Experimental Investigation on the Performance Analysis Domestic Refrigeration Using Eco Friendly R290 & R600a Refrigerant

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Abstract –
In residential refrigerators, R134a is the most often used refrigerant. The Kyoto Protocol requires that it be phased out as soon as possible because to its high global warming potential (GWP) of 1300. In the current study, a 200l single evaporator home refrigerator using a hydrocarbon refrigerant combination (made up of R290 and R600a in a weight ratio of 45.2:54.8) has been used as an alternative to R134a. While cycling running (ON/OFF) testing were only conducted at 32 ◦C ambient temperature, continuous running tests were conducted at various ambient temperatures (24, 28, 32, 38, and 43 ◦C). The hydrocarbon mixture was found to have a 3.25–3.6% higher coefficient of performance (COP) and lower values of energy consumption, draw down time, and ON time ratio by around 11.1%, 11.6%, and 13.2%, respectively. It was discovered that the hydrocarbon mixture's discharge temperature was between 8.5 and 13.4 K lower than R134a's. Overall performance has demonstrated that the hydrocarbon refrigerant mixture mentioned above may be the most suitable long-term replacement for R134a as it phases out.

1.INTRODUCTION

R134a is the refrigerant of choice for around 80% of home refrigerators in India because of its superior thermodynamic and thermophysical qualities. However, R134a's GWP is large (1300). Finding a long-term replacement is necessary to satisfy the needs of system performance, refrigerant-lubricant interaction, energy efficiency, environmental effects, safety, and servicing because of the increased GWP caused by R134a emissions from residential refrigerators. One of the six categories of greenhouse gases that must be reduced according to the Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC) is hydrofluorocarbons (HFCs), which are used as refrigerants [1]. The search for a more suitable HFC refrigerant replacement is critical from the perspectives of the environment, ecology, and human health [2]. Many investigators have reported that GWP of HFC refrigerants is more significant even though it has less than that of chlorofluorocarbons (CFC) refrigerants.

Refrigerators are one of the most energy-intensive domestic appliances in a home. A number of studies have found that hydrocarbon mixed refrigerants are an environmentally friendly and energy-efficient replacement for R12 in domestic refrigerators. One study, for example, used liquefied petroleum gas (LPG) (composed of R290, R600, and R600a, in the ratio of 30:55:15, by mass) as an alternative to R12 in domestic refrigerators at different mass charges of 50, 80, and 100 g. The results indicated that 80 g of LPG performed the best when compared to R12. Another study conducted by Jung et al. examined the effects of R290/R600a (in the ratio of 60:40, by mass fraction) as a substitute for R12 in 299 and 465 l domestic refrigerators. Refrigerators are recognized as significant energy consumers.

domestic appliance used in a home setting. Numerous researches have found that pure hydrocarbon refrigerants do not match R134a's volumetric cooling capacity and operating pressure, making them unsuitable as drop-in replacements [9]. In order to replace R134a, Somchai and Nares [10] conducted research using hydrocarbon mixes and HC/HFC mixtures at varying mass ratios in a 239 l household refrigerator at a temperature of 25 °C. The best option, according to reports, is a mixture of R290 and R600 with a mass fraction ratio of 60:40. In lieu of R134a, Fatouh and Kafafy [11] experimented using LPG (made up of 60% R290 and 40% commercial butane) in a 280-liter home refrigerator at an ambient temperature of 43 °C. According to their findings, the LPG refrigerator's COP was around 7.6% higher than the R134a refrigerator's, while its energy consumption and ON time ratio were about 10.8 and 14.3% lower, respectively. According to a theoretical analysis, a 30% increase in capillary tube length is needed when utilizing a ternary hydrocarbon refrigerant combination (made up of R290, R600, and R600a) with a 60% mass fraction of R290, as opposed to R134a [12].

When the R290/R600a refrigerant mixture changes states, it behaves like a zeotrope, not like a single material.

Temperature glide and composition shift result from the non-isothermal phase transition process of zeotropic mixtures, in contrast to pure refrigerants, whose compositions do not stay constant [13]. The liquid becomes rich in less volatile component (R600a) when the zeotrope evaporates inside the tubes, with the mixture's more volatile component (R290) evaporating first. The saturation temperature decreases due to an increase in the less volatile component (R600a) in the liquid; hence, the pressure drop is compensated.

When combined with non-metallic components used in hermetically sealed compressors, the aforementioned hydrocarbon combination is shown to be non-reactive and chemically stable [15]. Even in the event of a leak, the total amount of hydrocarbons in the system does not above the lower flammable limit under typical operating settings because the amount of hydrocarbon mixture used in the system is around half that of R134a.

The analysis of the literature reveals that numerous researchers [6–12] have investigated various hydrocarbon refrigerant mixes as substitutes for R12 and R134a in residential refrigerators. Further research is necessary to determine whether HCM, which is made up of 45.2% R290 and 54.8% R600a, can be used as a substitute for R134a in a variety of environmental temperatures. The current study's goal is to investigate the viability of utilizing the aforementioned HCM in a 200 l domestic refrigerator with various mass charges (40, 50, 60, and 70 g). The impact of surrounding temperatures on the refrigerator's performance characteristics during both continuous and cyclic operation at varying freezer air temperatures, with an ambient temperature of 32 ◦C, has been investigated.

2. EXPERIMENTAL SETUP:

To examine the performance of R134a, R600a, R600a/R290 (70/30 by weight percentage), R600a/R290 (60/40 by weight percentage), and R600a/R290 (50/50 by weight percentage) combination refrigerants, an experimental setup for a vapor compression refrigeration system was created. The experimental setup is seen in real time in Fig. 1, and a line diagram is displayed in Fig. 2. The system consisted of a 200-liter residential refrigerator with deep freezing capability that was initially intended to hold 150 grams of R134a refrigerant. Two loops make up this system: the first loop includes a compressor, condenser, filter-drier, expansion device, and calorimeter; the second loop, on the other hand, only has an evaporator in place of the calorimeter along with the remaining key components.

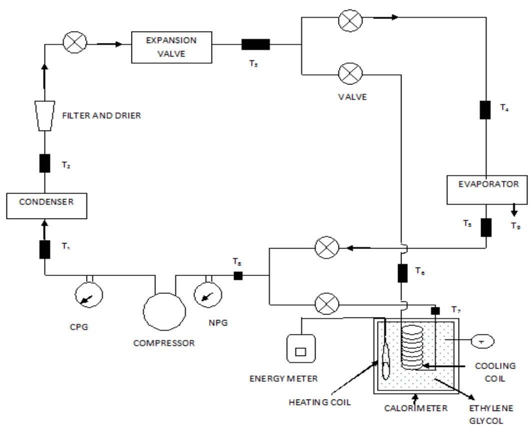
The system employed a hermetically sealed reciprocating compressor that was intended to run a 200-liter refrigerator with deep freezing capability using R134a refrigerant. An air-cooled condenser with force convection was employed. A 10-foot-long, 0.036-inch-diameter capillary tube served as the system's expansion device. System cooling effects determined by a calorimeter linked to the main loop. It had a temperature measuring device, an electric heater with a motor, a stirrer that rotated to keep the calorimeter at a constant temperature, and a cooling coil that measured 25 feet in length and 5/16 inches in diameter. Each of these gadgets was carefully put within a ten-liter insulated plastic ethylene glycol container. An electric heater and a dimmerstat, connected to a wattmeter, were installed in the calorimeter in order to compute R.E. (heat gain by heater equals heat removed by evaporator coil).

All these 9 thermocouples in the accuracy range of -50 ºC to 80 ºC with ± 0.1 ºC were fitted at inlet and outlet of all the major components. A drier was used after condenser to absorb moisture present in the refrigerant. In two pressure gauges,one is compound pressure gauge which is measured from -30 psi to 500 psi and one normal pressure gauge which is measured form -30 psi to 150 psi with ± 1 psi accuracy fitted at compressor discharge and suction side, respectively.Compressor power consumption was measured by a wattmeter with an accuracy of ± 0.5%.Energy consumption by the heating coils (inside calorimeter) was measured by a wattmeter with an accuracy of ± 0.5 %.Energy supply meter also used to calculate total energy consumption in KW/hr.

3.EXPERIMENTAL PROCEDURE

Using a vacuum pump, the system was evacuated to a negative pressure of -20 psi in order to remove any contaminants, moisture, and other extraneous materials that might have affected the precision of the experimental setup. Next, with the use of charging valves and an electronic weight mass meter, the refrigerator was charged in a varied mass fraction. For the base line test, we first calculated results using 250g of R134a refrigerant. Following that, we used 125g HCM in various mass fractions to determine which refrigerant was optimal for the system. All measurements are made once the system has reached steady state (the thermometer was kept at the measured value for ten minutes with the use of a dimmerstat).

Temperatures were monitored in 0C at 10-minute intervals using 9 thermocouples installed in all major equipment. Two pressure gauges were used to measure pressure on the suction and discharge sides of the compressor at 10-minute intervals. To compute pull down, the test system was cooled from air temperature to the desired temperature. R.E. at a specific evaporation temperature was determined by maintaining a calorimeter at that temperature with the use of a heating device. In this procedure, wattmeters attached to calorimeters provided R.E., while wattmeters attached to compressors provided power consumption. The procedure was repeated for all refrigerants evaluated at the measured evaporation temperature.



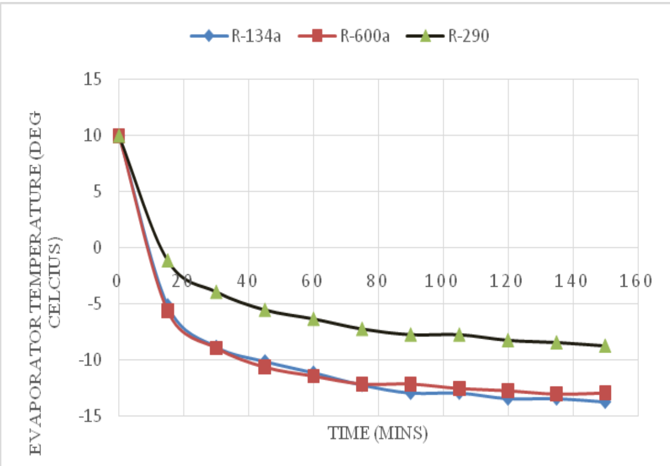
READINGS:

Refrigerants (category)	Chemical Formula	Normal Boiling point(˚C)	Critical Temperature(˚C)	ODP	GWP	Safety Group
R 134a	CH_3CH_2F	-26.07	101.6	0	1380	A1
R 290	C_3H_8	-42.1	96.8	0	20	A3
R 600a	C_4H_{10}	-11.67	135	0	20	A3

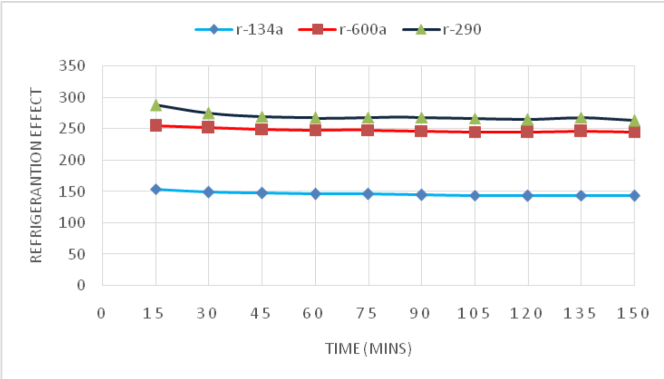
4.CALCULATION:

1. Compressor Work done (W_C) = ($h_2 - h_1$)kJ/kg
2. Refrigerant effect Per Kg (R_E) = ($h_1 - h_3$) kJ/kg
3. COP = Refrigerant Effect/Compressor Workdone

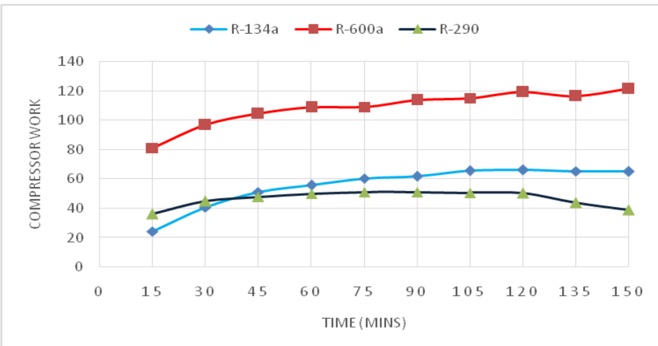
5. RESULT AND DISCUSSION:



As indicated in the picture, at the start of the refrigerator, the evaporating temperature of all refrigerant is set to 10°C. As the refrigerator runs, the evaporator temperature decreases and eventually reaches a constant temperature. During the first 15 minutes, all refrigerants have a significant reduction in evaporator temperature, with R290 having the highest temperature. R600a and R134a have low temperature drop. After 150 minutes, R600a has a low evaporation temperature.



As indicated in the picture, the refrigerant is high at first and then gradually decreases over time, and when the refrigerant effect becomes consistent, it is due to the temperature differential in the cabinet. The figure clearly shows that R290 has a higher refrigerant effect than any other refrigerant. However, the refrigerant effect is low for R134a refrigerant. Also The image also shows that the refrigerant effect eventually has a gas constant value.



As indicated in the image, the compressor work done is minimal at first, but as time passes, it increases and eventually becomes constant. The pace at which the compressor work done increases is nearly constant across all refrigerant types. The figure clearly shows that R134a and R290 require less compressor work than other refrigerants. Now, compressor work for refrigerant R600a is higher than that of other refrigerants.

3. CONCLUSIONS

In this work, comparative performance analysis of R290 & R600a with proportion blend on a standard vapour compression system was carried out for different evaporating temperatures at constant condensing temperature. The following conclusion can be drawn from the experimental work:

40% of R290 and 60% of R600a having the highest mass flow rate while 50% of R290 and 50% of R600a having the lowest.

60% of R290 and 40% of R600a composition consumes low power and while 70% of R290 and 30% of R600a composition consumes more.

For low capacity refrigeration there is a chance to use small compressor by using 10% of R290 and 90% of R600a composition which will reduce the power consumption. hence it is better suited to low capacity compressor 60% of R290 and 40% of R600a has the maximum COP while 70% of R290 and 30% of R600a composition has minimum 20% of R290 and 80% of R600a composition has highest Carnot COP while 10% of R290 and 90% ofR600a composition having low that discharge temperature is the temperature at outlet of the compressor. It shows effect on life of the compressor. 60% of R290 and 40% of R600a has low discharge temperature.

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