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Preparation and Performance Analysis of Graphite Nanoparticle in Domestic Refrigerator

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ABSTRACT

This article examines experimentally the performance of domestic refrigerators with isobutene (R600a) and graphite nano-lubricants as working fluids. Graphene has an extremely thin layer structure that fills the friction surfaces and reduces friction losses quickly. However, there is a lower coefficient of friction (COF) and higher thermal conductivity of nano-fluids generated using graphite in the base fluid. The graphite nanoparticles modified in the surface are verified to continuously suspend for a long period of time in the form of clusters. The refrigeration test examined the application of the graphite nano-lubricants in the domestic refrigerator with a volume concentration of 0.1%, 0.3%, and 0.5%. The findings show that nano-refrigerants in the refrigeration system work safely and normally. And also compressor and refrigerator output have been analyzed. Moreover, refrigerator energy usage decreased by 15.26%, 17.10%, and 21.16% with graphite nano-lubricant as a concentration of 0.1%, 0.3% and 0.5%, respectively.

Keywords : Nano-lubricant, graphite, energy consumption, Domestic refrigerator, Refrigerant oil, Coefficient of friction (COF)

I. INTRODUCTION

In this study, the various fractions of nanoparticles has been examined in several fields as lubricant additives. The nano-lubricant is generated by dissolving nanoparticles into the lubricant. The heat exchanger might be accomplished superior energy efficiency by minimizing the COF of the compressor. Compressors have a reduction in COF by 15%–20%, given by Kedzierski and Gong [1]. However, it is important to minimize COF by cultivating the lubrication efficiency of compressors so that compressors are operated safely and reliably. The improvement of the refrigeration system with nano-lubricant was caused by two ways- On the one side, adding nanoparticles could adjust the lubricant characteristics that could enhance the refrigerator compressor's energy performance. Kedzierski [2] found that the density and viscosity of the base fluid of CuO nanoparticles increased while Kole and Dey [3] found the same pattern by scattering Cu nanoparticles into the gear oil. The friction and anti-wear properties of fullerene added nano-lubricant in scroll compressors were examined by Lee et al. [4]. This results from the improvement of base lubrication by covering the rubber surfaces in fullerene nanoparticles. The lower friction and less wear resulted in higher levels of fullerene nanoparticles [13]. Furthermore, in the wear behaviour of sliding contact areas under intense contact pressure conditions, the viscosity of the lubricant possessed a significant part, given by Ciantar et al. [5]. Thus viscosity of nano-lubricant needs essential to be measured. Besides, refrigerator output should be checked for a certain time to ensure that the compressor is reliable and stable with nano-lubricants.

On the other hand, nanoparticles should increase the thermal performance of the base fluid. For example, Jiang et al. [6] initiate the thermal conductivity of CNT-R113 to be more than R113 nano-refrigerants. To increase the lubrication effect and heat transfer performance (HTP), the prerequisite form of nanomaterials must be taken into consideration. Nano-graphite has been selected from the various materials in this article for their ease-of-use, high thermal conductivity (approximately 110-190 W/m.K), and outstanding lubrication properties as an additive [7]. Furthermore, the improvement in HTP of the evaporator and condenser in the freezing system would minimize the temperature between the inside and outside the system, leading to an improved COP. The researchers attracted attention to the improvement by the frictional features of attaching nanoparticles to the base oil. The COF between contact surfaces can be decreased after the addition of nanoparticles to the lubricants [8] and filling and repairing of the contact surface [9]. Lee et al. [5] accessible the friction and anti-wear properties of nano-lubricants which are made up of chilled oil and fullerene nanoparticles. The study demonstrated a better lubrication efficiency on friction surfaces by minimizing losses in the surface metal by the existence of fullerene nanoparticles in the lubricants. Sanukrishna et al. [10] examined the effect on synthetic refrigerant oil by dispersing SiO_2, TiO_2, and Al_2O_3 nanoparticles and found that reduction in the COF of the three nano-lubricants is 24.7%, 14.3%, and 3.9% respectively. Nanoparticles upsurge the thermal conductivity as well as improve the HTP of the refrigerator. Ghorbani et al. [11] have measured HTC of R600a/POE oil/CuO at a volume concentrations of 0.5 v%, 1.0 v%, and 1.5 v%. The findings show that the HTC of the nanofluids has risen by 5.1%, 9.12%, and 14.6% respectively as compared with the R600a/POE oil. Based on both benefits, several studies have used the valuable properties of nanoparticles in the refrigerating systems.

The effect of R134a/PAG oils/CuO was experimentally studied by Sanukrishna et al. [12]. The authors found that 5.2% reduction in compressor work. The freezing capability in the cooling system was improved by 11.1%. The HTC of heat transfer was upgraded by 37%. This study is aimed at testing and checking, under semi-tropic operating conditions of the performance and protection of refrigerators using nano-lubricants. Primarily, different volume concentrations of graphite nano-lubricants have been prepared. After that graphite nanoparticles and nano-lubricants were observed. Secondary, in a refrigerator test device, a household chiller with isobutene (R600a) for the operating fluid was chosen. The refrigerator nano-lubricant and pure lubricant were further tested for energy consumption and freezing capability. The ultrasonic dispersion was used to measure the dispersion stability in graphite refrigerant oil. It was also tested for its thermal conductivity and COF. Graphite refrigerant oil is one of the dazzling consequences of innovation and technology that might improve the COP of the thermal systems remarkably and also there is significant enhancement in thermo-physical properties, heat transfer ability that increases the efficiency and reliability of the refrigeration system.

II. EXPERIMENTAL ANALYSIS AND PROCEDURE

There are two major compartments in this type of refrigerator- freezer and food compartments. The coolant flows first into the cooling evaporator and then into the evaporator. When a group of tests was completed, each domestic refrigerant output test involved soldering of different levels of graphite refrigerant oil. The compressor has been removed and the lubricants have been released fully inside the compressor. Different nano-refrigerant concentrations were filled into the compressor of the refrigerator and tests were done at 25°C (accuracy ± 0.50°C within 24 h) in the domestic refrigerator laboratory. The relative humidity was 45% -75% (range of accuracy of ±2.0% in 24 h) while flow rates for air were less than 0.25 m/s, and R600a refrigerant was used as a coolant in the refrigeration system. R600a refrigerant is charged into the compressor after the leak and vacuum inspection. The balance weight precision is ±0.01g. The compressor was supplied with graphite refrigerant oil, with the precision of ±0.1 mL. The schematic and experimental diagrams of the domestic refrigerator laboratory have been illustrated in Figure 1, Figure 2 respectively and Figure 1 shows precise information and specific measuring points. And Table 1, Table 2, and Table 3 are summarised as Parameter assessment, physical parameters, and performance parameters of the refrigeration system respectively.

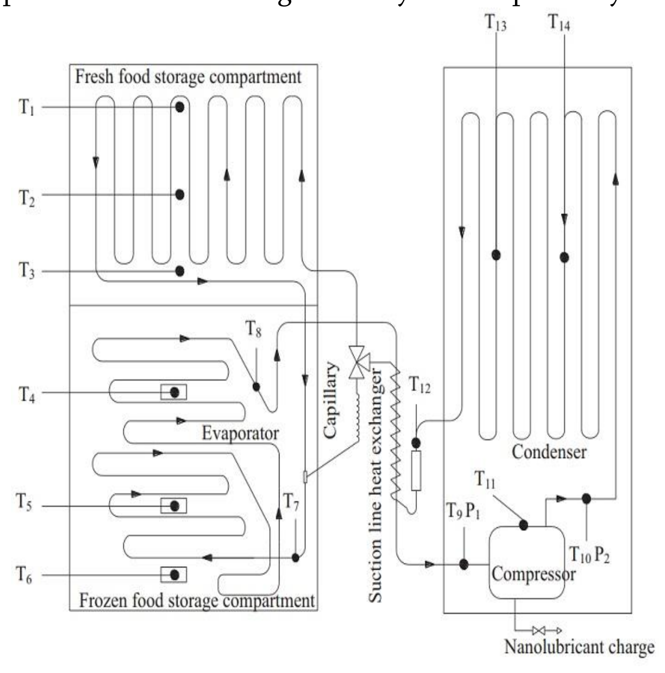

Figure 1. Schematic diagram of domestic refrigerator with specific measuring points

Table 1. Parameter assessment of domestic refrigerator

Parameter	Assessment	Parameter	Assessment
P1	Compressor inlet	T9	Evaporator middle
P2	Compressor outlet	T10	Evaporator lower
T1	Compressor inlet	T11	Dryer surface
T2	Compressor outlet	T12	Fresh food compartment upper
T3	Compressor shell temperature	T13	Fresh food compartment middle
T4	Condenser inlet	T14	Fresh food compartment lower
T5	Condenser outlet	T15	Freezer
T6	Evaporator inlet	T16	Freezer upper (M package)
T7	Evaporator outlet	T17	Freezer middle (M package)
T8	Evaporator upper	T18	Freezer lower (M package)

Table 2. Physical parameters of graphite nanoparticles

Performance parameters	Purity (vol. %)	Tap density (g/L)	Thermal conductivity (W/m.K)
Range	≥98.7	5.2	825~945

Table 3. Test performance parameters of domestic refrigerator

Device	Accuracy	Range
Digital thermocouple	±0.15 ºC	-40 ºC to 120 ºC
Digital pressure	±0.01 %	0 to 2 MPa

Digital watt	±0.1 %	≥5 mA

Figure 2. Experimental diagram of domestic refrigerator

In order to test their cooling rate, the four thermocouples were put in the fridge and freezer. To test the freezing capacity of the freezer, three "M" packages were arranged and all necessary experimental parameters are listed the spread indecisions of the measured variables. The experiment was as follows: In the laboratory, the environmental temperature was first set at 32°C. The cooling system was powered off and the door of the domestic refrigerator was opened for at least six hours to match internal temperature with the ambient temperature. The temperature control unit was then set to hold the freezer at 278K and 255K in a steady state condition. Then door was closed, power turned on, and the cooling rate test was carried out. After 24 hours of stable operation of the refrigerating unit, the top, middle and lower layers of the freezer easily positioned three M packages of 298K. The time of the temperature changes of M packages was reported between 25°C and -18°C. After completion of the freezing ability test, the fridge energy consumption is registered and the energy consumption test is carried out for 24 hours. A total of four benchmarking studies have been conducted. To ensure its reliability, the experiment was repeated.

III. PREPARATION OF NANO-LUBRICANS

The characteristics of graphite nanoparticles are thin, high surface energy, and high surface area. The graphite nano-lubricant was produced in the following two phases. Firstly, at different concentrations and magnetic agitation at 2000 rpm for 60 min at 50°C, modification nano-graphite was applied to the base lubricant for 60 minutes. The product was then vibrated with an ultrasound dispersing system for 1 hour at 50°C every 4 hours three times. Lastly, 0.1%, 0.2% and 0.5% of graphite nano-lubricants have been prepared. The stability of the nano-fluid suspension was perceived for a certain interval of time. Functional nano-graphite was acquired to spread well after sixty days. Figure 2 displays a photographic graphite standard set with three dispersants. And the overall requirements for domestic refrigerant efficiency testing is met by graphite nano-lubricants.

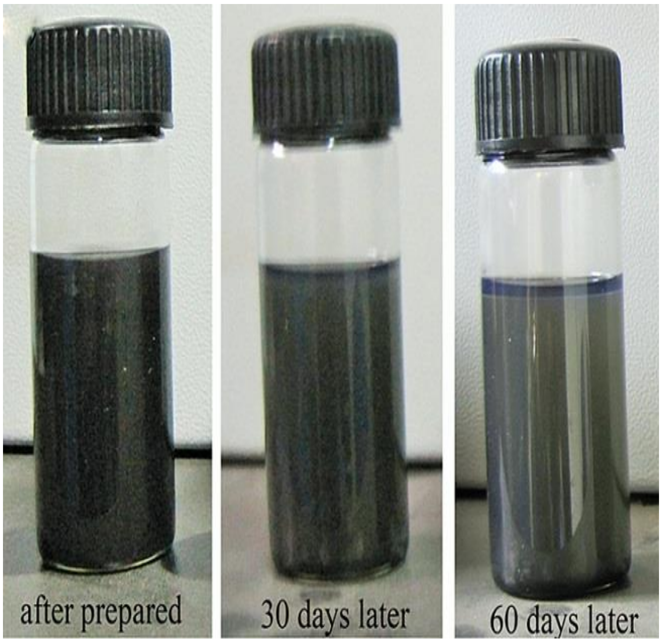

Figure 3. Nano-graphite with three dispersants

IV. EXPERIMENTAL ANALYSIS AND RESULTS

A. Thermal Conductivity of nano-refrigerants

The COF and diameter of the wear scars of nano-lubricants have been reduced by 17.5% with a concentration of 30 mg/L of graphite nano-lubricants and also the best friction efficiency was given at 30 mg/L. The consumption of energy is decreased by minimizing COF i.e., to be chosen for testing 10 - 30 mg/L graphite nano-lubricants and the thermal conductivity of refrigerant oil was analyzed. The experimental equipment included the TPS-2500S hot disc (measurement range of 0.005 - 500 W/m-K, measurement precision ±3.0%) and a constant temperature bath (range of 20-80°C, temperature variation of ±0.05°C) which was equipped with a constant water bath. The temperature rise along with increased thermal conductivity of each nano-lubricant concentration is revealed in Figure 4.

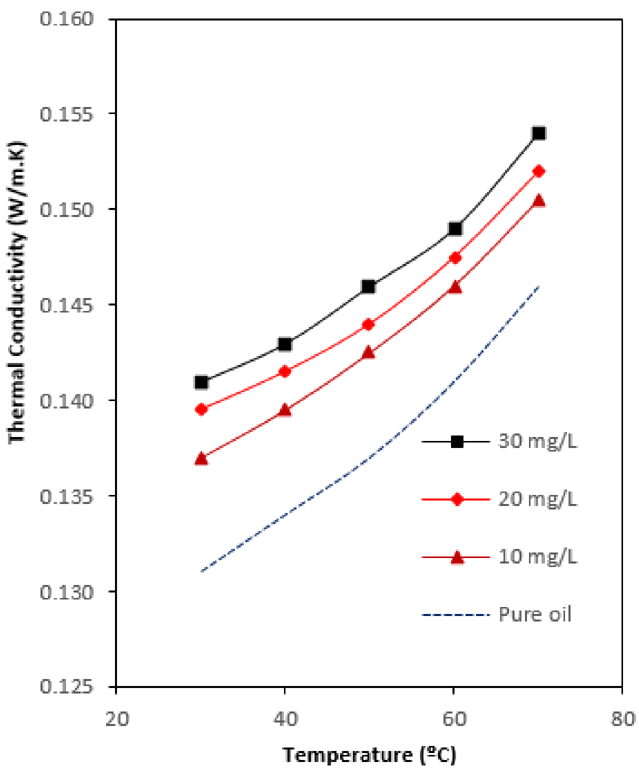

Figure 4. Thermal conductivity of graphite refrigerant oil with temperature

The thermal conductivity of the various mass fractions of graphite refrigerant oil is more than pure oil. At 70°C, refrigerant oil with 30 mg/L has increased its concentration by 5.9%. The COF diameter and the wear point were calculated with a four ball friction test and found that 8.8%, 15.7%, and 17.5% reduction in COF of graphite based refrigerant oil as compare to pure oil with 10 mg/L, 20mg/L, and 30 mg/L respectively.

B. Cooling rate comparison test

A thermocouple located on the lower third of the freezer measured the freezer temperature. The temperature fluctuates with time changes that are revealed in Figure 5. The freezer temperature was initially cooled faster using graphite refrigerant oil compare to freezer pure oil. As the mass fraction of nano-lubricants increased, the cooling rate accelerated. The shortest coolant period was at 30 mg/L of graphite lubricant oil takes 2.5 minutes less time to cool off than pure oils, while the freezer refrigeration rate increased 4.7% from 32°C to -15°C throughout cooling. The graphite lubricant oil minimized compressor electricity consumption and friction heat during the initial output phase, enabling the evaporator to cool quickly. The higher the COF, the faster the start-up, the lower the cooling rate. The control system controlled the temperature range and the test was stopped.

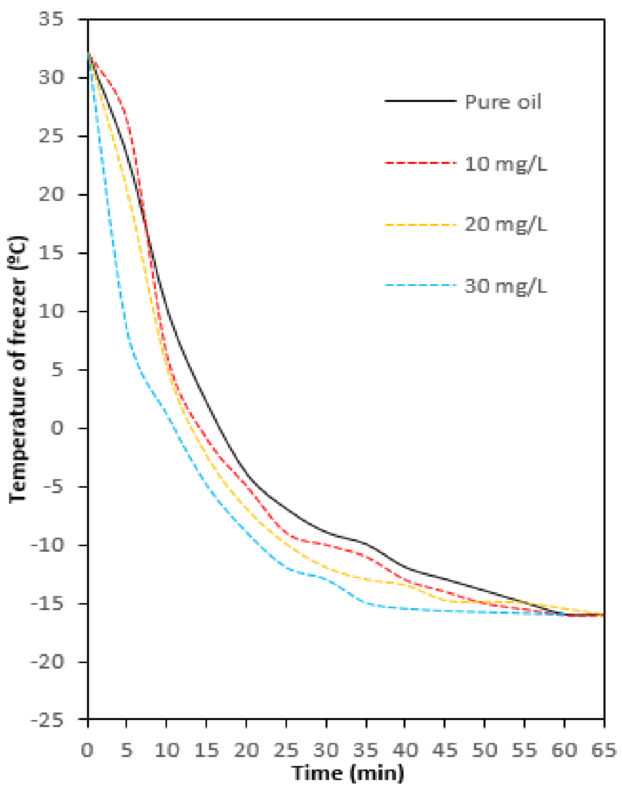

Figure 5. Comparison among freezer cooling rates

The food section was cooled from 32 - 4°C at a temperature of 10 - 30 mg/L and pure oil that is shown in Figure 6. And the temperature varies in the fresh food section over time and from experimental analysis at 30 mg/L, 5.6% increment in cooling rate has been found. During this step, refrigerants are entered into the condenser and then into the cooler to absorb heat. The fresh food compartment's temperature response is delayed and lower than the refrigerator response. The cooling curve of the food compartment was diverse from the refrigerator and the cooling rate changed significantly. Although the cooling temperature in the fresh food section was faster than pure oil.

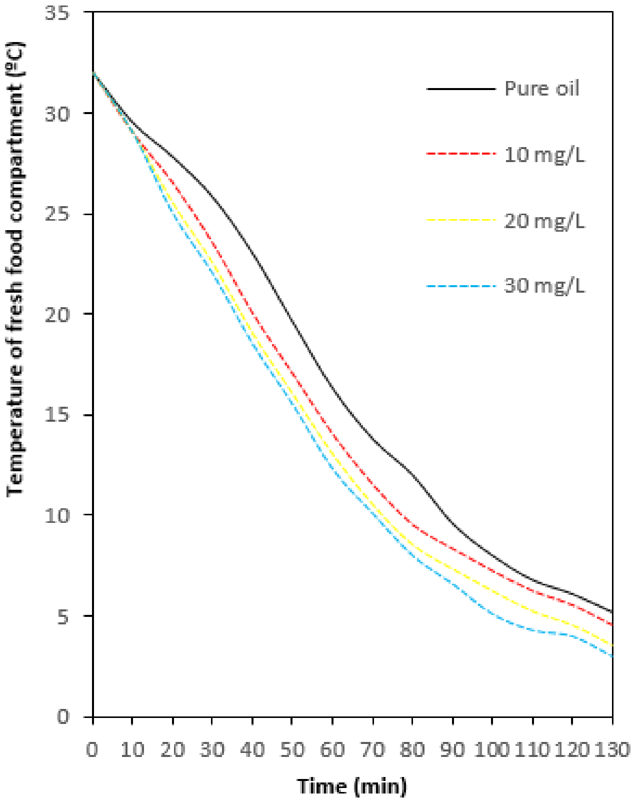

Figure 6. Cooling among fresh food compartment cooling rates.

C. Performance Analysis of Compressor

In this section, the changes in outputs during a stable starting cycle of the compressor with time are demonstrated. The cycle of the start comprises the working cycle and the domestic refrigerator stop cycle. The compressor is less dumped and released than pure oil by graphite refrigerant oil. The pressure released by the compressor was constantly decreased by 2.9%, 5.6%, 7.0% and a decrease in average release temperature of 2.5%, 4.6%, and 6.3% with 10 mg/L, 20 mg/L, and 30 mg/L graphite refrigerant oil i.e., shown in Figure 7. The suction pressure at initial state decreases drastically with time but after some time the suction pressure increases with time. The lowest suction pressure resulted at 30 mg/L graphite nano-lubricant. Graphite was auxiliary to reduce the compressor friction losses, leading to lower compressor release temperature and lower condensing, condensed and pressure ratios. The temperature change in the compressor shell with time is shown in Figure 8. Which specifies the shell temperature of the compressor is considerably abridged by the utilization of graphite refrigerant oil. The discharge temperature at initial state increases and after that it decreases with time increases. The better performance has been obtained at 30 mg/L of graphite nano-lubricant oil. And also there is faster response in cooling rate in the refrigeration system. Thus it is unblemished that the graphite refrigerant compressor oil works normally and safely as compare to pure oil.

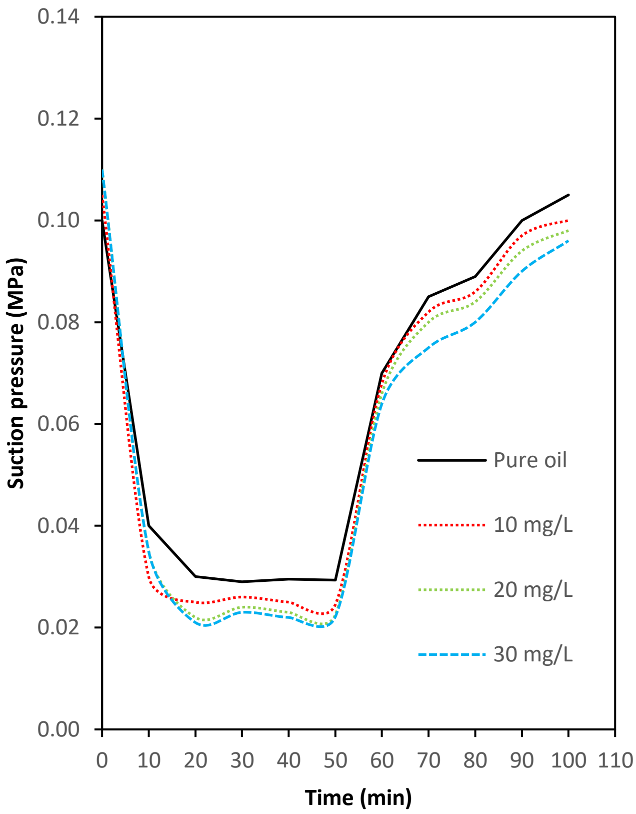

Figure 7. Suction Pressure vs time.

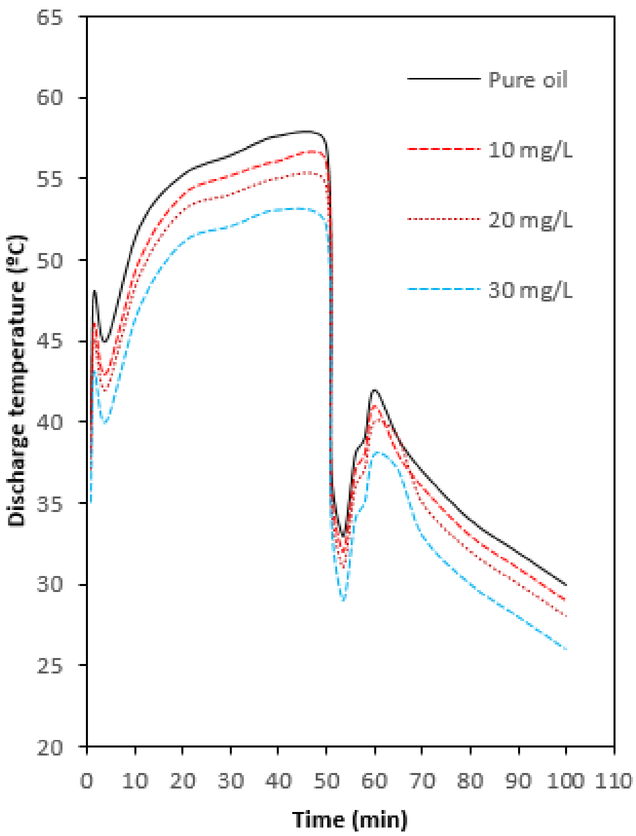

Figure 8. Discharge temperature vs time

D. Energy Consumption Test

The energy consumption test was conceded at 298K environment temperature as 60% humidity in the domestic refrigerator. In 24 hours, the energy consumption of a powerful domestically operated refrigeration system was evaluated by utilizing graphite refrigerant oil and pure oil. The domestic refrigerator efficiency parameters have been tracked and registered during stable service. This section summarises the various domestic refrigerants efficiency parameters for stable use. The domestic refrigerator's on-time ratio denotes the ratio of stable compressor working time to total time (in a single operating cycle). The intake temperature, outlet temperature, and condensing temperature reduces with rising particle fraction as a result of the reduction of frictional heat generation. The energy savings are the energy reduction rate in the domestic refrigerator with the use of the pure lubricant oil in three concentrations in 24 hours. Nano refrigerant oil reached 0.89 kWh, 0.85 kWh, and 0.82 kWh in 24 hours as compared with pure oil at 10mg/L, 20mg/L, and 30mg/L respectively. The increase in energy consumption concentration of nano-lubricants was not considered to have a direct impact anymore. Nano-lubricants in three concentrations have reduced their energy consumption by 15.26%, 18.10%, and 21.23% at 10mg/L, 20mg/L, and 30mg/L respectively. Figure 9 refers to energy consumption and energy saving by reference to the particle fraction. Furthermore, after sixty days of steady state, the 30 mg/L nano-refrigerant oil was checked and found that all data were standard.

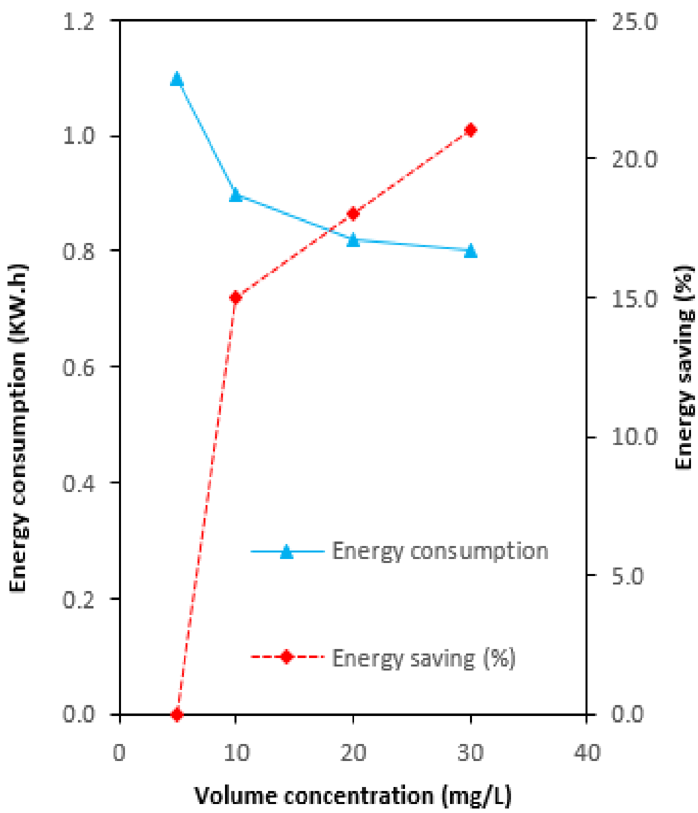

Figure 9. Variation in energy consumption and energy saving (at different concentrations)

V. RESULTS AND CONCLUSIONS

This paper studied the preparation and nature of graphite nano-lubricants experimentally and calculated their physical properties. Besides, 0.1%, 0.2%, and 0.5% mass fractions were tested for the efficiency of a domestic refrigerator with graphite nano-lubricant. The main findings are as follows:

- The evaporation temperature, condensation temperature, release pressure, temperature of discharge, aspiration pressure, and the compressor temperature have been decreased by the application of graphite nano-lubricant.
- Furthermore, the refrigerator energy consumption reduced by 15.26%, 18.10%, and 21.23% at 10mg/L, 20mg/L, and 30mg/L respectively. The downward trend, which leads to a substantial decline in energy consumption, has occurred at compressor temperature, pressure rate, and intime rate.
- The graphite refrigerant oil was tested for thermal conductivity and COF. And it was more heat-conductive than pure oil and also improved with particle fraction.
- The COF was 17.5% decreased with 30 mg/L as compared to pure oil.
- The cooling rate of the fresh food and freezer were increased by 5.6% and 4.7% respectively at a concentration of 30 mg/L.
- It also confirms that the graphite nano-lubricant can increase the efficiency of the refrigerant as utilizing R600a as a working fluid.

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Conflicts of Interest: The authors declare no conflict of interest.

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