International Conference on Mechanical, Industrial and Materials Engineering 2017 (ICMIME2017) 28-30 December, 2017, RUET, Rajshahi, Bangladesh.

Paper ID: TE-85

Study of power consumption characteristics of LPG and R134a in a vapor compression refrigeration system

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Abstract

The experiment is focused on the feasibility of *LPG* (60% propane and 40% commercial butane) as a drop in replacement of *R*134*a* as a refrigerant in a vapor compression refrigerator. An experimental setup of *VCR* system was built for this purpose. Changing the length of the capillary tube and varying the charge amount, the power consumption of *VCR* system was recorded with a data logger during stable operation with the thermostat. Experimental results showed that *LPG* as a refrigerant is better than *R*134*a* both in terms of power consumption and in terms of cost to obtain the same operational condition in the *VCR* system.

Keywords: *LPG*, *R*134*a*, Capillary tube, Power consumption, Data logger

1. Introduction

In developing country like Bangladesh, most of the vapor compression based refrigeration, air conditioning and heat pump systems continue to run on halogenated refrigerants due to its excellent thermodynamic and thermophysical properties apart from the low cost. However, the halogenated refrigerants have adverse environmental impacts such as ozone depletion potential (*ODP*) and global warming potential (*GWP*). Hence, it is necessary to look for alternative refrigerants to fulfill the objectives of the international protocols (Montreal and Kyoto) and to satisfy the growing demand worldwide.

The possibility of using hydrocarbon mixtures (*LPG*) as working fluids to replace *R*134*a* in domestic refrigerators has been evaluated in the present work. The coefficient of performance (*COP*), volumetric cooling capacity, cooling capacity, discharge temperature, energy consumption, pressure ratio, and refrigerant mass flow rate identified the performance characteristics of the considered domestic refrigerator.

Liquefied petroleum gas (*LPG*) of 60% propane and 40% commercial butane has been tested as a drop-in substitute for *R*134*a* in a single evaporator domestic refrigerator with a total volume of 100 liters (0.10 m^3). An experimental performance study on a Vapor Compression Refrigeration (*VCR*) system with *LPG* as a refrigerant was conducted and compared with *R*134*a*. The *VCR* system was initially designed to operate with *R*134*a*. Continuous running and cycling tests were performed on that refrigerator under Subtropical (ST Class: +16°*C* to +38°*C*) conditions using different capillary tube lengths and various charges of *R*134*a* and *LPG*.

Several researchers have examined propane (*R*290), iso-butene (*R*600a), cyclopropane(*RC*270) and Dimethyl ether (*DME*) as working fluids to replace *R*134*a* in domestic refrigerators. Maclainecross and Leonardi confirmed that hydrocarbon refrigerants have an environmental advantage and are safe if they are used in small quantities, thereby *R*290*a* can replace *R*22 and hydrocarbon mixtures can replace both *R*12 and *R*134*a* in applications using positive displacement compressors [1]. Thermodynamic parameters for *LPG* and *R*134*a* were compared by Austin, Senthil and Kanthavelkumaran who concluded that *LPG* can be very suitable replacements for *R*134*a* [2].

Many investigators evaluated experimental performance characteristics of domestic refrigerators operating with propane/isobutane mixture. Agarwal et al. and Richardson and Butterworth reported that the propane/iso-butane mixture at 50% mass fraction of propane yields higher *COP*, lower charge and lower compressor shell temperature as compared to *R*134*a* [3] [4] . Liu et al. confirmed that energy savings of up to 6% were achieved with a blend of 70% propane and 30% n-butane compared to *R*134*a*[5]. Maclaine-cross stated that *R*134*a* leakage and service emissions yield 15% increase in Total Equivalent Warming Impact(TEWI). He concluded that *R*290/*R*600*a* mixture with 55% propane matches the performance of *R*134*a* [6]. Experimental results of Jung et al. indicated that the mixture of propane and isobutane with 60% mass fraction of propane has higher *COP*, faster cooling rate, shorter compressor on-time and lower compressor dome temperatures than *R*134*a* [7]. Such results confirmed the successful use of the propane/butane mixture as an alternative to *R*134*a* in domestic refrigerators.

According to Sandip P. Chavhan and Prof. S. D. Mahajan domestic refrigerators working with *R*134*a* consume about 10% of the total residential energy budget annually. Unfortunately, *R*134*a* is considered as a harmful fluid to the environment due to its high (GWP=1300) [8].

2. Experimental setup

Figure 1. shows a schematic diagram of the experimental setup of refrigerator, which was originally manufactured to work with *R*134*a*. It consists of a chamber, an evaporator, a compressor, a condenser and a capillary tube. The cabinet was made of *GI* sheet with smooth and waterproof outside shell. Experimental data collection was carried out by a data logger, which was developed at Refrigeration and Air Conditioning Lab, Mechanical and chemical Engineering (*MCE*) Department, Islamic University of Technology (*IUT*).

Temperature sensors (*LM*35) interfaced with the data logger via a *PC* through the General Purpose Interface Bus (*GPIB*) cable for data storage. Temperature measurement is necessary to find out the enthalpy in and out of each component

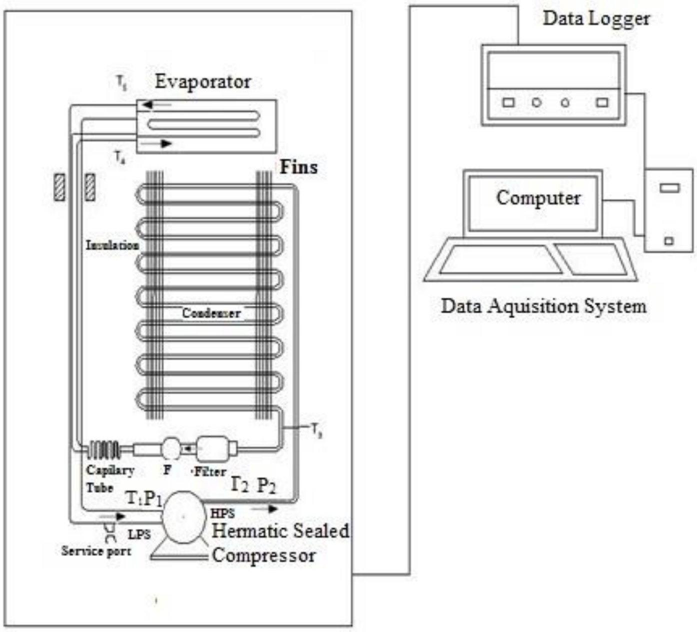

Fig. 1. Schematic diagram of the Experimental Setup.

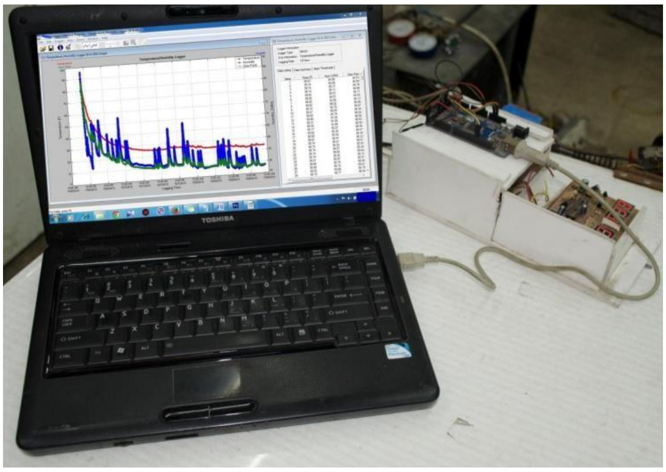

Fig.2Data logger connected with the laptop computer.

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The following assumptions were made in the design of the experimental vapor compression refrigerator:

(a) Steady state operation;

(b) No pressure loss through pipelines, that is, pressure changes only through the compressor and the capillary tube;

(c) Heat losses or heat gains from or to the system are neglected and of 75% isentropic efficiency

Figure 3 shows a schematic diagram of a single door, manual defrost and subtropical class and freezervolumes of 3.5ft^3 was originally manufactured to work with *R*134*a*. It consists of a cabinet, an evaporator, a compressor, a condenser and a capillary tube. The cabinet was made of *GI* sheet with smooth and waterproof outside shell. A power meter was connected with compressor to measure the power and energy consumption.

Experimental data collection was carried out by data logger, which was also develop at Refrigeration and Air Conditioning Lab., Mechanical and chemical Engineering (*MCE*) Department, Islamic University of Technology (*IUT*), *OIC*.

a b c

Fig. 3. A Single door manual defrost freezer from different view.

3. Experimental procedure

Energy consumption is defined as the product of electric power and running time. The following graph of this paper reveals that energy consumption decreases when either capillary tube length decreases or *LPG* charge increases. Experimental results were obtained for continuous and cycling operating modes at ambient air temperature of 33 ± 1°*C*, which simulates subtropical operating temperature according to Bangladesh Standard (*BDS*) [9] .It can be stated that freezer air temperature of -12°*C* or less should be achieved to accept the domestic refrigerator according to standard for this refrigerator class. To get a more accurate and reliable reading of the power consumption by the VCR we started to take the reading after 700 minutes in all the cases as the data becomes more accurate after that time. In order to calculate the power consumption, the value of voltage and current was taken with the help of the data logger which was developed in the lab. To check the accuracy of the data logger, the value of the data logger was compared with a digital multimeter and the accuracy was around 98%. The power consumption was first calculated in Watt by simply multiplying the obtained voltage and current (P= *V* × I) with the help of the data logger. To find out the power consumption of the *VCR* in kWh the following formula was used

$$\text{kWh} = \text{Watts} / 1000 \times \text{time in hours}$$

To obtain the power consumption by the refrigerator in a day it was multiplied with 24 and for a year it was multiplied with 365 with the previous value which is shown in the Table 1

The compartment average temperature was maintained to fixed temperature to -17.6˚*C* for all the arrangement. The following figure represent the power consumption of the *VCR* along with the time in various condition.

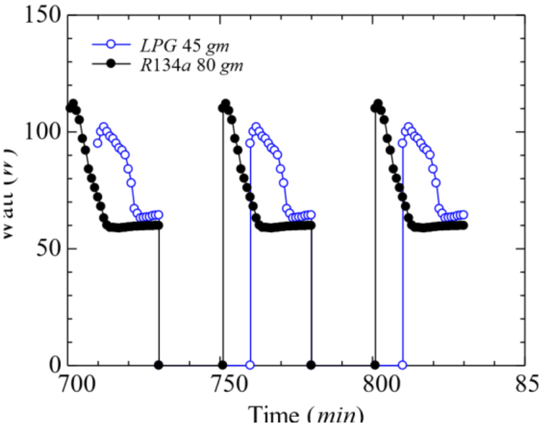

Fig. 4. Power consumption with Time for 4m capillary

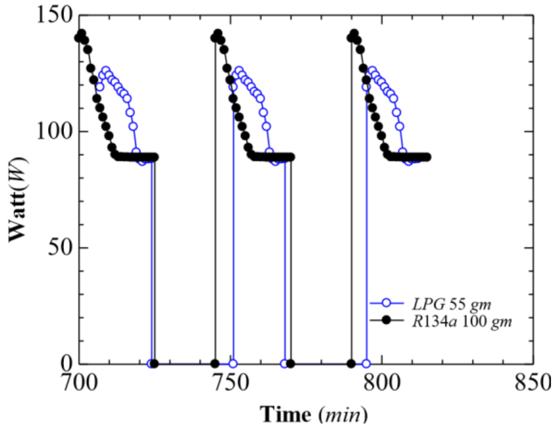

Fig. 5. Power consumption with Time for 4m capillary

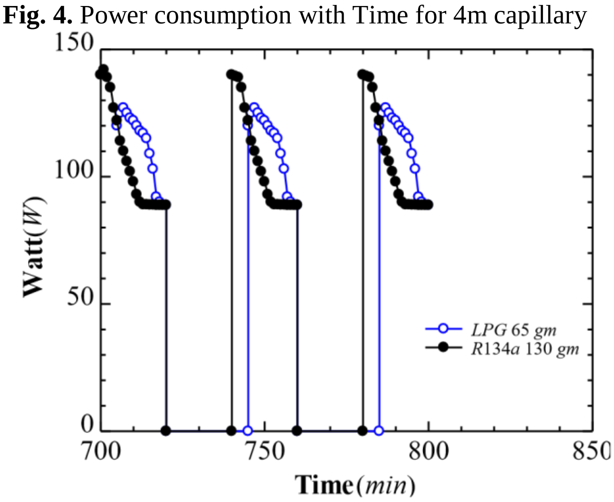

Fig. 6. Power consumption with time for 4m capillary

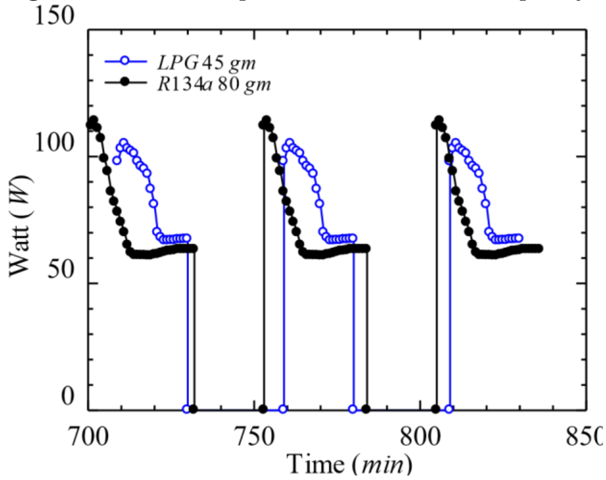

Fig. 7. Power consumption with time for 4.5m capillary

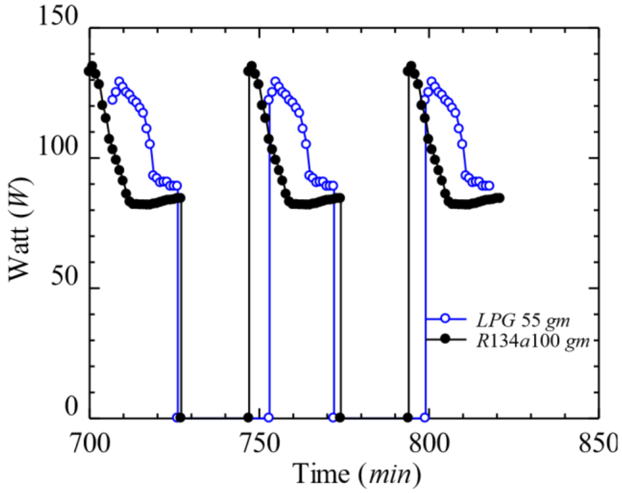

Fig. 8. Power consumption with time for 4.5m capillary

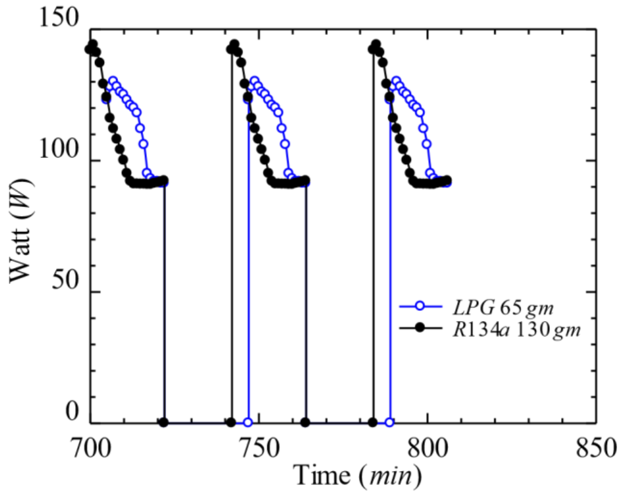

Fig. 9. Power consumption with time for 4.5m capillary

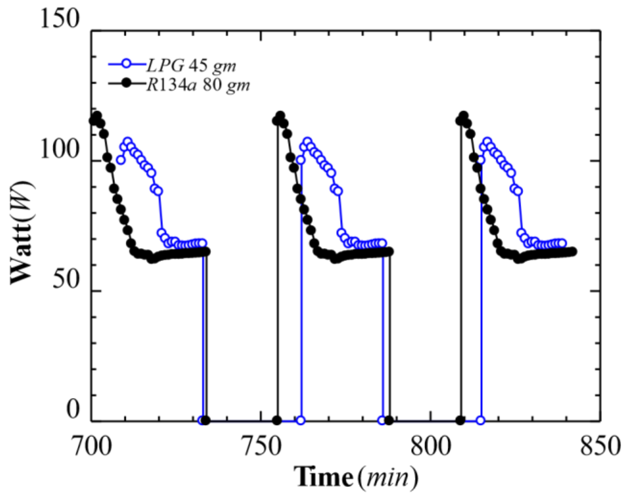

Fig. 10. Power consumption with time for 5m capillary

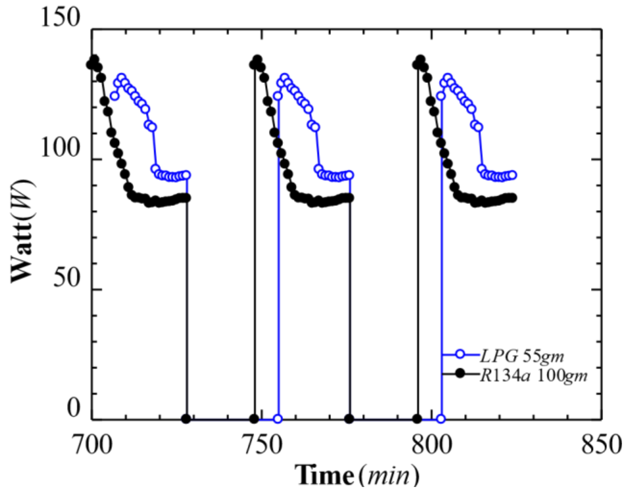

Fig. 11. Power consumption with time for 5m capillary

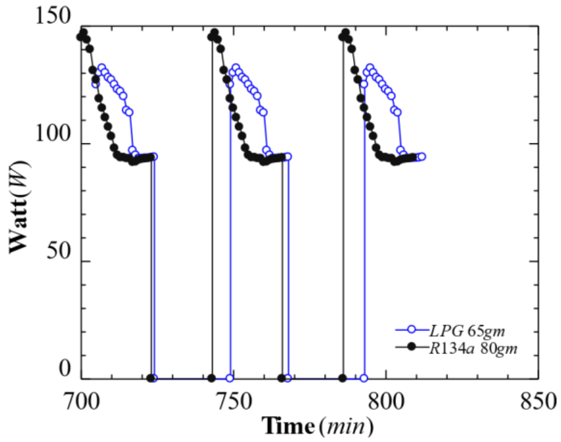

Fig. 12. Power consumption with time for 5m capillary

The following table is the summery of the experiment that was carried out to prove that *LPG* is the drop in replacement of *R*134*a* in terms of power consumption.

Table 1.Comparison of Energy Consumption

Refrigerant Name	Capillary length (m)	Refrigerant amount (gm)	Total cycle time (min)	Energy consumption (kWh /day)	Energy consumption (Kwh/year)
LPG	4	45	45	0.817	298.12
LPG	4	55	44	1.059	386.67
LPG	4	65	40	1.069	390.26
*R*134*a*	4	80	56	1.532	559.44
*R*134*a*	4	100	45	1.472	537.26
*R*134*a*	4	130	40	1.337	488.15
LPG	4.5	45	50	0.882	321.75
LPG	4.5	55	46	1.132	413.18
LPG	4.5	65	42	1.115	420.15
*R*134*a*	4.5	80	58	1.5403	420.15

*R*134*a*	4.5	100	42	1.568	572.48
*R*134*a*	4.5	130	42	1.418	517.59
LPG	5	45	53	0.94	343.23
LPG	5	55	48	1.206	440.34
LPG	5	65	44	1.224	446.72
*R*134*a*	5	80	67	1.704	622.09
*R*134*a*	5	100	56	1.648	601.8
*R*134*a*	5	130	43	1.463	533.99

Table 2. Refrigerant Cost Analysis

*R*134*a* Costing, BDT	*LPG* Costing, BDT
13.6kg cylinder price = 7425 Per kg *R*134*a* Refrigerant Price = 571	12kg cylinder price = 1000 Per kg *LPG* Refrigerant Price = 83

It is clearly visible from the unit cost of *R*134*a* and *LPG* refrigerant that the cost for *LPG* is 85% cheaper than *R*134*a*.

4. Conclusion

Continuous running and cycling tests were conducted to examine *LPG* of 60% propane and 40% commercial butane as a drop-in substitute for *R*134*a* in a single evaporator domestic refrigerator with a total volume of 100 liters under Subtropical conditions. The considered parameters include filling charges of *R*134*a* and *LPG* and capillary tube lengths for *R*134*a* and *LPG*. The test results revealed the following outcomes:

i) Freezer air temperature of -17.5°*C* can be achieved using *LPG* charge of 65*g* for capillary tube length ranges from 4*m*.
ii) Considering Performance characteristics minimum electric energy is achieved with *LPG* charge of 65*g* and capillary tube length of 4*m* combination.
iii) Comparison of experimental results of both *R*134*a* (with its custom capillary tube length of 4*m* and charge of 130*g*) and the best combination of *LPG* (capillary tube length of 4*m* and charge of 65*g*) revealed that Energy consumption using *LPG* are lower than those of *R*134*a* by 19.9 %.
iv) Using *LPG* is Cost Effective than *R*134*a* Refrigerant.

In conclusion, the reported results confirm that *LPG* is an attractive drop-in substitute for *R*134*a* in domestic refrigerators in terms of power consumption and cost.

5. Referances

[1] I. L. Maclaine-cross, E. Leonardi, "Performance and safety of *LPG* refrigerants, Proceeding of the 'Fuel for Change' Conference of Australian Liquefied Petroleum Gas Association Ltd., Australia, pp. 149-168, 1995.

[2] N. Austin, Dr. P. Senthil, and P. N. Kanthavel kumaran, "Thermodynamic Optimization of Household Refrigerator Using Propane-Butane as Mixed Refrigerant", International Journal of Engineering Research and Applications (IJREA), Vol. 2, Issue 6, November-December, 2012.

[3] S. A. Agarwal, M. Ramaswamy, A. Kant, "Evaluation of hydrocarbon refrigerants in single evaporator domestic refrigerator freezer", Proceedings of International CFC and Halon Alternative, Washington, USA, pp. 248-257, 1995.

[4] R. N. Richardson, J. S. Butterworth, "The performance of propane/isobutane mixtures in a vapor compression refrigeration system", International Journal of Refrigeration, Vol. 18, pp. 58-66, 1995.

[5] Z. Liu, I. H. Haider, R. Radermacher, "Simulation and test results of hydrocarbon mixtures in a modified Lorenz Metzener cycle", ASHRAE Trans. Vol. 101, pp. 1318-1328, 1995.

[6] I. Maclaine-cross, "Hydrocarbon refrigerants for car air conditioners", Proceeding of Seminar on ODS Phase-out Solution for the Refrigeration Sector, Kuta, Bali, Indonesia, pp. 11-17, 1999.

[7] D. Jung, C. Kim, K. Song, B. Park, "Testing of propane/isobutene mixture in domestic refrigerators", International Journal of Refrigeration Vol. 23, pp. 517-527, 2000.
[8] S. P. Chavhan, S. D. Mahajan, "A Review of an Alternative to *R*134*a* Refrigerant in Domestic Refrigerator", International Journal of Emerging Technology and Advanced Engineering, Vol.3, Issue 9, September 2013.
[9] Bangladesh Standard: Specification for Energy-Efficiency Rating of Household Refrigerators, Refrigerator-Freezers and Freezers, BDS 1850, 2012.