

PAPER • OPEN ACCESS

Experimental Performance of the Energetic Characteristics of a Domestic Refrigerator with Al₂O₃ Nanolubricant and LPG Refrigerant

To cite this article: M. A. Onakade *et al* 2019 *J. Phys.: Conf. Ser.* **1378** 042083

View the [article online](#) for updates and enhancements.



240th ECS Meeting ORLANDO, FL

Orange County Convention Center **Oct 10-14, 2021**

Abstract submission deadline extended: April 23rd

SUBMIT NOW

Experimental Performance of the Energetic Characteristics of a Domestic Refrigerator with Al₂O₃ Nanolubricant and LPG Refrigerant

M. A. Onakade ^{1*}, D. S. Adelekan ¹, O. S. Ohunakin ^{1,2}, O. E. Atiba ¹, J. Gill ^{1,3}, and A. A. Atayero^{1,4}

¹The Energy and Environment Research Group (TEERG), Mechanical Engineering Department, Covenant University, Ogun state, Nigeria.

²Senior Research Associate, Faculty of Engineering & the Built Environment, University of Johannesburg, South Africa.

³Department of Mechanical Engineering, IKGPTU Kapurthala, Punjab, India.

⁴IoT-Enabled Smart and Connected Communities (SmartCU) Research Cluster, Department of Electrical and Information Engineering, Covenant University, Ota, Nigeria

Corresponding Author: moyosore.onakade@stu.cu.edu.ng; olayinka.ohunakin@covenantuniversity.edu.ng

Abstract-

This paper studies the experimental performance of the energetic characteristics of a slightly modified domestic refrigerator infused with nano-lubricant containing different concentrations of Al₂O₃ (at 0, 0.2, 0.4 and 0.6 g/L) with liquefied petroleum gas (LPG) charge of 40g. Parameters investigated were power consumption, cooling capacity, coefficient of performance (COP), discharge temperature, volumetric refrigerating capacity (VRC) and pressure ratio. The findings showed that when the nano-based lubricants were compared with pure oil, the power at 0.6g/L concentration, gave the best performance of 67.01W, at different time over 180 minutes' periods. The discharge pressure of the system when compared to pure-oil at 0.6g/L concentrations exhibited acceptable value of 616.33kPa. For the cabinet temperature, it was seen that the 0.6g/L had the lowest recorded temperature of -8.7°C after 180 minutes. With the coefficient of performance, the 0.2g/L concentration had the highest average performance of 2.239 at 180 minutes. The highest average performance of 174.225 kW over 180 minutes was found as the refrigerating capacity at 0.2g/L concentration. The nano-lubricant can be concluded to work safely in the refrigerator but better optimization in nano-application will still be needed for better results.

Key words: Al₂O₃ nanoparticle, nano lubricant, liquefied petroleum gas (LPG)

1. Introduction

In recent times, the need for energy saving and environmentally friendly refrigeration system is a growing concern [1]. Refrigeration systems are expected to reduce their contribution to climate change, by reducing their global warming contribution and energy consumption, and having the characteristics of zero ozone layer depletion [2]. Because of this, researchers are adopting natural refrigerants such as hydrocarbons as possible replacement to traditional refrigerants, due



to the high energy efficiency, neutral reaction to ozone layer and low global warming potential [3]. The flammability of hydrocarbon-based refrigerants is managed and certified safe for household utilizations, provided the refrigerant charge is limited to 150g within the domestic refrigerators [4].

Recent adoptions of hydrocarbons-based refrigerants within domestic refrigerators have been very successfully. An experiment was conducted to evaluate the effect of liquefied petroleum gas (LPG) in a domestic refrigerator in the work of Fatouh and El Kafafy [5]. It was found that the hydrocarbon gave results which indicated a better performance than R-12 within the system. A decrease in power consumption, increase in mass flow rate and volumetric cooling capacity with a decrease in pulldown time was observed in the work of Harby [6]; the use of hydrocarbon was also found to be safer, with an attendant reduced cost because the refrigerant is readily available.

Recent works by researchers on the use of nanotechnology for heat transfer enhancement, is another way to optimize performance of refrigeration systems in order to save energy while achieving safe refrigeration. Ohunakin et al., [7], conducted an experiment seeking to find a retrofit for the commonly used R134a refrigerant because of the high global warming effect of the said refrigerant. In this experiment nanoparticles were used because of the inherent intrinsic qualities including: pressure drop, sedimentation, need for less pumping power and fouling. The adoption on nanoparticle in the lubricant was found to give a low power consumption at optimum concentrations of the nanoparticle in the lubricant, and a reverse when the concentration in the lubricant was higher since it resulted in a relatively high-power consumption. Several works on irreversible performance of a refrigerator with different LPG charges using TiO₂ nano-lubricant can be found in literatures [7-11]. It was found that increase in the nanoparticle concentration in the fluid caused a decrease in the irreversibility (exergy loss) in almost all the components of the domestic refrigerator.

2. Materials and Methods

2.1 Experimental Setup

The rig used for this experimental investigation was a domestic refrigerator consisting of a 95W R-22 compressor, an air-cooled condenser, a dryer and an evaporator. The rig was modified to incorporate valves at the compressor inlet and outlet. This enabled charging and discharging of refrigerant and digital pressure gauges, to monitor the refrigerant pressure. In addition, digital thermocouples K were installed to measure the temperature of the refrigerant across the various sub-components of the system as done in Adelekan et al., [12]. The power consumption of the refrigerator was measured using a Watt-meter. This experiment was carried out in a controlled environment having temperatures of 28°C. The test rig specification, and measuring range of the experiment are shown in Figure 1 and Table 1. Details of measuring instrument and nano-lubricant characteristics are as shown in Table 2 and Table 3.



Figure 1: Test rig

Table 1: Test rig specifications

| S/N | Components | Unit |
|-----|------------------|------------|
| 1 | Evaporator size | 50 L |
| 2 | Compressor type | R-22 |
| 3 | Defrost type | Manual |
| 4 | Condenser type | Air cooled |
| 5 | Refrigerant type | LPG |
| 6 | Freezing power | 6kg/34hrs |
| 7 | Frequency type | 50Hz |
| 8 | Power rating | 90 W |
| 9 | Door type | Single |

Table 2: Measuring instrument specification

| S/N | Characteristics | Range |
|-----|-----------------|--------------|
| 1 | Temperature | 0-2500 kPa |
| 2 | Pressure | -50 - 750°C |
| 3 | Power | 0-5000 Watts |

Table 3: Nanoparticle characteristics

| S/N | Parameters | Range |
|-----|---------------------------|--------------------------------|
| 1 | Particle type | Al ₂ O ₃ |
| 2 | Particle size | 13nm |
| 3 | Concentration used (g/L) | 0.2, 0.4, 0.6 |
| 4 | Nanoparticle manufacturer | ALDRICH |
| 5 | Trace metal basis | 99.8% |

2.2 Experimental Procedure

This experiment was carried out with a no load, closed door, continuous cycle (that is without turning it ON/OFF) with working condition of compressor with readings taken from all fitted thermometers and pressure gauges. The system was put on for timing of 180 minutes steady state operation of the test rig. Parameters including evaporator temperature (T_{air}), pressure readings (P_1 , P_2), temperatures at compressor inlet and compressor outlet were taken (T_2 and T_3). These parameters were used to estimate the required thermodynamic properties (such as H_1 , saturated vapor enthalpy (KJ/kg) at T_{air} , H_2 : superheated vapor enthalpy (KJ/kg), H_3 : saturated liquid enthalpy (KJ/kg) at T_3 and P_2 , and \dot{m} is mass flow rate). The following energetic characteristics were recorded including: refrigerating capacity, compressor work done, coefficient of performance, and pressure ratio (see equations 1-3). Power consumption of the system after every 10 minutes and after every temperature drop in the evaporator (T_{air}) were obtained for all the refrigerant charges: 40g of LPG paired with both the pure mineral oil lubricant, the sonicated Al_2O_3 mixture, and the mineral oil based lubricant of different concentrations. Spent LPG refrigerant was evacuated from the system after each test, using a vacuum pump and thereafter charged with refrigerant using a charging hose.

2.3 Performance Analysis

All experimental investigations carried out in this study utilized the under listed equations:

- Refrigerating Capacity is given by Eq. (1)

$$Q_e = \dot{m}(h_1 - h_3) \text{ (W)} \quad (1)$$
- Compressor Work Done is given by Eq. (2)

$$W_d = \dot{m}(h_2 - h_3) \text{ (KJ)} \quad (2)$$
- Coefficient of performance is given by (3)

$$COP = Q_e/W_d \quad (3)$$
- Pressure ratio is given by Eq. (4)

$$P_r = P_2/P_1$$

3. Result and Discussion

This section presents the results of varying nano-lubricants concentrations.

3.1 Power Consumption

Figure 2 shows the instantaneous and mean power consumption of the system. The addition of nano-particles to the system resulted in an increase in power consumption within the test rig. The range of increase of the system was within the mean percentage of 0.5-15.09 %. The lowest mean power consumption of 67.01W was observed at nano-concentration of 0.6g/L.

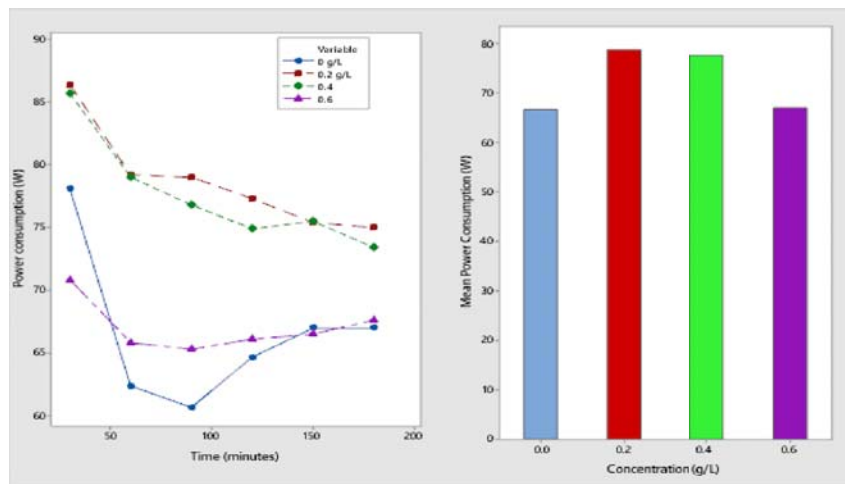


Figure 2: Instantaneous and mean power consumption

3.2 Steady State Cabinet Temperature

Figure 3 shows the steady state cabinet temperature against time. The addition of nanoparticles helped in improving the cabinet temperature when compared with pure lubricating oil without nano-particles inclusion. The lowest temperature recorded was -9.6°C for concentration at 0.4g/L .

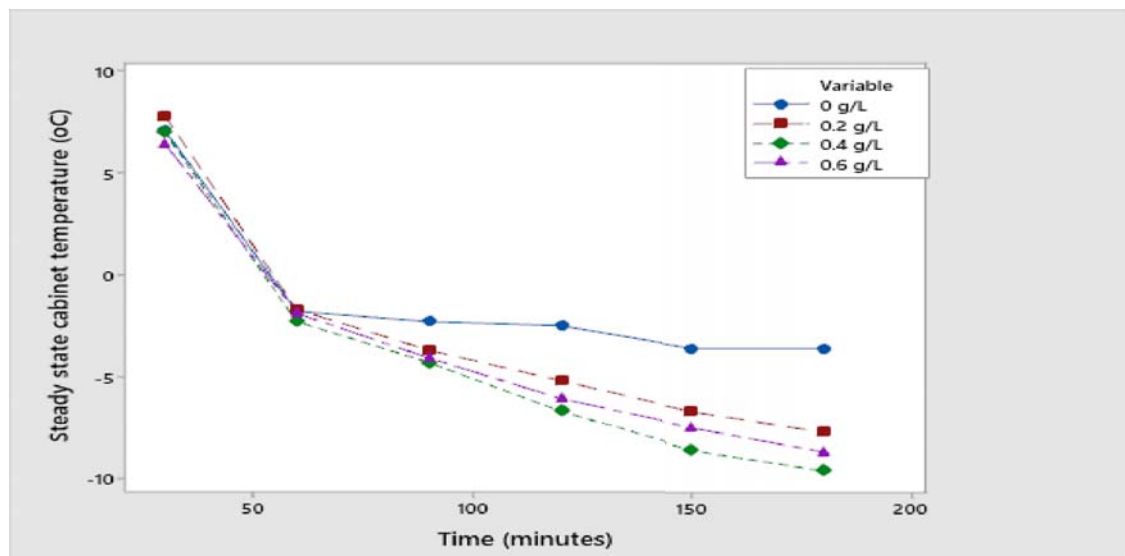


Figure 3: Instantaneous steady state temperature against time

3.3 Coefficient of Performance

Figure 4 shows the instantaneous coefficient of performance and mean coefficient of performance. The addition of nanoparticles increased the coefficient of performance by a mean percentage of 6.66 % at concentration of 0.2g/L .

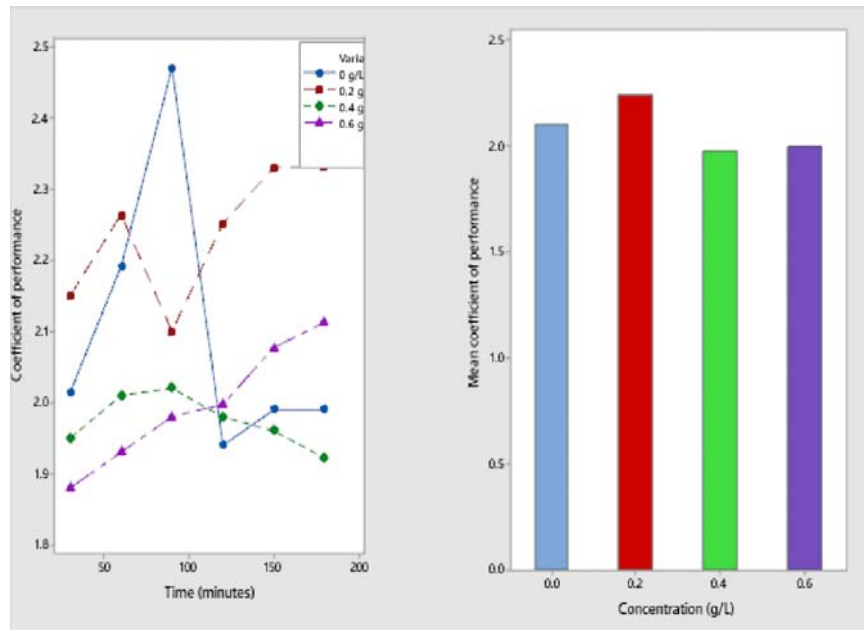


Figure 4: Instantaneous coefficient of performance and mean coefficient of performance

3.4 Pressure Ratio

Figure 5 shows the instantaneous pressure ratio and mean pressure ratio. It was found that the addition of the nanoparticle to the lubricant, improved the system pressure ratio because of the drop observed across all the concentrations. The drop was within a mean percentage range of 2.7-41.2%. The lowest mean pressure ratio recorded was 16.28 at nano-lubricant concentration of 0.2g/L.

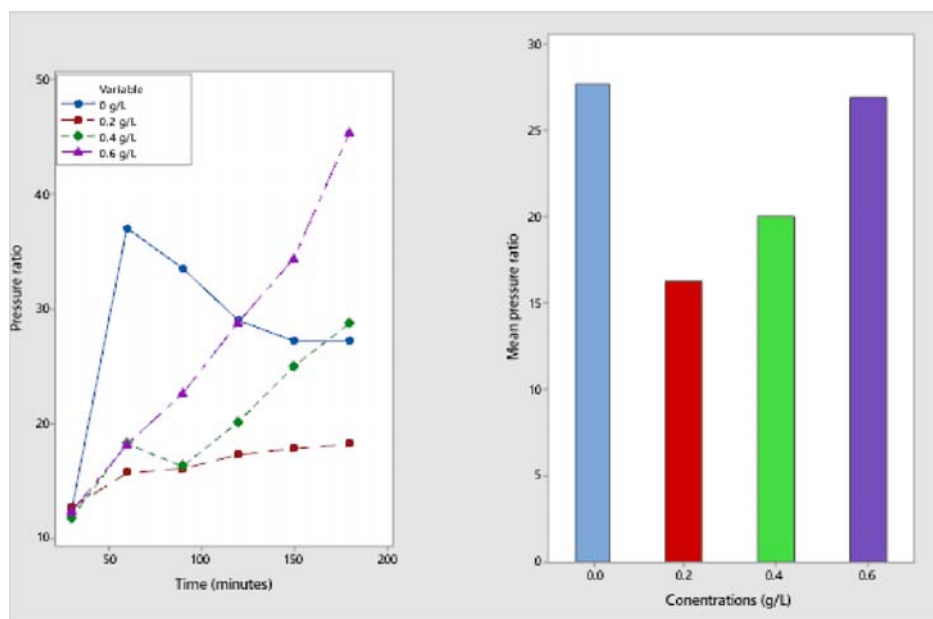


Figure 5: Instantaneous pressure ratio and mean pressure ratio

3.5 Discharge Pressure

Figure 6 shows the instantaneous discharge pressure and the mean discharge pressure. This shows that the addition of the nanoparticle dropped the discharge pressure with the 0.4 and 0.6g/L concentration of nano-lubricant, but increased that at concentration of 0.2 g/L. both 0.4 and 0.6g/L saw A mean percentage drop of 46% was found with both the 0.4 and 0.6g/L concentration, with the lowest mean discharge pressure recorded as 616.33kPa.

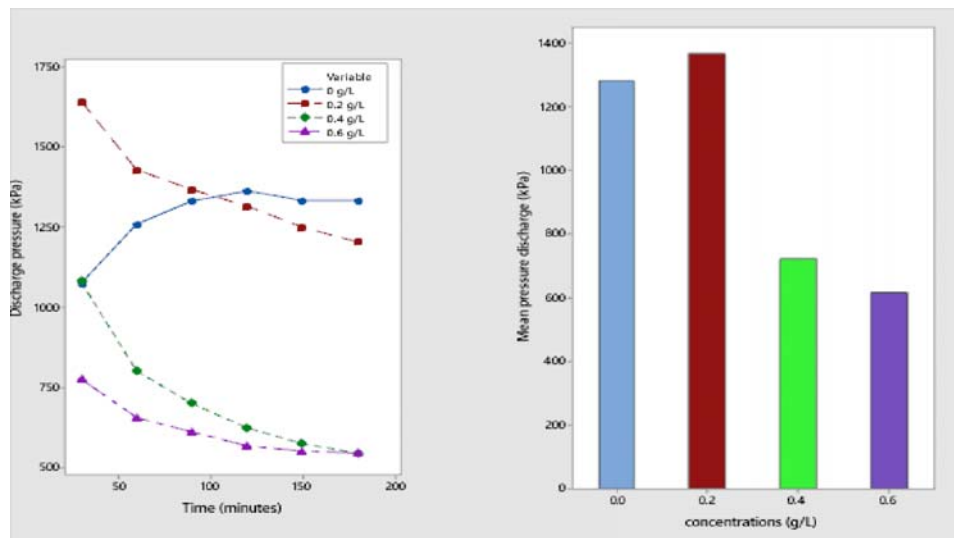


Figure 6: Instantaneous pressure discharge and mean pressure discharge

3.6 Refrigerating Capacity

Figure 7 shows the instantaneous refrigerating capacity and mean refrigerating capacity. The addition of nanoparticle to the lubricant increased the performance at 0.2 and 0.4 g/L concentrations in the lubricant. Increase in mean percentage was recorded as 15.5%, with the highest mean value of 174.225 kW at concentration of 0.2g/L.

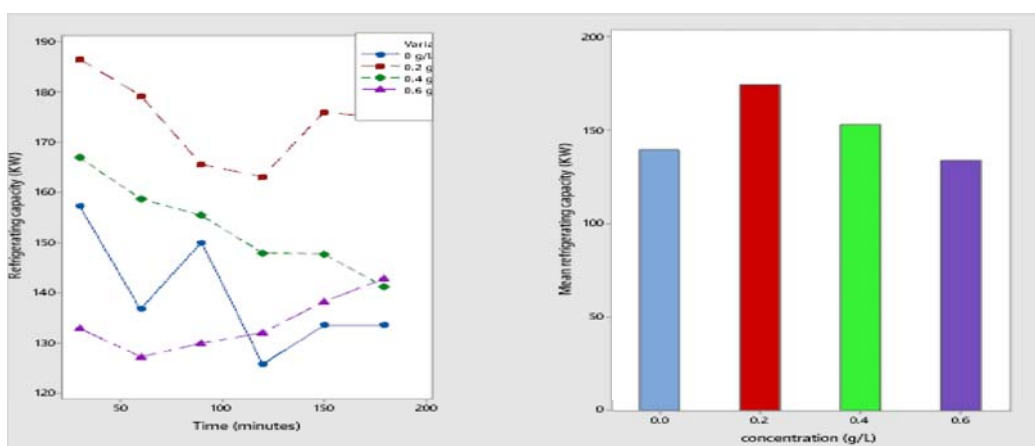


Figure 7: Instantaneous refrigerating capacity and mean refrigerating capacity

4. Conclusion

From the experimental investigation of the steady state performance of LPG charges with various concentrations of Al₂O₃ nano-lubricants in a domestic refrigerator, the following findings can be concluded:

- All investigated Al₂O₃ based nano-lubricants worked safely in the domestic refrigerator.
- All nano-lubricant concentrations showed lower steady state temperature in the evaporator when compared with that of pure lubricant oil.
- The lowest recorded mean power consumption was found to be 67.01W at 0.6g/L concentration of nano-lubricant.
- The nano-lubricant exhibited low discharge pressure for all concentrations of nano-lubricants when compared with the pure lubricating oil.

Acknowledgements

The authors wish to acknowledge the financial support offered by Covenant University in actualization of this research work for publication.

Reference

- [1] Ohunakin, O. S., Adelekan, D. S., Babarinde, T. O., Leramo, R. O., Abam, F. I., & Diarra, C. D. (2017). Experimental investigation of TiO₂- , SiO₂- and Al₂O₃- lubricants for a domestic refrigerator system using LPG as working fluid,” *Appl. Therm. Eng.*, vol. 127, no. 2017, pp. 1469–1477.
- [2] Calm, J. M. (2008a). *The next generation of refrigerants – Historical review , considerations , and outlook. 31*, 1123–1133.
- [3] Calm, J. M. (2008b). *The next generation of refrigerants – Historical review , considerations , and outlook 5, Int. J. Refrig.*, 31(7), pp. 1123–1133, 2008b.
- [4] Bhattad, A., Sarkar, J. & Ghosh, P. (2018). Improving the performance of refrigeration systems by using nanofluids: A comprehensive review, *Renew. Sustain. Energy Rev.*, 82, 3656–3669.
- [5] Fatouh, M. & El Kafafy, M. (2006). Experimental evaluation of a domestic refrigerator working with LPG,” *Appl. Therm. Eng.*, 26(14–15), 1593–1603.
- [6] Harby, K. (2017). Hydrocarbons and their mixtures as alternatives to environmental unfriendly halogenated refrigerants: An updated overview, *Renew. Sustain. Energy Rev.*, 73, 1247–1264.
- [7] Ohunakin, O. S., Adelekan, D. S., Gill, J., Atayero, A. A., Atiba, O. E., Okokpujie, I. P., & Abam, F. I. (2018). Performance of a hydrocarbon driven domestic refrigerator based

- on varying concentration of SiO₂ nano-lubricant. *International Journal of Refrigeration*, 94, 59–70.
- [8] Gill, J., Singh, J., Ohunakin, O. S. & Adelekan, D. S. (2018). Artificial neural network approach for irreversibility performance analysis of domestic refrigerator by utilizing LPG with TiO₂ – lubricant as replacement of R134a, *Int. J. Refrig.*, 89, 159–176.
- [9] Gill, J., Singh, J., Ohunakin, O. S. & Adelekan, D. S. (2018). ANN approach for irreversibility analysis of vapor compression refrigeration system using R134a/LPG blend as replacement of R134a. *Journal of Thermal Analysis and Calorimetry*, <https://doi.org/10.1007/s10973-018-7437-y>.
- [10] Gill, J., Singh, J., Ohunakin, O. S. & Adelekan, D. S. (2018). Energy analysis of a domestic refrigerator system with ANN using LPG/TiO₂–lubricant as replacement for R134a. *Journal of Thermal Analysis and Calorimetry*, <https://doi.org/10.1007/s10973-018-7327-3>.
- [11] Gill, J., Singh, J., Ohunakin, O. S. & Adelekan, D. S. (2018). Energetic and exergetic analysis of a domestic refrigerator system with LPG as a replacement for R134a refrigerant, using POE lubricant and mineral oil based TiO₂ -, SiO₂ - and Al₂O₃ - lubricants. *International Journal of Refrigeration* 91, 122–135.
- [12] Adelekan, D. S., Ohunakin, O. S., Babarinde, T. O., Odunfa, M. K., Leramo, R. O., Oyedepo, S. O., & Badejo, D. C. (2017). Experimental performance of LPG refrigerant charges with varied concentration of TiO₂ nano-lubricants in a domestic refrigerator. *Case Studies in Thermal Engineering*, 9, 55–61.