -6 | 29 | 26 |
| R600a | 140 | 61.9 | 140 | 47.3 | 29 | -0.8 | 29 | 9.7 |

Where,

P1, T1 - Compressor outlet / Condenser inlet

P2, T2 - Condenser outlet / Expansion inlet

P3, T3 - Evaporator inlet / Evaporator inlet

P4, T4 - Evaporator outlet / Compressor inlet

**Table 2.** Test conducted for the following refrigerants shown below with load under 10 Kg

| Refrigerant | P1 (psi) | T1 (°C) | P2 (psi) | T2 (°C) | P3 (psi) | T3 (°C) | P4 (psi) | T4 (°C) |
|---|---|---|---|---|---|---|---|---|
| R134a | 210 | 68.4 | 210 | 52.2 | 6 | -3.8 | 6 | 16.6 |
| R290 | 130 | 51 | 130 | 30 | 29 | -1.6 | 29 | 27.4 |
| R600a | 140 | 62.6 | 140 | 46.6 | 29 | 1.1 | 29 | 11.9 |

**Table.3.** Comparison of following refrigerants shown below under no load condition

| NO. | Refrigerant | Actual COP |
|---|---|---|
| 1. | R – 134a | 2.2 |
| 2. | R - 290 | 5.7 |
| 3. | R – 600a | 2.2 |

**Table .4.** Comparison of following refrigerants shown below under load condition

| S.NO. | Refrigerant | Actual COP |
|---|---|---|
| 1. | R – 134a | 1.3 |
| 2. | R - 290 | 4.5 |
| 3. | R – 600a | 2.0 |

## CONCLUSION

In this study, a refrigerator with a capacity of 80 liter is used for the performance analysis of alternative new refrigerants substitute for R134a. Considering the comparison of coefficient of performance (COP) and the main environmental impacts of ozone layer depletion (ODP) and global warming potential (GWP), refrigerant R290 (PROPANE) was found to be the most suitable alternative refrigerant with COP=5.7 when compared with R600a(ISOBUTANE) of

COP=2.2 and R134a(TETRAFLUOROETHANE) OF COP=2.2 for no load test. Again, for load test, refrigerant R290 (PROPANE) was also found to be the most suitable alternative refrigerant with COP=4.5 when compared with R600a (ISOBUTANE) of COP=2.0 and R134a (TETRAFLUOROETHANE) OF COP=1.3. Therefore, R290 is concluded as the best environmental friendly refrigerant in the HC category. The performance COP of the system, increases with increase in evaporating temperature for a condensing temperature in the analysis. All system including various refrigerant blends were improved by analyzing the effect of the super heating / sub cooling case.

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