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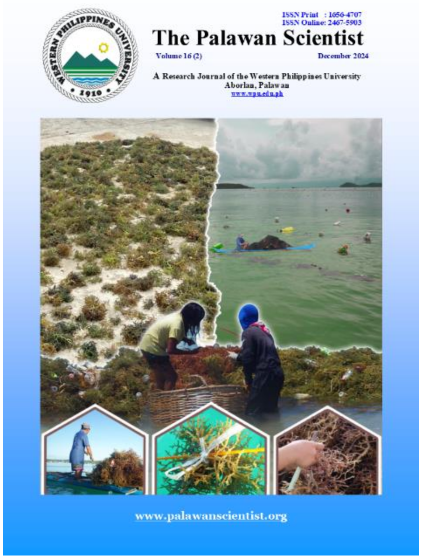



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# An experimental study of liquefied petroleum gas refrigeration system

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## ABSTRACT

Despite prevalent electrical shortages in various regions, refrigeration remains imperative for diverse applications. This study explored the viability of recovering underutilized energy in the context of sustained demand for electricity in both urban and rural areas of the Philippines. Liquefied petroleum gas (LPG), commonly used in the Philippines for heating and cooking, has properties that can be used as refrigerant, and stands out for its zero-ozone depletion potential (ODP) and low global warming potential (GWP). The study focused on the design and development of a refrigerator using LPG as the refrigerant and compressor. Various factors, such as pressure drop, temperature change, enthalpy change, and heat loss, were analyzed throughout the experimental process, encompassing design formulation, analysis, simulation, fabrication, experimentation, and performance evaluation. Raw data from three 3-hour tests were collected and analyzed. Results indicated a time-dependent decrease in pressure, a notable water temperature change, and an increase in the coefficient of performance (COP) value over time. The maximum COP achieved was 1.78, coupled with a water temperature of -3.50 ˚C. Despite the obtained COP being lower than that of a typical domestic refrigerator, the observed refrigeration effect was evident. The findings underscore LPG's potential as a viable and environmentally responsible alternative in refrigeration systems.

**Keywords:** alternative refrigeration, COP, evaporator, refrigerant, refrigerating effect

## INTRODUCTION

Refrigerants are the working medium used in refrigerating systems which evaporates by taking the heat from the space that is to be cooled, thus producing the cooling effect (Emani et al. 2017). Domestic refrigerators commonly use refrigerants that contain chlorofluorocarbon (CFC) and hydrofluorocarbon (HFC) which contribute to very high ozone layer depletion and global warming (Hashim et al. 2020). CFCs and HFCs contribute to ozone depletion by releasing free chlorine radicals into the atmosphere and the continuous reaction of chlorine and oxygen results in the destruction of ozone molecules (Raiyan and Rehman 2017). National Aeronautics and Space Administration (NASA) (2015) explained that the effects of these refrigerants are a serious threat to our natural habitat, as they have contributed a negative impact on the variety of life on earth (biodiversity). That being explained, many researchers studied the use of hydrocarbon refrigerants as substitutes for ozone-depleting fluids. Fernando (2022) defined hydrocarbon as an organic chemical compound that is composed exclusively of hydrogen and carbon atoms. He added that hydrocarbons are naturally occurring and form the basis of crude oil, natural gas, coal, and other important energy sources and that they are highly combustible and are highly effective as a source of fuel. Hydrocarbons have excellent environmental characteristics, good miscibility with mineral oils, and acceptable compatibility with common materials employed in refrigeration equipment (Liu et al. 1995). Air Conditioning and Refrigeration Industry Board (ACRIB) (2001) reported that hydrocarbon refrigerants are fully compatible with most of the lubricants, elastomers, plastic refrigeration materials used as ‘O’ rings, valve seats, seals and gaskets used in refrigeration systems and that hydrocarbon refrigerants use the same evaporator and condenser sizes as fluorocarbon refrigerants operating at the same pressures and are compatible with most compressor types. The study of Iyer et al. (2006) found that no problems were encountered with the compressor, and no degradation of lubrication oil was detected after 5000 h of operation using different hydrocarbon mixtures as alternative refrigerants.

Liquefied petroleum gas (LPG) is comprised of hydrocarbons and normally contains propane ($C3H8$) and butane ($C4H4$) as major constituents along with small amounts of some other hydrocarbons (Rehman et al. 2023). LPG is available in a variety of mixes, ranging from pure propane to various ratios of butane and propane to pure butane (Raslavicius et al. 2014). Rayos (2017) discussed that in the Philippines, LPG is a combination of 40% propane and 60% butane. According to Satwik et al (2016), LPG is colorless, non-toxic, heavier than air, half the weight of water, and odorless, and it is odorized only for detection of leaks. Extensive research and guidelines were published on the compatibility and flammability of hydrocarbon as refrigerants (Mohanraj et al. 2011). In the study of Manohar et al. (2020), the LPG refrigeration system was compared with a domestic refrigerator. They concluded in their study that LPG refrigeration system has a very low initial and operating cost and does not require any external energy source to operate, unlike domestic refrigerators. Additionally, the system contains no moving components, which reduces maintenance costs even further.

Srinivas et al. (2014) investigated the use of LPG as an alternative to R134a as a refrigerant in a household refrigerator. It has been discovered in their study that LPG has a greater cooling impact than R134a refrigerant which are used in domestic refrigerators. They added that LPG has all of the necessary qualities to qualify as a refrigerant. Moreover, in the study conducted by Oyelami and Bolaji (2016), an experimental refrigerator was developed as a test rig and the findings revealed that the system operated better with LPG than with R134a. As a result, the LPG refrigerant can be successfully implemented. Furthermore, according to the research study by Manohar et al. (2020), the coefficient of performance (COP) of an LPG refrigerator is higher than that of a domestic refrigerator, and a domestic refrigerator has more moving components and is, therefore, less ecologically friendly. The maintenance requirements for a household refrigerator are higher, and the operation is noisier as well. With all the gathered advantages of LPG as a refrigerant, somehow LPG as a refrigerant has disadvantages, and one of them is flammability. Hydrocarbons are highly flammable substances and must be handled with caution (El-Morsi 2015). Although LPG is flammable, according to the Australian Institute of Refrigeration, Air Conditioning and Heating (AIRAH) (2013), small factory-sealed appliances can have a flammable refrigerant charge of up to 150 g in each separate refrigerant circuit and can be located anywhere without restriction. Qurashi and Wankhede (2013) reported that refrigerators designed to work with R-134a had a charge that varied from 105 to 150 g. However, the charge can be reduced to 70 to 90 g when hydrocarbon refrigerants are used. Also, ACRIB (2001) states that sealed systems containing a hydrocarbon charge of less than 150 g can be situated in any location, regardless of room volume.

In the Philippines, LPG is primarily used for cooking. Convenience is one of the reasons why most of the households use LPG in their homes. Not only is it used for households but also for businesses. Street food vendors use LPG because it is locally available and can easily be transported from one place to another. Thus, the researchers came up with the idea of utilizing the high consumption of LPG through the concept of refrigeration, thereby eradicating the use of R134a, an HFC refrigerant that is still widely used in the Philippines that has high Global Warming Potential. This study was conducted to develop a refrigeration system utilizing LPG as both the compressor and refrigerant. The objective is to investigate the feasibility and efficiency of this unconventional approach, addressing design considerations, material compatibility, and overall system performance. Specifically, the study aimed to design and simulate an LPG refrigeration system, utilizing SOLIDWORKS software to determine design parameters, identify optimal materials, and conduct Computational fluid dynamics (CFD) simulations of the refrigeration chamber; to fabricate and experiment with an LPG refrigeration system by constructing the system according to the designed specifications; and to determine the fabrication parameters for the developed system design and, subsequently, conduct experimentation to collect raw data, including gauge pressure measurements at the inlet and outlet in pounds per square inch (psi), initial and final water temperatures in degrees Celsius, mass consumption in kilograms, and mass flow rate in kilograms per second; the performance analysis of the LPG refrigeration system involves calculating the system's power output (W), heat loss from the water (Q), and coefficient of performance (COP).

## METHODS

### Working Principle

According to Heisler (2002), the refrigerant's state upon entering the evaporator is liquid, however, once it exits, it has absorbed the heat from the load thus evaporating it into vapor. He added that this process allows the heat from inside the cold compartment to be absorbed and transferred preferably away from the system. As a replacement for freon, the system uses LPG as a refrigerant. The LPG tank contains the refrigerant (LPG), which is the main source of the process. According to Elgas (2019), LPG in a cylinder exists both as a liquid and a vapor. The upper portion of the cylinder contains pressurized LPG vapor, whereas the lower portion contains LPG liquid. LPG cylinders are generally filled to 80% capacity which means 80% liquid and 20% vapor (ES Systems 2021). In this case of the LPG as the refrigerant, it must be in liquid form and at a lower pressure to produce refrigeration in the system. Thus, in this study, the LPG tank was turned upside down so that only the liquid would pass through the hose which was connected to the evaporator. The outlet pressure of a regular LPG cylinder without a regulator is approximately 70-50 psi. The LPG pressure must be dropped to 15 psi to produce a refrigerating effect (Sathayan et al. 2018). In order to attain the required pressure drop, a throttling device was used in this study. It was installed at the inlet part of the evaporator which was connected to the inlet hose. Based on the study of Adhav et al. (2017), the actual cooling effect is provided by circulating the LPG through the evaporator coil. In this study, the evaporator coil was attached inside the evaporator compartment. The discharged LPG in the outlet of the evaporator coil which was already a vapor was then directed to a burner through a hose. The burner stove must constantly be used to run the LPG from the cylinder and get a cooling effect in the cooler setup. To maintain the cooling temperature of the refrigerator when in times the burner is not used in accordance with the absence of the LPG input, the evaporator was filled with water.

### Material Selection

The approaches that were employed in the study of Manohar et al. (2020) to construct the LPG refrigeration system was used in this study. The refrigeration system were included in the LPG tank, ball valve, evaporator, and burner. The materials chosen were based on prior study and their availability in Cagayan de Oro. A commercially available 2-L capacity insulated plastic water jug was selected as an evaporator compartment due to its availability. It was also insulated with polyurethane which has good insulation properties according to Demharter (1998). Holes were drilled 5 and 20.32 cm below the upper mouth of the jug for the inlet and outlet of the evaporator coil which in this case is a copper tubing. This copper tube was coiled inside the wall of the cylindrical evaporator compartment. It was coiled in a cylindrical shape for lesser friction loss and easy coiling of copper tube as shown in Figure 1A. Copper tube was used in this study as it has good heat transfer capacity, good resistance to corrosion, and is cheaper in cost (Hashim et al. 2020). A copper tube was coiled inside the water jug connected to a fitting for the throttling valve and hoses as illustrated in Figure 1B. The evaporator coil comprises 0.476 cm copper tubing in 18 revolutions with a diameter of 8.89 cm at 22.86 cm height to facilitate the rapid entry and escape of LPG in the upper and bottom portions, respectively. To attain a pressure drop from the tank, a throttling device was installed at the inlet part of the evaporator so there was a pressure decrease throughout the system. The throttling device that was used in this study is a simple ball valve since it is widely available and adjustable. An iron-cast heavy-duty stove which measures 55.88 cm x 40.64 cm x 24.13 cm was used to exhaust the LPG. Commercial gas and liquid hoses with a diameter of 3/8" were utilized since they were more affordable and fittings were readily available. An 11-kg-LPG tank was used in this experiment for easy grip and mobility. The LPG tank and LPG composition used were Prycegas, which is locally available. An innovative set-up also was implemented by the researchers to make the system easier to move from one place to another. Aside from the main components, angle bars that were cut and wielded were added. This was the most used method in fabricating this innovative set-up.

### Data Gathering Instruments

The LPG tank was weighed in its emptied state and full state using a weighing scale as shown in Figure 1C. This device is used to measure the mass flow rate of the system during the experiment. After measuring the mass of the LPG, the pressure experimentation parameters were set to approximately 15 psi and measured by a Bourdon-type pressure gauge as shown in Figure 1D. Two temperature probes shown in Figure 1E were attached to the inlet and outlet part of the evaporator. This measures the water temperature of heated or chilled water and other liquids in mechanical systems. Additionally, another temperature probe was utilized to measure the water temperature in the evaporator chamber. It was programmed with respect to the code language of Arduino as shown in Figure 1F. The temperature reading of the refrigeration chamber was recorded in different time intervals in 10 min within 180 min of run time.

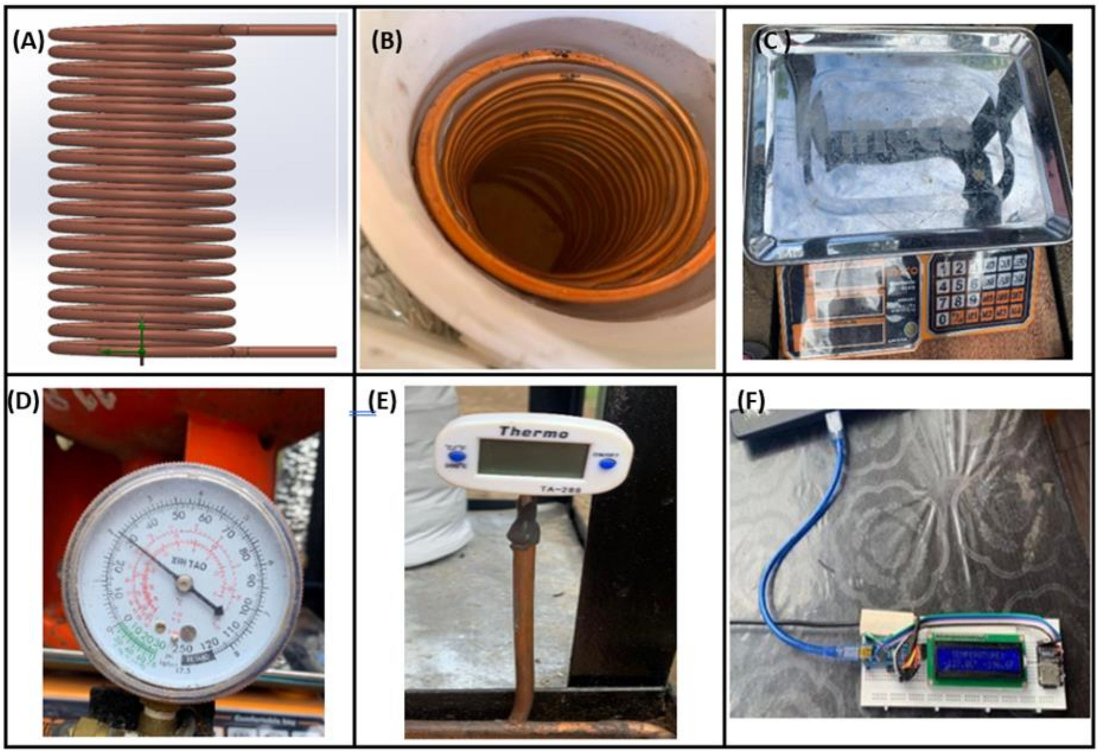


**Figure 1.** (A) 3D drawing of the Copper Tube coiled cylindrically; (B) Actual Copper Tube coiled inside the Evaporator Chamber; (C) Weighing Scale used for measuring the LPG mass; (D) Pressure Gauge used in measuring the outlet and inlet pressure; (E) Temperature Probe used in measuring the inlet and outlet temperature of the evaporator; and (F) Arduino set used in measuring the Evaporator temperature.

**Experimental Setup**

After gathering all the instruments and materials needed for the study, the design system was constructed as shown in Figure 2A. Its setup with labeled instruments and materials used is shown in Figure 2B. Necessary fittings were carefully connected and a leak test was conducted through the bubble method.

**Calculation of Performance**

The researchers determined the raw data during the experimentation. The raw data for the LPG refrigeration system includes pressure drop, mass flow rate, and change of temperature which was obtained from the data gathering instruments. The researchers then calculated the performance of the system based on the raw data from the experimentation. The calculation of the performance data for the LPG refrigeration system includes enthalpies, heat loss of water, work, and coefficient of performance (COP).

The LPG cylinders are generally filled with 80% liquid and 20% vapor ES Systems (2021), and by using the properties of propane and butane, enthalpies were acquired with respect to the composition ratio of LPG (60% butane, 40% propane). Work was solved through the unsteady state formula by finding the internal energies and enthalpies with respect to temperature from the starting and final time. Conservation of energy of unsteady state Heat loss of water was acquired by using the heat removed formula, using the specific heat capacity of water, the mass of water, and the change of temperature as can be seen in Equation 1. Finally, COP was determined by dividing the heat loss of water (Q) by the work (W) of the system. Thermal insulation was used to reduce heat loss to the atmosphere. Therefore, any heat loss or addition to the environment as a result of conduction,

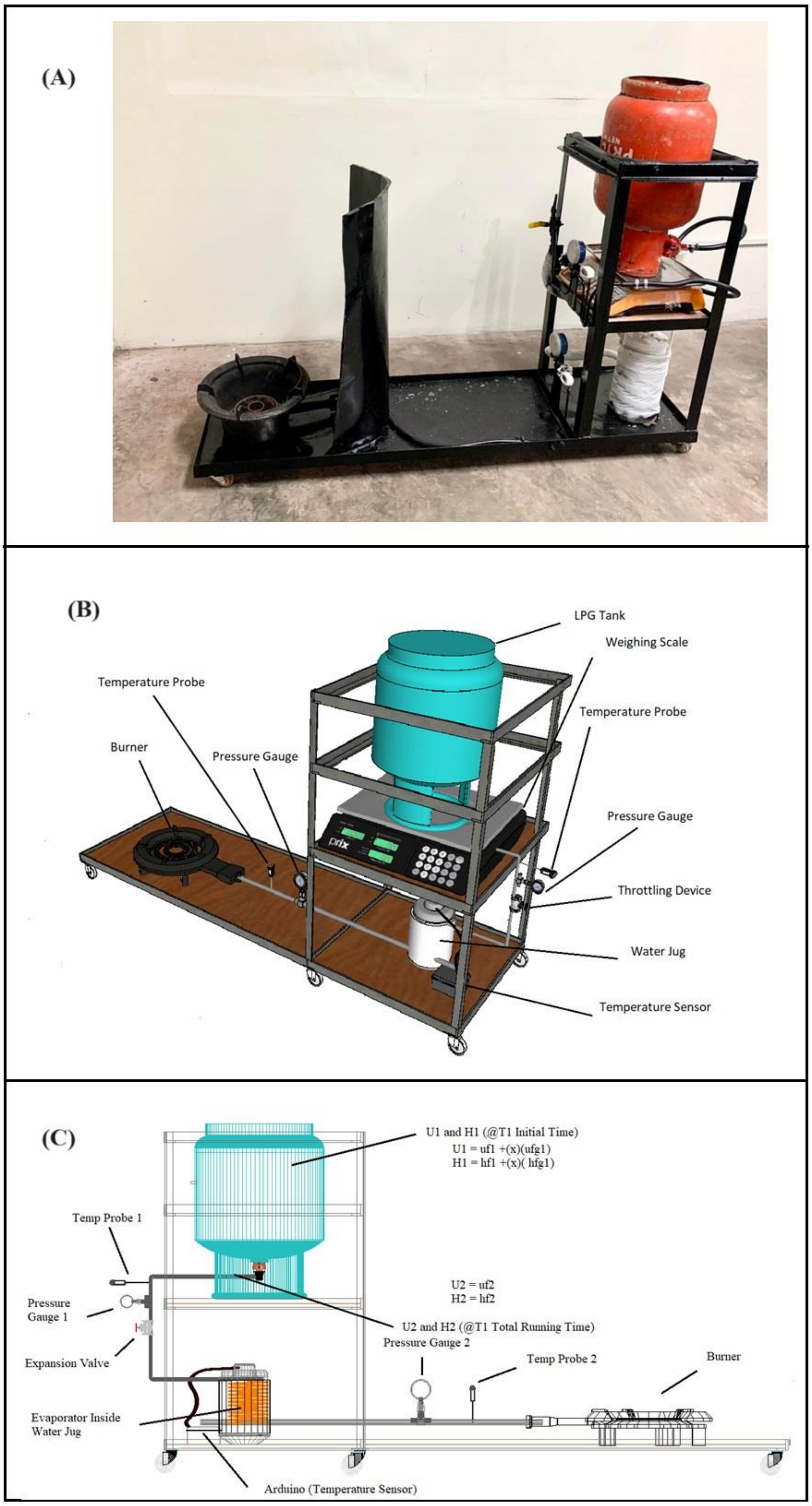


**Figure 2.** (A) Actual setup of LPG Refrigeration System; (B) LPG Refrigeration Set-Up with labeled parts; and (C) Schematic Diagram of LPG Refrigeration System.

convection, or radiation is negligible. The change in kinetic and potential energy in the evaporator is negligible.

In a steady flow process, it is assumed that the system's mass and energy are constant and do not change over time. In a process with an unsteady flow, mass and energy inside the control volume fluctuate continually. The fluid flows into and out of the system (Avinash 2018).

Conservation of energy of unsteady state,

$$m_2(u_2+KE_2+PE_2)-m_1(u_1+KE_1+PE_1)= m_{in}\sum(h_{in}+KE_{in}+PE_{in})-m_{out}\sum(h_{out}+KE_{out}+PE_{out})+Q-W \quad \text{(Eq. 1)}$$

The LPG refrigeration system has only one exit and no inlet mass flow (refer to Figure 2C). Therefore, the summation of terms involving the inlet mass can be omitted. Since there is no heat transfer between the LPG inside the tank and the surroundings, the system is adiabatic. Potential energy (PE) and kinetic energy (KE) were neglected as can be seen in Equation 2.

$$m_2u_2-m_1u_1=-m_{out}h_{out}-W \quad \text{(Eq. 2)}$$

where:

- inlet temperature of the system is equal to the temperature of the LPG inside the tank
- $u_1 = u_f + xu_{fg}$ (internal energy at two-phase mixture), @ inlet temperature in initial time
- $u_2 = u_f$ (internal energy at saturated liquid), @ inlet temperature in final time
- $h_1 = h_f + xh_{fg}$ (enthalpy at two-phase mixture), @ inlet temperature in initial time
- $h_2 = h_f$ (enthalpy at saturated liquid), @ inlet temperature in final time
- $h_{out} = (h_1 + h_2) / 2$
- $m_{out} = m_1 – m_2$

Heat loss is the reduction of space's heat due to heat transmission through walls, roofs, windows, and other building surfaces. The heat loss is computed by multiplying the mass, the temperature differential between the inside and outside surfaces, and the material's specific heat capacity, as can be seen in Equation 3. The total heat loss of the object consists of radiation, convection, and conduction losses. There is no substance capable of totally preventing heat loss; materials can only lessen it. The unit of heat loss is the Watt.

$$Q=\frac{mC_p\Delta T}{t} \quad \text{(Eq. 3)}$$

where:

- m = mass of water
- $C_{pw}$ = specific heat capacity of water (4.187 kJ/kg-K)
- $C_{pi}$ = specific heat capacity of ice (2.0935 kJ/lg-K)
- DT = change of temperature
- t = running time

The COP of a refrigerator is defined as the heat extracted from the cold reservoir $Q_{cold}$ (i.e., inside a refrigerator) divided by the amount of work W performed to remove the heat (i.e., the work done by the compressor), as can be seen in Equation 4. The COP varies heavily on the outdoor temperature and the desired inside temperature. At a temperature differential of approximately 25°C, the COP may be approximately 2.5, although it may approach 3.5 for a difference of approximately 8°C (Connor 2019).

$$COP=\frac{Q_A}{W} \quad \text{(Eq. 4)}$$

where:

W = work input (W)
$Q_A$ = refrigerating capacity (W)
COP = coefficient of performance

## Experimental Procedure

**Examining the status of all system components.** The system must be fully functional and devoid of leaks and faulty components. Due to the combustible nature of LPG, all personnel operating the prototype wore protective gear. All connection points were checked using the soap solution method in order to check for leaks. Before each test, the tubing and evaporator were cleaned with a vacuum pump to eliminate moisture and blockages.

**System Components Setup**. The container was filled with water (about 2 L), and a temperature measurement device was positioned within the evaporator without contacting it. At the beginning of data collection, the researchers made sure that the water was at temperature ranging from 22℃ to 29℃. Data acquisition devices were then turned on. Additionally, the LPG cylinder was then placed on the digital scale. To transfer liquid LPG into the system, the cylinder was turned upside down. With the burner valve open and the ball valve closed, the ball valve was gradually opened and the burner valve was adjusted to achieve 15 psi at exit pressure.

**Determining the raw data.** Raw data was determined using the measuring device that was attached to the system, such as a pressure gauge, which measures the pressure of LPG from the system's inlet and outlet in pounds per square inch (psi), a temperature sensor, which measures the water's temperature in degrees Celsius, and weighing scale, which measures the mass flow rate. In order to determine the mass flow rate, LPG was weighed on a scale, and the mass loss of LPG was computed by dividing it to the time interval.

**Data Gathering.** LPG intake and outlet pressures, water temperature, and LPG cylinder mass were measured at ten-minute intervals at the end of three hours or 180 min of operation. In addition, water temperature was measured at 5 min intervals throughout three more 60 min periods.

**Calculating the enthalpies and heat loss of LPG based on raw data.** In determining enthalpies, the pressure derived from the dataset served as a reference point for the computation of enthalpies, with respect to the LPG composition properties table. The composition of LPG in the Philippines is 60% butane and 40% propane. Consequently, in calculating enthalpies, it is necessary to multiply by 60% of the butane properties and 40% of the propane properties.

**Calculating the work of the system.** Using the enthalpies and the mass flow rate from the raw data, the work (kW) of the system was computed. The heat loss formula from the water was also used to calculate the heat loss of water in the system. Then the performance of the system (COP) was determined by dividing the heat loss from the water by the work of the system.

## RESULTS

### CFD Simulation

The simulation solely concentrates on the refrigerated chamber up until the point where the mass enters the upper portion of the evaporator as shown in Figure 3. It has been found that the temperature was low near the evaporator coils and it is highest in the lower section of the coiled evaporator. A time-dependent approach was used to collect the data in the software. The simulation ran for a maximum of 60 min. Iterations were done at 5 min intervals for maximum, minimum, and average temperatures inside the refrigeration chamber. The result is illustrated in Figure 4A. The graph in Figure 4B compares the experimental and simulated values of computational fluid flow on the temperature gradient in relation to time from the SOLIDWORKS program.

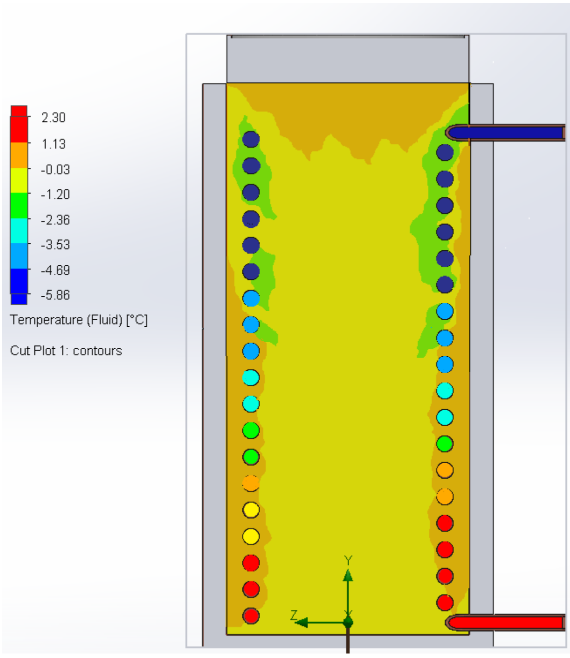


**Figure 3.** Simulation cut plot of Evaporator Chamber.

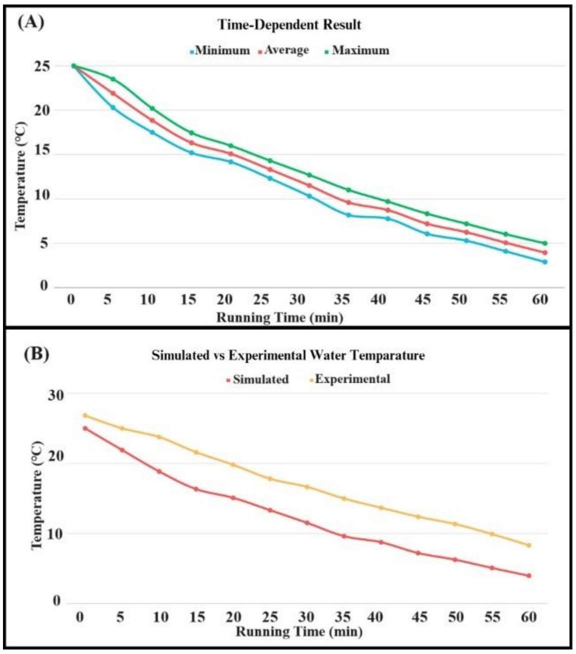


**Figure 4**. (A) Temperature vs running time using computational fluid dynamics simulation; and (B) temperature graph comparison of simulated and experimental results.

## Experimental Performance of LPG

The researchers conducted five test experiments in total, where each test ran for 180 min with a 10 min interval. Table 1 shows the LPG consumed by the system in a 3-hour duration with a 10-minute interval. Rapid consumption of LPG was observed during the first half of the duration time with approximately 1.8 kg of LPG. In every 10 min, the average consumption is 0.218 kg. The curve of the absolute pressure at which the LPG refrigerant leaves the evaporator with respect to time has been plotted in Figure 5A. From the graph, a linear relationship can be observed between the two parameters. Pressure drop is the difference between the outlet and inlet pressure. As time increased, the pressure drop also increased from 4.8 psi to 17 psi every 10 min. Similarly, Figure 5B shows how the water temperature behaves against time. A drastic temperature change was also observed in 80 min from 25°C down to 2°C. As time increased, moderate changes were observed that upon approaching the freezing point, it further extended towards negative values. In this study, the system has reached -3.5 degrees Celsius in 3 h with an average inlet pressure of 30.4 psi.

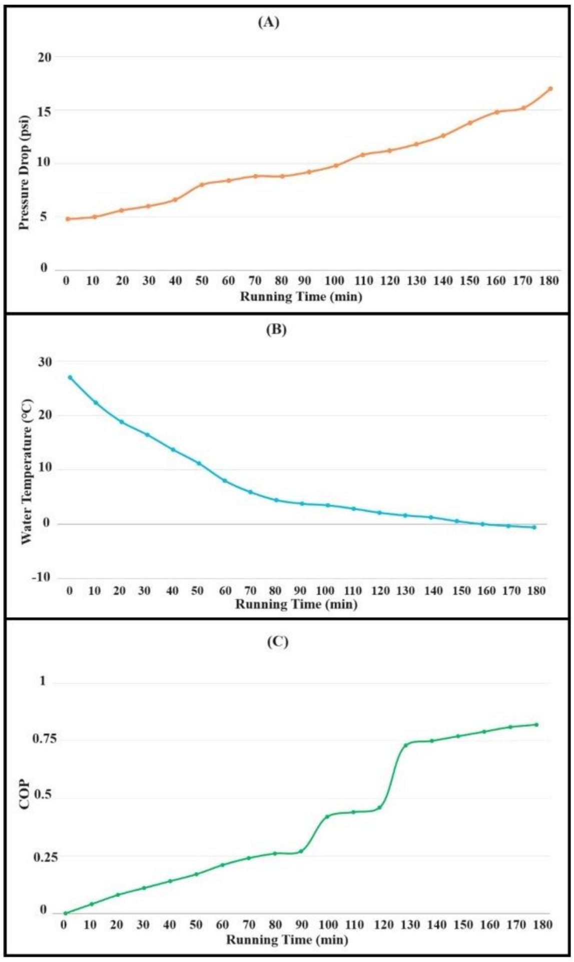


**Figure 5**. (A) Pressure drop vs time graph of experimental result; (B) water temperature vs time graph of experimental result; and (C) COP vs time graph of experimental result.

**Table 1**. Average consumption of mass from experiment.

| Test | Average Consumption Every 10 min (kg) |
|---|---|
| 1 | 0.222 |
| 2 | 0.203 |
| 3 | 0.184 |
| 4 | 0.258 |
| 5 | 0.221 |
| Average | 0.218 |
| Standard Deviation | 0.0274 |

## Coefficient of Performance

The COP of the system was calculated based on the raw data collected. In a duration of 3 h with 10 min intervals, COP ranging from 0.02 to 1.78 was achieved. This proves that the value of COP increases with respect to time as can be seen in Figure 5C. In this study, the properties of butane and propane which are the components of LPG in the Philippines are considered in the calculation of work.

## DISCUSSION

### CFD Simulation

Comprehensive and nuanced comparison was undertaken between Computational Fluid Dynamics (CFD) simulation results and experimental data to enhance the understanding of fluid flow phenomena in this study. This aimed to provide a comprehensive assessment of the reliability and precision of both sets of data within the context of this study. By using simulation, researchers were able to vary input parameters to analyze their influence on the system's behavior. Detailed examination of specific flow characteristics, and visual representations, such as contour plots were utilized to facilitate a clear and insightful comparison. Furthermore, with CFD simulation, researchers were able to assess the performance of coil orientation and whether or not it can create a cooling effect, thus, it facilitated virtual prototyping and design optimization. Additionally, insights into the temperature at different points of the refrigerant inside the copper coil and water inside the evaporator chamber were drawn. Based on the simulated design, the temperature is significantly lower at the entrance of the evaporator and higher in the lower section. When comparing the time-dependent results obtained from the simulation with the actual experimental outcomes, it was observed that the actual results exhibited slight variations. These discrepancies can be attributed to the influence of weather conditions during the experimental trials. It became evident that factors such as temperature and humidity have contributed to the observed differences in the time-dependent behavior between the simulated and actual scenarios. Recognizing this condition, external environmental factors are significant in the interpretation of experimental results and highlights the challenges associated with precisely replicating conditions in simulations when natural variables, such as weather, come into play.

### Fabrication and Experimentation with LPG Refrigeration System

As the refrigerant circulates through the system, its pressure and temperature change. For the refrigeration cycle to function, it encompasses three main stages: mass consumption, pressure drop, and temperature change. Mass consumption is an essential part of the refrigeration system since it is used for the calculation of work done by the system. An average mass consumption of 0.218 kg was recorded after the five experimental tests. This result of mass consumption was dependent on the starting pressure of 30 psi and the outlet pressure that ranged from 28 psi to 10 psi. When the outlet pressure is high, the mass consumption of the system increases and when the outlet pressure drops, the mass consumption decreases. This means that the mass consumption and the outlet pressure are directly proportional. The system has shown a pressure drop of 15 psi on average. This pressure drop occurred when the LPG refrigerant passed through the expansion valve. The discussion of Blackwell (2015) stated that to cool the refrigeration chamber, the refrigerant is transmitted through the expansion valve, which reduces its pressure by restricting the amount of flow through the valve. This restriction means that there will be less refrigerant in the next section of the conduit, allowing the refrigerant that passes through to expand slightly. This was supported by the study of Shah and Gupta (2014), where an average pressure drop of 20 psi was recorded with an initial pressure of 80 psi from which a high-pressure regulator was utilized. In addition, they have stated that the use of a low-pressure regulator will result in a different pressure change. After passing through the expansion valve, the LPG refrigerant then enters the evaporator which is housed in the refrigerating chamber and reduces the water temperature. Blackwell (2015) explained that the refrigerant enters the evaporator as a low-temperature, low-pressure liquid. Upon entering the evaporator, the refrigerant begins to boil and evaporate, causing a cooling effect in the chamber. The refrigerant exits the evaporator as a low-pressure, saturated gas and then flows through the pipes to the burner for combustion. The inverted elevated LPG setup is more effective in minimizing the cooling time than the usual setup. Using the 0.476 cm diameter copper tube with 18 revolutions, the lowest temperature achieved was -3.50°C in 3 h and a water temperature of 11.19°C as achieved in 50 mins. Correspondingly, Manohar et al (2020) achieved a water temperature of 23.4°C after 50 min; a 0.70-cm OD copper tube with a thickness of 0.15 cm was used. This implies that the size of the copper tube used in this study provides faster cooling than that of the size used in the study previously mentioned. However, under continuous operation, the LPG lasts for 10 h only.

### Performance of LPG Refrigeration System

The efficiency of the refrigeration system is measured in terms of its COP. The higher the value of COP, the more efficient the system is (Connor 2019). The highest COP calculated for this unsteady state system is about 1.78 which is comparatively smaller than the domestic refrigerator which is 2.5 (Shah and Gupta 2014). The investigation conducted by Manohar et al. (2020) demonstrated an elevated COP of 6.3. This achievement was attributed to a higher mass flow rate, leading to an increased refrigerating effect, coupled with a reduced work input, specifically 42.39 watts. Their assumption, wherein the work input is considered equivalent to the power required for filling one cylinder, resulted in a lower value for work. As compared to this study, the work done in the LPG refrigeration system has been meticulously calculated using empirical formulas and LPG properties. Through a detailed analysis of pressure drop, temperature change, and enthalpy change, along with a comprehensive understanding of LPG's thermodynamic characteristics, the computation of work done is accurately derived. This approach not only ensures the precision of the results but also contributes to a thorough comprehension of the system's performance based on empirical correlations and the specific properties of LPG.

The discrepancies noted between simulated results and experimental data underscore the significant impact of external environmental variables, thus emphasizing the need for careful consideration of real-world conditions in simulation models to enhance predictive accuracy and reliability. The exploration through fabrication and experimentation reveals critical insights into the system's operational dynamics, notably the direct relationship between mass consumption and outlet pressure and the cooling efficiency of specific system configurations. These findings illuminate the practical aspects of system design, such as component selection and setup orientation, that directly influence performance outcomes. The limitation observed in the system's continuous operation duration indicates that there is a need for further refinement in design to extend usability and efficiency in real-world applications. Lastly, the performance evaluation, centered on the Coefficient of Performance (COP), sheds light on the LPG refrigeration system's efficiency compared to conventional systems. The evaporator achieved a cooling effect of -3.5℃, resulting in the formation of ice within the chamber. This indicates that the refrigeration system effectively met the specified parameters as stipulated in this study. Moreover, the system has reached a coefficient of performance of 1.78 which is lower than that of a domestic refrigerator. It is recommended to use a plate-tube type of evaporator in the chamber to achieve a greater value of refrigerating effect, which will then lead to a higher value of COP.

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No funding was provided to the authors by any organization in the work submitted.

## ETHICAL CONSIDERATIONS

This research does not have any animal or human subjects.

## DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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## REFERENCES

Adhav AS, Dudhe SS, Jadhav VD, Pagar SA and Salunke GB. 2017. Electricity Free Refrigeration using LPG.https://www.academia.edu/31673800/Electricity_Free_Refrigeration_using_LPG. Accessed on 20 July 2023.

AIRAH (Australian Institute of Refrigeration, Air-Conditioning and Heating Incorporated) 2013. Flammable refrigerants safety guide. https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=308694f4fef24df206277b9061aeb322695d4541. Accessed on 26 March 2023.

Blackwell W. 2015. Sustainable Retail Refrigeration. John Wiley & Sons Ltd. The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK. pp 351.

Connor N. 2019. What is Coefficient of Performance - COP - Refrigerator, Air Conditioner - Definition. Thermal Engineering. https://www.thermal-engineering.org/what-is-coefficient-of-performance-cop-refrigerator-air-conditioner-definition/. Accessed on 26 March 2023.

Demharter A. 1998. Polyurethane rigid foam, a proven thermal insulating material for applications between +130°C and −196°C. Cryogenics, 38(1): 113–117. https://doi.org/10.1016/s0011-2275(97)00120-3.

Elgas. 2019. How Much Pressure is in LPG & Propane Gas Cylinder-Bottle. https://www.elgas.com.au/blog/1969-how-much-pressure-is-in-lpg-propane-cylinders-in-what-state/. Accessed on 14 April 2023.

ES Systems. 2021. What is liquefied petroleum gas and how does it work? https://esenssys.com/liquefied-petroleum-gas-guide/#. Accessed on 14 April 2023.

El-Morsi M. 2015. Energy and exergy analysis of LPG (liquefied petroleum gas) as a drop in replacement for R134a in domestic refrigerators. Energy, 86: 344-353. https://doi.org/10.1016/j.energy.2015.04.035

Emani MS, Roy R and Mandal BK. 2017. Development of refrigerants: a brief review. Indian Journal of Scientific Research , 14(2): 175-181.

Fernando J. 2022. Hydrocarbons: Definition, Companies, Types, and Uses. https://www.investopedia.com/terms/h/hydrocarbon.asp. Accessed on 20 May 2023.

Heisler H. 2002. Advanced Vehicle Technology. Elsevier. Linacre House, Jordan Hill, Oxford. 654pp.

Iyer GV, Mastorakis NE and Theologou AI. 2006. Experimental investigations on eco-friendly refrigeration and air conditioning systems. In Proceedings 4th WSEAS International Conference on Fluid Mechanics and

Aerodynamics, 2017: 445-450. https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=a01a977fed030c1098719b0e668baaeb922f8afe. Accessed on 21 July 2023

Liu BY, Tomasek ML and Radermacher R. 1995. Experimental results with hydrocarbon mixtures in domestic refrigerator/freezers (No. CONF-950104-). American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, GA (United States). https://www.osti.gov/biblio/87488. Accessed on 10 March 2024.

Manohar M, Sahu PK, Sahu PK, Singh D and Chandra A. 2020. Design Analysis and Performance of Low Cost Refrigeration System using LPG. https://www.ijesc.org/upload/1c58ceee9a810532dab0c45ce2b82687.Design%20Analysis%20and%20Performance%20of%20Low%20Cost%20Refrigeration%20System%20using%20LPG.pdf. Accessed on 20 July 2023.

Mohanraj M, Muraleedharan C and Jayaraj S. 2011. A review on recent developments in new refrigerant mixtures for vapour compression-based refrigeration, air-conditioning and heat pump units. International Journal of Energy Research, 35(8): 647-669. https://doi.org/10.1002/er.1736

NASA (National Aeronautics and Space Administration). 2015. NASA Study Shows That Common Coolants Contribute to Ozone Depletion. https://www.nasa.gov/press-release/goddard/nasa-study-shows-that-common-coolants-contribute-to-ozone-depletion. Accessed on 11 January 2023.

Oyelami S and Bolaji BO. 2016. Design and construction of a vapour compression refrigeration system as test rig to investigate the performance of Liquefied Petroleum Gas (LPG) as refrigerant. http://repository.fuoye.edu.ng/handle/123456789/2308. Accessed on 20 July 2023.

Rehman HU, Awan A, Khan N, Naseer F and Ali K. 2023. Using Liquefied Petroleum Gas (LPG) as an Environmentally Friendly Alternative Refrigerant. https://www.xisdxjxsu.asia/V19I03-60.pdf. Accessed on 22 July 2023.

Raiyan MF and Rehman OA. 2017. Effects of Chlorine-based refrigerants on atmosphere and search for alternative refrigerants-A review. https://www.researchgate.net/publication/324830749_Effects_of_Chlorine_based_refrigerants_on_atmosphere_and_search_for_alternative_refrigerants-A_review. Accessed on 21 July 2023.

Rayos AH. 2017. LPG Industry Regulatory Framework (Household LPG) and Gasoline Station Training and Loan Fund. Department of Energy. https://www.doe.gov.ph/sites/default/files/pdf/announcements/epower_fontana_04_04_lpg_industry_regulatory_framework.pdf?withshield=1. Accessed on 27 May 2023.

Sathayan S, Gopakumar MG, Krishnan SJ, Gopan N and Nithin S. 2018. Design of Lpg Refrigeration System. International Journal of Innovative Research in Science, Engineering and Technology, 7(6): 2319-8753. https://doi.org/10.15680/IJIRSET.2018.0705054

Satwik N, Kumar BS, Krishna TG, Ravinda M and Kumar BK. 2016. Refrigeration System by using LPG (Liquefied Petroleum Gas). International Journal and Magazine of Engineering, Technology, Management and Research, 3(5): 226-235.

Shah IH and Gupta K. 2014. Design of LPG refrigeration system and comparative energy analysis with domestic refrigerator. International Journal of Engineering Sciences & Research Technology, 3(7): 206-213.

Srinivas P, Chandra RP, Kumar MR and Reddy N. 2014. Experimental investigation of LPG as refrigerant in a domestic refrigerator. Journal of Mechanical Engineering Research and Technology, 2(1): 470-476.

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