THE POSSIBILITY OF USING LIQUIFIED PETROLEUM GAS IN DOMESTIC REFRIGERATION SYSTEMS

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ABSTRACT

Domestic refrigerators annually consume approximately 17,500 metric tons of traditional refrigerants such as Chlorofluorocarbon (CFC) and Hydroflourocarbon (HFC) which contribute to very high Ozone Depletion Potential (ODP) and Global Warming Potential (GWP). Good progress is being made with the phase out of CFC 22 from new equipment manufacture by replacing LPG since it possesses an environmentally friendly nature with no ODP. LPG is expected to results in comparable product efficiencies based on its characteristics. Therefore, this two types of refrigerants (LPG and CFC 22) to be examined using a modified domestic refrigerator in term of their performance characteristics parameters such as pressure and temperature at specified location at the refrigerator and the safety requirements while conducting the experiment. Based on the present work, it is indicate that the successful of using LPG as an alternative refrigerant to replace CFC 22 in domestic refrigerators is possible by getting LPG COP as 13 compared to 10 for CFC22.

Keywords: *Domestic refrigerator, alternative refrigerant, LPG, CFC 22, ODP, GWP.*

1. INTRODUCTION

The refrigerants chlorofluorocarbon (CFCs) and hydrochlorofluorocarbon (HCFCs) both have high ozone depleting potential (ODP) and global warming potential (GWP) and contributes to ozone layer depletion and global warming [1][2]. Therefore these two refrigerants are required to be replaced with environmentally friendly refrigerants to protect the environment. The hydrofluorocarbon (HFC) refrigerants with zero ozone depletion potential have been recommended as alternatives such as Tetraflouroethane (R134a). It is the long-term replacement refrigerant for R22 because of having favorable characteristics such as zero ODP, non-flammability, stability and similar vapor pressure as that of R22 [3]. The ODP of R134a is zero, but it has a relatively high global warming potential. Many studies are being carried out which are concentrating on the application of environmentally friendly refrigerants in refrigeration systems [4][5]. The issues of ozone layer depletion and global warming have led to consideration of hydrocarbon (HC) refrigerants such as propane, isobutene, *n*-butane or hydrocarbon blends as working fluids in refrigeration and air-conditioning systems [6].

Hydrocarbons are designated as highly flammable refrigerants by American Society of Heating, Refrigerating and Air Conditioning (ASHRAE) Standard 34, the industry standard for refrigerant classification [7]. The hydrocarbon as refrigerant has several positive characteristics such as zero ozone depletion potential, very low global warming, non-toxicity, high miscibility with mineral oil, good compatibility with the materials usually employed in refrigerating systems [1]. The main disadvantage of using hydrocarbons as refrigerant is their flammability. If safety measures are taken to prevent refrigerant leakage from the system then a flammable refrigerant could be as safe as other refrigerants. When GWP is one of the important parameters that taken into consideration in this study let us see how the refrigerants are influence by GWP. GWP is a measure of how much a given mass of greenhouse gas is estimated to contribute to global warming in the other word, it is the ratio of heat trapped by one unit mass of the greenhouse gas to that of one unit mass of CO_2 over a specified time period [8]. It is a relative scale which compares the gas to that of the same mass of carbon dioxide (whose GWP is 1). A GWP is calculated over a specific time interval. The GWP value for HFC 134a is 1300 for LPG is 11 and CFC 12 is 2125 over 100-year [9]. Any opportunities to accelerate transition to alternative refrigerants will have favorable effects on the environment.

LPG has a distinct advantage versus CFC 22 if decisions were based solely on the GWP parameter [1]. Numerous manufacturers independently selected refrigerants following extensive integrated assessments in the areas of safety, environmental compatibility, performance, reliability and economy. Both CFC 22 and LPG provide safe reliable and efficient performance in properly designed domestic refrigerators and freezers [10]. Their applications are uniquely different, but equally effective. Regional differences in consumer-driven product attributes strongly influence or dictate refrigerant choice. Principals among these are single versus multiple storage temperatures, manual versus automatic defrosts and storage volume needs. Quantity of refrigerant used is the only variable other than composition to reduce refrigerant GWP. Domestic refrigerators typically contain a 50 to 200 gram refrigerant charge

[11]. The amount used is determined during design development to optimize performance. To overcome the problem stated above, this study will evaluate LPG performance characteristic to the existing refrigerant although it is highly flammable. LPG is the best refrigerant to replace existing ozone depletion and global warming refrigerants like CFC and HFC [12]. This study will show the LPG is possible, safe, environmental friendly and has high energy efficiency. Other than that, this study includes the safety requirements and proposed the modification cabinet of domestic refrigerator using LPG.

This paper includes the safety measures to be considered during the refrigerator modification and LPG installation, the performance characteristics compared to R22 refrigerant and the coefficient of performance (COP). In order to get this COP, there are some parameters need to be considered. The following approach will give a brief description on determining the COP.

The enthalpy values of the refrigeration cycle states were extracted from the thermodynamic tables and charts of propane and butane. The enthalpy of the LPG mixture, h_m, at each state is evaluated from the Equation (1.1),

$$h_m = Z_p h_p + Z_b h_b \qquad (1.1)$$

where Z_p, are Z_b, are the mass fraction of propane and butane, respectively. Their values are 0.3, and 0.7, respectively. A computer program was designed using basic language to calculate the refrigerator performance parameters such as refrigeration capacity (Q_e), compressor power consumption (W) and COP. Refrigeration capacity (Q_e) can be estimated by calculating the rate of heat removal from the water load using Equation (1.2).

$$Q_e = \left(M_w C_{pw} \Delta T_w + M_c C_{pc} \Delta T_c\right) dt \qquad (1.2)$$

where M_w and M_c are the mass of the water load and its container, Cp_w and Cp_c are the speciffic heats of water and container, respectively, and dt is the time interval which is equal to 10 min. The refrigeration capacity, Q_e is also expressed as Equation (1.3)

$$Q_e = m\left(h_{eo} - h_{ei}\right) \qquad (1.3)$$

where $h_{e,i}$ and $h_{e,o}$ are the LPG enthalpies at inlet and exit of the evaporator. Equations (1.2) and (1.3) can be used to find the LPG mass flow rate, m. To calculate work, Equation (1.4) will be used.

$$W = m\left(h_{m,1} - h_{m,2}\right) \qquad (1.4)$$

where $h_{m,1}$ and $h_{m,2}$ are the LPG enthalpies at inlet and outlet of compressor. By applying equations (1.3) and (1.4), the COP of the refrigerator can be determined directly by equation (1.3) be divided by equation (1.4). The overall efficiency of the refrigeration is basically depending on the compressor. Equation (1.5) shows the way of calculating the overall efficiency, η.

$$\eta = \frac{\left(h_{2s} - h_1\right)}{\left(h_2 - h_1\right)} \qquad (1.5)$$

where h_{2s}, h_2 and h_1, are isentropic enthalpy, actual enthalpy outlet of compressor and actual enthalpy inlet of compressor respectively.

The objective of the present investigation is to examine LPG of propane/n-butane by 30%/70% as a drop-in candidate for R22 in the existing domestic refrigerator and freezer. This requires performance characteristics evaluation for LPG by using the same rig as R22 without any major modification. Thus, a single door, manual defrost refrigerator with total volume of 0.283 m3, which was originally manufactured to work with R22, was equipped with necessary instrumentations. The performance characteristics of the domestic refrigerator and safety parameter for flammable refrigerant were investigated through continuous running and cycling tests. Finally, performance characteristics of both LPG and R134a were compared.

2. METHODOLOGY

2.1 Experimental Setup

The domestic refrigerator used in the present work was manufactured by a local manufacturer. Figure 1.0 shows the specifications of a single door, manual defrost and tropical class refrigerator which was originally manufactured to work with R22. It consists of a cabinet, an evaporator, a compressor, a condenser, an expansion valve and a capillary tube. The cabinet was made of pressed steel with smooth and water proof outside shell. Expanded polystyrene panels were installed between the outer and the inner shell to minimize heat gain. Figure 2.0 shows the schematic diagram of all the temperature and pressure sensors attached to the refrigerator equipments.

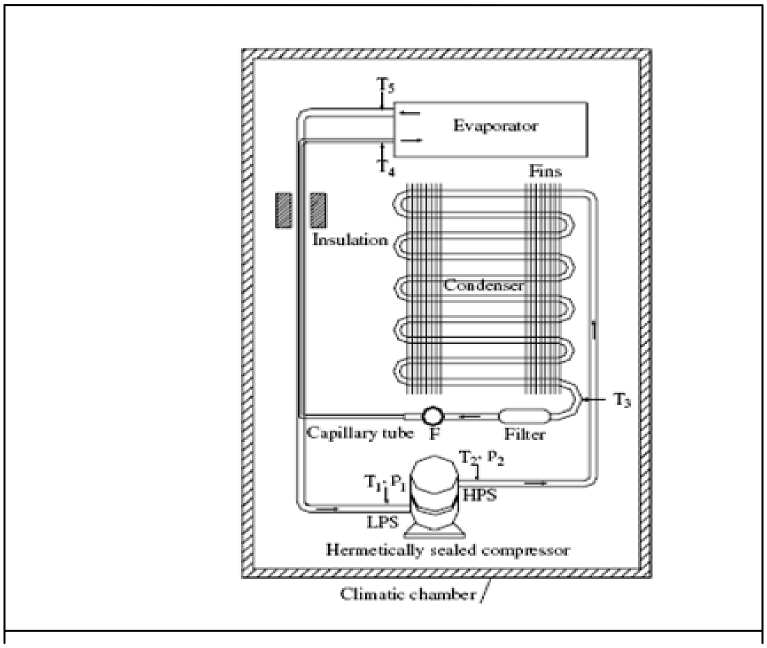

Figure 1.0 Schematic Diagram of Equipments in Fridge Circuit

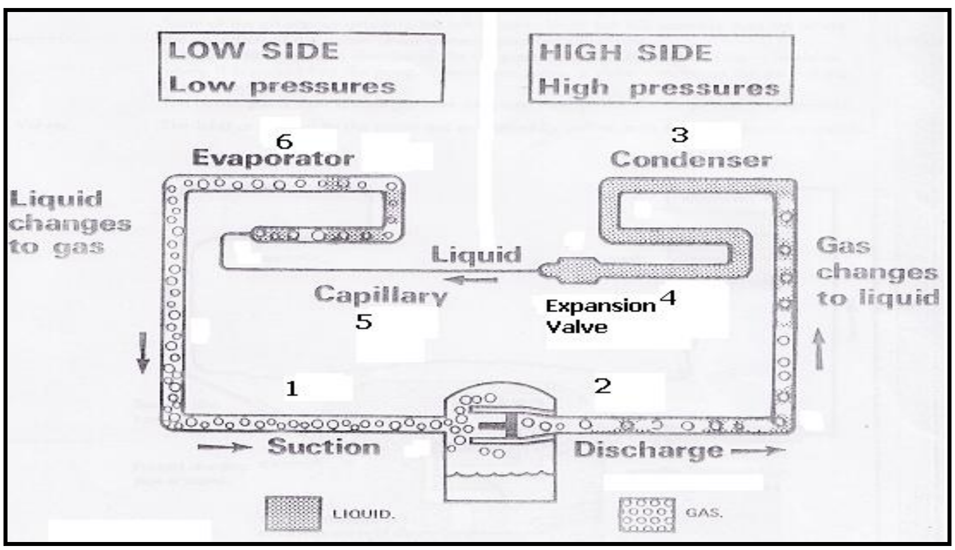

Figure 2.0 Schematic Diagram of Temperatue and Pressure Sensor Location

This domestic refrigerator was instrumented with eight Type-K thermocouples, two pressure gauges and a watt meter. Filter drier is installed before the capillary tube to absorb the moisture which may exist in the refrigerant circuit. As the refrigerant is condensed in the condenser, it flows through the high-side filter-drier into a capillary tube attached to a section of the suction line. This provides a heat exchange between the capillary tube and the suction line. Thermocouples were used to record the temperature at various locations within the refrigerator as follows: air inside the freezer compartment, upper section and exit of condenser, middle section and exit of evaporator, compressor inlet and discharge, ambient air and load water inside a metal container that represent the load to the refrigerator. Pressure gauges were used to measure the pressure of both suction and discharge lines of the refrigerator compressor.

2.2 Modification

2.2.1 Heat Exchanger

The refrigeration system efficiency will normally not cause a need for changing evaporator or condenser size, which means, the outer surface can be left the same as with R 22 or R 134a. Inside design of the evaporator could possibly need some modification, because the refrigerant volume flow increases by 50 % to 100 % according to the larger compressor swept volume. This leads to increased pressure drop in the refrigerant channels or tubes, if the cross flow section stays the same. To keep the refrigerant flow speed within the recommended range of 3 to 5 m/s it may be necessary to make the cross flow sections wider. In evaporators this can be done by either increasing channel system height, for example from 1.6 mm to 2 mm, or by designing parallel channels instead of single ones. A parallel channel design however has to be developed very careful to avoid liquid accumulations.

2.2.2 Capillary Tube

Changing a refrigeration system with capillary from CFC 22 to LPG usually experience and theoretical modeling show the need for a flow rate almost similar to R 22 again. The suction line heat exchanger is very important for system energy efficiency of LPG. Effect on efficiency is even higher for LPG, than for CFC 22. The large increase in COP for LPG is caused by a high vapor heat capacity. In combination with the need for keeping the refrigerant charge close to maximum possible in the system, thus giving no superheat at evaporator outlet, the suction line heat exchanger has to be very efficient for preventing air humidity condensation on the suction tube. In many cases an elongation of the suction line and capillary gives efficiency improvements. The capillary itself has to be in good heat exchanging contact with the suction line for as long a part of total length as possible.

2.3 Instrumentation

The temperatures around the fluid circuits were all measured using type K thermocouples. These had been previously calibrated against a platinum resistance thermometer, it is estimated that the accuracy of the temperature measurements was $\pm 0.5^{o}C$. The pressures in the refrigeration circuit were measured using standard test gauges that had been calibrated. In this case the accuracy was taken to be ±1%.

2.4 Test procedure

Two experiments will be performed in this study:

a) The refrigerator will run at steady state condition with the freezer unloaded at $-20^{O}C$. A load of one liter water in a steel container at $80^{O}C$ was then placed in the freezer compartment. All temperatures and pressures were then recorded for each 1 min interval.

b) In the second experiment, T_c was changed by employing an air heater, fitted with a fan, to heat the ambient air around the condenser surface. Each experiment will be ended at the steady state conditions of the refrigerator. Time required to attain this condition exceeded 5 hours.

All experiments were carried out several times with the system being charged with LPG. The capillary tube size and length also were taken into consideration during this study.

3. RESULT AND DISCUSSION

3.1 Performance Characteristics

The results of all the parameters (temperature and pressure) are as in Figure 1 until Figure 5. Figure 1 shows the variation of temperature at location number 1, 4 and 5 for both refrigerants. At compressor suction line (T_1), the refrigerant has to be in the vapor phase in order for the compressor to compress the refrigerant at its maximum capacity. This graph shows that T_1 for both refrigerants satisfy the need for the compressor as at the interval of $4^{o}C$ to $6^{o}C$, they are in vapor phase. Refrigerant at the expansion valve suction line (T_4) has to be in liquid phase. At the interval of $-4^{o}C$ to $0^{o}C$, both refrigerants are in liquid phase. It changes phase from superheated vapor to liquid by a condenser located between compressor and expansion valve. Difference of about $1^{o}C$ for both refrigerants was due to different in vapor pressure or boiling point of each refrigerant. So basically, the temperature achieved satisfied the requirement for a domestic refrigerator.

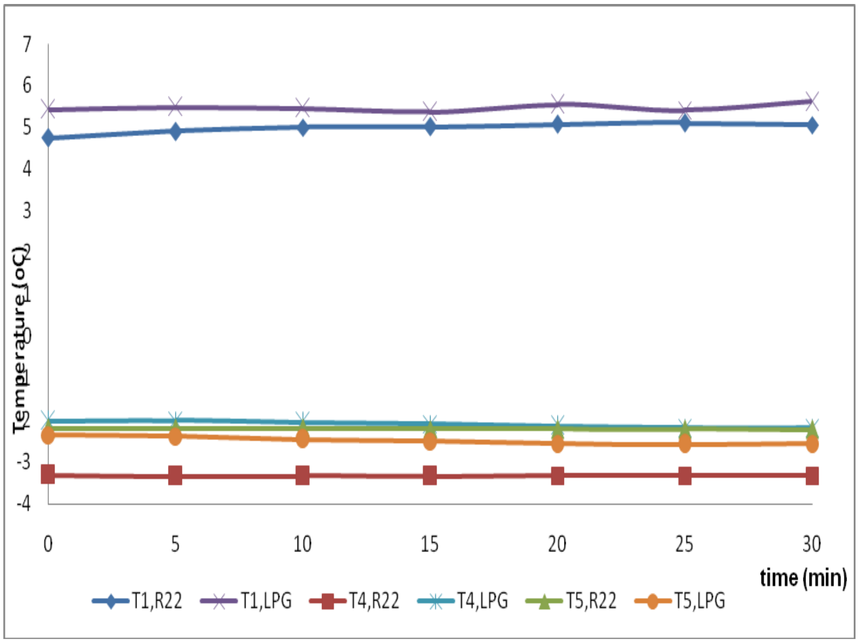

Figure 1: Temperature Profile

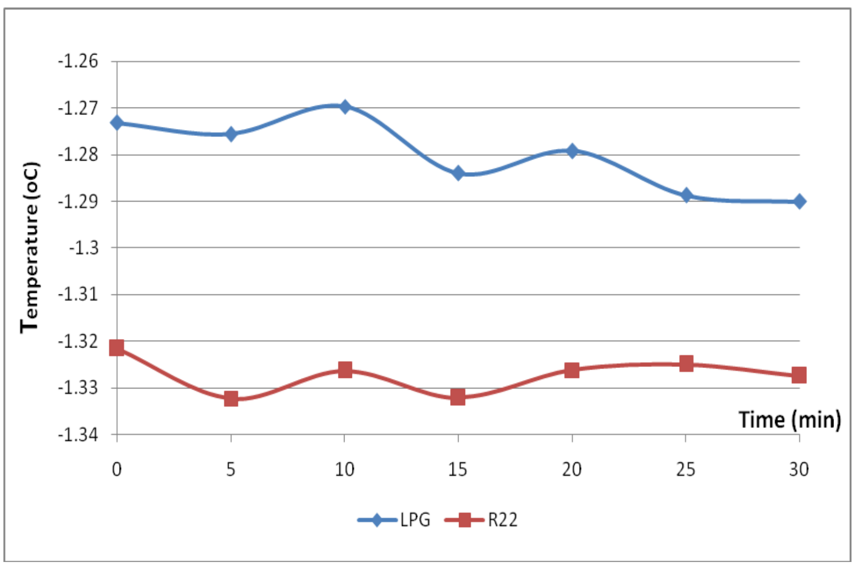

Figure 2: Compartment Temperature

R22 can achieve can reach the minimum temperature up to -1.33^{o}C and LPG until -1.29^{o}C as shown in figure 2. The difference of about 0.04^{o}C was due to the atmospheric temperature. While running the R22 experiment, there was no ventilation at the fridge compartment. It was all well ventilated but for LPG, there was some ventilation at the fridge compartment. This happened when the process of inserting LPG in the fridge circuit. The compartment fridge supposed to be ventilating the same as R22 but the best we can do was to seal the fridge door to minimize the ventilation. From figure 2, we can see some fluctuation. Temperature fluctuation was basically due to unstable running compressor. According to the theory, as long as the compartment temperatures achieve -1^{o}C, the fridge still can be operated normally. So we can say that both refrigerants operate very well in their line but obviously R22 show better temperature profile.

From figure 3, we can see that the compressor reach its optimum pressure after three days. For R22 there was not much increment because at 70 to 80 psia, and R22 are already stable at its gaseous phase. The pressure of LPG first was 65 psia but after two days of operation, the pressure increased up to 100 psia from 80 psia. This shows that

LPG reaches its optimum pressure condition after 3 days. This happen because for a heavier refrigerant as LPG, compressor needs time to stabilized its condition before it can reach its optimum condition. This then conclude that, compressor work with LPG have higher efficiency compared to R22. Refrigeration compressors provide air conditioning, heat pumping, and refrigeration for large-scale facilities and equipment. They compress low-pressure, low-volume gas into high-pressure and high-temperature gas. Refrigeration compressors also remove vapor from the evaporator.

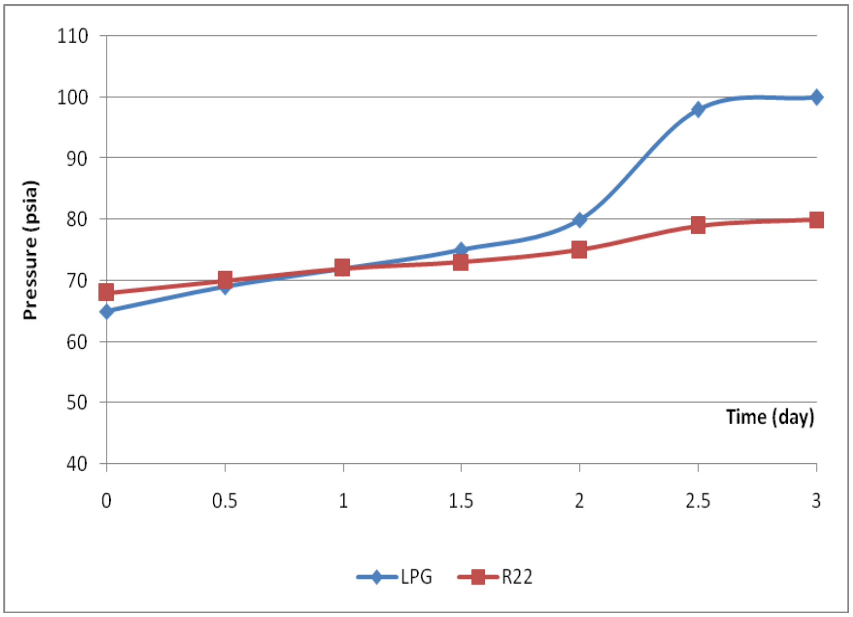

Figure 3: Pressure Profile

Calculated COP of both LPG and R22 as function of time are presented in Figure 4. In three days, the COP of both tested refrigerant was increased and obviously LPG achieve a higher COP compared to R22. The COP was increase rapidly after day 2 because at this point, the compressor already achieves its optimum flow. Then it continuously increases until LPG and R22 reaches a stable value which is 13.5 and 10.1 respectively.

As we can see in Figure 5, the overall compressor efficiency will give the life time for a compressor to work by using each refrigerant. Stated by theory, the higher the compressor efficiency, the longer the compressor can be used. Figure 5 shows that R22 has higher compressor efficiency compared to LPG. This is because the fridge compressor was meant to be working with R22. In other hand, we do not make any modification or changes upon the compressor. After all, the LPG still reach its target which was more than 80% efficiency.

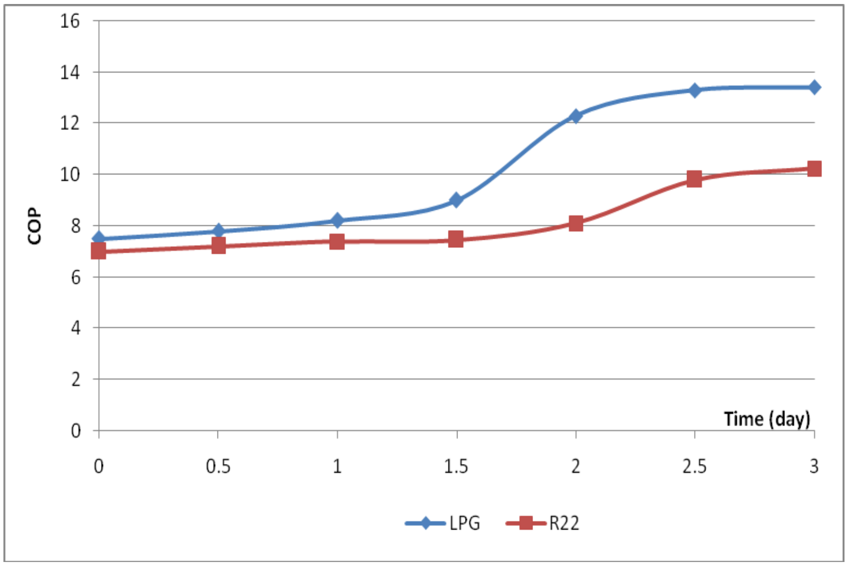

Figure 4: Coefficient of Performance

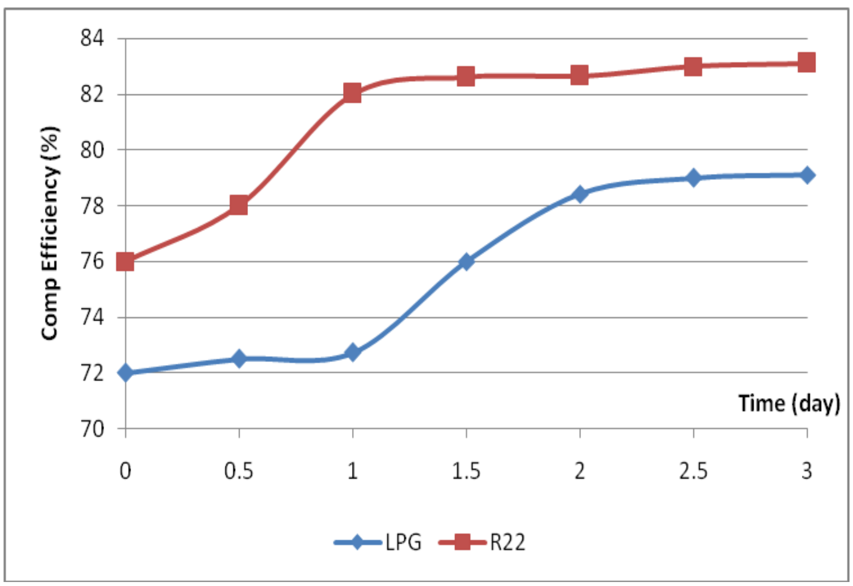

Figure 5: Compresor Efficiency

3.2 Safety Requirements

A cautious approach for making safe the refrigerator tested for this paper would be use non-sparking electrics for low-level compressors, use a continuous liner with no holes in the chilled food compartment with the protected cooling circuit or have no sources of ignition in the compartment and guidance to users on the need for ventilation and the position of ignition sources other than the refrigerator. There is some point where the refrigerator has to take deep consideration throughout the experiment to protect from any disorder. They were, the ability of the refrigeration circuit to contain an excessive pressure without leaking, the possibility of a leak from the refrigeration circuit, the possibility of the leaked refrigerant forming an explosive mixture and the possibility of an explosive mixture being ignited.

Researches also have to consider all joints in the refrigeration system are potential sources of leaks and that there is a reasonable probability of a leak occurring from one. It also considers that if a refrigeration circuit is likely to be physically damaged there is also a reasonable probability of a leak occurring. Such an occurrence could be caused by scraping the circuit to remove ice. Protected circuits are, in concept, where no part of the cooling system is inside a food storage compartment. Therefore, if a leak occurs, an explosive mixture will not form inside the compartment. Circuit that has a part of the cooling system inside the food storage compartment and can be considered to be as leak-proof is one of the examples. Because an explosive mixture will not occur at any alert, precautions need not be taken to prevent a spark from occurring in the compartment.

4. CONCLUSION

The performance of LPG as an alternative refrigerant to CFC 22 in domestic refrigerators will be studied. The following are the conclusion:

1. No operation problems encountered with the refrigerator compressor where no degradation of lubricating oil has been detected for a better COP and refrigerator efficiency.
3. LPG is safe to act as a refrigerant comply with the safety parameter that was highlighted.
4. This study was successfully completed within the time range which is between 4 months.

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