Migration Letters

Volume: 21, No: S3 (2024), pp. 1337-1345

ISSN: 1741-8984 (Print) ISSN: 1741-8992 (Online)

www.migrationletters.com

Performance Of A Vapour Compression Refrigeration System Using Different Concentrations Of Go Nanolubricants And A Safe Charge Of R600a Refrigerant

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ABSTRACT

Energy consumption is a major issue in vapour compression refrigeration systems. In many commercial and residential applications, the cooling system now consumes a significant amount of energy. Therefore, there is an immediate need to improve cooling systems' energy efficiency. This study created three distinct samples of graphene-oxide nanolubricant with concentrations of 0.1, 0.3, and 0.5 g/L by dissolving the nanoparticles in polyolester (POE) oil. Then tests were conducted using the nanolubricant concentrations in 30, 40, and 50 g of R600a (isobutane) refrigerant, respectively. The outcomes were contrasted with the polyolester (POE) oil, which functioned as the primary lubricating substance. According to the results, a 40-g mass charge of R600a in 0.3 g/L graphene-oxide nanolubricant exhibits the greatest performance, with a maximum refrigeration effect of 0.197719 Kw, the highest coefficient of performance (COP) of 1.72, and the system's lowest power consumption of 0.115 Kw. As a consequence, pure polyolester (POE) oil may be replaced with graphene-oxide nanolubricant in the vapour compression system.

Keywords: *Graphene-oxide, Global warming, Natural refrigerant, Nanolubricants, Isobutane refrigerant, polyolester (POE) oil.*

Introduction

Today's lifestyle is significantly impacted by refrigeration systems. In addition to providing comfortable and healthy places to live, it is also seen as essential for enduring harsh weather and storing food [1]. In the modern world, refrigeration systems are more crucial than ever to ensuring that people can work or live in a comfortable environment. The primary causes of this are global warming,[1] rising temperatures, and higher living standards, especially in emerging nations [2, 3]. Refrigeration systems are predicted to contribute less to climate change by reducing their global warming effect, energy consumption, and ozone layer depletion [4, 5]. The United Nations' Kyoto Protocol proposed limiting the use of greenhouse gases as well as hydrofluorocarbons (HFCs) as refrigerants in refrigeration systems [6, 7]. As a result, researchers are considering natural refrigerants, which have recently been used as a replacement for hydrofluorocarbon (HFC) refrigerants in vapour compression systems (VCRS) with R600a, due to their excellent energy efficiency, neutral influence on the ozone layer, and relatively low global warming potential [5, 8]. However, the flammability difficulties associated with the handling of hydrocarbon-based refrigerants are substantial impediments to their widespread usage in small- to medium-scale refrigeration systems [9]. Due to their lower working temperatures and pressure conditions and flexibility in placement within homes, small residential refrigerators with

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capacities under 150 g have insignificant concerns about hydrocarbon utilisation and flammability [10].

In recent decades, the use of nanosized particles (1–100 nm) may have emerged as an alternate strategy to improve the cooling system's performance. According to reports, metal (or metal oxide) nanoparticles increase the rate of heat transfer [11]. The two methods that are most frequently used to add nanoparticles to refrigeration systems are the one-step method and the two-step method. In the one-step process, nanoparticles are produced and dispersed directly into the base fluid. Nanoparticles are separately produced in a two-step procedure, then disseminated to ensure the stability of the nanofluid. In general, a two-step approach is preferred over a one-step method [12, 13].

The utilization of nanotechnology in cooling systems is a recent advancement that is starting to capture interest. Nanoparticles are dispersed into the base lubricant to enhance the efficiency of the vapor compression refrigeration system, which also improves the refrigerant's overall transport qualities. In addition, certain nanoparticles have the capacity to improve system lubricity and lower wear. The most popular refrigerant now used in residential refrigerators is R600a. As a result, R600a's performance in VCRS has to be improved [8]. A more effective development in this direction could be graphene oxide nanolubricants. A high-potential nanoparticle is graphene oxide. It possesses a low density, a high specific surface area (SSA), hydrophilicity, insolubility, and high thermal conductivity [14]. The use of graphene-oxide nanoparticles as lubricant additives is generating a lot of attention among scientists. However, the chemical and physical characteristics of nanoparticles, such as their shape, size, and concentration in the base lubricant, play a significant role in how well a refrigerant performs in a refrigeration system.

According to certain studies, nanoparticles have been used as lubricating oil additives. In the experiment of Babarinde et al.[8]The nanoparticles of graphene were added in to the base lubricant(mineral oil).The result showed that the highest coefficient of performance is seen in graphene nanolubricants, which also have lower evaporator temperatures and also lowest consumption of power in the refrigeration system compared to the base lubricant (mineral oil).Adelekan et al. [9] R600a (isobutane) was used as the working fluid in an experiment using titanium dioxide (TiO_2) nanoparticles. The results indicated that the COP range and mean discharge temperature were 50–62°C and 3.23–4.03, respectively. Adelekan et al. [10]also used titanium dioxide (TiO_2) nanoparticle were added into the R600a (isobutene) and the outcomes show that R600a-TiO_2 nano-refrigerant performs more effectively and securely than a pure R600a system in the refrigerator. Saravanan et al. [11]carried out experimental research on a household refrigerator with varying concentrations of Al_2O_3, TiO_2 nanoparticles, and nanocomposites particles distributed in to the base lubricant (POE oil).The findings demonstrate that R134a (Tetrafluoroethane) with lubricant made of nanocomposite materials (50% Al_2O_3/50% TiO_2/POE oil) offers the best performance, with the highest actual COP (2.33), The system attained its maximum second-law efficiency at 40.9%, the least amount of compressor work (61.24 kJ/kg), the least amount of power consumed (92.2 W), and the least amount of total irreversibility (36.19 kJ/kg). Subhedar et al. [15] The experiment was designed to evaluate the efficiency of an R-134a refrigerant in a refrigeration system using a nanolubricant containing varying volume percentages of Al_2O_3 in mineral oil (0.05%, 0.075%, 0.1%, and 0.2%).The results indicate that the nano lubricant improves COP by roughly 85% as compared to base fluid. Zhelezny et al. [16]Al_2O_3 and TiO_2 nanoparticles and mineral compressor oil were used to evaluate the natural refrigerant isobutane (R600a) over a broad temperature and concentration range. It has been shown that adding nanoparticles to refrigerant/oil mixtures increases their viscosity and lowers their surface tension. Narayanasarma et al. [17] Experimental analysis was done to assess the suitability of a suspension of SiO_2 nanoparticles in polyol ester (POE) oil for use as a nanolubricant in refrigerant compressors. These aspects included thermal, corrosion, rheological, oxidative stability, and environmental kindness. The result shows that whenever temperature and proportion of mass rise, the POE/SiO_2 nanolubricant's thermal conductivity increases. Ohunakin et al. [18] Experimental research was done on a home refrigerator system using liquefied petroleum gas (LPG) as the operating fluid and low quantities nanoparticles of TiO_2, SiO_2, and Al_2O_3 dispersed within a mineral oil lubricant. At 180 minutes, the steady-state evaporator air temperatures of all nanolubricant-based LPGs were found to be lower than those of pure mineral oil-based LPGs.Al_2O_3-lubricant gave a higher power consumption of the refrigerator system when compared to the base refrigerant (LPG), although TiO_2 and SiO_2 nano-lubricants resulted in power consumptions 13% and 12% lower, respectively, than those with the base refrigerant (LPG).

The objective of the present study is to evaluate the performance of a refrigeration system that utilizes R600a as the refrigerant and incorporates a nanolubricant containing graphene oxide.

Methodology

2.1 Preparation of graphene oxide (GO) nanolubricants

In experimental research, the preparation of nanolubricants is the crucial stage. In the current work, nanolubricants were created by adding graphene oxide to polyolester oil. The graphene oxide nanoparticles of sizes 0.8 to 2 nm were procured from Ad-Nano Technologies Pvt. Ltd. The thermos-physical properties of the graphene oxide nanoparticle used are given in Table 1. The graphene oxide nanopowder was examined utilizing a scanning electron microscope (SEM), as illustrated in Figure 1.

In the current study, three different samples with nanolubricant concentrations of 0.1, 0.3, and 0.5 g/L were made from one liter of polyolester oil. Each of the nanoparticles was weighed using a digital weighing balance with a measuring range of 0.001 to 110g.The polyolester oil was mixed with graphene oxide nanoparticles at different concentrations (0.1, 0.3, and 0.5 g/L).The graphene oxide nanolubricants was then held at room temperature on a magnetic stirrer for 60 min. with a speed range of 1200 rpm to improve the homogeneity of nanoparticle dispersion within the lubricant, as illustrated in Figure 2 & 3. The nanoparticles are blended in lubricant oil with different concentration with the help magnetic stirrer then using ultrasonication process for proper mixing and separation of bounding of nano particals in lubricants.

The stability of the synthesized nanolubricant was verified through a sedimentation test. Continuous monitoring over a 5-day period revealed that the nanolubricant remained visibly stable, showing no signs of sedimentation (refer to Figure 4).

Table 1. Properties of graphene oxide used in this study

Properties	**GO nanopowder**
Purity	~99%
Thickness	~0.8-2 nm
Layers	1 to 3
Amount of Carbon	~60 to 80%
Amount of Oxygen	~15 to 32%
Odour	Odourless
Colour	Black Powder
Surface Area	110 to 250* m2/g

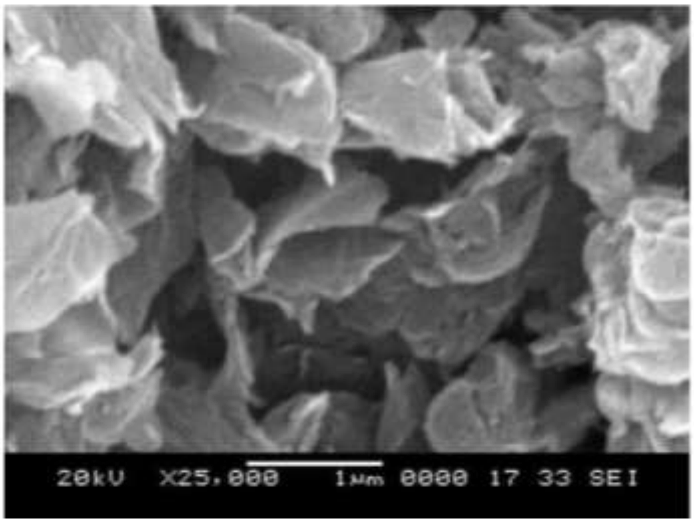


Figure 1. SEM of graphene oxide Nano powder

Figure 2. Graphene oxide nanoparticle mixed with polyolester oil

Figure 3. Magnetic stirrer

Figure 4. Sedimentation test after 5 day

2.2 Experimental test set-up

The compressor, air-cooled condenser, expansion device, and evaporator tank with built-in cooling coils to chill the water are all included in the vapour compression refrigeration test apparatus shown in Figure 5.Thermocouples were used to measure the refrigerant's temperature at the evaporator, water tank, and condenser’s inlet and outlet. The pressures in the condenser and evaporator were measured using two pressure gauges. An energy meter was used to measure the refrigeration system's power consumption.

The experimental test setup is intended to use 100 g of R134a refrigerant. Using a vacuum pump, the system was thoroughly cleaned out and flushed. R600a refrigerant is taken into account in this test setup because of its physical properties, such as 0% ODP and extremely low GWP. Due to their flammability, hydrocarbon refrigerants are only permitted in bulk charges of 150 g. As a result of R600a's reduced density compared to R134a, the refrigerant mass charges varied from 30 g to 50 g. Polyolester oil (POE) was chosen as the basic lubricant for this experiment due to its compatibility with R600a and the refrigerator parts. The experimental test rig was built to function with 100 g of R134a refrigerant.

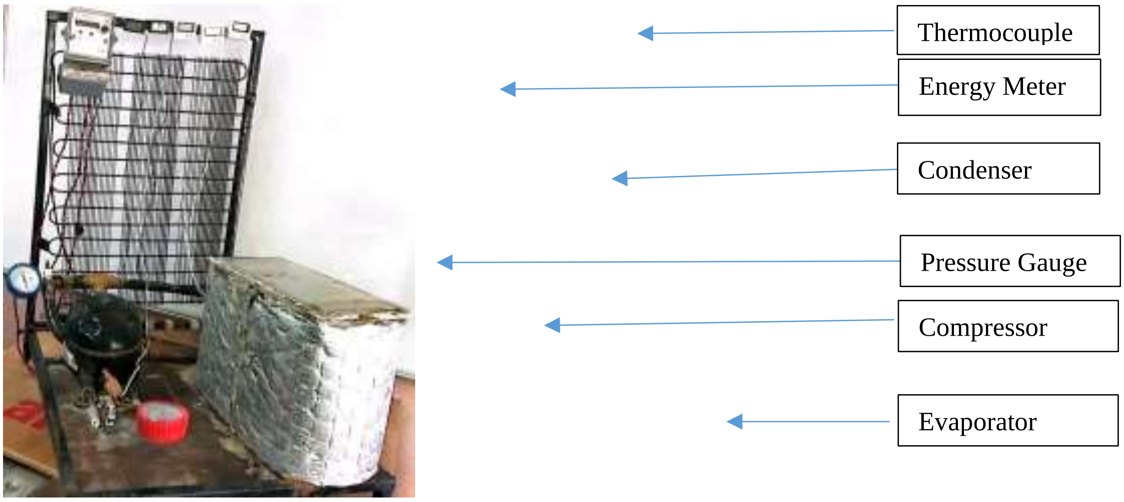


Figure 5. Experiment test rig

The experimental test set-up was filled with nitrogen (N2) gas at a pressure of 60 to 70 bar and held at that pressure for 2 hours. As a result, no leaks were detected in the system. The system was evacuated through the removal of nitrogen (N2) gas. To get rid of any pollutants, the system was completely evacuated using a vacuum pump connected to the compressor's port. This procedure was followed for all trials. The compressor was charged with the refrigerant R600a via the charging line. A 10-minute stabilization period was given to the system each time.

The following equations were used to determine the system's performance:

Refrigeration effect = $m\ Cp_w\ (T_i - T_f)\ /\ t$ KW (i)

Work input = (Ef - Eo) * 3600/t KW (ii)

Coefficient of performance = Refrigeration effect / Work input (iii)

2.3 Uncertainty analysis

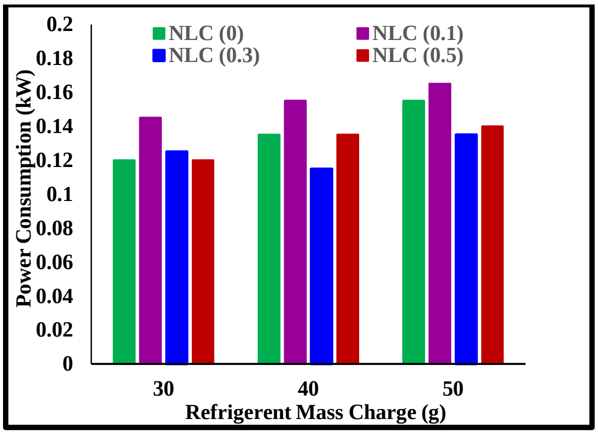
This work's uncertainties were calculated using the Schultz and Cole approach. The required parameter R's uncertainty was obtained from Eq. (v), [18, 19].

$$U_R = \left[\sum_{i=1}^{n}\left(\frac{\partial R}{\partial v_i}U_{V_i}\right)^2\right]^{\frac{1}{2}} \qquad \text{(v)}$$

Where R is the required parameter, U_R is the overall level of uncertainty, Uvi and n stand for the total number of variables and, respectively, the degree of uncertainty for each independent variable. An experimental uncertainty of less than 3% exists for each parameter.

Result and Discussion

Variable R600a mass charges and different concentrations of polyolester (POE) oil/R600a nanolubricant were employed to assess the system's performance. In Figure 6, the compressor's power usage is depicted for various nanolubricant concentrations. The power demands for 30, 40, and 50 grams of R600a were calculated using concentrations of 0.1, 0.3, and 0.5 g/L of graphene-oxide nanolubricant. Notably, the system exhibited its lowest power consumption at 0.115 kW when charged with 40 grams of R600a in a 0.3 g/L graphene-oxide nanolubricant concentration. Conversely, the system consumed more power at 0.165 kW when utilizing 50 grams of R600a with a 0.1 g/L nanolubricant concentration.



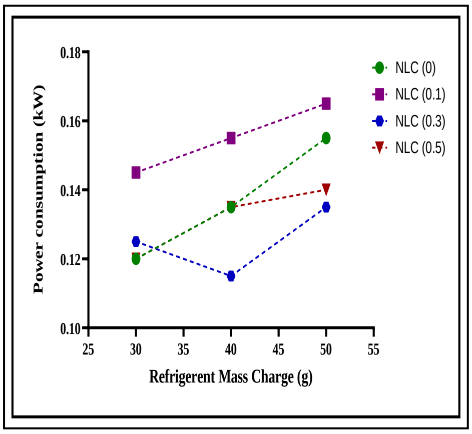


Fig. 6. Effect of the graphene-oxide nanolubricant on the system's power consumption

The refrigeration effect of the system is shown in Figure 7**.** For every mass charge of R600a in the system, the graphene-oxide nanolubricant has a greater cooling impact than the base lubricant. The use of graphene-oxide nanoparticles as a lubricant additive raises the lubricant's thermal conductivity, which improves the refrigeration effect. The system's maximum refrigeration effect, of 0.197719 KW, is provided by the 40g mass charge of R600a in 0.3 g/L graphene-oxide nanolubricant. When using 30, 40, and 50 g mass charges of R600a in the system, the experimental setup provides the lowest refrigeration effects of 0.1343, 0.1628, and 0.1372 KW for pure lubricant (polyolester oil).

The refrigeration effect of the system can only be achieved with a very low concentration of graphene-oxide nanoparticles in the base lubricant (polyolester oil), as shown in Figure 7. The refrigeration effect of graphene-oxide nanolubricant is still greater than that of the base lubricant, even at higher concentrations of the nanolubricant. The results show that dispersion of graphene-oxide nanolubricants improves the refrigeration effect, resulting in an increase in the performance coefficient.

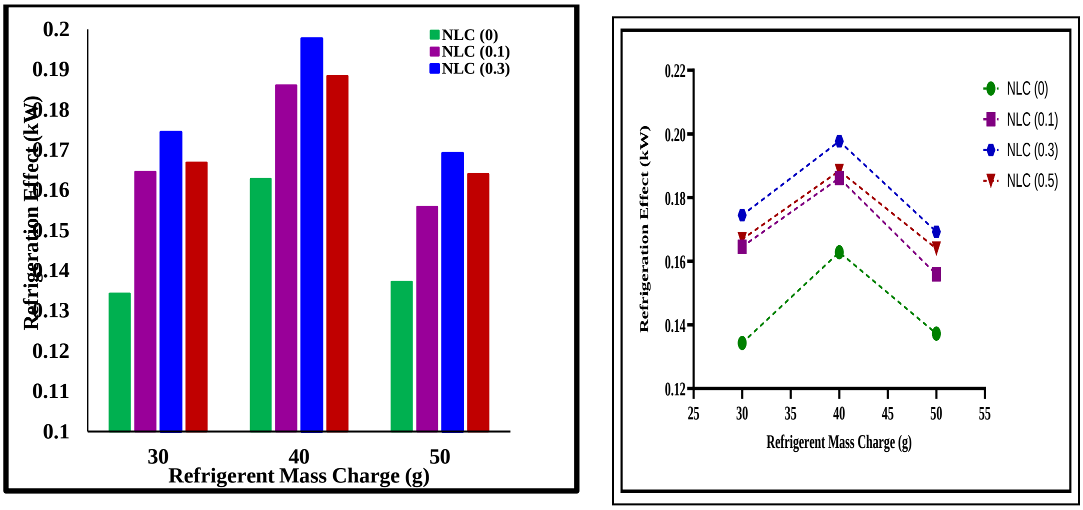


Fig. 7. Effect of the graphene-oxide nanolubricant on the system's refrigeration effect.

One of the most important considerations when selecting an alternate working fluid for a refrigeration system is the coefficient of performance (COP). It is the ratio of refrigeration effect to refrigeration system power consumption. The system's COP values are shown in Figure 8. In comparison to the base lubricant, the graphene-oxide nanolubricant has a higher coefficient of performance (COP). R600a's 30, 40, and 50 g mass charges in graphene-oxide nanolubricant have higher coefficients of performance (COP) than R600a's in the base lubricant, which range from 1.13 to 1.40, 1.20 to 1.72, and 0.94 to 1.25, respectively. At a concentration of 0.3 g/L graphene-oxide nanolubricant, the greatest coefficient of performance (COP) enhancement of 1.72 was attained. Reduced Power consumption and a greater cooling effect from the system's graphene-oxide nanolubricant are the two factors contributing to the system's increased coefficient of performance (COP).

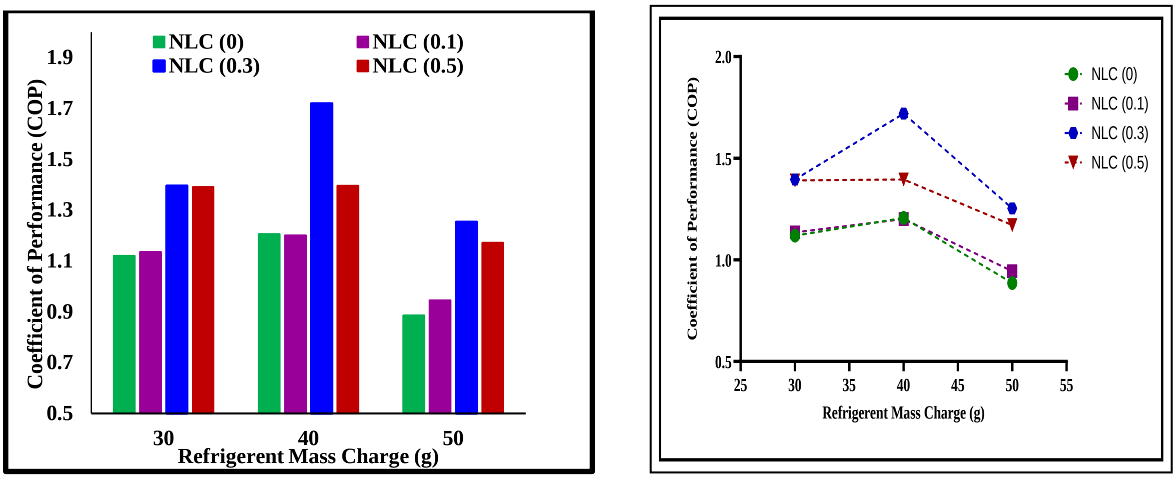


Fig. 8. Effect of the graphene-oxide nanolubricant on the system's coefficient of performance.

Conclusion

In this experimental study, the refrigeration effect, power consumption, and coefficient of performance (COP) were used to assess and compare the performance of graphene-oxide nanolubricant with that of base lubricant in an experimental test setup. Different concentrations of graphene-oxide nanolubricant (0.1, 0.3, and 0.5 g/L) were tested on the various mass charges of R600a refrigerant (30, 40, and 50 g). The following findings were reached regarding the utilisation of graphene-oxide nanolubricant concentration in the vapour compression refrigeration test rig based on the system's experimental performance:

- In the vapour compression refrigeration test rig, different mass charges of R600a and concentrations of graphene-oxide nanoparticles performed safely.
- Lower evaporator temperatures and power usage were seen throughout the experiment at concentrations of 0.1, 0.3, and 0.5 g/L of graphene-oxide nanolubricant. Therefore, it may be used in R600a-using refrigeration systems as a replacement for pure polyolester (POE) oil.
- In the vapour compression refrigeration test rig using R600a, polyolester (POE) oil can be replaced by graphene-oxide nanolubricant because it performs efficiently in terms of coefficient of performance (COP), power consumption, and refrigeration effect.

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