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Performance of a Domestic Refrigerator infused with Safe Charge of R600a refrigerant and various concentrations of TiO_2 nanolubricants

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Abstract

Widespread adoptions of hydrocarbon-based refrigerants in domestic refrigerators are limited due to lack of economically viable flammability risk reduction methodology. This study presents an experimental investigation of a safe R600a refrigerant mass charge of 30 g and various concentrations of TiO_2 nano-lubricants (0.2, 0.4 and 0.6g/L) in a slightly modified R134a domestic refrigerator. Performance parameters investigated at selected evaporator temperatures were instantaneous and mean power consumption, per power ton refrigeration (PPTR), discharge temperature and coefficient of performance (COP) respectively. Findings showed that the mean PPTR and power consumption range were 0.79 - 1.05 and 73 - 86.33 W. In addition, mean discharge temperature and COP range were 50 - 62^{o}C and 3.23 - 4.03 respectively. In conclusion, the adoption of TiO_2 nanoparticles enhanced the cooling rate and energy saving potential of the system considerably

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Keywords: Domestic refrigerator; Nanoparticle; R600a; TiO_2.

1. Introduction

The urgency for chloro-fluorocarbons (CFCs), hydro-chlorofluorocarbons (HCFCs) and hydro-fluorocarbon (HFCs) refrigerants phase out are encouraging increased adoptions of hydrocarbon-based refrigerants witnessed

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recently. Justifications for increased adoptions of hydrocarbon working fluids includes; (i) negligible global warming potential and neutral reaction to Ozone layer [1], (ii) improved performance with lower mass charges [2], (iii) compatibility with existing sub-components [3] and (iv) energy-exergy performance improvement [4]. However, flammability risks associated with hydrocarbon based refrigerant handling are major restrictions to their widespread

Nomenclature

h	refrigerant enthalpy (kJ/kg)
PPTR	Power per ton refrigeration
P	Pressure (kPa)
T	Temperature (°C)
COP	Coefficient of performance

adoption in small-medium scale refrigeration applications. Thus, numerous attempts to ameliorate these flammability concerns abound in recent literatures. In Ohunakin et al. [5], conditions for hydrocarbon based refrigerant applications in domestic refrigerator were listed as; (i) sealing of the system containing the hydrocarbon refrigerant and/or minimize the number of connections, (ii) Limiting the maximum charge of hydrocarbons, (iii) Applying a ventilation source to minimize the concentration of HC in the ambient air lower than the flammability limit, and (iv) Eliminating the source of ignition associated with the system. Corberan et al., [6] studied the risk assessment of using hydrocarbons in domestic refrigerators and concluded that they are safe regardless of their location provided their mass charges are less than 150g. The flammability risk of liquefied petroleum gas (LPG) refrigerant was reduced by increasing R134a mass fraction in LPG/R134a refrigerant blends [7-8]. In addition, direct variation between flammability limit and mass charge was established for hydrocarbons by Rasti et al.[2] as shown in Eq. 1.

$$m = 2.5 lfl^{5/4} HA^{0.5} \quad (1)$$

Where, m is the mass–charge of hydrocarbon refrigerant, lfl is the lower flammability limit of the hydrocarbon refrigerant, H and A is the height and the area of the room where the experiment is being conducted. Hence, from Eq. (1), safety of hydrocarbon-based domestic refrigerator is feasible by reducing hydrocarbon refrigerant charge. Reducing hydrocarbon refrigerant mass charge beyond considerable limits would negatively impact on their performances. Thus, the infusion of nanoparticles in such refrigeration system applications are being studied recently [9-11]. In a recent study by Bi et al., [10], the performance of selected concentrations (0.1, 0.3 and 0.5g/L) of TiO_2 nanoparticle in a domestic refrigerator using R600a was studied and inference of improvements in the system was reported. However, the research focused on time based variation of fridge-freezer compact temperatures and pressures. Thus, based on authors' inclusion of selected concentrations (i.e. 0.2, 0.4 and 0.6g/L) of TiO_2 nanoparticle in a domestic refrigerator using 40g mass charge of LPG refrigerant improved performances at selected cabinet air temperature performance [9]; This work experimentally investigates the energetic performance of a domestic refrigerator infused with 40g R600a refrigerant mass charge and similar concentrations of TiO_2 nanoparticles.

2. Methodology

The experimental investigation in this research utilized only 40 g charge of R600a refrigerant with different compressor oil lubricants [i.e. pure lubricant (0 gL^{-1}), and different concentration of TiO_2 nano-based lubricant (0.2 gL^{-1}, 0.4 gL^{-1} and 0.6 gL^{-1})] for the test. The experiment was performed under a no-load continuous running compressor working condition without ON/OFF. Parameters including T_1, T_2, T_3, P_1, P_2, W and mass flow rate (m) were captured at selected evaporator air temperature values of 20, 15, 10, 5, 0 and -5 °C, for all the experiment. NIST refrigerant software Ref-Prop 9.1 was used for the R600a refrigerant, to obtain the saturated vapour enthalpy (h_1), superheated vapour enthalpy (h_2), saturated liquid enthalpy (h_3), using the corresponding pressures and temperatures of the refrigerants at different sections of the test rig. The repeatability of experiments was ensured for all trials by conducting each test three (3) times. The under-listed governing Eqn. 2-3 were adopted in this investigation:

$$PPTR = 3.5\frac{(h_2 - h_1)}{(h_1 - h_3)} \quad (2)$$

$$COP = \frac{h_1 - h_3}{h_2 - h_1} \quad (3)$$

Fig. 1 illustrates the experimental test rig. The rig consists of evaporator, compressor, condenser, capillary tube and dryer. The configuration of the test rig is shown in Table 1. The rig was equipped with digital thermocouples (6800II Type K) to monitor the suction (T_1) and discharge (T_2) temperatures of the compressor, condensing temperature (T_3), evaporator air temperatures (T_{AIR}) and pressure gauges (HONGSEN HS-5100L) to capture the suction pressure (P_1) and discharge pressure (P_2). A wattmeter (RoHS-D02A) was also fitted to the test rig to monitor the instantaneous power consumption (W) of the refrigerator system, throughout the experiment. All investigations were carried out in a closed door air-conditioned laboratory that is equipped with a 10 tonne capacity air conditioner, to ensure stability of 29^{o}C pre-set ambient temperature.

A two-step approach in line with the work of Adelekan et al, [3] was adopted to produce the required TiO_2/mineral oil nano-lubricant concentrations (0.2, 0.4 and 0.6 g/L). The prepared nanolubricants stability were monitored for nanoparticle sediments in line with the description of Fuskele and Sarviya., [11] and they were found to be considerably stable. A Branson M2800H was adopted for homogenizing the required TiO_2/mineral oil nano-lubricant mixture while the required quantities of the 15nm size TiO_2 nanoparticles produced by Alfa Aesar per experimental trial were measured using OHAUS PA114 digital measuring scale (having maximum measurement capacity of 110 g). The lubricating oil characteristics can be found in Table 2.

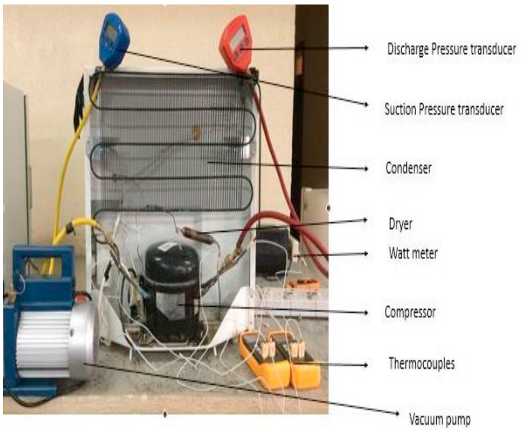

Fig 1: Experimental Set Up

Table 1: Test rig Configuration

S/N	Component	Units
1	Compressor type	HFC
2	Compressor Power rating	120 Watts
3	Evaporator size	50 Litres
4	Capillary tube length	2m
5	Condenser type	Air cooled
6	Compressor Oil type	Mineral oil
7	Door type	Single
8	Defrost type	Manual
9	Refrigerant type	R134a

Table 2: Characteristics of the Compressor Oil

S/N	Description	Units
1	Oil Name	Capella D mineral oil
2	Density at 15^{o}C	0.91 kg/L
3	Kinematic viscosity at 40^{o}C	68 mm^2/s
4	Kinematic viscosity at 100^{o}C	6.8 mm^2/s
5	Viscosity index	22
6	Code	41562

3. Results and Discussion

The instantaneous and average power consumption within the compressor when charged with different concentrations of nano-lubricants is shown in Fig. 2. It can be seen that power consumptions varies directly with evaporator temperature. In addition, 0.2 g/L nano-lubricant concentrations had relatively reduced power consumption values than 0. 0.4 and 0.6 g/L lubricant at the same evaporator temperature within the domestic refrigerator. In addition, with the mean power consumption decreased and increased with increasing concentration nano based-lubricants in comparison to the pure lubricant. The use of 0.2 g/L lubricant gave 6.2% reduction in the mean power consumption of the system when compared to the baseline (0g/L) having mean power consumption value of 77.83 W. Beyond 0.2 g/L, the mean power consumption of the rig increased by 8.87% and 10.92 % for 0.4 g/L and 0.6 g/L. Furthermore, the highest mean power consumption was obtained as 86.33W, using 0.6 g/L compressor lubricant, while 0.2g/L nano-lubricant gave the lowest as 73 W.

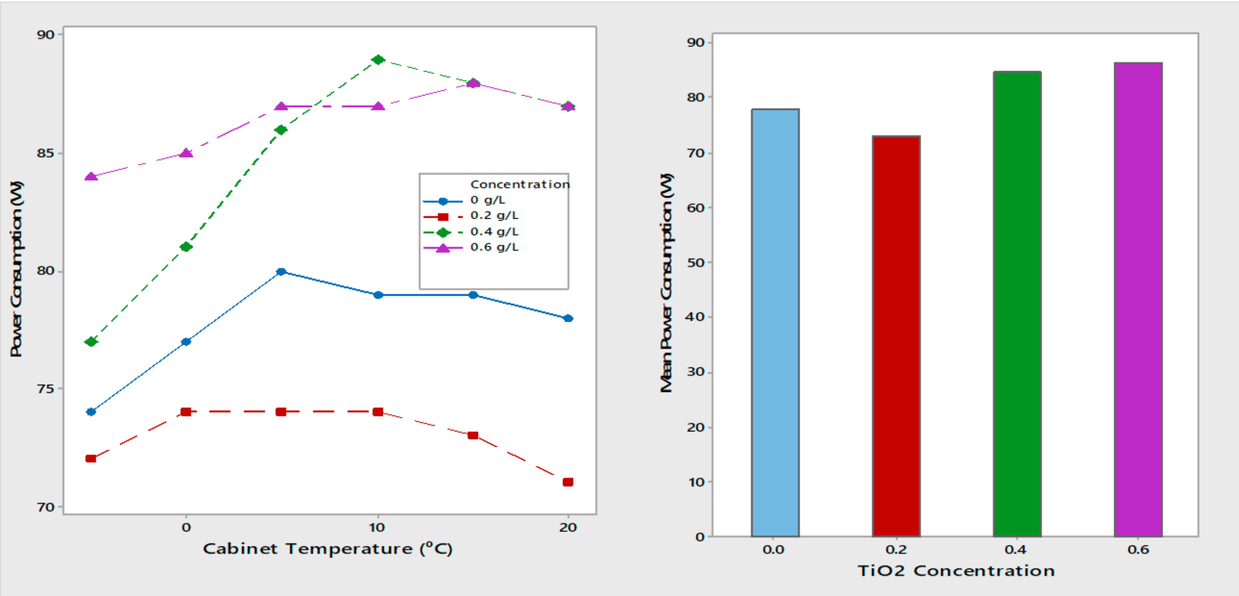

Fig 2: Instantaneous and Mean Power Consumption Variation.

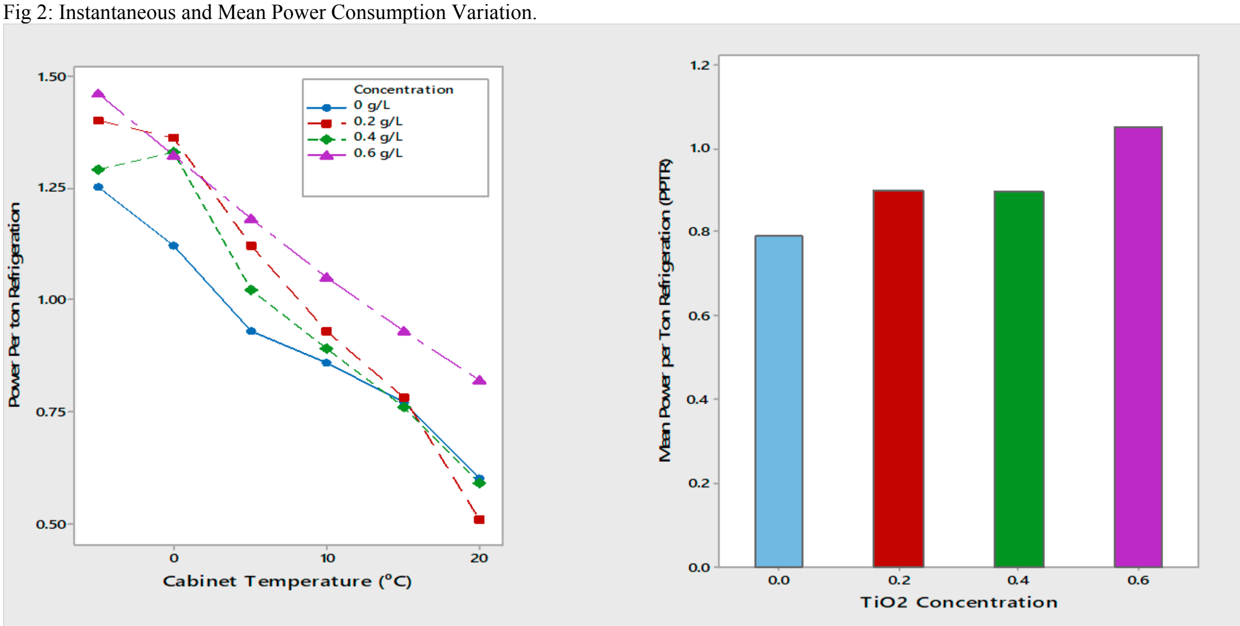

Fig 3: Instantaneous and Mean Power per Ton Refrigeration Variation

In fig. 3 the instantaneous and mean power per ton refrigeration variation can be seen. The relatively lowest mean and instantaneous PPTR were obtained with 0 g/L, while 0.6 g/L compressor lubricant gave the highest. Mean PPTR values obtained with the rig were 0.79, 0.9, 0.897 and 1.05 for 0, 0.2, 0.4 and 0.6g/L compressor oil lubricant.

The instantaneous and mean discharge temperature variation within the system is shown in fig.4. The instantaneous and mean discharge temperatures of the rig vary directly increasing TiO_2 concentrations. The lowest and highest mean discharge temperature values of 50 and 60°C were seen with the infusion of 0 and 0.6g/L compressor lubricants. The result obtained in this investigation affirms the assertions of Bobbo et al. [12], that the high discharge mean discharge temperature seen within 0.2, 0.4 and 0.6g/L lubricant could be due to increase in the viscosity of the R600a refrigerant.

In fig 5, the coefficient of performance variations within the rig is described. The coefficient of performance of the compressor lubricants varies directly with cabinet air temperature. Also, the inclusion TiO_2 nanoparticles into the system gave relatively lower coefficient of performance in comparison to 0g/L. This results therefore justifies the conclusion for optimizing capillary tube lengths within domestic refrigerator using hydrocarbon based refrigerants by Fatouh et al., [13] and Gill et al., [14].

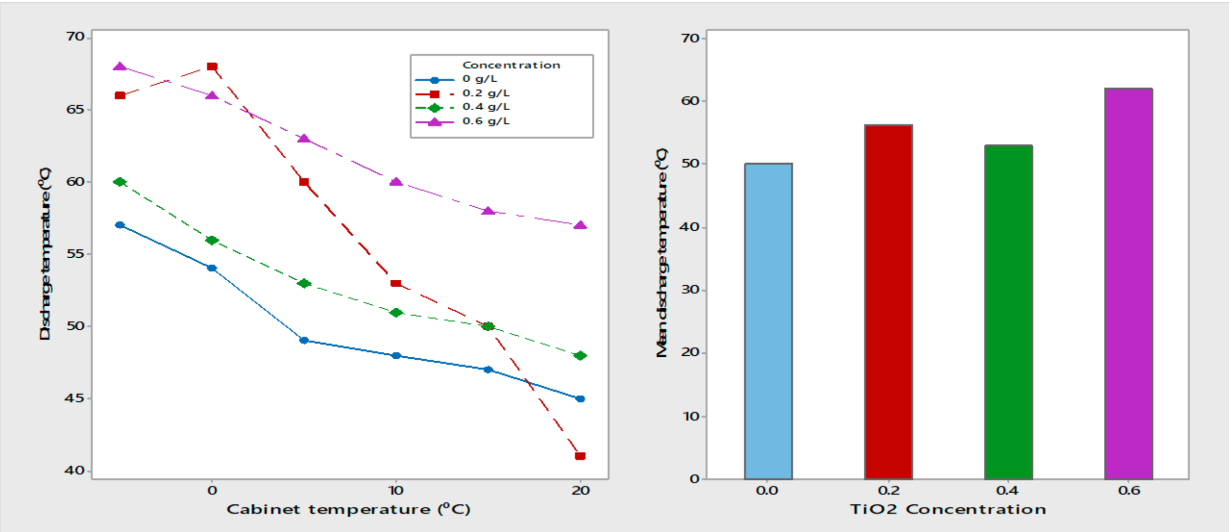

Fig 4: Instantaneous and Mean Discharge temperature Variation

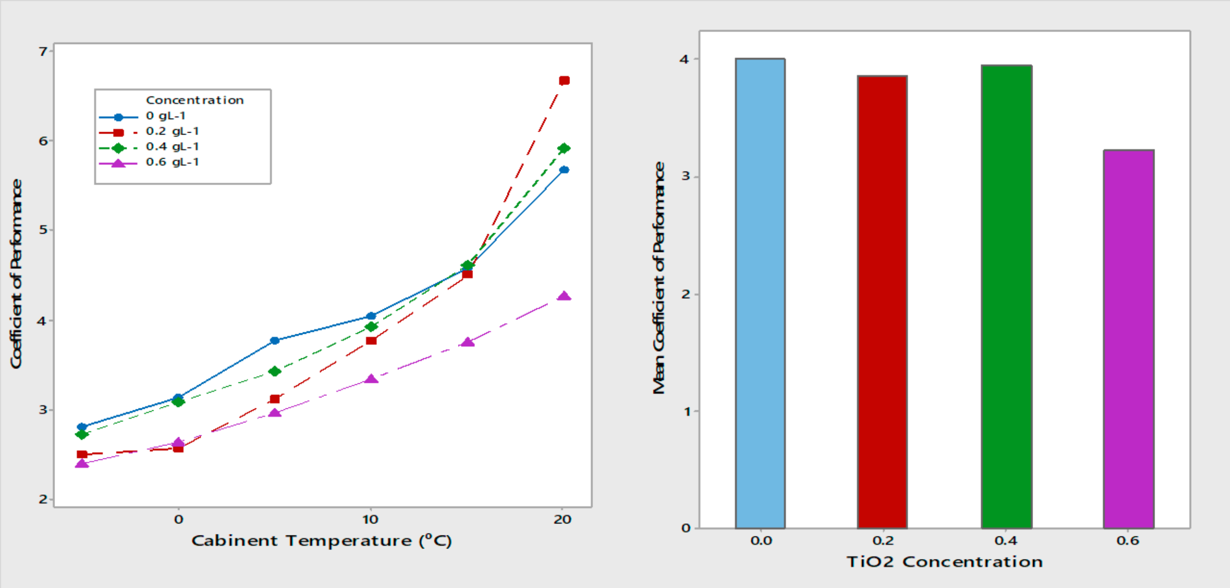

Fig. 5: Instantaneous and Mean Coefficient of Performance Variation

4. Conclusion

It can be concluded from the performance of the domestic refrigerator infused with safe mass charge (40g) of R600a refrigerant and various concentrations of TiO_2 nanolubricants that the system worked safely with the selected concentrations and improved both the energetic and cooling performances. The other findings seen with the evaluated performances were:

- The mean power consumption of the system were lower by about 6.2 % for 0.2g/L lubricant than baseline (0 g/L) lubricant and increased by 8.87 % and 0.92% for 0.4g/L and 0.6g/L lubricants.
- The utilization of TiO_2 based nanolubricants (i.e. 0.2, 0.4 and 0.6 g/L) within the system gave higher mean PPTR values than baseline lubricant.
- The mean discharge temperatures of the test rig with TiO_2 based nanolubricants (i.e. 0.2, 0.4 and 0.6 g/L) were relatively higher than baseline lubricant by about 6- 24 %.
- The coefficient of performance of the test rig with TiO_2 based nanolubricants were relatively lower than 0g/L by about 1.33- 9.33 %.

In summary, the utilization of nanotechnology alone may not be sufficient to improve the sustainability in all regards of low mass charges of R600a in domestic refrigerators.

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References

[1] O.S. Ohunakin, D.S. Adelekan, T.O. Babarinde, R.O. Leramo, F.I. Abam, C.D. Diarra. Experimental investigation of TiO_2, SiO_2 and Al_2O_3-lubricants for a domestic refrigerator system using LPG as working fluid. Appl Therm Eng 127 (2017).
[2] M. Rasti, S. Aghamiri, M.S. Hatamipour. Energy efficiency enhancement of a domestic refrigerator using R436A and R600a as alternative refrigerants to R134a. Int J Therm Sci 74 (2013) 86–94.
[3] D.S. Adelekan, O.S. Ohunakin, T.O. Babarinde, M.K. Odunfa, R.O. Leramo, S.O. Oyedepo. Experimental performance of LPG refrigerant charges with varied concentration of TiO_2 nano-lubricants in a domestic refrigerator. Case Stud Therm Eng 9 (2017).
[4] J. Gill, J. Singh. Component-wise exergy and energy analysis of vapor compression refrigeration system using mixture of R134a and LPG as refrigerant. Heat Mass Transf. (2017) 1–14.
[5] O.S. Ohunakin, D.S. Adelekan, J. Gill, A.A. Atayero, O.E. Atiba, I.P. Okokpujie. Performance of a Hydrocarbon Driven Domestic Refrigerator based on Varying Concentration of SiO_2 Nano-lubricant. Int. J. Refrig.94 (2018) 59-70.
[6] J.M. Corberán, J. Segurado, D. Colbourne, J. Gonzálvez. Review of standards for the use of hydrocarbon refrigerants in A/C, heat pump and refrigeration equipment. Int. J. Refrig. 31 (2008) 748–756.
[7] J. Gill, J. Singh. Experimental Analysis of R134a/LPG as Replacement of R134a in a Vapor-Compression Refrigeration System. Int. J.

Air Cond. and Ref. 5(2) 1750015.
[8] J. Gill, J. Singh, O.S. Ohunakin, D.S. Adelekan, ANN approach for irreversibility analysis of vapor compression refrigeration system using R134a/LPG blend as replacement of R134a. J Therm Anal Calorim (2018) 1–17.
[9] D.S. Adelekan, S. Ohunakin, J. Gill, A. Atayero, C.D. Diarra, A. Asuzu. Experimental performance of a safe charge of LPG refrigerant enhanced with varying concentrations of TiO_2 nano-lubricant in a domestic refrigerator. doi:10.1007/s10973-018-7879-2.
[10] S. Bi, K. Guo, Z. Liu, J. Wu. Performance of a domestic refrigerator using TiO_2-R600a nano-refrigerant as working fluid. Energy Convers Manag 2011;52:733–7. doi:10.1016/j.enconman.2010.07.052.
[11] V. Fuskele, R.M Sarviya. Recent developments in Nanoparticles Synthesis , Preparation and Stability of Nanofluids. Mater Today Proc 2017;4:4049–60. doi:10.1016/j.matpr.2017.02.307.
[12] S. Bobbo, L. Fedele, M. Fabrizio, S. Barison, S. Battiston, C. Pagura. Influence of nanoparticles dispersion in POE oils on lubricity and R134a solubility. Int J Refrig 2010;33:1180–6.
[13] M. Fatouh, M. El Kafafy. Assessment of propane/commercial butane mixtures as possible alternatives to R134a in domestic refrigerators. Energy Convers Manag 2006;47:2644–58.
[14] J. Gill, J. Singh, O.S. Ohunakin, D.S. Adelekan. Energy analysis of a domestic refrigerator with ANN using LPG/TiO_2–lubricant as a replacement for R34a. J of Therm. Analysis and Calor. (2018) 1-14.