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Thermodynamic Optimization of Household Refrigerator Using Propane –Butane as Mixed Refrigerant

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Abstract

A household refrigerator designed to work with R-134a was used as an investigation unit to assess the prospect of using mixed refrigerants. The recital of the refrigerator using mixed refrigerant was investigated and compared with the performance of refrigerator when R-134a was used as refrigerant. The effect of condenser temperature and evaporator temperature on COP, refrigerating effect was investigated. The energy consumption of the refrigerator during experiment with mixed refrigerant and R-134a was measured. The outcome shows the permanent running and cycling results showed that R134a with a charge of 100 g or mixed refrigerant with charge of 80 mg or more satisfy the required freezer air temperature of −12 °C. The lowest electric energy consumption was achieved using mixed refrigerant with heat level is less than -15°C. This mixture achieved higher volumetric cooling capacity and lower freezer air temperature compared to R134a. Experimental results of the refrigerator using mixed refrigerant were compare with those using R134a. Pull-down time, pressure ratio and power consumption of mixed refrigerant refrigerator were under those of R134a refrigerator by about 7.6%, 5.5% and 4.3%, respectively. Also, actual COP of mixed refrigerant refrigerator was higher than that of R134a by about 7.6%. Lower on-time ratio and energy consumption of mixed refrigerant refrigerator by nearly 14.3% and 10.8%, respectively, compared to those of R134a refrigerator were achieved. The COP and other result obtain in this experiment show a positive indication of using mixed refrigerant as refrigerants in household refrigerator.

Key words: Butane, R134a, Mixed Refrigerant, Chlorofluorocarbons, propane, Isobutane, COP

1. INTRODUCTION

Normal frost was disseminated and used in both commercial and domicile application in the middle of 1880s to refrigerate food. The suggestion that cold could be produced by the forced evaporation of an impulsive liquid under reduced had been previously pursued by William Cullen in the eighteenth century. A refrigerator is a cooling appliance comprising a thermally insulated screened-off area and a heat pump - element or perfunctory means - to transfer heat from it to the external atmosphere cooling the contents to a temperature below ambient. Refrigerators are extensively used to store foods which deteriorate at ambient temperatures; spoilage from bacterial growth and other processes is much slower at low temperatures.

An apparatus described as a “refrigerator maintains a temperature a slight degrees above the freezing point of water; a similar device which maintain a temperature below the freezing point of water is called a “freezer”. The refrigerator is a fairly modern invention among kitchen appliances. It replaced the ice box, which had been a common domestic appliance for almost a century and a half earlier. For this explanation, a refrigerator is sometimes referred to as an "ice box". Freezers keep their contents frozen. They are used in households and in industry and commerce. Most freezers operate around -18 °C (0 °F). Domestic freezers can be included as a separate compartment in a refrigerator, or can be a separate appliance. Domestic freezers are generally standing units resembling refrigerators, or chests resembling upright units lay on their backs. Many standing modern freezers come with an ice slot machine built into their door.

Chlorofluorocarbons (CFCs) and hydro chlorofluorocarbons (HCFCs) have many suitable properties, for example, non flammability, low toxicity and material compatibility that have led to their common widespread use by both consumers and industries around the world, especially as refrigerants in air conditioning and refrigerating systems. Results from many researches show that this ozone layer is being depleted. The general consensus for the cause of this event is that free chlorine radicals remove ozone from the atmosphere, and later, chlorine atoms continue to convert more ozone to oxygen. The presence of chlorine in the stratosphere is the result of the migration of chlorine containing chemicals. The chlorofluorocarbons (CFCs) and hydro chlorofluorocarbons (HCFCs) are a large class of chemicals that behave in this manner. (Radermacher and Kim, 1996, Akash and Said, 2003).

Hydrocarbon particularly propane, butane and isobutene are proposed as an environment benign refrigerant. Hydrocarbons are free from ozone depletion potential and have negligible global warming potential. Lee and Su (2002) conducted an experiment study on the use of isobutene as refrigerant in domestic refrigerator. The performance was comparable with those of CFC-12 and HCFC-22 was used as refrigerant.

Commercial fridge and freezer units, which go by many other names, were in use for almost 40 years prior to the common home models. They used toxic gas systems, which occasionally leaked, making them unsafe for home use. Practical household refrigerators were introduced in 1915 and gained wider acceptance in the United States in the 1930s as prices fell and non-toxic, non-flammable synthetic refrigerants such as Freon or R-12 were introduced. It is notable that while 60% of households in the US owned a refrigerator by the 1930s, it was not until 40 years later, in the 1970s, that the refrigerator achieved a similar level of penetration in the UK.

Refrigerant selection involves balancing conflicting requirements such as: ability to transfer heat, chemical stability, and compatibility with compressor lubricants, flammability, and toxicity. Akash and Said (2003) studied the performance of mixed refrigerant from local market (30%propane, 55% n-butane and 15% isobutene by mass) as an alternative refrigerant for CFC-12 in domestic refrigerator with masses of 50g, 80g and 100g.

The result showed that a mass charge of 80g gave the best performance. Scientist and researcher are searching the environment benign refrigerant for the domestic refrigerator and freezer. Finally we decide to choose the mixed refrigerant as an alternate source of HFC-134.

2. EXPERIMENTAL SETUP AND TEST PROCEDURE

This section provides a description of the facilities developed for conducting experimental work on a domestic refrigerator. The technique of charging and evacuation of the system is also discussed here. Experimental data collection was carried out in the research laboratory of our institution. The experimental setup of the test unit and apparatus is shown in the Fig. 1.

Fig. 1, Experimental setup of the investigation unit and apparatus

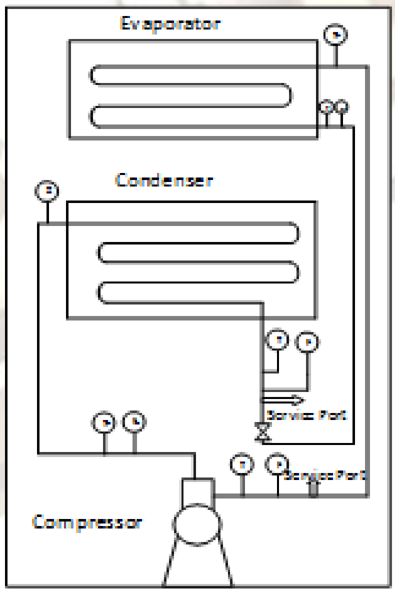

Fig. 2, Schematic diagram of the investigation unit and apparatus

2.1 Experimental Methodology

The experimental setup of the household refrigerator used in the experiment is shown in Fig 1. The domestic refrigerator consists of an evaporator, wire mesh air-cooled condenser and hermetically sealed reciprocating compressor. The 165 liters domestic refrigerator of tropical class originally designed to work with HFC134a was taken for this study. The refrigerator was instrumented with one pressure gauge at the inlet of the compressor for measuring the suction pressure, one temperature sensor mounted at inside the refrigerator (freezer) compartment. As per the refrigerator manufactures recommendation quantity of charge requirement for HFC134a was 100 g. In the experiment, refrigerant charge is 10% higher due to the presence of instruments and connecting lines etc. To optimize the mixed refrigerant charge, the refrigerator is charged with 80g. The refrigerator was charged with 110 g of HFC134a and the base line performance was studied. After completing the base line test with HFC134a, the refrigerant was recovered from the system and charged with 80g of mixed refrigerant and the performance was studied. The refrigerant charge requirement with hydrocarbons is very small due to their higher latent heat of vaporization. During the experimentation the atmospheric is maintained at 28 ± 2^{o}C. The experimental procedures were repeated and take the reading from the various modes. Service port is installed at the inlet of expansion valve and compressor for charging and recovering the refrigerant is shown in Figure. Digital Temperature Indicator was used to measure the inside freezer temperature.

2.2 Test Procedure

The system was evacuated with the help of vacuum pump to remove the moisture and charged with the help of charging system. The temperature inside the chamber was maintained at 25°C and 28°C. When the temperature and humidity inside the chamber was at steady state, the experiments were started. The experiment has been conducted on the domestic refrigerator at no load and closed door conditions.

3. RESULTS AND DISCUSSIONS

From this section the comparison of the performance parameter of the refrigerants and energy consumption by the refrigerator was discussed This investigation deals with mixed refrigerant (hydrocarbon mixtures of propane, butane and isobutane) in order to assess their feasibility for replacing HFC-134a in refrigeration systems by comparing their relevant parameters.

The refrigerating effect is the main purposes of the refrigeration system. The liquid refrigerant at low pressure side enters the evaporator. As the liquid refrigerant passes through the evaporator coil, it continually absorbs heat through the coil walls, from the medium being cooled. During this, the refrigerant continues to boil and evaporate. Finally the entire refrigerants have evaporated and only vapor refrigerant remains in the evaporator coil. The liquid refrigerant still colder than the medium being cooled, therefore the vapor refrigerants continue to absorb heat. The experiment was performed on the domestic refrigerator purchased from the market, the components of the refrigerator was not changed or modified. This indicates the possibility of using mixed refrigerant as an alternative of HFC-134a in the existing refrigerator system.

The COP of the domestic refrigerator using R-134a as a refrigerant was considered as benchmark and the COP of mixed refrigerant compared. The time versus COP is plotted at the refrigerant R-134a and mixed refrigerant (without load & different mode) in the same graph. The results displayed in Figs. 2, 3, 4 and 5 shows a progressive increase in COP as the temperature varies.

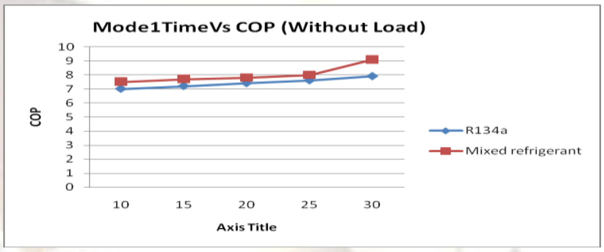

Fig. 3. Mode 1 Time Vs COP (Without Load)

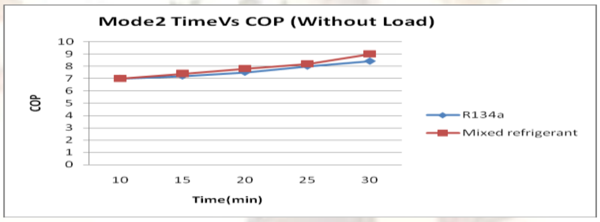

Fig. 4. Mode 2 Time Vs COP (Without Load)

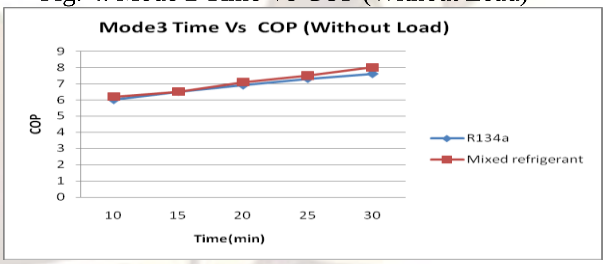

Fig 5. Mode 3 Time Vs COP (Without Load)

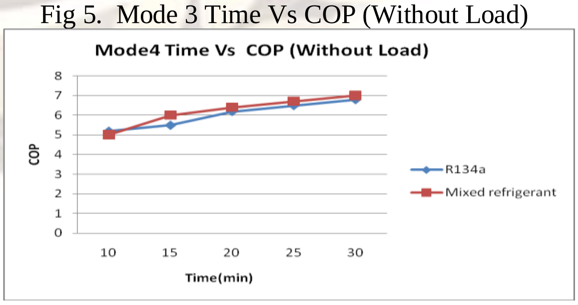

Fig. 6. Mode 4 Time Vs COP (Without Load)

The time versus COP is plotted at the refrigerant R134a and mixed refrigerant (without & different mode) in the same graph. The results displayed in Figs., 7, 8,9 and 10 shows a progressive increase in COP as the temperature varies.

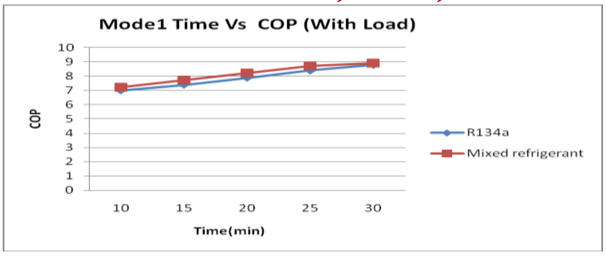

Fig. 7. Mode 1 Time Vs COP (With Load)

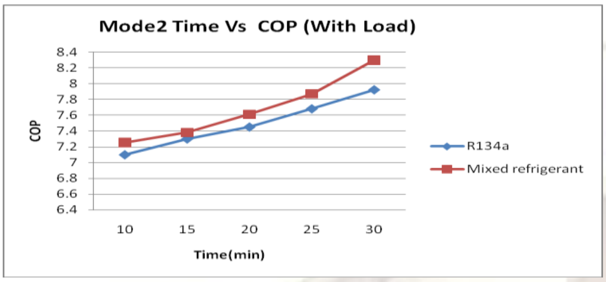

Fig. 8. Mode 2 Time Vs COP (With Load)

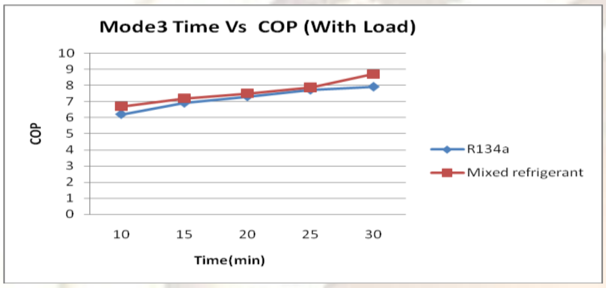

Fig. 9. Mode 3 Time Vs COP (With Load)

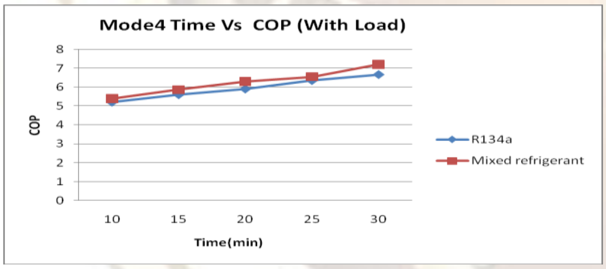

Fig. 10. Mode 4 Time Vs COP (With Load)

4. CONCLUSION

This project invested an ozone friendly, energy efficient, user friendly, safe and cost-effective alternative refrigerant for HFC134a in domestic refrigeration systems. After the successful investigation on the performance of mixed refrigerants the following conclusions can be drawn based on the results obtained. This experimental investigation carried out to determine the performance of a domestic refrigerator when a propane/butane mixture is used as a possible replacement to the traditional refrigerant R134a.

The used mixed refrigerant which is locally available and comprises in various properties like, 24.4% propane, 56.4% butane and 17.2% isobutene. The performance parameters investigated are the refrigeration capacity, the evaporator temperature and the coefficient of performance (COP). The refrigerator worked efficiently when mixed refrigerant was used as refrigerant instead of R134a. The evaporator temperature reached -20°C with COP value of 6.4 and an ambient temperature of 30°C. The results of the present work indicate the successful use of this mixed refrigerant as an alternative to R134a in domestic refrigerators. The co-efficient of performance for the mixed refrigerant is comparable with the co-efficient of performance of HFC-134a The domestic refrigerator was charged with 140g of HFC-134a and 80g of mixed refrigerant. This is an indication of better performance of mixed refrigerant as refrigerants. The following conclusions can be elicited from our investigation

1. Every mode of mixed refrigerant yields higher COP than HFC-134a.
2. From using the mixed refrigerant in domestic refrigerator, we were observed the freezer temperature lower than that of the R134a.
3. When the evaporator temperature increases, COP will be increases and the condenser temperature decreases, COP will also increases.

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