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# Assessment of LPG as a possible alternative to R-12 in domestic refrigerators

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**Abstract**

In this paper, experimental results on the performance of liquefied petroleum gas (LPG) as a possible substitute for refrigerant R-12 in domestic refrigerators are presented. LPG is obtained from the local market with the composition of about 30% propane, 55% *n*-butane and 15% iso-butane by mass fraction. The domestic refrigerator used was designed to work on R-12. Various mass charges of 50, 80 and 100 g of LPG were used during this study. The results show that LPG compares very well to R-12. For example, the coefficient of performance was higher for all mass charges at evaporator temperatures lower than −15 °C. Overall, it was found that a mass charge of 80 g of LPG had the best results when used in this refrigerator. The condenser was kept at a constant temperature of 47 °C. Cooling capacities were obtained. They were in the order of about three- to fourfold higher for LPG than those for R-12.



*Keywords:* Domestic refrigerators; Refrigerant R-12; Liquefied petroleum gas; Coefficient of performance

## 1. Introduction

Since the 1930s, chlorofluorocarbons (CFCs) have been widely used in the field of refrigeration due to their favorable characteristics. In particular, they were used for small refrigeration units and domestic refrigerators. Refrigerant R-12 was the most dominant. It was one of the first refrigerants to be developed in the refrigeration industry. It is safe, somewhat inexpensive, nonflammable and very stable. Subsequently, CFCs were found to be the main cause of ozone layer depletion. Also, they were found to cause the greenhouse effect or global warming. The discovery

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of the ozone hole over the Antarctic led to the Montreal Protocol in 1989 [1]. Therefore, CFCs had to be regulated and banned from the refrigeration industry [2–5].

Hydrochlorofluorocarbons, such as R-22, cause less harm to the ozone layer. They contain less chlorine atoms in their chemical structure than CFCs. However, they still contain chlorine atoms in its chemical structure, which is liberated in the stratosphere, causing ozone depletion potential. They have less ozone depletion potential than CFCs, but they are considered to be harmful as well. They also cause the greenhouse warming effect [3–7]. The global warming potential of R-12 is considered to be 8500 times that of $CO_2$ over 100 years [1]. Greenhouse gas emissions led to the Kyoto Protocol in 1997 that targets developed countries [8].

Hydrofluorocarbons, such as R-134a, have almost zero ozone depletion potential, since they do not contain chlorine atoms in their chemical structure. Similar to R-12, they are safe, non-flammable and have vapor pressures similar to that of R-12. However, they have lower energy efficiency and are more expensive than R-12. They also have a low negative environmental effect of global warming potential [4,5]. According to Rachidi et al. [2], R-134a presents some inconvenience related to lubricant solubility. They have very high pressure ratios and poor heat transfer at low temperatures.

Recently, much attention has been paid to the so-called "natural fluids", which are claimed to be more environmentally friendly than synthetic fluids [3–6,9–11]. They are hydrocarbons and their mixtures. They are proposed to be used as refrigerants in domestic refrigerators to replace potentially ozone depleting fluids. They offer other advantages of being very inexpensive and available in large amounts. They are environmentally friendly with zero ozone depletion potential, and they do not cause the greenhouse warming effect. The main disadvantage is that they are highly flammable substances and must be handled with caution. Also, blends or mixtures of some refrigerants can be considered as substitutes or alternatives to existing refrigerants [12].

The objective of this work is to show experimentally that liquefied petroleum gas (LPG) can replace R-12 in domestic refrigerators. It is inexpensive, commercially available in local markets, and it is generally used in gas heaters and cooking stoves. It is a mixture of the following hydrocarbons: pentane, iso-butane and *n*-butane.

## 2. Experimental

In this study, an ordinary type of domestic dual compartment refrigerator/freezer unit was used. It had a gross capacity of 240 l and was designed to work on R-12 as its refrigerant. The test was conducted initially using 160 g mass charge of R-12. It was then performed using various charges of 50, 80 and 100 g of LPG as the working refrigerant. LPG was commercially available in local markets, and it is generally used as a fuel in gas cooking stoves and domestic gas heaters. It is very inexpensive, comprised of 30% propane, 55% *n*-butane and 15% iso-butane on a mass basis.

When conducting the experiments, pressure gauges were used to record the pressures at both the low and high sides of the compressor. Thermocouples were used at different locations of the cycle in order to record temperatures simultaneously using data acquisition.

A schematic diagram of the basic vapor compression refrigeration cycle is shown in Fig. 1. Briefly, the process of refrigeration takes place in the evaporator, by which heat is transferred to the refrigerant causing it to evaporate in the evaporator. Generally, the vapor leaves the

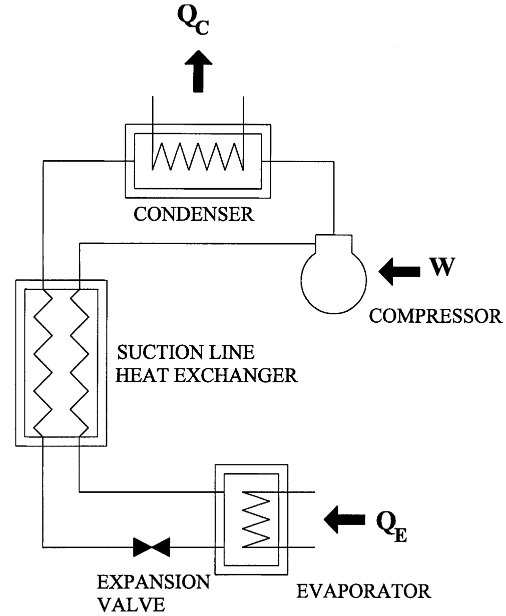


Fig. 1. Schematic diagram of freezer/refrigerator system.

evaporator as superheated refrigerant. It passes then through the suction line heat exchanger, gaining more heat before entering the compressor. In the compressor, it is compressed to a higher condensing pressure. Passing through the condenser at a temperature higher than the surroundings, heat is then rejected to the surroundings. At this time, the state of the refrigerant is subcooled in the condenser. It exchanges heat with the vapor leaving the evaporator in the suction line heat exchanger, and it is cooled even further. Finally, the refrigerant is expanded in an adiabatic process, causing a sharp drop in its temperature. It enters the evaporator as saturated liquid at low temperature and pressure, and then the cycle is complete.

In order to obtain some ideas about the thermodynamic behavior of LPG, vapor pressure lines were plotted for the gases that comprised our LPG sample as shown in Fig. 2. The gases are propane (R-290), *n*-butane (R-600), and iso-butane (R-600a). They are compared to the vapor pressure line of R-12. As shown by the figure, the vapor pressures of the three gases are near and surround that of R-12. The vapor pressure line of R-290 is higher than that of R-12. On the other hand, the vapor pressure lines of R-600 and R-600a are lower than that of R-12. Therefore, the vapor pressures of the mixture of three gases, i.e. LPG, are close enough to the range of R-12, and it can be used without making any major modification to the machine.

## 3. Results and discussion

Fig. 3 shows the variation of coefficient of performance (COP) with evaporator temperature for the three mass charges of LPG as compared to R-12. It shows that LPG compares very well to R-12. For example, the values of the COP were higher for all mass charges at evaporator

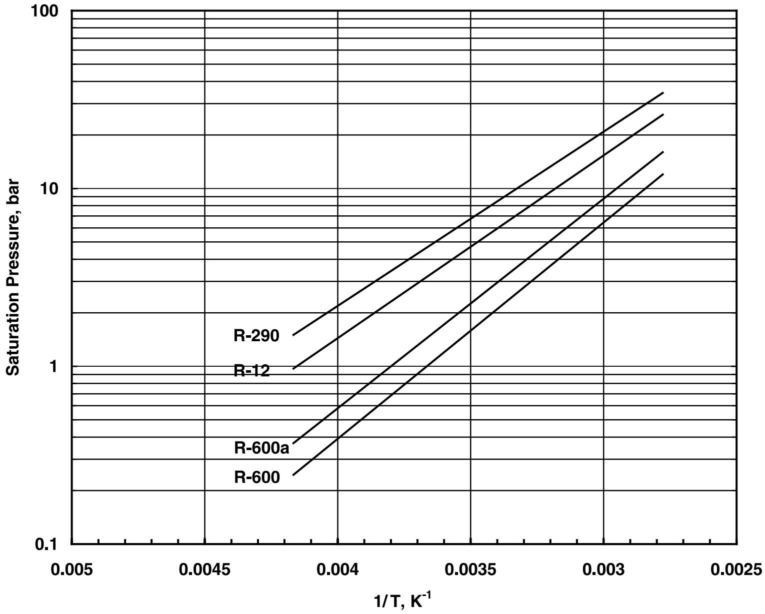


Fig. 2. Vapor pressure lines of refrigerant R-12, propane (R-290), *n*-butane (R-600), and iso-butane (R-600a).

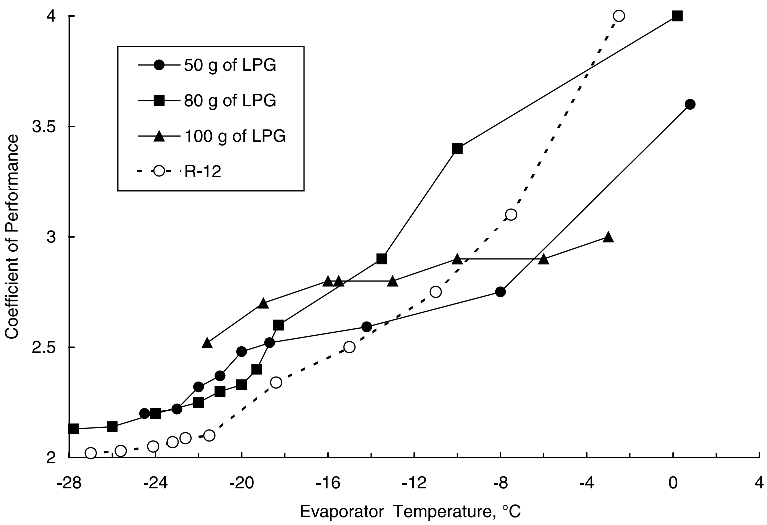


Fig. 3. Variation of COP with evaporator temperature for R-12 and different charge masses of 50, 80 and 100 g of LPG.

temperatures lower than −15 °C. At an evaporator temperature of about −10 °C, the COP was about 3.4, 2.9 and 2.7 for mass charges of 80, 100 and 50 g of LPG, respectively, whereas the COP for R-12 was about 2.85. The condenser temperature was kept at 47 °C. These results are in agreement with those reported in the literature [3–7,9].

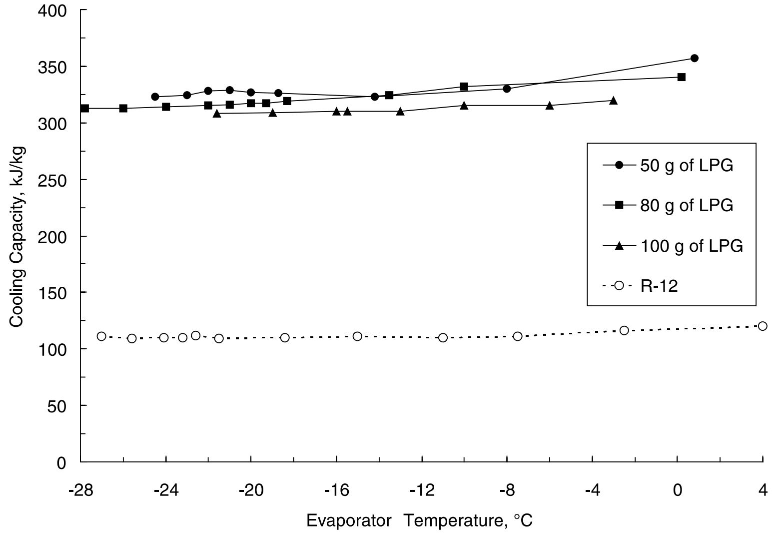


Fig. 4. Variation of cooling capacity (in kJ/kg) with evaporator temperature for R-12 and different charge masses of 50, 80 and 100 g of LPG.

The cooling capacities at various evaporator temperatures are shown in Fig. 4. They are much higher for LPG than for R-12 due to the higher enthalpies of R-290, R-600 and R-600a relative to those of R-12. Their order is in the range of 300–350 kJ/kg for the LPG gases and about 110 kJ/kg for R-12. Fig. 5 shows the variation of the specific compressor work at various evaporator temperatures. It was higher for LPG than R-12 due to the higher enthalpy values of LPG. In

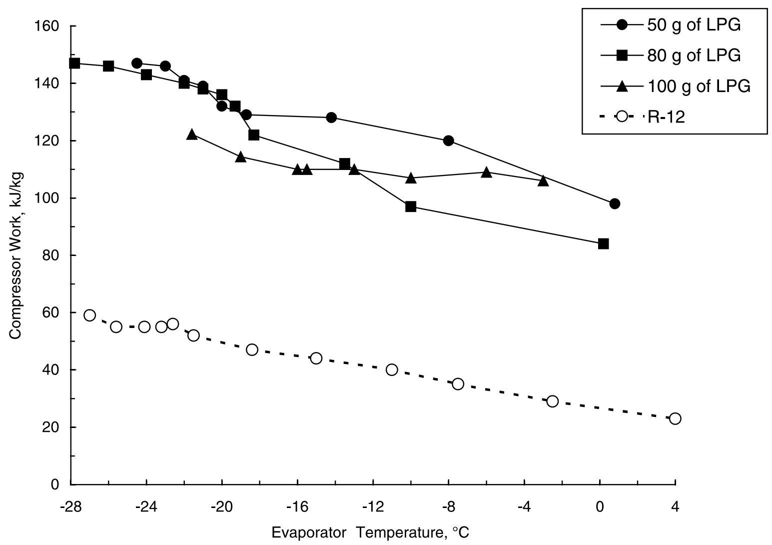


Fig. 5. Variation of compressor work (in kJ/kg) with evaporator temperature for R-12 and different charge masses of 50, 80 and 100 g of LPG.

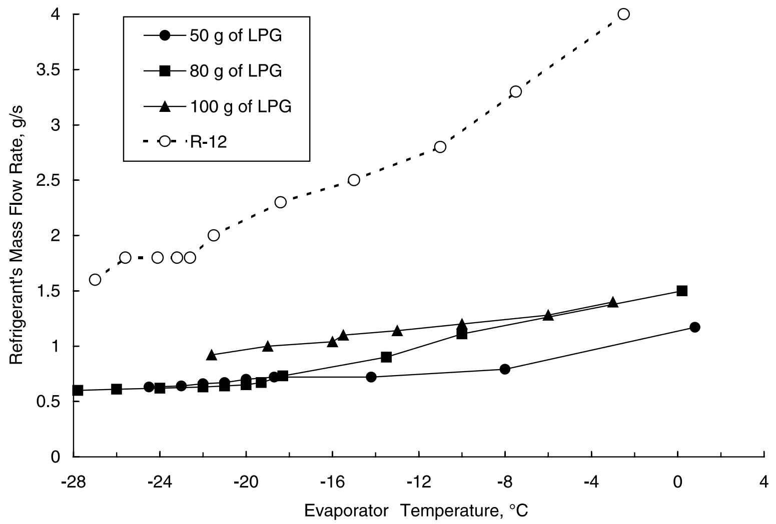


Fig. 6. Variation of refrigerant mass flow rate with evaporator temperature for R-12 and different charge masses of 50, 80 and 100 g of LPG.

general, the values were about doubled when LPG was used. The refrigerant mass flow rates were plotted as a function of evaporator temperature. They are presented in Fig. 6. The mass flow rates were much higher for R-12 than LPG (three- to fourfold higher). For example, at an evaporator temperature of −10 °C, the mass flow rate was approximately equal to 3 g/s for R-12, whereas it ranges between 0.7 and 1.0 g/s for LPG. The COPs versus different values of refrigerant mass flow

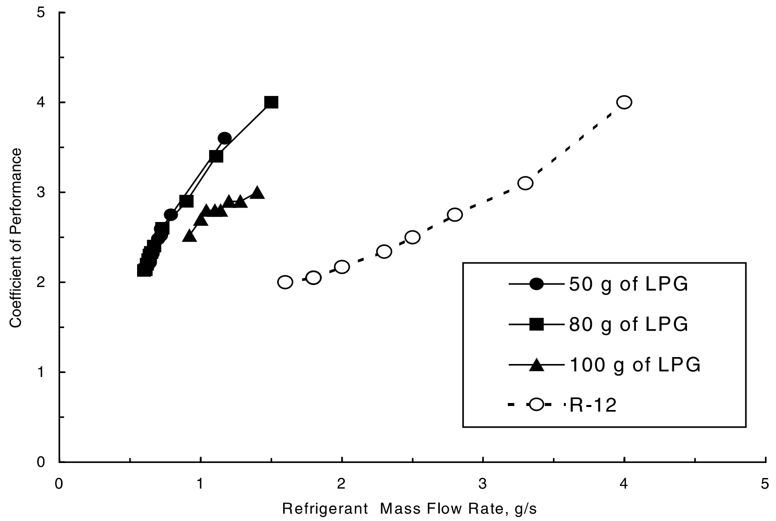


Fig. 7. Variation of COP with refrigerant mass flow rate for R-12 and different charge masses of 50, 80 and 100 g of LPG.

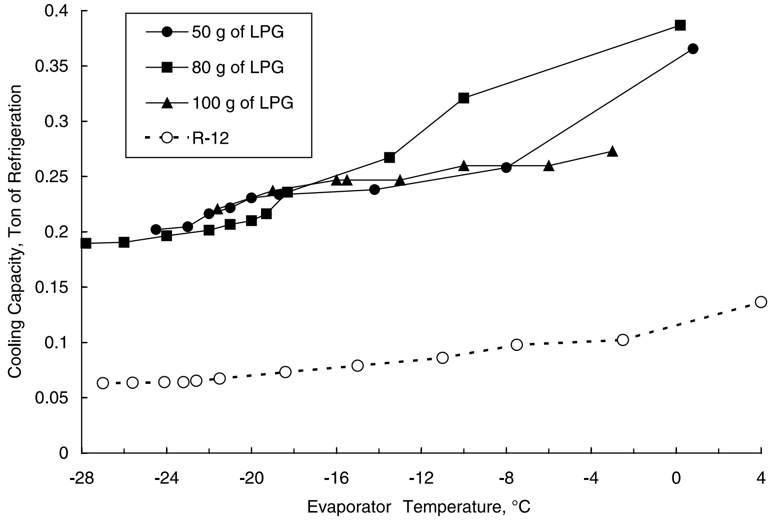


Fig. 8. Variation of cooling capacity (in tons of refrigeration) with evaporator temperature for R-12 and different charge masses of 50, 80 and 100 g of LPG.

rates are shown in Fig. 7. Again, in general, the mass flow rates are higher for R-12 than for LPG due to the higher enthalpies for LPG than those for R-12.

Finally, the cooling capacities in tons of refrigeration are plotted in Fig. 8 for the refrigerants studied. It is clear that LPG is a better refrigerant than R-12 in this manner. The best performance was when 80 g of LPG was used. For example, at an evaporator temperature of −8 °C, the cooling capacity was about 0.1 ton of refrigeration for R-12. On the other hand, it was roughly equal to 0.32 ton for 80 g mass charge of LPG, and it was about 0.25 ton for 50 and 100 g mass charges of LPG.

## 4. Conclusions

The performance of LPG as a possible alternative to R-12 was studied experimentally. The refrigerator worked satisfactory with LPG without making any modification to the machine. The COP values were comparable to those of R-12, and in some instances, they were even higher than those of R-12. No operating problems were encountered with the refrigerator compressor and no degradation of lubricating oil was detected. The cooling capacities were higher for LPG than those of R-12.

The use of LPG as an alternative to R-12 can contribute to reduction of greenhouse warming and elimination of ozone depletion potential caused by various refrigerants.

The only problem that can be associated with LPG is that it is a flammable substance and must be handled with caution. One must remember that most kitchens use LPG in gas cookers. It is considered as the main fuel for combustion in stoves in most countries. Therefore, people are already used to handling LPG with care in domestic usage.

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