Pure Butane as Refrigerant in Domestic Refrigerator Freezer

M.A. Sattar, R. Saidur and H.H. Masjuki

Abstract— *This paper presents an experimental investigation on the performance of a domestic refrigerator using pure butane as a refrigerant. A domestic refrigerator designed to work with R-134a as refrigerant was used as test unit to assess the possibility of pure butane as refrigerant. The experiments are conducted with the refrigerants under the same no load condition at a surrounding temperature of 25°C and 28°C. The refrigeration capacity, the compressor power, the coefficient of performance (COP), condenser duty and heat rejection ratio were investigated. The performance parameter and power consumption of the refrigerator when R-134a was used as refrigerant is considered as baseline. The performance of pure butane is compared with the performance of R-134a. The compressor consumes 2.08kWh/day and 2.25kWh/day when R-134a is used refrigerant but when butane is used it consumes 2.197kWh/day and 2.199kWh/day at 25°C and 28°C ambient temperature respectively. The result shows a better performance of butane than R-134a. The results support the possibility of using butane as an alternative to R-134a in domestic refrigerators, without any modification of the domestic refrigerator.*

Keywords— **Butane, Refrigeration capacity, COP, Condenser duty.**

1. INTRODUCTION

Natural ice was harvested, distributed and used in both commercial and home applications in the mid-1800s to refrigerate food. The idea that cold could be produced by the forced evaporation of a volatile liquid under reduced pressure had been previously pursued by William Cullen in the eighteenth century. These same volatile liquids could be condensed from a vapor state by application of cooling and compression was also known by the 1800s. Combining these two ideas led to the development of what would ultimately become the dominant means of cooling –the vapor compression refrigerating system. Since the invention of the vapor compression refrigeration system in the middle of the 18th century and its commercial application at the end the 18th century, the application of refrigeration has entered many fields. The application includes the preservation of food and medicine, air-conditioning for comfort and industrial processing. Stratospheric ozone absorbs the sun's high-energy ultraviolet rays and protects both humans and other living things from exposure to ultraviolet radiation. 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 hydrochloro-fluorocarbons (HCFCs) are a large class of chemicals that behave in this manner. These chemicals 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 [1,4]. Scientist and researcher are searching the environment benign refrigerant for the domestic refrigerator and freezer. Hydrocarbon especially 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 experimental 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. Akash and Said (2003) studied the performance of LPG 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. S. Devotta *et al* (2001) selected HFC-134a, HC-290, R-407C, R-410A, and three blends of HFC-32, HFC-134a and HFC-125 and found that HFC-134a offers the highest COP, but its capacity is the lowest and requires much larger compressors. The characteristics of HC-290 are very close to those of HCFC-22, and compressors require very little modification. Therefore, HC-290 is a potential candidate provided the risk concerns are mitigated as had been accomplished for refrigerators. S. J. Sekhar *et al* (2004) investigated an experiment to retrofit a CFC12 system to eco-friendly system using of HCFC134a/HC290/HC600a without changing the mineral oil and found that the new mixture could reduce the energy consumption by 4 to 11% and improve the actual COP by 3 to 8% from that

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of CFC12. S. J. Sekhar *et al* (2005) investigated refrigerant mixture of HCFC134a/HC in two low temperature system (domestic refrigerator and deep freezer) and two medium temperature system (vending machine and walk in cooler) and found that the HCFC134a/HC mixture that contains 9% HC blend (by weight) has better performance resulting in 10-30% and 5-15% less energy consumption (than CFC) in medium and low temperature system respectively. Hydrocarbons (HCs) are an environmentally sound alternative for CFCs and HFCs. HCs as a refrigerant have been known and used since the beginning of this century. The development of the inert CFCs in the 1930s put the HC technology in the background. CFCs have been applied since then in numerous refrigeration equipments. Eventually the damaging aspects of CFCs became clear and solutions for the problem had to be sought [14]. There is currently little information on the application of Hydrocarbon as refrigerant in the refrigerator with out modification. In this experiment a domestic refrigerator design to work with HFC-134a were investigated without modification. The experiments were conducted with R-134a and pure butane. According to the ISO standard, the test period shall be at least 24 h long with no door openings. Relative humidity should be kept within 45%–75% inside the chamber. Environment temperature should be kept within 25±0.5°C to 32±0.5°C [15]. So in this experiment the environment temperature was considered at 25°C and 28°C and relative humidity was maintained at 60%.

2. EXPERIMENTAL SETUP AND TEST PROCEDURE

2.1 Experimental methodology and apparatus

The schematic diagram of the test unit and apparatus is shown in Figure 1. The thermocouple sensors (T-type) and pressure sensors were fitted at inlet and outlet of the compressor, condenser, and evaporator as shown in Figure 1. Thermocouples and pressure sensors were interfaced with a HP data logger via a PC through the GPIB cable for data storage and analysis.

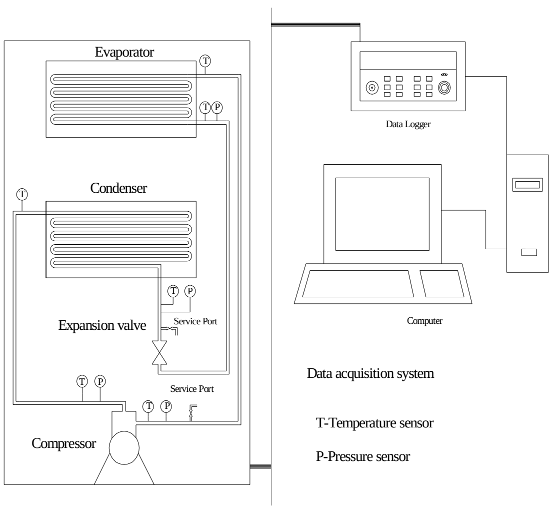

Fig. 1. Schematic diagram of the test unit and apparatus.

Service port is installed at the inlet of expansion valve and compressor for charging and recovering the refrigerant is shown in Figure 1. Yellow jacket 4cfm vacuum pump was used to evacuate the system through this service port. Yellow jacket Digital electronic charging scale has been used to charge the system. A power meter was connected with compressor to measure the power consumption. The specification of the refrigerator is shown in Table 1.

Table 1. Technical specifications of refrigerator freezer test unit

SPECIFICATIONS	
Freezer Capacity (liter)	80
Fresh Food Compartment Capacity (liter)	220
Power Rating (W)	160
Current rating (A)	0.9
Voltage (V)	220
Frequency (Hz)	50
No of door	2
Refrigerant type	134a(CF3CH2F)
Defrost system	Auto Defrost

2.2 Test procedure

The refrigerator has been fitted with the pressure sensors and thermocouples. The system was evacuated with the help of vacuum pump to remove the moisture. The system was charged with the help of digital electronic charging scale after evacuation. The pressure transducer and thermocouple were connected with the data logger. The data logger is interfaced with the computer and software has been installed to operate the data logger from the computer. The data logger was set to scan the data from the temperature sensor and pressure sensor at an interval of 15 minutes within 24 hours. A power meter was connected with the refrigerator and interfaced with the computer. Power meter software was installed in the computer to operate from the computer. The power meter stores the power consumption of the refrigerator at an interval of one minute within 24 hours. The pressure and temperature from the data logger was used to determine the enthalpy of the refrigerant using REFPROP7 software. All equipment and test unit was placed inside the environment control chamber. The temperature and humidity inside the chamber was controlled. The dehumidifier has been used to maintain humidity. The unit can maintain humidity from 60% to 90% with an accuracy of ±5%. The humidity has been maintained at 60% RH for all the experiment. The temperature inside the chamber was maintained at 25°C and 28°C. The experiment has been conducted on the domestic refrigerator with no load and closed door condition.

3. RESULTS AND DISCUSSIONS

3.1 Power consumption by the compressor when different refrigerants were used

The energy consumption by the HFC134a and pure butane are shown in the Table 2.

Table 2. Energy consumption by compressor at 25°C and 28°C

Refrigerant used	Room temperature, 25°C	Room temperature, 28°C
	Energy consumption, kWh/day	Energy consumption, kWh/day
HFC134a	2.077	2.254
Butane	2.197	2.199

3.2 Effect of evaporator and condenser temperature on co-efficient of performance

The COP against inlet refrigerant temperature of the evaporator is plotted at 25°C and 28°C ambient temperatures and shown in Figures 2 and 3. The Figures 4 and 5 show a progressive increase in COP as the evaporating temperature increases. The COP of the domestic refrigerator is plotted against condenser temperature of the refrigerator and shown in Figures 6 and 7. The Figures 4 and 5 show that COP increases as the temperature of the condenser decrease.

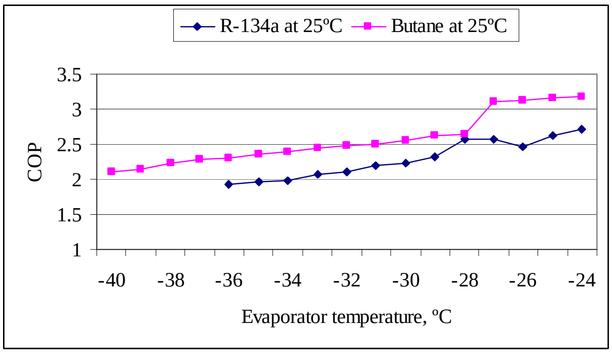

Fig. 2. Effect of evaporator temperature on co-efficient of performance.

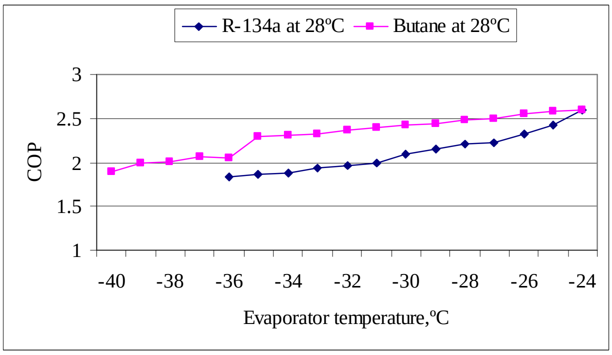

Fig. 3. Effect of evaporator temperature on co-efficient of performance.

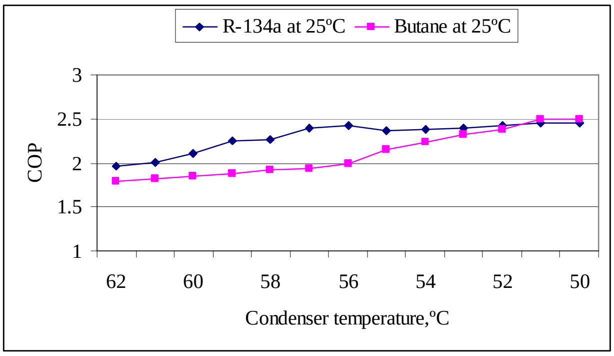

Fig. 4. Effect of condenser temperature on co-efficient of performance.

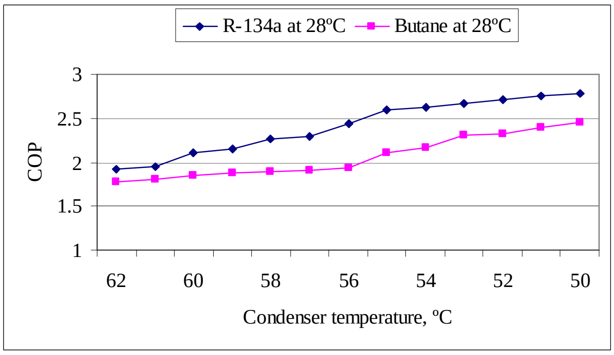

Fig. 5. Effect of condenser temperature on co-efficient of performance.

3.3 Effect of evaporator temperature on refrigerating effect and compressor work.

The refrigerating effect and inlet refrigerant temperature is shown in Figures 6 and 7.The refrigerating effect increases as the temperature of the evaporator increases as shown in Figures 6 and 7. The refrigerant effect when pure butane is used is higher than R-134a because the value of enthalpy of the pure butane is higher than that of HFC134a.

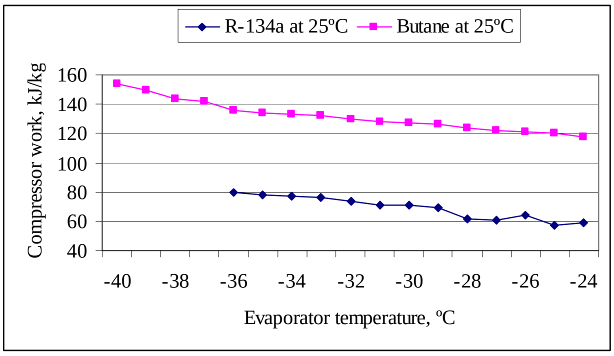

Fig. 8. Effect of evaporator temperature on work of compression.

The work of compression and inlet refrigerant temperature is shown in Figures 8 and 9. The work of compression increases as the temperature of the evaporator decreases. This is due to the fact that when the temperature of the evaporator decreases the suction temperature also decreases. At low suction temperature, the vaporizing pressure is low and therefore the density of suction vapor entering the compressor is low. Hence the mass of refrigerant circulated through the compressor per unit time decreases with the decreases in suction temperature for a given piston displacement. The decreases in the mass of refrigerant circulated increases in work of compression.

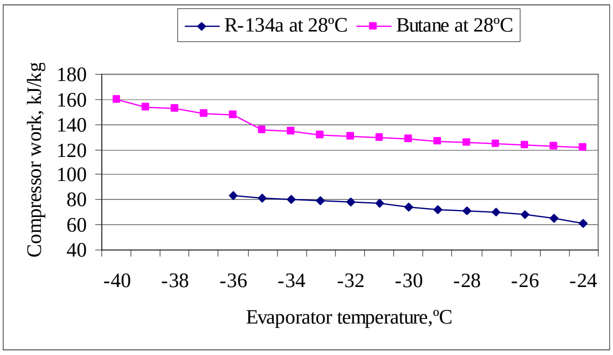

Figure 9 effect of evaporator temperature on work of compression.

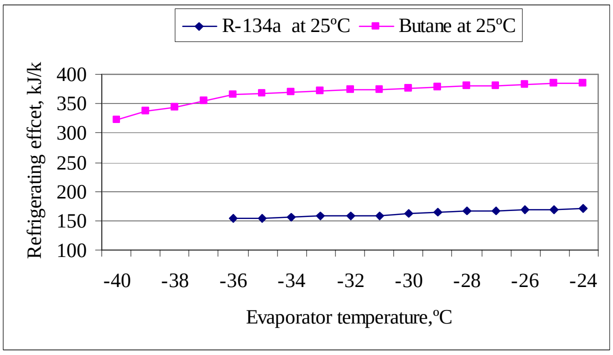

Fig. 6. Effect of evaporator temperature on refrigerating effect.

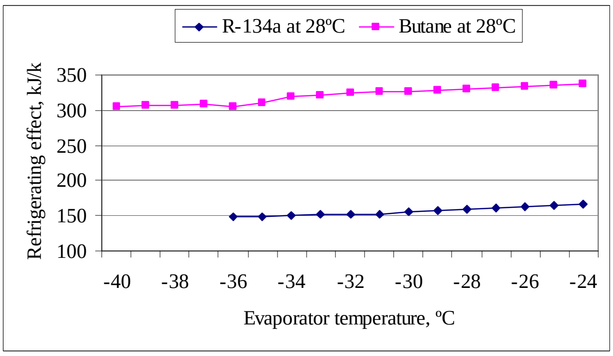

Fig. 7. Effect of evaporator temperature on refrigerating effect.

3.4 Effect of evaporator temperature on condenser duty for different refrigerants

The function of the condenser is to remove heat of the hot vapor refrigerant discharged from the compressor. The heat from the hot refrigerant is removed by transferring heat to the wall of the condenser tubes and then from the tubes to the condensing medium. The condenser duty and evaporator temperature is shown in Figures 10 and 11. The figures show that the condenser duty increases as the temperature of the evaporator decreases.

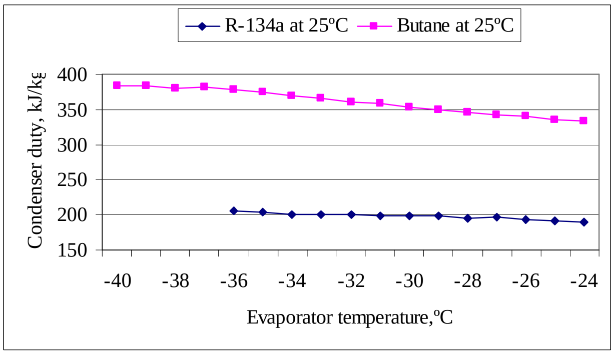

Fig. 10. Effect of evaporator temperature on condenser duty.

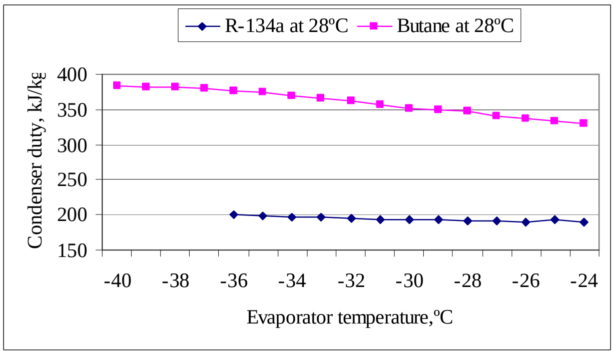

Fig. 11. Effect of evaporator temperature on condenser duty for iso-butane.

3.5 Heat rejection ratio for different refrigerant

The required rate of heat transfer in the condenser is predominantly a function of the refrigerating capacity and the temperatures of evaporation and condensation. A term often used to relate the rate of heat flow at the condenser to that of the evaporator is the heat-rejection ratio. Heat rejection ratio at the condenser temperature is shown in Figures 12 and 13.

4. CONCLUSIONS

This project invested an ozone friendly, energy efficient, user friendly, safe and cost-effective alternative refrigerant for HFC134a in domestic refrigeration systems. The following conclusion can be drawn based on the result obtained after the successful investigation.

- The co-efficient of performance of pure butane is comparable with the co-efficient of performance of HFC134a.
- The energy consumption of the pure butane is about similar to the energy consumption of

refrigerator when HFC134a is used as refrigerant.

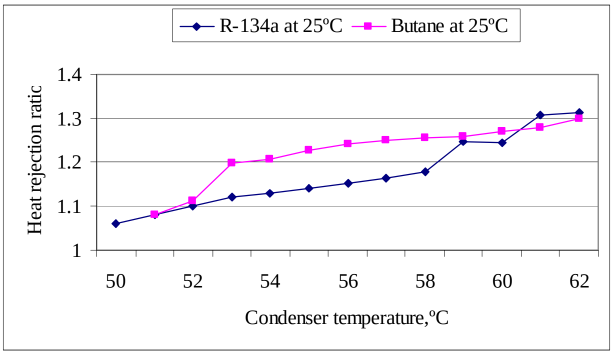

Fig. 12. Effect of condenser temperature on heat rejection ratio

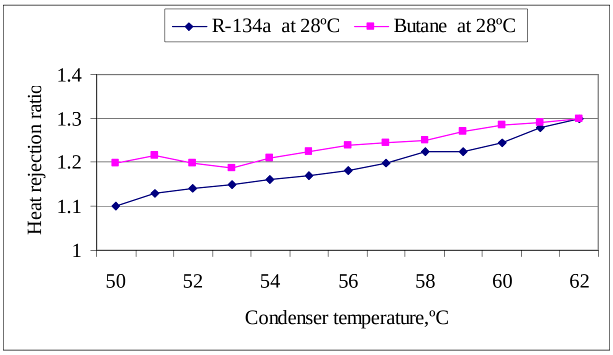

Fig. 13. Effect of condenser temperature on heat rejection ratio.

- Pure butane offers lowest inlet refrigerant temperature of evaporator. So for the low temperature application pure butane is better than HFC134a.
- The amount of charge of pure butane is less than the manufacturer recommended charge of HFC134a in the present test unit. The domestic refrigerator was charged with 140gm of HFC134a and 70gms of butane. This is an indication of better performance of the HC as refrigerant.
- 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 butane in the existing refrigerator system without modification of the components.
- Chemical and thermodynamics properties of Hydrocarbon meet the requirement of a good refrigerant. Hydrocarbons are environmentally friendly. Hydrocarbon is cheaper than the R-134a and easily available. Some standards allow the use HC as refrigerant if small amount of refrigerant is used.

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