Experimental Investigation on Vapour Compression Refrigerator System Using Propane as Working Fluid with Graphene Oxide Nanoparticles & Pag Lubricant

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Abstract-The effectiveness of different GO nanoparticle concentrations in PAG oil lubricant as a retrofit to R134a in a domestic refrigeration unit is investigated in this experimental study. In order to evaluate suction, discharge, condensing pressures, temperatures, and power utilization in compliance with ISO 8187 requirements, the test rig is outfitted with a K type thermocouple, watt-meter, and pressure gauges. Pull-down time, compressor power input, thermal conductivity, coefficient of performance, and viscosity were all evaluated as performance factors. The results revealed that all of the selected parameters of propane refrigerant infused with various concentrations of nano-lubricants reached -7°C (ISO 8187) or lesser evaporator temperatures at minimum refrigerant charges when compared to the domestic refrigerator with R134a refrigerant. All of the nanolubricant-based refrigerants shows better performance than R134a refrigerant, with COP values ranging from 2.07 with a 50-gram charge of propane using 0.6g/L GO nanolubricant to 2.67 with a 50-gram charge of propane using 0.2g/L GO lubricant. The compressor consumes 52 W (with a 50g charge of propane using 0.2g/L) and 83 W (with a 100g charge of R134a refrigerant using pure compressor oil lubricant) for all mentioned charges of GO-lubricant-based propane compared to R134a refrigerants. Furthermore, the power intake of the compressor increased at high concentrations of nanoparticles in the lubricant and dropped at low concentrations of nanoparticles in the propane refrigerant. The suction and discharge ends of the compressor for R134a with pure mineral oil lubricant had low thermal conductivity values, whereas the suction and discharge ends of the compressor for the retrofit working fluid (pure propane refrigerant and propane with various concentrations of nano-lubricants) had high thermal conductivity values.
Keywords: *Hydrocarbon refrigerants; R134a; propane ; nanoparticle; GO(Graphene oxide) ; PAG lubricant*

1. Introduction

Conventional refrigerants with GWPs greater than 150 (like the frequently used R134a refrigerant) have been completely phased out in response to recommendations made by the United Nations (Kyoto Protocol, etc.) for more environmentally friendly strategies (Bolaji and Huan, 2013, 18; Mota-Babiloni et al., 2015). To qualify as a sustainable alternative, any refrigerant that will replace or retrofit R134a must include all of the same great features as R134a [See Gill et al. (2018), 89]. According to Calm (2008, 31) and Babarinde et al. (2015, 16), hydrocarbon (HC)-based refrigerants like propane have characteristics similar to those of R134a, but their use in refrigeration systems has been constrained due to their intrinsic flammability (Corberán et al., 2008, 31). El-Morsi (2015, 86) describes LPG. The use of LPG in refrigeration systems is an increasing trend. Harby (2017, 73) lists several methods for reducing the risk of flammability of HC refrigerants in applications, including (i) using a ventilation source to minimize the concentration of HC in the ambient air below the flammability limit; (ii) removing the system's source of ignition; (iii) sealing the system containing the hydrocarbon refrigerant and/or minimizing the number of connections; and (iv) limiting the maximum charge of hydrocarbons. A study by Rasti et al. (2013, 74), which employed a correlation model to estimate flammability and application space, revealed that a similar HC-based refrigerant was safe, suggesting that flammability issues with HC-based working fluids in home refrigerator systems may not be a huge deal.

According to Ohunakin et al. (2017, 127), R12 and R134a refrigerants are still extensively utilized in conventional refrigerators in Nigeria. This results from the influx and use of secondhand or outdated refrigeration units that are imported. Existing refrigeration systems must be retrofitted as quickly as practical with natural refrigerants, but any suggested approach must be straightforward, safe, and economically viable. As a result, over the past ten years, improved HC refrigerant applications in refrigeration systems have been noted, particularly in countries that produce large amounts of oil (See Babarinde et al., 2015, 16; El-Morsi, 2015, 86; Rasti et al., 2013, 74; Ohunakin et al., 2017, 127; Adelekan et al., 2017, 9–14; Bi et al.). According to an experimental study by Fatouh and El Kafafy (2006, 47), using pure iso-butane or propane to replace R134a refrigerant directly revealed drawbacks (like high operating pressures, a low coefficient of performance (COP), and the need to replace the refrigerator's compressor). In El-Morsi's (2015) research, retrofit was carried out theoretical cycle calculation rather than trials, and similar results were found. In the study of Rasti et al. (2013), it was experimentally demonstrated that replacing R134a with mixes of R600a and R436a reduced energy usage and the optimal charges of refrigerant blends. The refrigeration system will require an improved compressor. The cons of using hydrocarbons as refrigerants are discussed in the review articles by Calm (2008, 31) and Corberán et al. (2008, 31), including flammability and handling safety concerns for small, medium, and large refrigeration systems. The use of HC refrigerants in refrigeration systems decreased indirect emissions of greenhouse gases (i.e., decreased Total Equivalent Warming Impact), according to Poggi et al. (2008, 31), who also suggested suitable techniques for reducing the amount of refrigerant used in the system. The use of various HC mixes to replace R134a refrigerants as well as the use of artificial intelligence in refrigeration have both been the subject of numerous studies (Gill et al., 2018, 89; Gill and Singh, 2017a, 88; Gill and Singh, 2017b, 82). Manufacturers are now producing vapor compression refrigeration (VCR) systems at a faster rate with improved economic, environmental, and safety features. The use of nanoparticles in refrigeration is also a topic of research. Choi and Eastman (1995, 38) were the first to use nanoparticles in fluids, which are known to have a maximum exterior size range of 1-100 nm. Nanoparticles have recently been preferred over other passive heat transfer improvement techniques (such as baffles, strip inserts, and fins) that were previously used in engineering applications because of the inherent negligible sedimentation, fouling, pressure drop, flow channel erosion, and need for less pumping power observed with their applications (Celen et al., 2014, 44; Saidur et al., 2011b, 15). Condenser, capillary tube, dryer, evaporator, and compressor are the usual components of a VCR system [See Figures 1-2]. The condenser and evaporator subcomponents engage in continuous convective and phase change heat transfer operations (condensation and evaporation) during the condensation and boiling phase heat transfer processes. Nanoparticles have been shown in studies (Vanaki et al., 2016, 54; Tawfik, 2017, 75) to significantly increase process efficiency at each of these steps. Other attempts to improve the efficiency of VCRs have mainly focused on (i) either increasing environmental efficiency, as recommended in the work of Calm (2008, 31), or improving the performance of the refrigerator's subcomponents (See Belman-Flores et al., 2015, 51), and (ii) energy-exercice conservation for the refrigeration system to be considered viable (El-Morsi, 2015, 51). As a result of the influences of enhanced Brownian motion and thermophoresis effects caused by slip mechanisms within the working fluids (refrigerant or compressor lubricant) and nanoparticles (Dogonchi and Ganji, 2016, 69; Malvandi and Ganji, 2014, 84), nanoparticles have been identified to achieve all of the stated characteristics (Saidur et al., 2011a, 15). The performance of nanoparticles in VCRs has been discovered to be influenced by nanoparticle type, size, application temperature, concentration, and other variables (Alawi et al., 2015, 69). Significant improvements in system efficiency and the thermo-physical properties of working fluids, particularly in terms of thermal conductivity and viscosity, have been documented in the literature [12–13]. Similar conclusions were reached by Bi et al. (2011, 52), who found that reducing the energy consumption (at 0.1, 0.3, and 0.5g/L) by experimentally adjusting the TiO2 nano-lubricant in the R600a refrigerator system. Alawi et al. (2015) and Azmi et al. (2017) conducted in-depth analyses of the energy reduction potentials of several types of nanoparticles in VCRs. TiO2 and Al2O3 nanoparticles have been demonstrated to significantly lower the direct emission of greenhouse gases linked to fossil fuels in an R134a refrigerator system. Furthermore, Bobbo et al. (2010) discovered that the COP and tribological parameters of the VCR compressor greatly improved. Nanoparticle applications in refrigeration systems have been demonstrated to influence compressor lubricating oil, refrigerant solubility, and tribological properties (anti-wear and extreme pressure properties that invariably affect compressor power consumption), all of which lead to a reduction in the amount of refrigerant charged into the system (Poggi et al., 2008, 31). These outcomes are in addition to nanofluids' inherent benefits.

According to the known research on nanotechnology in refrigeration systems, nanoparticle kinds, concentrations, and application parameters have a major impact on the performance of nanofluids. Most of these research used R600a as their primary refrigerant. On the other hand, because propane is more commonly available than R600a, it makes more economic sense to replace R134a with it. The dearth of information on the use of commercially accessible GO nanoparticles justifies the experimental exploration of GO-based nanolubricants in hydrocarbon refrigerant-based DVCRs presented in this paper. In line with the work of Bi et al. (2011, 52), Ohunakin et al. (2017, 127), and Gill et al. (2018, 89), the aim of this study is to investigate the effects of different concentrations of GO nanoparticles with specific charges of propane refrigerant on the functionality of a domestic refrigerator system at steady state. The refrigerant used in this experiment was propane.

2.0 Methodology

2.1 Experimental Setup

A home refrigerator system with a 25-liter evaporator cabinet served as the test device. Table 1 provides a description of the test apparatus. It had a Tecumseh compressor that was designed to use a 100-gram optimal charge of R134a refrigerant, along with valves for sensing pressure fluctuations and charging and discharging of refrigerant at the compressor's suction and discharge ends. In order to measure the suction temperature and pressure (T1 and P1), discharge temperature and pressure (T2 and P2), condensing temperature (T3), evaporator air temperature (TAIR), and compressor energy consumption (W) throughout the experimental trials, a test rig with thermocouples, a pressure gauge, and a watt meter was used. For all experimental trials, the test environment maintains a constant, pre-set ambient air temperature of 30 °C around the test rig. The temperature of the test chamber was measured using a thermometer with a range of 0-400 °C. According to Poggi et al.'s (2008) recommendation for refrigeration systems, the experiment was carried out using pure and various concentrations of GO nano-lubricants by (i) analyzing the test rig's performance to determine the ideal charge of R134a and (ii) contrasting it with chosen charges of the retrofit (i.e., Propane at 40, 50, and 60g). Nanowings (HSN-Code 25049090) created the GO nanoparticle, which has a purity of 99.5% and a particle size range of 15 to 30 nm. Propane and R134a, the refrigerants used in this experiment, were 99.8% pure and produced locally. Table 2 displays the lubricating oil's parameters.

Table-1 Details of test rig

S.No	Refrigerator Description	Units
1	Evaporator size	25Litres
2	Power rating	110W
3	Voltage rating	220-240V
4	K-Type thermocouple	-50°C -700°C
5	Pressure gauge	5-5000 Pa
6	Watt-meter	1-3000W
7	Refrigerant	Propane
8	Refrigerant weight	40g,50g and 60g
9	Nanoparticle	Graphene oxide
10	Nanolubricant concentration	0.2,0.4 and 0.6g/L
11	Lubricating oil	PAG
12	Condenser type	Shell & Tube
13	Coolant	Graphene oxide

		nanofluid

Table -2 Characteristics of Lubricating oil

S.No	Characteristics of Lubricating oil	Units
1	Oil type	Mineral oil
2	ISO Viscosity grade	46
3	Flash point	263
4	Density at 15°C g/cm^3	1.03
5	Kinematic viscosity cSt at 40°C	46.9
6	Kinematic viscosity cSt at 100°C	9.9
7	Viscosity index	204

Fig 2: Experimental set up/Test Rig with shell &Tube condenser

A two-step nanofluid technique was used to synthesize the various GO nanoparticle-compressor PAG oil combinations (nano-lubricant) at the right concentrations (0.2 g/L, 0.4 g/L, and 0.6 g/L). According to the research of Bi et al. (2011), 52, a measured quantity of GO nanoparticle was acquired using a digital measuring balance, and it was then added to the necessary volume of PAG oil-based compressor lubricant. Figure 3a depicts a GO nanoparticle under scanning electron microscopy. The mixture was manually vibrated using an ultrasonic vibrator to create uniform, significantly separated GO-based nanolubricant concentrations, as shown in Figure 3b. Thus, uniformity was enhanced. The

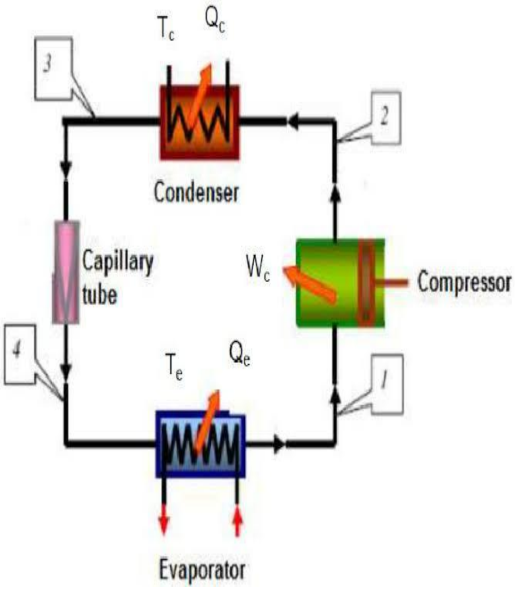

Figure 1: Line diagram of VCR System

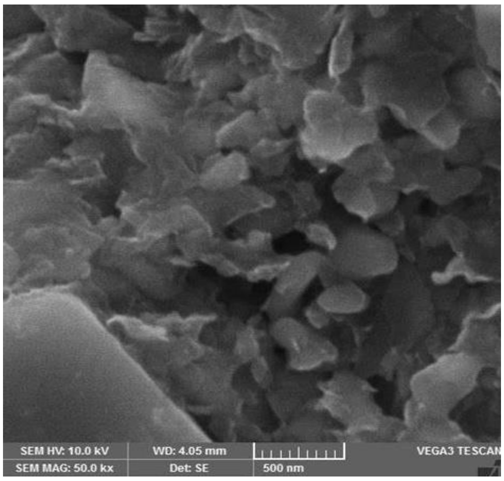

Figure 3a &3b SEM image of Graphene Oxide nanoparticles, Ultrasonic bath tub

homogenous mixtures, which contain various nanolubricant concentrations, are fed into the compressor for each attempt. A clear solution was eventually achieved after the compressor had been flushed with a pure PAG oil solution to remove any remaining nanoparticles. To remove all traces of charged refrigerant, a vacuum pump (1/4 HP vacuum pump) was used to evacuate the apparatus.

2.2experimentation And Analysis

All installed gauges' pressure and temperature measurements were used to evaluate every experiment in steady state (for 60 minutes), without a load, and in continuous cycle operation without ON/OFF compressor working circumstances. All measured data (pressures, temperatures, and compressor power consumption) were used to calculate the corresponding refrigerant properties, such as saturated vapor enthalpy (h1), superheated vapor enthalpy (h2), saturated liquid enthalpy (h3), refrigerant suction and discharge viscosity, and thermal conductivity. The behavior of the refrigerant's heat transfer within the rig was ascertained by employing each of them, and Equation 1 was used to calculate the coefficient of performance (COP).

$$COP = \frac{Q}{W} = \frac{\dot{m}(h_1 - h_3)}{\dot{m}(h_2 - h_1)} \qquad (1)$$

where W is the power used by the compressor, Q is the amount of cooling it can provide, and m/s is the mass flow rate. The study also assumed that the enthalpies at the condenser exit and evaporator inlet are equal (h3 = h4), that the difference between the discharge and condensing pressures is negligible, that the difference between the evaporator intake and outlet pressures is negligible, and that the impact of sub-cooling within the system is minimal. The change in the applied mass flow rate (m/s) was discovered and validated for all experimental trials, according to Gill and Singh's (2017c, 78) study. This was done by dividing the measured compressor power consumption by the corresponding specified compressor work inputs (i.e., h2-h1 (kJ/kg-1)) at steady state to obtain the mass flow rate each trial. Estimates of the essential thermo-physical characteristics of the working fluid (such as thermal conductivity and viscosity) were calculated inside the test rig at the state points (such as the suction and discharge points) using NIST Ref-Prop software and the relevant pressures and temperatures.

2.3 Uncertainty Analysis

The methodology developed by Schultz and Cole (1979, 189) was used to evaluate the level of uncertainty in this paper. Sheikholeslami and Ganji (2016, 229) claim that Equation (2) can be used to estimate the uncertainty of a desired parameter, such as R:

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

where n is the total number of variables, UVi is the level of uncertainty for each independent variable, and UR is the level of uncertainty overall (Akhavan-Behabadi, 2015, 66). Table 3 displays the parameters' level of uncertainty. The parameter with the highest level of uncertainty was less than 3%.

Table-3 Uncertainity of the Experimental Parameters

S.No	Parameters	Absolute Uncertainity
1	T_{air}	± 0.2°C
2	T_2	± 0.4°C
3	T_3	± 0.4°C
4	Suction Pressure	± 2 kPa
5	Discharge Pressure	± 5kPa
6	Power	± 0.4W

3.0 Results And Discussion

3.1 Pull-down Time

The time required for the evaporator air temperature to decrease to the necessary cooling level in accordance with ISO 8187 is shown in Table 4. According to variations in the pull-down times of the investigated refrigerants (R134a and propane), with pure compressor oil and varying concentrations of GO nanoparticle-mineral oil-based compressor oil mixtures, all of the chosen charges of propane refrigerant with various concentrations of nanolubricants achieved -5°C (recommended by ISO 8187) or lower values of evaporator air temperatures inside the rig at steady state. The steady-state evaporator air temperatures inside the refrigerator cabinet were -8°C, -12°C, and -10°C with a 60g charge of propane and 0.2g/L nano-lubricant, a 40g charge of propane and 0.4g/L nano-lubricant, and a 50g charge of propane and 0.2g/L GO nano-lubricant. These results corroborated earlier findings (Adelekan et al., 2017, 66; Bi et al., 2011, 52) that nanofluids in heat exchangers had increased heat transfer capabilities and that nanoparticle concentrations might improve their efficiency. The work of Malvandi and Ganji (2014, 84), who discovered that the greater critical heat flux of nanofluids boosts the cooling performance of thermodynamic systems, provided additional evidence in favor of these conclusions.

3.2 VARIATION IN COMPRESSOR DISCHARGE TEMPERATURE

Figure 4 displays the compressor discharge temperature change on the test rig. For all chosen charges of propane refrigerants in steady state, the compressor provided a lower discharge temperature using pure mineral oil and specific proportions of GO nano-lubricant mixes. For propane refrigerant, the projected reduction in compressor discharge temperatures from R134a ranged from 1.83 to 27%. Additionally, it was discovered that the test rig's capacity to lower compressor discharge temperature increased with increasing nanoparticle concentrations and refrigerant charges. However, as the optimum concentration of GO nanoparticles in the lubricant was reached, the compressor discharge temperature did considerably drop; going beyond this optimum caused a noticeable increase in compressor discharge temperature.

Table 4: Characteristics of Pull down time

S. No	Time (Minutes)	100g R134a (pure)	40g Propane				50g Propane				60g Propane			
			Pure	0.2 g/L	0.4 g/L	0.6 g/L	Pure	0.2 g/L	0.4 g/L	0.6 g/L	Pure	0.2 g/L	0.4 g/L	0.6 g/L
1	0	22	22	22	22	22	22	22	22	22	22	22	22	22
2	20	5	4	3	3	4	2	3	6	4	2	4	7	5
3	40	1	-1	1	-3	1	-2	-1	2	-1	-1	2	2	0
4	60	-1	-3	-1	-5	-1	-4	-3	1	-3	-3	1	1	-1
5	80	-2	-5	-2	-8	-1	-6	-4	-2	-4	-5	-1	-2	-2
6	100	-3	-7	-3	-11	-2	-6	-5	-4	-4	-5	-2	-4	-3

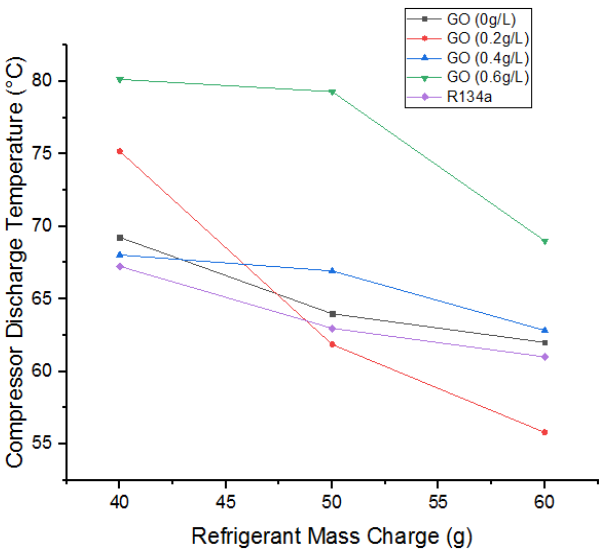

Figure 4 : variation in the compressor discharge temperature of the test rig with mass flow rate.

Ohunakin et al. (2017, 127) discovered a similar tendency in their research. The compressor discharge temperature was 52°C when 50g of propane and 0.2g/L of nanolubricant were used; when 60g of propane and 0.2g/L of nanofluid were used, the temperature was 76°C. According to Azmi et al. (2017, 69) and Bobbo et al. (2010, 33), low compressor discharge temperatures increase compressor dependability by extending the tribological qualities of the lubricating oil. As a result, residential refrigerators will have greater durability and potential for energy savings.

3.3 Variation In Cooling Capacity

Figure 5 displays the diversity in cooling capacity within the test rig. When utilized in systems with pure compressor lubricating oil, specific propane refrigerant charges (40, 50, and 60g) have less cooling power than R134a.

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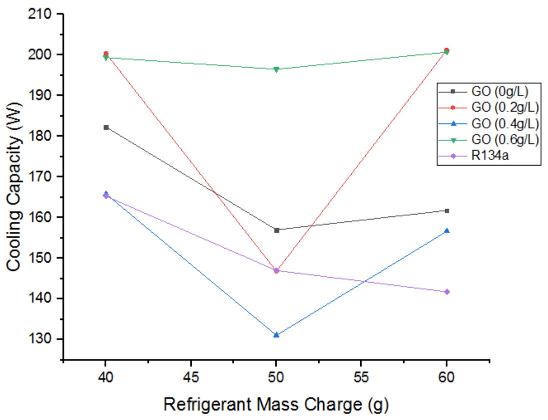


Figure 5: variation in cooling capacity within the test rig with mass flow rates

Since these propane charges were fewer than the 100g charge of R134a refrigerant, it was discovered that the mass flow rates of propane in the system were lower than those of that refrigerant. Performance of the system with different GO nanolubricant concentrations revealed that cooling capacities vary greatly with refrigerant charges and nanoparticle concentrations. As the amount of added nanoparticles to the lubricant grew, the cooling capacity dropped. This decline in cooling capacity peaked with repeated GO nanoparticle additions to the lubricant, and cooling capacity was considerably enhanced with further increases in nanolubricant concentration. A maximum cooling capacity of 210.78 W was attained with a 60g charge of propane and a 0.2g/L GO nanolubricant mixture; this represents a 10.87% improvement in cooling capacity over the baseline refrigerant (i.e., a 100g charge of R134a with pure lubricating oil). The lowest cooling capacity attained was 131.48 W with a 50g charge of propane and a 0.4g/L GO nanolubricant combination; this indicated a loss in cooling capacity of 29.91% when compared to the operation of the conventional refrigeration system.

3.4 Variation In Compressor Power Consumption

Figure 6 displays the compressor's power usage as determined by a Wattmeter during the experiment. The figure shows that selected charges of propane with different concentrations of GO-based lubricants resulted in lower power consumption when compared to refrigerant driven with pure lubricant. This is consistent with the findings of Sheikholeslami and Ganji's (2017, 229) work, in which nano-fluids were used as working fluids to achieve more effective performance. This result validates the assertion made by Akhavan-Behabadi et al. (2015, 66), who discovered that boiling heat transfer of R-141b nanoparticles decreased with large depositions of nanoparticles. At higher concentrations of GO, more power was seen to be consumed in contrast to the decreases seen with the usage of nanofluids at lower concentrations of GO nanoparticles. The experiment's lowest compressor power consumption, at 50 grams of propane and 0.6 grams per liter of GO nanolubricant, was 63 W, while its greatest power consumption, at 60 grams of propane and 0.4 grams per liter of GO-based lubricant, was 93 W.It may be assumed that the proper use of nanoparticles in fluids, such as nanolubricants, will result in a notable decrease in the power consumption of residential refrigerators (see Table 5). This supports the claims made in the study by Bobbo et al. (2010, 33), which linked improved tribological characteristics with nanoparticles to the performance gained in their investigation, as well as the similar result attained in the study by Alawi et al. (2015, 69).

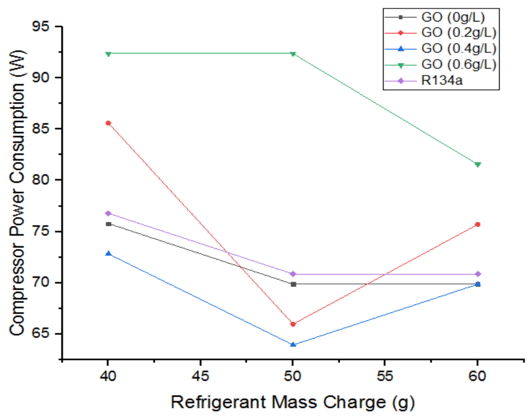


Figure 6: Variation in compressor power consumption with Refrigerant mass charge

Table 5: Percentage of Energy Consumption of VCR System with GO Nanolubricant

S.No	Refrigerant	GO Nano lubricant (g/L)	Energy Saving Percentage [(E_{R134a}- $E_{nanofluid}$)/E_{R134a}] X 100	Reduction Yes/No
1	100g R134a	0	------	--------
2	40g Propane	0	13.64	Yes
		0.2	20.62	Yes
		0.4	20.62	Yes
		0.6	0.00	-----
3	50g Propane	0	25.28	Yes
		0.2	13.65	Yes
		0.4	17.14	Yes
		0.6	27.60	Yes
4	60g Propane	0	20.62	Yes
		0.2	10.16	No
		0.4	10.16	No
		0.6	6.68	Yes

3.5 Variation In Coefficient Of Performance

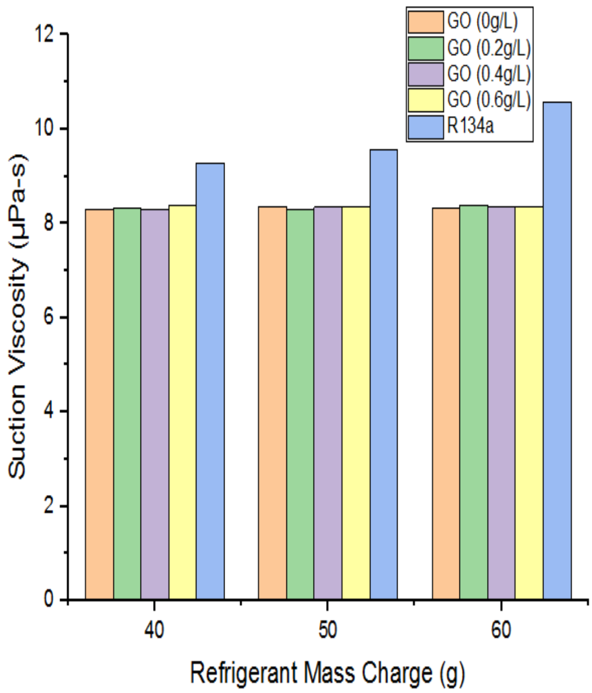


Figure 7 displays the fluctuations in the evaporator-to-compressor power ratio in steady state. In comparison to the baseline (R134a refrigerant with pure mineral oil lubricant), almost all of the selected nano-lubricant-based refrigerants produced higher coefficients of performance (COP). The COP for a 50g charge of propane containing 0.6g/L GO nano-lubricant was 2.07, while the COP for a 50g charge of propane containing 0.2g/L GO nano-lubricant was 2.67.

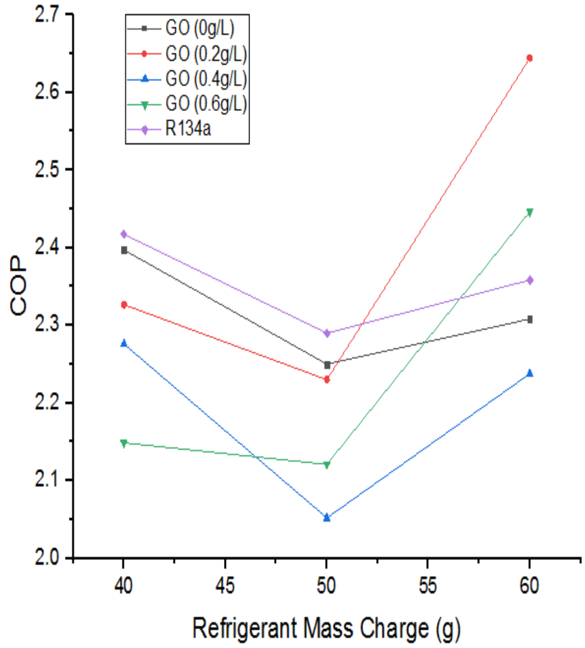
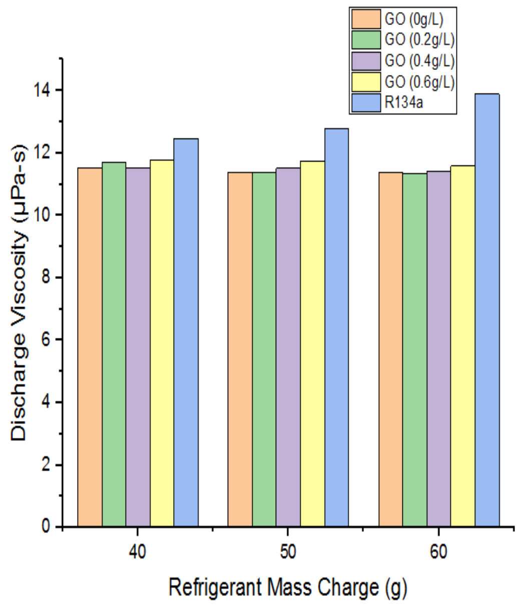


Figure 7: Variation of COP with varied Refrigerant Mass charge



3.6 Variation In Viscosity

Figures 8a and 8b display the flow resistance of propane refrigerants infused with varying concentrations of GO nanolubricant. At the suction and discharge ends of the compressor, viscosity has decreased as a result of the presence of nanofluid, specifically GO nanolubricant, which has greatly increased the intensity of Brownian motion. The maximum viscosity, which had a value of 10.09 Pa at steady state, was obtained using the baseline (i.e., R134a using pure compressor oil lubricant). With a 40g charge of propane using pure lubricant and a 50g charge of propane using 0.4g/L GO-based nanolubricant, the lowest viscosity at the suction end of the compressor was achieved. Similarly, at the compressor's discharge end, R134a (baseline refrigerant mixtures) produced the highest viscosity value, The lowest value was produced by 50g of propane combined with 0.2 g/L of GO nanolubricant. According to the research by Afrand et al. (2016, 102), applications using nanoparticles have been associated with reduced viscosity. According to Bobbo et al. (2010), lubricants migrate significantly into the evaporator (where boiling heat transfer happens) as a result of their solubility in refrigerant. If lubricant migration into the evaporator is minimal, efficiency will be maintained. Additionally, regulating the concentration of nanoparticles in the fluid improves efficiency in heat exchange applications like evaporators. This is due to the heat transfer surface having no or very few coatings, which improves boiling heat transfer by reducing viscosity and enhancing Brownian motion (Sharif et al.)

3.7 VARIATION IN THERMAL CONDUCTIVITY

Figure 9 displays the variations in nanolubricant concentrations in the refrigerants' heat transfer potential. The graph demonstrates a notable increase in heat conductivity. Low thermal conductivity values of 10.32 mW/mK and 17.55 mW/mK were measured at the suction and discharge ends of the compressor for the baseline (i.e., R134a with pure PAG oil lubrication). High thermal conductivity values were found at the suction and discharge ends of the compressor for the retrofit (pure propane refrigerant and propane with varied concentrations of nano-lubricants). At the suction end of the compressor, thermal conductivity readings ranged from 14.05 to 14.23 mW/mK, while at the discharge end, they varied from 22.25 to 25.08 mW/mK.

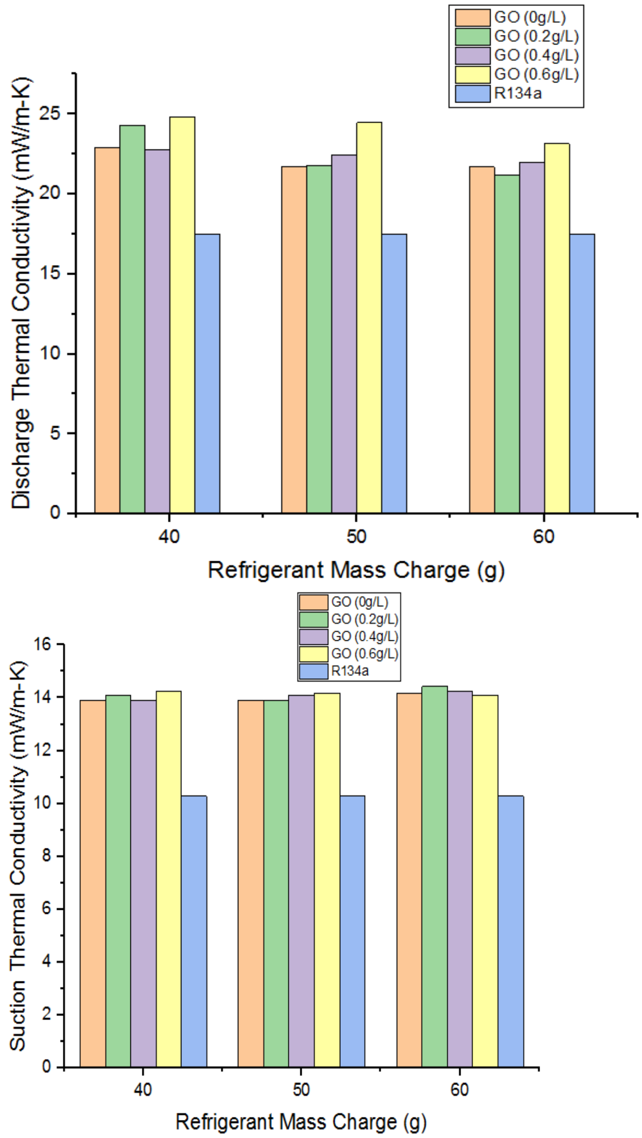


Figure 9a & 9b: variation of suction &Discharge Thermal conductivity with Refrigerant Mass Charge

Table 6: Experiments summary

Refrigerant	GO Nanolubricant(g/L)	T_{air}(°C) at state	T_2 (°C)	Power consumption (W)	COP	M (kg/S)	Refrigerant Viscosity (μPa-S)		Refrigerant Thermal Conductivity (mW/m-K)	
							Suc	Disch	Suc	Disch

		adystate					tion	arge	tion	arge
100g R134a		-14	68	83	2.20	1.32	10.02	13.77	10.32	17.55
40g Propane	0	-11	67	70	2.6	0.52	6.08	9.29	14.26	24.12
	0.2	-11	58	64	2.27	0.5	6.08	9.05	14.26	23.06
	0.4	-9	57	64	2.33	0.53	7.03	9.02	14.44	22.94
	0.6	-10	70	80	2.35	0.62	7	9.64	14.34	25.50
50g Propane	0	-11	58	63	2.25	0.46	6.08	9.0	14.25	23.03
	0.2	-7	52	70	2.67	0.67	6.09	8.89	14.63	22.2
	0.4	-11	64	67	2.30	0.49	6.08	9.25	14.25	23.93
	0.6	-10	63	58	2.07	0.41	7	9.18	14.34	23.61
60g Propane	0	-9	59	64	2.26	0.5	7.03	9.06	14.44	23.15
	0.2	-8	76	89	2.17	0.62	7.06	9.74	14.53	25.98
	0.4	-9	75	89	2.14	0.61	7.03	9.68	14.44	25.76
	0.6	-9	65	76	2.47	0.62	7.03	9.36	14.44	24.36

4.0 Conclusion

This experiment shows that, when pull-down time, compressor discharge temperature, compressor power consumption, coefficient of performance, suction and discharge thermal conductivity, and viscosity of the nano-fluid within the system are taken into consideration, using GO-PAG lubricant with propane as the working fluid as a suitable replacement for R134a refrigerant can result in improved performance. The experiment also reveals the following results:

- All of the stated propane refrigerant charges infused with different concentrations of GO nano-lubricants achieved evaporator air temperatures of -8°C (ISO 8187) or lower at propane charges lower than the typical R134a refrigerant. Additionally improving heat transfer efficiency is the use of nanolubricants.
- The steady state evaporator air temperatures were 60g of propane and 0.6g/L GO nano-lubricant, -9°C with 40g of propane and 0.4g/L GO nano-lubricant, and -7°C with 50g of propane and 0.2g/L GO nano-lubricant, respectively.

□□ Nearly all of the selected propane charges—both those that were pure and those that contained varying amounts of GO nanolubricants—exhibited lower steady-state compressor discharge temperatures than the reference (the R134a refrigerant). The lowest compressor discharge temperature (56°C) was produced by a 50-gram mass charge of propane using 0.2g/L, while the highest was produced by a 60-gram mass charge of propane using a 0.6g/L GO nano-lubricant blend.

□□ Nearly all of the selected propane charges—both those that were pure and those that contained varying amounts of GO nanolubricants—exhibited lower steady-state compressor discharge temperatures than the reference (the R134a refrigerant). The lowest compressor discharge temperature (56°C) was produced by a 50-gram mass charge of propane using 0.2g/L, while the highest was produced by a 60-gram mass charge of propane using a 0.6g/L GO nano-lubricant blend.

- The baseline (i.e., R134a with PAG oil lubricant) was found to have high thermal conductivity values at the suction and discharge ends of the compressor compared to the retrofit (pure propane refrigerant and propane with various concentrations of GO nano-lubricants).

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