ARTICLE

PERFORMANCE EVALUATION AND COMPARATIVE ANALYSIS OF A LOW COST NON CYCLIC INTEGRATED REFRIGERATION AND HEATING SYSTEM IN BOTSWANA

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ABSTRACT

Due to the energy costs associated with refrigeration and environmental problems associated with refrigerants, an alternative refrigeration system is required to replace the current refrigeration systems and refrigerants. In this study, a liquefied petroleum gas refrigeration system is designed and fabricated in order to solve the problems stated above. Liquefied petroleum gas is an environmentally friendly refrigerant as it has zero ozone depletion potential and has a low global warming potential of 1. The refrigeration system designed in this study does not use electric power for operation but rather, it uses liquefied petroleum gas which is contained in a cylinder at a pressure of 12.5 bar. Liquefied petroleum gas is passed through the evaporator where it gives the refrigeration effect, afterwards, it is passed to the stove where it is combusted to give heat energy. Therefore, the liquefied petroleum gas refrigeration system gives the dual purpose of refrigerating and heating simultaneously. The refrigeration system designed, has coefficient of performance of 3.24 which is higher than that of domestic refrigerators which use R134a as a refrigerant. This COP is achieved using a mass flow rate of $9.52x10^{-4}$kg/s. The refrigeration capacity of this refrigeration system is 240W and the minimum temperature at which this refrigeration system operates is -13°C.

KEY WORDS
Alternative refrigerant, propane, CFCs, coefficient of performance, evaporator

INTRODUCTION

Refrigeration is the process of extracting heat from a substance and maintaining the temperature of the substance below that of the surroundings. The process of extraction heat must be carried out continuously as heat from the surrounding will be transferred to the space being refrigerated. A refrigerator is one of the appliances which are running throughout the whole year without being stopped, which have resulted in making refrigerators one of the most energy consuming domestic appliance. Therefore it would be important to develop a low-cost refrigeration system which does not consume electric energy. As a result of the Montreal protocol signed by the United Nations (UN) in 1987 the chlorofluorocarbons (CFCs) refrigerants were banned for use as they are known to be damaging the ozone layer. Due to environmental problems associated with refrigerants, a lot of currently used refrigerants have come under criticism. The commonly used refrigerant, R-134a, although having zero ozone depletion potential, has a high global warming potential of 1300 [1]. As a consequence of these environmental problems, researches are being carried out around the world to come up with an environmentally friendly refrigerant. This study investigates the use of LPG in refrigeration systems as a refrigerant. LPG is an environmentally friendly refrigerant as it does not have ozone depletion potential [2]. The use of LPG as a refrigerant will be convenient for refrigeration in regions where there is no supply of electric energy, as this study proposes LPG refrigeration system which does not use electric power. The refrigeration system presented in this study serves the dual purpose of refrigeration and producing heat in a stove.

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PROBLEM STATEMENT

The consumption of energy, which is usually in the form of electrical energy, used by refrigeration systems is high. This makes the operating cost of refrigeration systems particularly high because refrigeration systems are appliances which are run throughout the whole year in industries as well as in homes[3]. This puts pressure on suppliers of electric energy to produce more electricity for supply, However, there has been shortage of electric power in Botswana and many countries around the world.

There is need for alternative refrigeration in the rural areas of Botswana where there is no or limited supply of electric energy [4]. Refrigeration systems are an essential appliance in homes and industries as they are used for preservation of food and other industrial processes. This is especially true in cattle post where there is need for refrigeration of meat and dairy products. It is therefore important to ensure that all homes and industries, including those in rural areas where there is no electricity, should have refrigeration systems. Halo carbon (HC) refrigerants have been the most used refrigerants up until now, due to their good thermodynamic properties required for refrigeration [5]. He went on to state that, the problem associated with these refrigerants is that they have high ozone depletion potential. The refrigeration industry is now in turmoil and will remain so for some years ahead as chemists try to find replacement refrigerants for those causing damage to the ozone layer.

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As a consequence of the problems outlined above, there is a need for a new refrigerant required to replace the currently used harmful refrigerants. Baskaran and Mathews (2012)[6] sated that R134a has been used to replace these halo-carbon refrigerants because it has zero ozone depletion potential, but it has been observed that R134a has a high global warming potential of 1300. Therefore, there is a need for an environmentally friendly refrigerant which does not have ozone depletion potential and has no or low global warming potential too.

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REFRIGERATION SYSTEMS

To achieve refrigeration in home and industries several refrigeration systems have been developed, the cyclic refrigeration system and the non-cyclic refrigeration system being the most common. These refrigeration systems are described below.

Cyclic Refrigeration

The cyclic refrigeration process is the most used refrigeration process in both homes and industries. The cyclic process allows heat to be extracted from the evaporator at low temperature and low pressure. This heat is then transferred to the surroundings at higher temperature and higher pressure, in the condenser. The block diagram in [Fig. 1] shows the cyclic refrigeration processes explained by Nag [5].

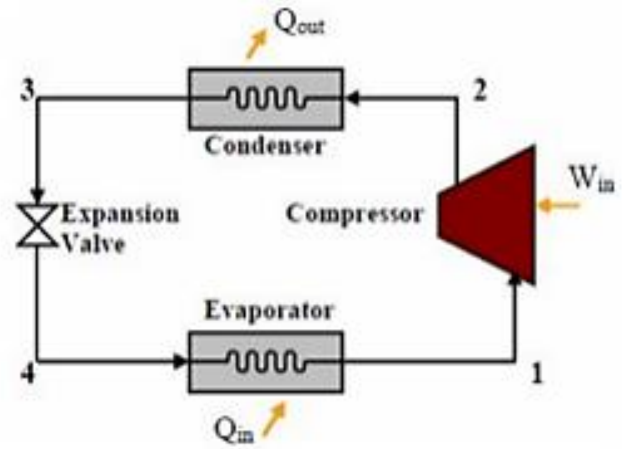

Fig. 1: Vapour compression refrigeration system cycle. [5]

Refrigeration compressors often utilizes electric motors. The compressor has to be running continuously as the refrigeration system operate on continuous basis. As refrigeration systems are appliances which are kept running for the whole year non-stop, they end up consuming a lot of electric energy making refrigeration an expensive process.

Non-cyclic refrigeration system

The non-cyclic refrigeration system is one of the earliest refrigeration systems used. In this refrigeration, a cold substance known as a refrigerant is used to absorb heat from an evaporator and the refrigerant is discarded after absorbing heat. Melting of ice or snow was one of the earliest non-cyclic refrigeration methods and is still employed. Ice melts at 0˚C. When it is placed in an evaporator, it absorbs the heat and then melts. After melting, it is discarded and replaced with new ice. This type of refrigeration system is of low cost when there is free abundant ice, like in the arctic region of the earth where there is abundant ice. Nag (2009) [5] further went on to state that another medium of non-cyclic refrigeration is solid carbon dioxide. "At atmospheric pressure, carbon dioxide cannot exist in a liquid state, and consequently, when solid carbon dioxide is exposed to the atmosphere, it sublimates, i.e. it goes directly from solid to vapour, by absorbing the latent heat of sublimation (620 kJ/kg at 1 atm, -78.5 ˚C) from the surroundings. The carbon dioxide is then discarded after absorbing heat. The low temperature of -78.5 ˚C at which carbon dioxide sublimates makes it suitable for low temperature refrigeration.

The LPG refrigeration system presented in this study uses the Non-cyclic Refrigeration system type. This is effective because LPG is abundant and is sold at low prices. The LPG is combusted after being used for refrigeration and the heat can be used for various process such as cooking or running and an Internal Combustion Engine. This makes LPG an efficient refrigerant in the Non-cyclic Refrigeration system.

Liquefied Petroleum Gas (LPG) as a refrigerant

The environmental effects of refrigerants have been considered recently as most refrigerants are known to be contributing heavily to global warming. "The inert nature of many chlorofluorocarbons (CFC) and hydro-chlorofluorocarbons (HCFC), particularly CFC-11 and CFC-12, made them preferred choices among refrigerants for many years because of their good thermodynamic properties, non-flammability and non-toxicity. However, their stability in the atmosphere and their corresponding global warming potential and ozone depletion potential raised concerns about their usage. This led to their replacement with hydro fluorocarbons (HFCs), especially R-134a, which have zero ozone depleting, and have lesser global warming potentials [7]. However R-134a still has a high global warming potential of 1300 compared to that of carbon-dioxide which is 1 [8]. Liquefied petroleum gas is a byproduct in petroleum refineries and usually

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comprises of 56.4% propane, 24.4% butane and 17.2% isobutene, but the ratios of the mixture may differ slightly from supplier to supplier [9].

LPG is cheaper and it is environmentally friendly having no ozone depletion potential (ODP). It is widely used for cooking purposes. LPG is sold in cylinders of 3.9 kg, 9 kg, 14 kg, 19kg and 48 kg. These cylinders are fitted with valves to control the flow of LPG. Ghariya and Gajjar (2013)[10]stated that, LPG has the following properties:

- It is- Colorless, Odorless (LPG is odorized so that leaks can be detected)
- Heavier than air (this makes it harm if it leaks, as it will displace surround air (oxygen))
- Non-toxic and explosive (which is a disadvantage of using LPG)

Ghariya and Patel (2015)[11]has compared LPG with CFC-12. They performed an experiment to determine the performance of the two refrigerants under different mass charges. Mass charges of 50g, 80g and 100g of the two refrigerants were used. LPG had the highest coefficient of performance (COP) in all the mass charges and was able to maintain the temperature of the evaporator below -5°C. The temperature of the condenser was kept at a temperature of 47°C. They also found that at a mass charge of 80g, the LPG refrigeration system had the highest COP.

This study presents a refrigeration system which uses LPG as a refrigerant and LPG is combusted before being released to the atmosphere. The combustion process of LPG gives carbon-dioxide as the byproduct. This makes LPG to have a global a warming potential of 1, equal to that of carbon-dioxide. This is a low global warming potential compared to that of R-134a which is 1300. LPG has zero ozone depletion potential, which is one of the desired qualities in a refrigerant.

OBJECTIVES AND SCOPE OF THE STUDY

The main objective of this study is to design and fabricate a low-cost liquefied petroleum gas (LPG) refrigeration system and to study the thermodynamic properties of the system. Thus, developing efficient and cost effective refrigeration systems for rural area in Botswana where there is no electricity [12]. Other motivations are-to identify advantages and disadvantages of LPG refrigeration system over other refrigeration systems and to compare the cost and performance of LPG refrigeration systems and other refrigeration systems. This study is useful for both industrial and domestic purposes as it attempts to lower the cost of refrigeration for both domestic and industrial refrigeration systems. This study is especially useful in industries which require refrigeration and heating simultaneously as the LPG refrigeration system designed in this study offers both refrigeration and heating at the same time. Examples of such industries are hotels and restaurants where the LPG used for refrigeration could also be used for cooking and heating water. This refrigeration system could also be useful for refrigeration of perishable goods such as meat and dairy products in transportation trucks. Cost will be highly reduced if they also use LPG as a fuel for locomotion.

LITERATURE REVIEW

A number of researches have been carried out in an attempt to find a refrigerant which has desirable thermodynamic properties and at the same time, being environmentally friendly. Most refrigeration systems use R134a as a refrigerant Propane refrigeration systems have been considered as an alternative refrigeration system to replace current refrigeration systems by Niyaj and Sapali (2017)[13].They studied the use of propane in domestic refrigerators. Their study is important in developing LPG refrigeration system as propane is one of the components in LPG. The major criteria for their investigation were energy consumption, safety and environmental effect of propane refrigeration system. The results revealed that propane could be used to replace CFC-12, which is one of the commonly used refrigerants. This is because propane consumed less energy than CFC-12 and has zero ozone depletion potential while CFC-12 has ozone depletion potential. Thermodynamic properties of LPG have been investigated by Akash and Said (2009)[14].They used LPG in a vapor compression refrigeration system and compared it with CFC-12. The results obtained showed that LPG give lower temperatures for equal input of energy for both gases. They also found an alternative refrigerant which could replace CFC-12. These findings are of profound importance as CFC-12 which has high ozone depletion potential could be replaced by refrigerants which have no ozone depletion potential. In an attempt to also find an alternative refrigerant to replace CFC-12, Sattar et al (2007)[15]further conducted an experimental study on the use of isobutene in a domestic refrigerator. Isobutene is one of the constituents of LPG. The results showed that isobutene has a higher coefficient of performance than CFC-12 and HCFC-22 in refrigeration systems. They further stated that, unlike CFC-12 and HCFf-22, isobutene has no ozone depletion potential and also have lower global warming potential (GWP) than the two refrigerants. Sattar et al (2008)[16]investigated experimentally the refrigeration capacity, compressor power and coefficient of performance (COP) to determine the performance of CFC-12 as compared to butane. Butane is present in LPG. The results indicated that butane outperformed CFC-12 in all the criteria listed above. As a consequence of this, LPG should be able to compete successfully against R134a in order to be considered a viable refrigerant. Unlike CFC-12, R134a has zero ozone depletion potential. However R134a has a global warming potential of 1300, which is why an alternative refrigerant is needed to replace it. Mohanraj et al (2009)[17]investigated if LPG can be used to replace R134a in a domestic refrigerator with a total volume of 0.283 m^3.

They performed an experiment to compare the two refrigerants for performance in capillary tubes of varied lengths and varied mass charges. The coefficient of performance (COP) of LPG refrigerator was 7.6% higher (average for different capillary tube length and different charges) than that of R134a. This result shows that LPG is more energy efficient than R134a. Being able to replace R134a with LPG will be a great achievement as R134a has a higher global warming potential than LPG. Austin et al (2012)[18]have also performed an experiment in an attempt to find a refrigerant which could successfully replace R134a as a refrigerant. They compared the performance of R134a to that of a mixture of butane and propane. Their experiment is important in this study as butane and propane are both present in LPG. They found that the power consumption of butane-propane mixture refrigeration system was lower than that of R134a by 4.3%. Also, the COP of butane-propane mixture refrigeration system was higher than that of R134a by 7.6%. Just like Mohanraj et al (2009)**,** they were able to identify a refrigerant which competed successfully against R134a and also have lower global warming potential.

A capillary tube is one of the expansion devices used in refrigeration systems. Javidmand and Zareh (2014)[19]performed an experiment to determine the performance of the capillary tube in a proposition to use LPG as a refrigerant. In their experiment they concluded that, there was an increase in mass flow rate by 106%, when the capillary inner diameter was increased from 1.12mm to 1.52mm. This shows that sizing the capillary tube well is an important aspect in designing the LPG refrigeration system as slight changes in the dimensions of the capillary tube gives a considerably high change in the mass flow rate of the refrigerant. Their study also showed that, when the coil diameter of capillary tube was decreased from 190mm to 70mm, the mass flow rate was decreased by 13%, 7% and 9% for 1.12mm, 1.4mm and 1.52mm inner diameter of capillary tube respectively. These results show that the size of the coil diameter influences the mass flow rate of the refrigerant. However, these results show that the changes are minimal.

Therefore, if the coil can be designed to have a large diameter, the pressure losses and reduction in mass flow rate can be neglected in order to simplify calculation without compromising much on accuracy. Mass flow rate increases with increase in capillary tube inner diameter and coil diameter whereas mass flow rate decreases with increase in length of the capillary tube[20]. Therefore, determining the inner diameter and length of the capillary tube are critical in the design of the capillary tube. The different research, studies and experiments discussed above shows that, refrigerants which have desirable thermodynamic properties and are environmentally friendly could be developed in order to replace the currently used refrigerants. A major problem about the currently used refrigerants is that they have high ozone depletion potential as well as high global warming potential. The above studies have shown that LPG competes successfully against the currently used refrigerant.

MATERIALS AND METHODS

The thermodynamic characteristics of various refrigerants were compared to those of LPG to determine the best refrigerant. However, in this case, important characteristics were considered as no one refrigerant is the best in all characteristics. The performance evaluations of the refrigeration system were performed. The pressure enthalpy chart of LPG was used to determine the performance of the refrigeration system. The refrigeration system performances evaluated in this study are the refrigeration effect of the refrigeration system, the coefficient of performance of the refrigeration system and the refrigeration capacity. The refrigerating effect is evaluated by determining the difference between the enthalpy of LPG at the entrance of the Evaporator and the enthalpy at the exit of the evaporator. The work input was evaluated by determining the energy required to fill the LPG cylinder used in the refrigeration system. An experiment was set-up to determine temperature drop in the evaporator over time. This was done to determine the least temperature reached in the evaporator and how long it was taking for the evaporator to cool.

Design of LPG refrigeration system

LPG is stored in the cylinder at pressure of 12.5 bar. The pressure regulator ensures that LPG is released at a reduced and constant pressure. From the LPG cylinder, LPG is passed through the pressure regulator into the pressure pipe. The pressure pipe is able to withstand a maximum pressure of 100 MPa. From the pressure pipe, LPG is passed through the capillary tube where its pressure is reduced due to the small internal diameter of the capillary tube. The decrease in pressure of LPG results in the decrease in temperature of LPG. From the capillary tube, the low pressure and low temperature LPG is supplied to the evaporator. The evaporator box is constructed using hard board. Hard board is selected for use because of its low cost and its ease to shape and manipulate. Hard board will also contribute to insulation of the evaporator as it has a low thermal conductivity of 0.17 W/m-K. Hard board is shown in brown color in [Fig. 2]. The evaporator box is insulated using polystyrene foam. Polystyrene foam is selected because it has a low thermal conductivity of 0.3 W/m-K as stated by the American Society for Testing and Materials [21]. The thickness of polystyrene foam used is 20mm. Polystyrene foam is shown in white color in [Fig. 2]. In the evaporator, LPG absorbs heat and maintains the temperature of the evaporator below the surrounding temperature. The LPG refrigeration system is set up as shown by the diagram in [Fig. 2] below.

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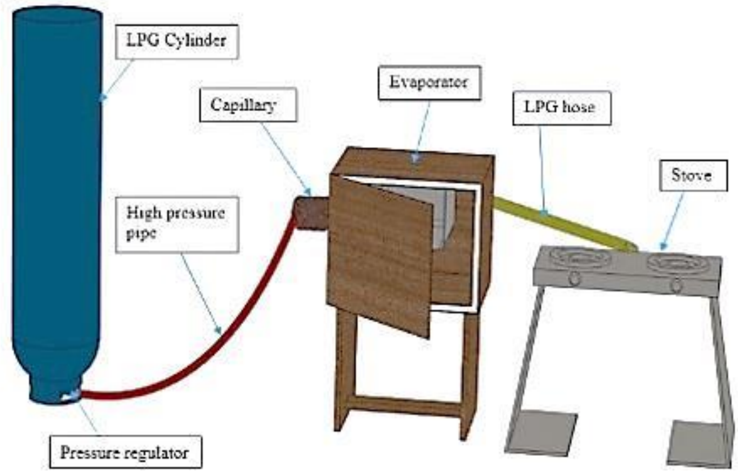

Fig. 2: Setup of the refrigeration system.

From the evaporator, LPG is passed to the gas burner (stove) where it is combusted to produce heat energy. The heat produce can be used for processes such as cooking. Sugumar et al (2015)[22] stated that refrigerant pressure loss increases as the diameter of the capillary tube decreases. This ensures that a shorter capillary can be used and still give the require pressure drop since pressure drop is directly proportional to the length of the capillary tube and indirectly proportional to the internal diameter of the capillary tube as considered by [23]the Darcy-Welsbach equation below from.

$$\Delta P = f\left(\frac{L}{D}\right)\left(\frac{\rho V^2}{2}\right) \quad (1)$$

Where: $\Delta P$is the pressure loss, f is the friction factor, L is the pipe length. Bhatt et al (2011)[24]determined that the maximum mass flow rate required for safe combustion of LPG is 9.52x10^{-4} kg/s. The allowable internal pressure for copper capillary tube is calculated as considered by Bhatt et al (2011)[24] shown in using equation (2)-

$$P = \frac{2S(t-C)}{D-0.8(t-C)} \quad (2)$$

Where: S (maximum allowable stress in tension) = 71.016 MPa, t (wall thickness) = 1.5mm, D (outside diameter) = 3.8mm C (constant for copper tube) = 0 (C=0 as cooper has high resistance to corrosion), the allowable pressure of the copper capillary tube is calculated to be 79.6 MPa. Therefore the maximum pressure used in the capillary tube should not exceed 79.6MPa.In the capillary tube, the enthalpy decreases so that the first law of thermodynamics is satisfied, the sum of enthalpy and the kinetic energy must remain constant, as shown by the steady state equation considered by Ram Gopal [25];

$$h_1 + \left(\frac{V_1^2}{2}\right) = h_2 + \left(\frac{V_2^2}{2}\right) \quad (3)$$

Due to the small internal diameter of the capillary tube, the velocity of the fluid increases as it enters the capillary tube. Hence, if the kinetic energy increases the enthalpy must decrease. A mass flow rate which is safe for burning at the stove should be selected. The pressure selected for the LPG refrigerant at the entrance of the capillary tube is 5.7 bars, as it is below the pressure in the LPG cylinder and therefore can be maintained for a long time. The pressure in the LPG cylinder is 12.7 bars[25]. A pressure of 5.7 bars is also safe to be used with the capillary tube as the allowable pressure of the capillary tube is 79.6 MPa as calculated. h_f = enthalpy of saturated liquid = 215.9 kJ/kg. The propane properties table for calculation is used because propane is the most abundant gas in LPG. Furthermore, the properties of propane do not deviate much from the properties of the other two gases present in LPG which are butane and isobutene.

Conservation of mass equation [23] $\dot{m} = \frac{A \times V_1}{v_1} = \frac{A \times V_2}{v_2}$ (5)

Conservation of Energy Equation[23] $1000h_1 + \frac{V_1^2}{2} = 1000h_2 + \frac{V_2^2}{2}$ (6)

The conservation of momentum equation[23] $\left[(p_1 - p_2) - f\left(\frac{\Delta L}{D}\right)\left(\frac{V_m^2}{2v}\right)\right]A = \dot{m}(V_1 - V_2)$ (7)

Mean velocity $V_m = \frac{V_1 + V_2}{2}$ (8)

As the refrigerant flows through the capillary tube, its pressure and saturation temperature progressively drop and the dryness fraction, x, continuously increases[1]. At any point in the capillary tube, the refrigerant properties can be calculated as shown by equations (9), (10) and (11) below.

$$h = h_f(1-x) + xh_g \quad (9)$$

$$v = v_f(1-x) + xv_g \quad (10)$$

$$\mu = \mu_f(1-x) + x\mu \quad (11)$$

The friction factor is determined using the Blasius correlations considered by K.T. trinh[26]. In Blasius correlation, equation (12) is used to determine the friction factor.

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$$f = \frac{0.33}{Re^{0.25}} = \frac{0.33}{\left(\frac{VD}{\mu\, v}\right)^{0.25}} \qquad (12)$$

The mean friction factor applied to the incremental length is calculated as shown in equation (13) below;

$$f_m = \frac{f_1+f_2}{2} \qquad (13)$$

The length of the capillary tube is determined using the analytical method for capillary tube design. The incremental lengths are evaluated for a change in temperature of 1°C. Combination of equation (5) and (6) gives equation (14) below:

$$1000h_2 + \left(\frac{v_2^2}{2}\right)\left(\frac{\dot{m}}{A}\right)^2 = 1000h_1 + \frac{V_1^2}{2} \qquad (14)$$

Substituting equation (9) and (10) into (14) gives equation (15).

$$1000h_{f2} + 1000(h_{g2} - h_{f2})x + \left[\{v_{f2} + (v_{g2} - v_{f2})x\}^2 \left(\frac{\dot{m}}{A}\right)^2\right] = 1000\, h_1 + \frac{V_1^2}{2} \qquad (15)$$

The incremental length, ΔL, is calculated below considered by Bhatt et al [24]:

$$\Delta L = \frac{(P_2-P_1) - G(V_2-V_1)}{\left(\frac{G}{2D}\right)(f_m)(V_m)} \qquad (16)$$

Where: The mass velocity, $G = \frac{4\dot{m}}{\pi D^2}$ (17)

The iterations for the incremental length, ΔL, were performed up to a pressure of 2 bars. This pressure gives a desirable temperature of -25°C (from LPG property tables) and a dryness fraction, x, of 0.38. The length of the capillary tube at this pressure is 2.93m. Properties of LPG at 2.0 bars are:

- h_f = enthalpy of saturated liquid = 139.5 kJ/kg
- h_g = enthalpy of saturated vapour = 546.2 kJ/kg
- v_f = specific volume of saturated liquid = 0.00177 m³/kg
- v_g= specific volume of saturated vapour = 0.220 m³/kg

Heat transfer coefficient of the evaporator as considered by [27], $U = \frac{1}{\frac{L_P}{K_P}+\frac{L_h}{K_h}}$ = 1.425 W/m²K

Total Thermal resistance, $R_t = \frac{1}{AU} = \frac{1}{1.0442 \times 1.425} = 0.672$ W/K

The refrigerating effect is evaluated by determining the difference between the enthalpy of LPG at the entrance of the Evaporator and the enthalpy at the exit of the evaporator. The properties of LPG in the evaporator are evaluated at a pressure of 2.0 bars. The properties of LPG at pressure of 2.0 bars evaluated are as shown below:

- h_f = 139.5 kJ/kg, h_g = 546.2 kJ/kg, h_{fg} = 406.7 kJ/kg, Saturation Temperature, T_2 = -25 ˚C

The enthalpy of LPG at the entrance of the evaporator, $h_2 = h_f + xh_{fg}$= 294.0 kJ/kg. It is assumed that the refrigerant leaves the evaporator as a dry vapour as it happens in an ideal refrigeration cycle. In this case, properties of LPG at the exit of the evaporator are equal to those of dry vapour LPG at a pressure of 2.0 bars. From the diagram, $h_3 = h_g$ = 546.2 kJ/kg. Where h_3 is the enthalpy of LPG at the exit of the evaporator. Therefore, the refrigeration effect is, $h_3 - h_2$ = 546.2 - 294.0 = 252.2 KJ/Kg

Where: h_2 is the enthalpy at the entrance of the evaporator and h_3 is enthalpy at the exit of the evaporator as shown in [Fig. 3] below.

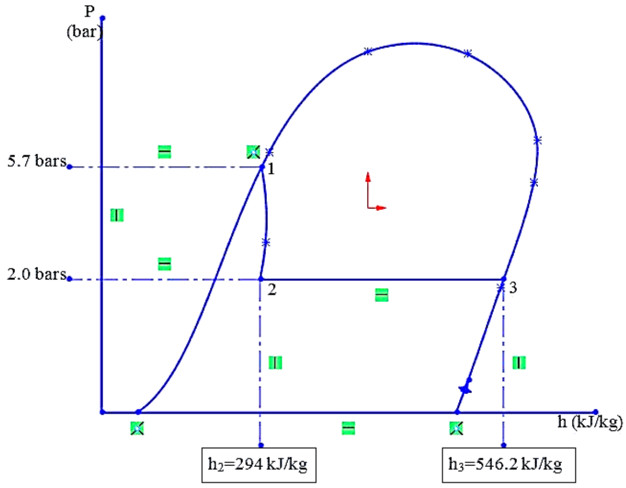

Fig. 3: The p-h diagram of refrigeration system.

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Refrigeration capacity = $\dot{m}$ (h_3 – h_2)=9.52x10⁻⁴(546.2 - 294.0) = 240 W. In order to determine the coefficient of performance (COP), the work input of the refrigeration system should be determined. The work input has to be determined when evaluating the COP. Sathayan*et al* (2018) [28]calculated the work required to fill 1kg of LPG in a cylinder to be 77.832 kJ.

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Therefore, the coefficient of performance (COP) is calculated as shown below.

$$COP = \frac{Refrigeration\,effect}{Work\ Input} = \frac{h_3 - h_2}{W} = \frac{252.2}{77.832} = 3.24$$

RESULTS AND DISCUSSION

An effective refrigeration system should able to reach low temperatures in a short period of time. An experiment was setup in order to determine how effective the LPG refrigeration system designed is. In this experiment, a thermocouple thermometer was used to measure the temperature in the evaporator at time intervals of 5 minutes. The experiment was carried out over a time of 100 minutes. In this experiment, the temperature was taken in two sections of the evaporator which are the freezing section and the non-freezing section, as shown in [Fig. 4]. The freezing section is inside the tube and plate heat exchanger while the non-freezing section is outside the heat exchanger.

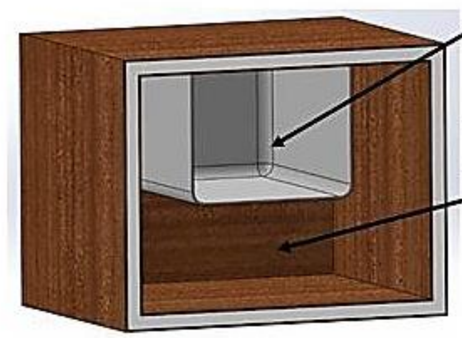

Fig. 4: Evaporator (shown without the door).

[Table 1] and [Table 2] below shows the temperature of the freezing section and non-freezing section of the evaporator over a time of 100 minutes at 5 minutes time intervals respectively. A graphical representation of the temperature variation is shown in [Fig. 5] below.

Table 1: Temperature in the freezing Section of the evaporator with time

S.N.	Time(min)	Temp(°C)	S.N.	Time(min)	Temp(°C)	S.N.	Time(min)	Temp(°C)
1	0	27.2	8	35	-3	15	70	-11
2	5	14.1	9	40	-5	16	75	-11
3	10	3	10	45	-5	17	80	-11
4	15	1	11	50	-5	18	85	-12
5	20	-1	12	55	-7	19	90	-12
6	25	-1	13	60	-9	20	95	-13
7	30	-2	14	65	-10	21	100	-13

Table 2: Temperature in the non-freezing section of the evaporator with time

S.N.	Time(min)	Temp(°C)	S.N.	Time(min)	Temp(°C)	S.N.	Time(min)	Temp(°C)
1	0	27.2	8	35	12.5	15	70	5.3
2	5	24.3	9	40	11.2	16	75	5
3	10	19.4	10	45	10.1	17	80	4.4
4	15	17.1	11	50	10.1	18	85	3.7
5	20	15.7	12	55	7.6	19	90	3.3
6	25	14.9	13	60	6.7	20	95	3
7	30	13.9	14	65	5.8	21	100	3

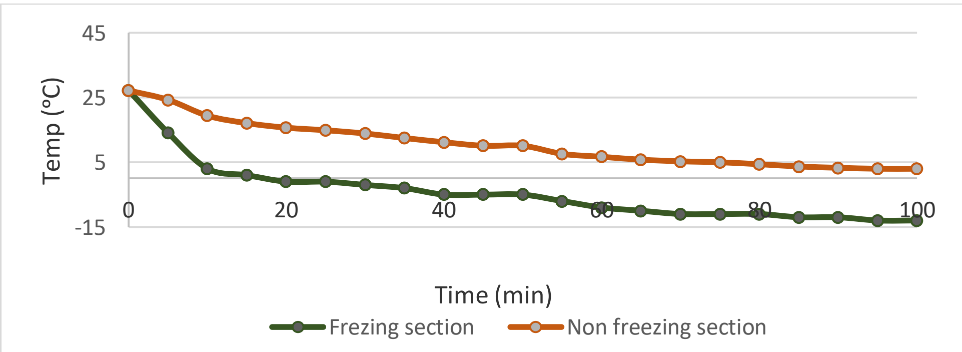

Fig. 5: the temperature distribution in the evaporator over time.

The results of the experiment show that LPG refrigeration system designed in this study is an effective refrigeration system as low temperatures were reached in the evaporator and maintained well. The graph in [Fig. 5] above shows the temperatures to be decreasing in a logarithmic fashion. This due to the fact that the temperature difference between the refrigerant and the evaporator decreases over time.

According to Akintunde (2013) [29], Domestic refrigerators which utilize R134a as a refrigerant have a coefficient of performance (COP) of 2.03 and give an evaporator temperature of -5°C. This shows that the performance of LPG refrigeration system is impressive as it gave a minimum temperature of -13°C having a COP of 3.24. These are important results considering that LPG is more environmentally friendly than R134a as it has a lower global warming potential than R134a. He also performed an experiment to improve the performance of R134a by making a 50:50 blend of R134a and R600a. This new refrigerant had a coefficient of performance (COP) of 2.30 and still gave an evaporator temperature of -5°C.

LPG as refrigerant, still outperforms this refrigerant in both the evaporator temperature and coefficient of performance. These results show that LPG can be used to substitute R134a as a refrigerant as it is more environmentally friendly and performs better than R134a in refrigeration systems.

CONCLUSION AND RECOMMENDATIONS

The study has given satisfactory results and shown that a low-cost refrigeration system can be fabricated using LPG as the total cost of components required to fabricate the refrigerator is P850.00, excluding the experimental setup costs. This refrigeration system also has low running costs as it has no moving parts and therefore requires less maintenance as compared to refrigeration systems which use compressors. The LPG refrigeration system designed in this study gives a coefficient of performance (COP) of 3.24 which is higher than that of domestic refrigeration systems using R134a as a refrigerant, as they give COP of 2.03. This study has also shown that LPG can successfully replace R134a in refrigeration systems as it has a higher coefficient of performance and gives lower temperatures. This study has shown that an efficient refrigeration system which is environmentally friendly and has low cost can be achieved using LPG as a refrigerant. The authors would recommend the LPG refrigeration system presented in this study should be studied further with the aim of popularizing LPG refrigeration system so that it can be used more, in homes and industries. This will help in reducing the increase global warming as LPG is an environmentally friendly refrigerant. This will also help in the electric energy crisis which persists across the world as the refrigeration system presented in this report does not require the use of electric energy. The authors also recommend that in a situation where heating is not required continuously, a compressor and a condenser should be designed and added in the refrigeration system. This will ensure that when heating is not required at a certain time, LPG will be re-circulated in the system, and only be released to the gas burner when heating is required.

CONFLICT OF INTEREST

None

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FINANCIAL DISCLOSURE

None

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