Comparative performance analysis of R600a and R436a as an alternative of R134a refrigerant in a domestic refrigerator

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Abstract. R134a is the most widely used refrigerant in domestic refrigerators. R134a is a Hydrofluorocarbon (HFC) with high GWP of 1430 and hence, it must be phase out soon under the Kyoto protocol. Hydrocarbon (HC) refrigerants have zero ODP and very low GWP. In the present work, an experimental investigation has been made with HC refrigerant R600a (isobutane) and Hydrocarbon mixture (HCM) refrigerant R436a (composed of R290 and R600a in the ratio of 54:46 by weight) as an alternative to R134a refrigerant in 170 L domestic refrigerator. The performance characteristics such as coefficient of performance (COP), energy consumption, pull down time, discharge temperature, pressure ratio and evaporator inlet temperature of R600a and R436a were compared with those of R134a. The system was modified by replacing HFC compressor with HC compressor and using optimized capillary. In the modified system, for 45g of R436a, the power consumption reduces by 41.66% as compared to R134a in original system also it reduces by 15.66% than optimized charge of R600a in modified system. COP for optimized charge of R436a with modified system increases by 60.25% than R134a and 27.11% R600a. Pull down time for R436a also reduces considerably than R134a and R600a. The overall performance has proved that the R436a refrigerant could be the best long term alternative to phase out R134a.

1. Introduction

R134a is the most widely used refrigerant in domestic refrigerators due to its excellent thermodynamic and thermo physical properties but it must be phase out soon under Kyoto protocol due to its high global warming potential (GWP). Hence in order to meet the global ecological goals, conventional refrigerants must be replaced by more environment friendly and energy efficient refrigerants.

Many researchers have reported that hydrocarbon mixtures were found to be environment friendly alternative refrigerants [1-4]. Mehdi Rasti et.al.[1] shows while using HC compressor, the optimum refrigerant charges for R436a and R600a are both 50g. Energy consumption of R600a and R436a reduces by 14.6% and 18.7% . M. Mohanraj et.al. [2] investigate that, the hydrocarbon mixture has lower values of pull down time and compressor discharge temperature by about 11.6% and 8.5°C to 13.4°C and 3.2% to 3.6% higher COP than that of R134a . M. Mohanraj et.al [3] shows that the 70 g mixture of 45% HC 290 and 55% HC 600a has better COP, lower power consumption, lower pull-down time and lower discharge temperature than HFC134a. Mehdi Rasti [4] found that in comparison to the base refrigerator working with R134a, the ON time ratio and the energy consumption per day were reduced by 13% and 5.3%, respectively. Although the original R134a charge for this refrigerator was 105 g, the optimum charge for R436A was reduced to 55 g that exhibits 48% reduction in refrigerant charge. The properties of refrigerants used in domestic refrigerator are shown in Table 1.
Table 1. The properties of some refrigerants used in domestic refrigerators.[1,4]

| Refrigerant | Molecular weight | Normal boiling Point \(^\circ\)C | Critical temperature \(^\circ\)C | Critical pressure MPa | Safety group | ODP | GWP  |
|-------------|------------------|-------------------------------|-----------------------------|----------------------|--------------|-----|------|
| R134a       | 102.0            | -26                           | 101.1                       | 4.06                 | A1           | 0   | 1430 |
| R600a       | 58.1             | -12                           | 134.7                       | 3.64                 | A2           | 0   | <20  |
| R436a       | 49.33            | -34.3                         | 130.1                       | 3.39                 | A3           | 0   | <20  |

The literature review brings out the fact that many researchers have studied with the different pure HC and HCM refrigerants as an alternative to R134a in domestic refrigerators. However, the possibility of using R436a needs further investigation. The objective of present study is to check the feasibility of using R436a in a 170 lit domestic refrigerator with change in both compressor as well as capillary dimensions with different amount of charges. (45 g, 55 g and 65 g)

1. Experimental setup
The experiment was carried out on 170 lit single door domestic refrigerators which was originally designed for 85 g of R134a working on HFC compressor. The capillary in the system is of length 2.7m and 0.00078m in diameter. The refrigerator was instrumented with two pressure gauges at inlet and outlet of the compressor for measuring the suction and discharge pressures. Temperatures at 12 different locations were measured using multichannel temperature scanner and energy consumption was recorded using energy meter. Specifications of the measuring instruments used in experiment are listed in Table 2.

Table 2. Specifications of the measuring instrument used in the experiment.

| Measuring instrument               | Measurement range | Accuracy |
|------------------------------------|-------------------|----------|
| Pressure gauges                    | 0 to 40 bar       | ± 3%     |
| SZ7504 Temperature scanner         | -55 to 99\(^\circ\)C | ±1\(^\circ\)C |
| Energy meter                        | 5.30A, 240V       | ±2%      |
| Weighing scale                      | 0 to 5 kg         | ±1g      |

Figure 1. Experimental setup with the measuring instruments.
2. Experimental procedure
The 170 lit domestic refrigerator originally designed to work with 85 g of R134a was taken for study. In the experiment, the refrigerant charge is 10% higher due to the presence of measuring instruments, connecting lines etc. The refrigerator was charged with 94 g of R134a refrigerant and the baseline performance was studied. Then the system was charged with 50 g of R600a and 50 g of R436a refrigerant one by one without any mechanical alteration in the system and the performance was recorded.

No load pull down tests were carried out for 45 g, 55 g and 65 g of R600a and R436a refrigerants in the same system by replacing HFC compressor with HC compressor. Then the same tests were carried out for same amount of charges of R600a and R436a using HC compressor just by replacing original capillary of length 2.7 m and 0.00078 m diameter with capillary of length 3.5 m and 0.00065 m diameter as calculated using TechniSolve software cap tube 1.0.8.0.[5-6]. Before charging the system with different refrigerant the system was evacuated and flushed with nitrogen gas every time to eliminate traces of prior refrigerant, impurities, moisture and foreign materials which may affect the performance of the system. Specifications for various tests are listed in Table 3.

Table 3. Test specifications.

| Test | Refrigerant | Charge (g) | Compressor Type | Capillary Specification |
|------|-------------|------------|-----------------|------------------------|
| 1    | R134a       | 94         | HFC             | d = 0.00078 m, l = 2.7 m |
| 2    | R600a       | 50         | HFC             | d = 0.00078 m, l = 2.7 m |
| 3    | R436a       | 50         | HFC             | d = 0.00078 m, l = 2.7 m |
| 4    | R600a       | 45         | HC              | d = 0.00078 m, l = 2.7 m |
| 5    | R600a       | 55         | HC              | d = 0.00078 m, l = 2.7 m |
| 6    | R600a       | 65         | HC              | d = 0.00078 m, l = 2.7 m |
| 7    | R436a       | 45         | HC              | d = 0.00078 m, l = 2.7 m |
| 8    | R436a       | 55         | HC              | d = 0.00078 m, l = 2.7 m |
| 9    | R436a       | 65         | HC              | d = 0.00078 m, l = 2.7 m |
| 10   | R600a       | 45         | HC              | d = 0.00065 m, l = 3.5 m |
| 11   | R600a       | 55         | HC              | d = 0.00065 m, l = 3.5 m |
| 12   | R600a       | 65         | HC              | d = 0.00065 m, l = 3.5 m |
| 13   | R436a       | 45         | HC              | d = 0.00065 m, l = 3.5 m |
| 14   | R436a       | 55         | HC              | d = 0.00065 m, l = 3.5 m |
| 15   | R436a       | 65         | HC              | d = 0.00065 m, l = 3.5 m |

4. Result and discussion

4.1. Pull down time
Pull down time is the time required to attain the desired cabin and freezer temperature from the ambient temperature. According to ISO-8187 standard [ISO, 1991] for refrigerator, the required temperatures are -12°C and 6°C for freezer and cabin respectively [7].

4.1.1. Pull down time for cabin temperature. Figure 2, shows the variation in temperature with respect to time for various tests. For HFC compressor the pull down time for cabin was 116 min for R134a which was reduced by 22 min and 35 min for R600a and R436a respectively. 45 g of R600a and R436a found to be insufficient to attain the desired cabin temperature even in HC type compressor without change in capillary dimensions. In HC compressor for 55 g and 65 g the pull down time reduces by 38 min and 41 min for R600a and 44 min and 46 min for R436a respectively. After optimizing the capillary the pull down time reduces by 43 min and 46 min for 55 g and 65 g of R600a refrigerator and 56 min and 57 min for R436a refrigerator. For 45 g of R436a the pull down time reduced by 53 min but...
45g of R600a could not attain desired cabin temperature even after replacing compressor and capillary.

![Figure 2. Cabin temperature vs. time.](image)

**Figure 2.** Cabin temperature vs. time.

4.1.2. *Pull down time for freezer temperature.* Figure 3. shows the change in freezer temperature according to time for various tests. For the same initial system without any mechanical alteration, the pull down time was 90min which was reduced by 14min and 27 min for R600a and R436a. 45g of R600a found to be insufficient in every test to attain the desired freezer temperature. When the original HFC compressor was replaced by the HC compressor, the pull down time was reduced by 32min and 36min for 55g and 65g of R600a and 37min and 40min for 55g and 65g of R436a. After replacing the original capillary along with compressor the pull down time was reduced by 38min and 40min for 55g and 65g of R600a and for R436a it was reduced by 45min, 48min and 50min for 45g, 55g and 65g respectively.

![Figure 3. Freezer temperature vs. time.](image)

**Figure 3.** Freezer temperature vs. time.
4.2. Coefficient of performance
Figure 4. predicts the changes in COP with respect to the variation in refrigerant and amount of refrigerants used for various tests. The COP of original system is 2.34. Among all the tests for R600a 55 g in HC compressor and modified capillary dimensions found to have best COP of 2.95. In the modified system 45 g of R436a attains maximum COP which is 3.75. COP of R436a increases by 27.11% than the best result of R600 and 60.25% than R134a.

![Figure 4. Variation in C.O.P. with different refrigerant.](image)

4.3. Power consumption
Figure 5. shows the variation in power consumption according to the change in refrigerants and amount of refrigerant charged in the system. The power consumption for original system with 94 g of R134a having HFC compressor is 0.24 kW. The least power consumption of 0.166 kW was recorded for R600a by using modified system i.e. with HC compressor and optimized capillary dimensions. 45 g of R436a with modified system requires minimum power of 0.14 kW which is less than best result of R600a by 15.66% and by 41.66% that of R134a respectively.

![Figure 5. Variation in Power consumption with different refrigerant.](image)

4.4. Pressure ratio
Pressure ratio has great impact on the compressor life. Lower is the pressure ratio more is the compressor life. Figure 6. compares the pressure ratio with change in refrigerant and the amount of refrigerant charged. The pressure ratio for best result of R134a, R600a and R436a was found to 13.33, 9 and 7.22 respectively. i.e. by using 45 g of R436a with HC compressor and modified capillary, pressure ratio decreases by 45.83% for R134a and 19.77% that of best result of R600a.
4.5. Discharge temperature
Discharge temperature of R134a, pure HC refrigerant and HCM refrigerants are compared in Figure 7. The discharge temperature of R436a is 42°C for 45g charge using HC compressor and modified capillary. The discharge temperature of R600a with 55g and 65g of charge is 44°C and 46°C using modified system. Discharge temperature of R134a in original system is 72°C. Hence the best result is obtained by R436a which is lower by 30°C and 2°C than R134a and R600a.

4.6. Evaporator inlet temperature
Comparison of inlet evaporator temperature for a refrigerator with different refrigerant and different charge amount at pull down time is shown in figure 8. The result shows that the inlet evaporator temperature with 45g charge, HC compressor and modified capillary is 6°C colder than that of R600a with 55g charge, HC compressor and modified capillary and 9°C colder than R134a in original system.
5. Conclusions
The performance of a domestic refrigerator originally designed for R134a was investigated using R600a and R436a refrigerants.

- The optimum charges for refrigerants R600a and R436a were reduced to 55g and 45g when the original system is modified with implementation of HC compressor instead of HFC compressor and by replacing the original capillary of length 2.7m and 0.00078m diameter with the capillary of length 3.5m and 0.00065m diameter.
- In the modified system the pull down time of cabin and freezer reduces by 43min and 38min for R600a and by 53min and 45min for R436a respectively as compared to baseline system and baseline refrigerant R134a having cabin pull down time 116min and freezer pull down time of 90min.
- The COP of the modified system increases by 60.25% and 26% with optimized charge of R436a and R600a than the original system with R134a refrigerant. However, in the modified system for optimized charge the COP of R436a increases by 27.11% than R600a.
- The power consumption of R436a decreases by 41.66% and for R600a by 30.83% as compared to R134a refrigerant. The power consumption of R436a reduces by 15.66% as compared to R600a refrigerant.
- The pressure ratio of the modified system with optimized charge of R436a and R600a reduces by 45.83% and 32.48% that of R134a in original system. The pressure ratio of R436a with optimized charge reduces by 19.77% that of optimized charge of R600a in the modified system.
- Discharge temperatures of optimized charge of R436a and R600a in modified system are 30°C and 28°C lower than R134a in original system. Discharge temperature of R436a is lower by 2°C than R600a in modified system.
- The evaporator inlet temperature of R436a and R600a with optimized charge in modified system is 9°C and 3°C colder than R134a. The evaporator inlet temperature of R436a is 6°C colder than R600a in modified system.

From the above conclusions, R436a is found to be best alternative to R134a in 170L domestic refrigerator with HC compressor and modified capillary dimensions.
Acknowledgements
The authors would like to thank Dynamic traders, Aurangabad for technical support and Maharashtra Institute of Technology, Aurangabad for guidance.

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