Proceedings of the
International Conference on Mechanical Engineering 2007
(ICME2007) 29- 31 December 2007, Dhaka, Bangladesh

ICME07-TH-35

ENERGY AND THERMODYNAMIC PERFORMANCE OF REFRIGERATOR USING PURE HYDROCARBON AND MIXTURE OF HYDROCARBONS AS REFRIGERANTS

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ABSTRACT

This paper presents an experimental investigation on the performance of a domestic refrigerator using pure butane and mixture of propane, butane and isobutene as refrigerants. The experiment was conducted with a refrigerator designed to work with HFC-134a 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. It can be stated that the performance of butane is comparable with the performance of the HFC134a. The result shows a better performance of butane than HFC-134a. The results support the possibility of using butane as an alternative to HFC134a in domestic refrigerators without any modification of the domestic refrigerator.

Keywords: Butane, COP, Heat rejection ratio, Refrigerating effect, Condenser duty.

1. INTRODUCTION

The use of natural fluids as refrigerant has attracted renewed interest during the last decades. Hydrocarbon belongs to this group of natural fluids. Hydrocarbon refrigerant were accepted before the introduction of CFC and HCFC-fluids (Granryd, 2001). The short atmospheric live times of hydrocarbons take their GWPs close to zero. Moreover hydrocarbons provide zero ozone depletion potential, low toxicity, chemical stability, together with suitable thermodynamic, physical and chemical properties. The only disadvantage is that hydrocarbons are flammable if careless and unexpected leakage occurs. It is safer in smaller application (Maclaine-cross, 2004).

Hydrocarbon being an environment benign refrigerant draws attention to the scientist and researcher. 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. 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.

Alsaad and Hammad (1998) investigated the refrigeration capacity, compressor power and coefficient of performance (COP) to determine the performance of a medium size CFC-12 domestic refrigerator working with a propane/butane mixture experimentally. The result indicated the successful application of the mixture of propane and butane for the replacement CFC-12 in domestic refrigerator. Somchai *et al.,* (2005) performed an experiment to study the application of mixture of propane, butane and isobutene in a domestic HCFC-134a refrigerator and found that propane/butane 60%/40% is the most appropriate alternative refrigerant to HCFC-134a. 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. 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 of CFC12.

There is currently little information on the application of hydrocarbon as refrigerant in domestic refrigerator without modification of the system components. In this experiment a domestic refrigerator designed to work with HFC-134a were investigated without modification. The refrigerator was charged with pure n-butane, and mixture of propane, n-butane and iso-butane. The component of the domestic refrigerator remained unmodified the experiment. The co-efficient of performance, condenser duty, refrigerating effect, compressor work, and energy consumption of the compressor were investigated. The performance of the refrigerator using R-143a was considered as a benchmark and then the performance of the refrigerator using hydrocarbon and their mixture was compared.

2. EXPERIMENTAL SETUP AND TEST PROCEDURE

Facilities developed for conducting experimental test on a refrigerator has been discussed in the following section. The mechanism of charging and evacuation of the system is also discussed here. Experimental data collection was carried out at ECL (Energy Conservations Laboratory), Mechanical engineering department, University of Malaya. The schematic diagram of the test unit and apparatus is shown in the Figure 1.

2.1 Experimental Methodology and Apparatus

The temperature and pressure of the refrigerant at inlet/outlet of each component of the refrigerator was measured with copper-constantan thermocouples (T type) and pressure sensors. The thermocouple sensors fitted at inlet and outlet of the compressor, condenser, and evaporator are shown in Figure 1. The pressure transducers were fitted at the inlet and outlet of the compressor and expansion valve 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. Temperature and pressure measurements are necessary to find out the enthalpy in and out of each component of the system to investigate the performance.

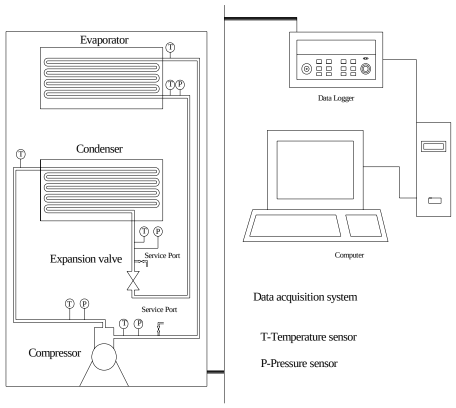

Fig 1 Schematic diagram of the test unit and apparatus

A service port was installed at the inlet of expansion valve and compressor for charging and recovering the refrigerant. The location of the service port is shown in Figure 1. The evacuation has also been carried out through this service port. A power meter was connected with compressor to measure the power and energy consumption.

2.1.1 System Evacuation

Moisture combines in varying degree with most of the commonly used refrigerants. This moisture reacts with the lubricating oil and with other materials in the system, producing highly corrosive compound. The resulting chemical reaction often produces pitting and other damage on the valves seals, bearing journal, cylinder wall and other polished surface of the system. It may cause the deterioration of the lubricating oil and the formation of sludge that can gum up valves, clog oil passages, score bearing surface and produce other effect that reduce the life of the system.

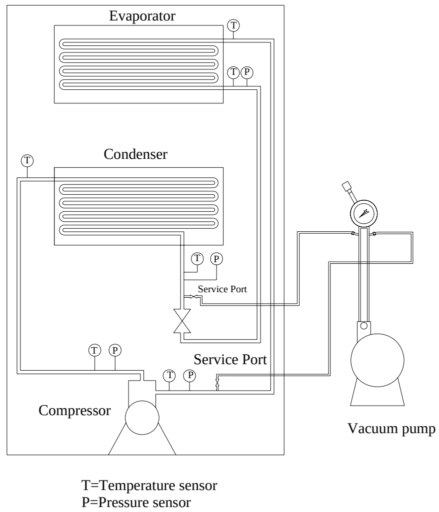

Fig 2: Schematic diagram of the evacuation system

Yellow Jacket 4cfm vacuum pump was used to evacuate the system for removing moisture. This supervac system evacuates the system fast and better which is deep enough to get rid of contaminant that could cause system failure. The evacuation system which is shown in the Figure 2 consists of a vacuum pump, a pressure gauge and hoses.

2.1.2 System Charging

Refrigerants were charged into the system with the help of Yellow Jacket digital electronic charging scale. This is an automatic digital charging system that can charge the desired amount accurately. The mechanism of the charging is shown in the Figure 3.

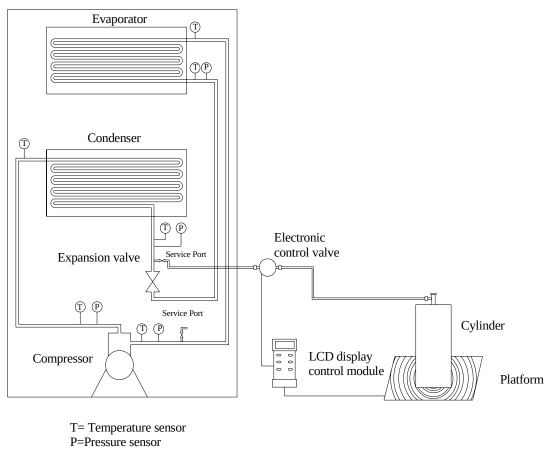

Fig 3: Schematic diagram of the charging system

The charging system consists of a platform, an LCD, an electronic controlled valve and charging hose. The refrigerant cylinder was placed on the platform which measured the weight of the cylinder. The LCD displays the weight and also acts as a control panel. One charging hose was connected with the outlet of the cylinder and inlet of the electronic valve and another one was connected with the outlet of electronic valve and inlet of the service port. Using this charging system, the refrigerants were charged into the system according to desired amount.

2.1.3 Test Unit

The test unit is a Samsung refrigerator purchased from the market which was originally designed to work with R-134a refrigerant. The specification of the refrigerator is presented in Table 1.

Table 1: Technical specifications of refrigerator freezer test unit

SPECIFICATIONS	Value
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 system was evacuated with the help of vacuum pump to remove the moisture and then charged into the system with the help of charging system. The pressure transducers and thermocouples fitted with the system were connected with the data logger. The data logger was interfaced with the computer and software has been installed to operate the data logger from the computer and to store the data. The data logger was set to scan the data from the temperature sensors and pressure sensors at an interval of 15 minutes within 24 hours. A power meter was connected with the refrigerator and interfaced with the computer and power meter software was installed. The power meter stores the instantaneous power and cumulative energy consumption of the refrigerator at an interval of one minute within 24 hours. The pressures and temperatures of the refrigerants from the data logger were used to determine the enthalpy of the refrigerant using REFPROP7 software. All equipment and test unit was placed inside the environment control chamber where the temperature and humidity was controlled. The humidity has been maintained at 60% RH for all experimental work. The temperature inside the chamber was maintained at 25°C and 28°C. The experiment has been conducted on the domestic refrigerator at no load and closed door conditions.

3. RESULTS AND DISCUSSIONS

The discussion and comparison of performance of butane and mixture of propane, butane and isobutene with that of HFC-134a is presented in the following Section.

3.1 Power Consumption by the Compressor When Different Refrigerants Were Used.

The total energy consumption by the compressor within 24 hours is presented in Table 2. It is evident from the Table 2 that the compressor consumes more energy at 28°C than at 25°C for all refrigerants. The compressor consumed 2% less energy than that of HFC-134a at 28°C when butane was used. The compressor consumed 22% and 14% more energy than that of HFC-134a at 28°C when mixture 1 and mixture 2 was used as refrigerants respectively.

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
M1	2.626	2.758
M2	2.515	2.579

3.2 Effect of Evaporator and Condenser Temperature on Co-efficient of Performance

The effect of evaporator temperature on co-efficient of performance is presented in Figures 4 and 5 at 25°C and 28°C surrounding temperature. The result displayed in Figures 4 and 5 shows a progressive increase in COP as the evaporating temperature increases. It is found from Figures 4 and 5 that the COP of butane is better than others at both surrounding temperature. The effect of condenser temperature on COP is shown in Figures 6 and 7. The COP increases as the temperature of the condenser decreases.

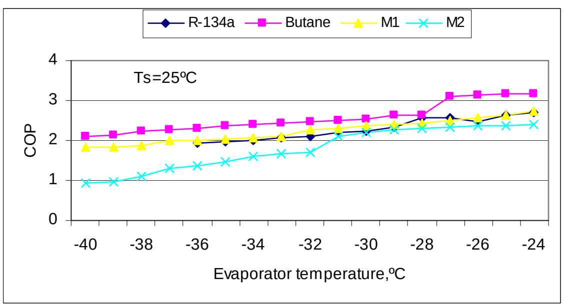

Fig 4: Effect of evaporator temperature on co-efficient of performance

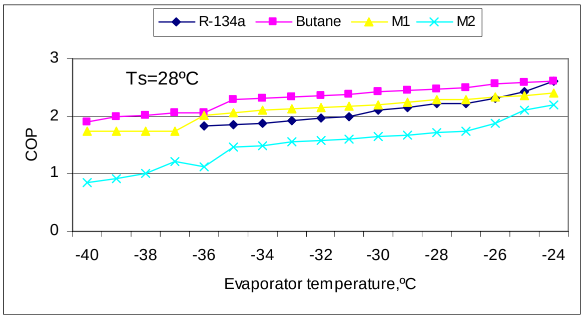

Fig 5: Effect of evaporator temperature on co-efficient of performance

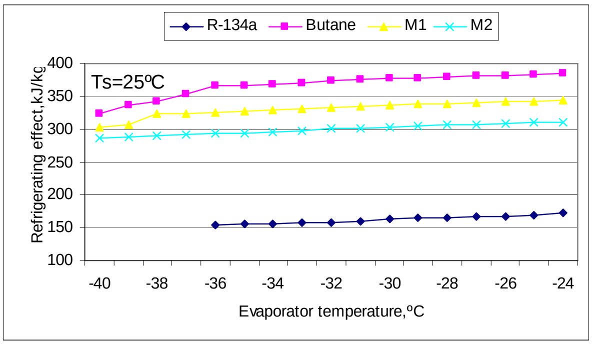

Fig 8: refrigerating effect versus evaporator temperature

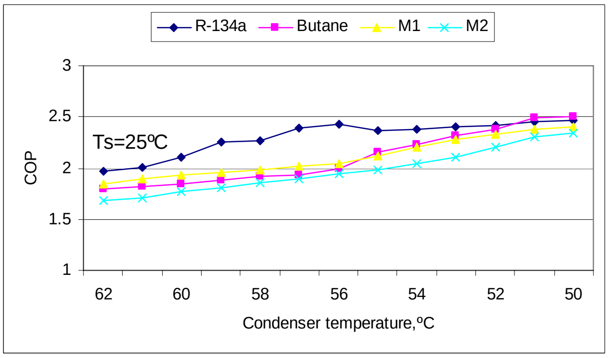

Fig 6: Effect of condenser temperature on co-efficient of performance

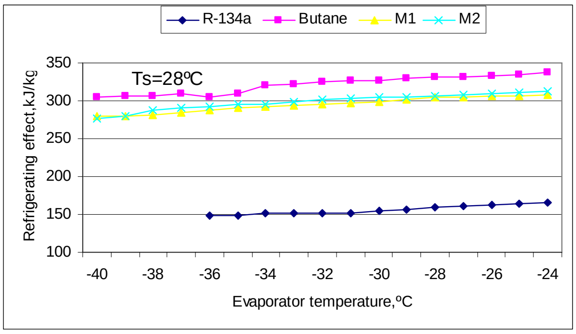

Fig 9: refrigerating effect versus evaporator temperature

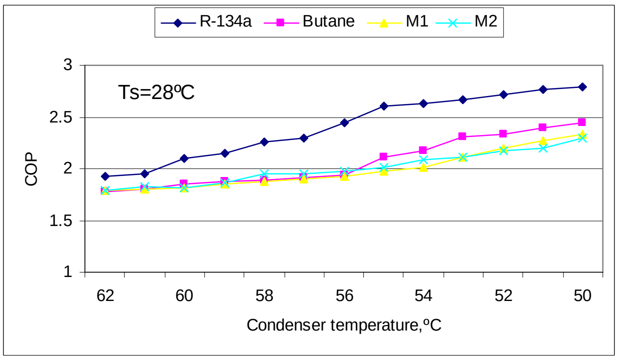

Fig 7: Effect of condenser temperature on co-efficient of performance

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

The effect of evaporator temperature on refrigerating effect is shown in Figures 8 and 9.The refrigerating effect increases as the temperature of the evaporator decreases as shown in Figures 8 and 9. The refrigerant effect of pure butane and blends of propane, butane and iso-butane is higher than that of R-134a because the value of enthalpy of the pure butane and their blends are higher than that of HFC134a at same temperature and pressure. The refrigerating effect when pure butane is used is the highest as shown in the Figure 8 and 9.

The effect of evaporator temperature on compressor work is shown in Figures 10 and 11. It is found from the Figures that the compressor work 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 compressor work.

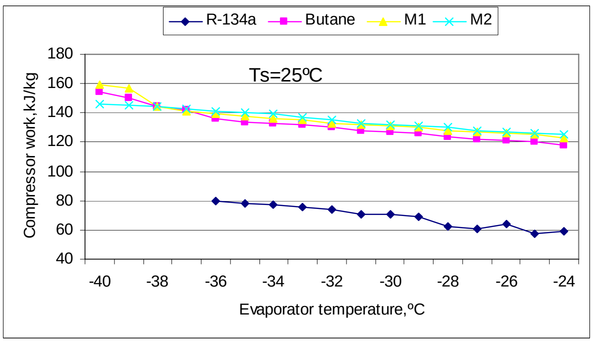

Fig 10: effect of evaporator temperature on work of compression

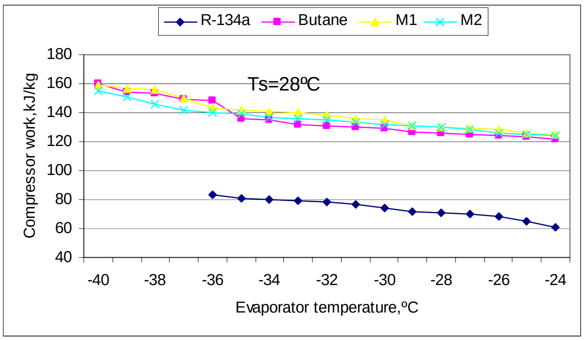

Fig 11: effect of evaporator temperature on work of compression for Butane

3.4 Effect of evaporator temperature on condenser duty for different refrigerants

The effect of evaporator temperature on condenser duty is shown in Figures 12 and 13. The Figures show that the condenser duty increases as the temperature of the evaporator decreases. This is due to the fact that if the temperature of the evaporator decreases the compressor work increases that is explained in the previous section. As the compressor work increases the heat added to the hot refrigerant during compression increases so the condenser requires more heat to remove. It is evident from the Figures 12 and 13 that the condenser duty of butane and their blends is better than HFC-134a.

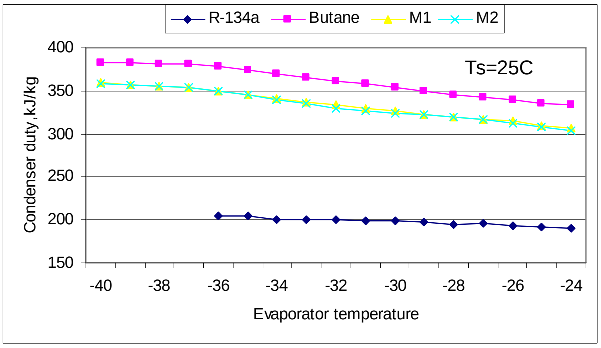

Fig 12: effect of evaporator temperature on condenser duty

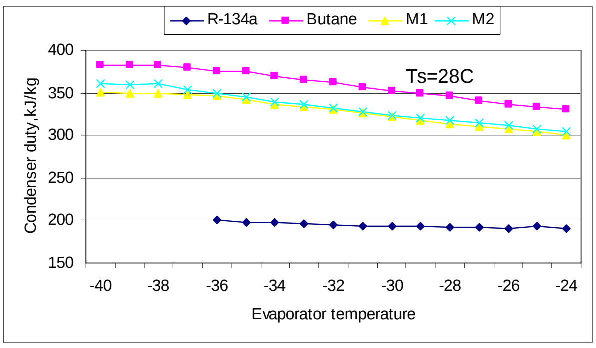

Fig 13: effect of evaporator temperature on condenser duty

3.5 Heat rejection ratio for different refrigerant

The effect of evaporator temperature on heat rejection ratio is shown in Figures 14 and 15. The heat rejection ratio when pure butane and their blends were used is higher than that of HFC-134a as shown in Figures 14 and 15. The heat rejection in the condenser depends on the refrigerating effect and the work done by the compressor. The condenser removes the heat of the hot vapor refrigerant discharged from the compressor. The hot vapor refrigerant consists of the heat absorbed by the evaporator and the heat of compression added by the mechanical energy of the compressor motor.

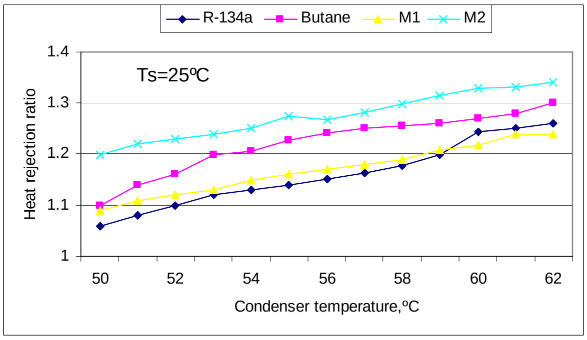

Fig 14: Heat rejection ratio at different condensing temperature

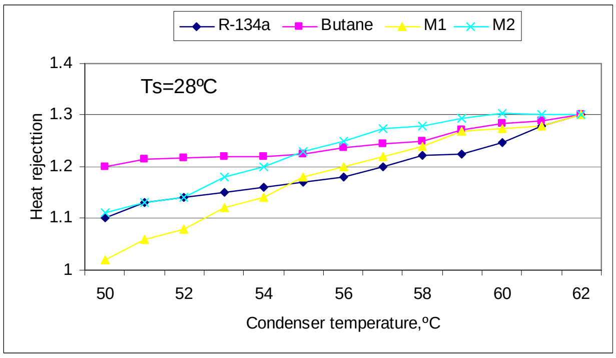

Fig 15: Heat rejection ratio at different condensing temperature

4. CONCLUSIONS

After the successful investigation on the performance of butane and their blends as refrigerants the following conclusion can be drawn based on the result obtained.

- The co-efficient of performance of butane and their blends is comparable with the co-efficient of performance of HFC134a.
- The energy consumption of the compressor when pure butane and their blends were used is almost similar to the energy consumption of refrigerator when HFC134a was used as refrigerant.
- Butane and their blends offer lowest inlet refrigerant temperature of evaporator. So for the low temperature application pure butane and their blends is better than HFC134a.
- The domestic refrigerator was charged with 140g of HFC-134a and 70g of butane and blend of propane, butane and iso-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 pure butane and their blends in the

existing refrigerator system without modification of the components.

5. ACKNOWLEDGEMENT

The authors gratefully acknowledge the financial support by the Ministry of Science Technology and Innovation (MOSTI), Malaysia to carry out this research project. The project was funded under the project IRPA No: 03-02-03-1011.

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