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Research Article

Viscosity and Density of Polyolester Oils Based on CuO/CeO_2 Mixture Nanoparticles

Huda Elslam Abdali Salem Mohamed[1]*, Unal Camdali[2] and Metin Aktas[3]

[1]*Faculty of Mechanical Engineering Technology, Benghazi, Libya*

[2]*Department of Mechanical Engineering, Ankara Yildirim Beyazit University, Ankara Turkey*

[3]*Department of Energy, Ankara Yildirim Beyazit University, Ankara Turkey*

***Corresponding Author:** Huda Elslam Abdali Salem Mohamed, Faculty of Mechanical Engineering Technology, Benghazi, Libya.

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Abstract

The compressor is the heart of the refrigeration system and to enhance its performance, extend its life and preserve its moving parts such as pistons, rotors, valves, connecting rods and cranks lubrication should be improved. Recently the studies focus on the use nanoparticles with lubricants in refrigeration and air conditioning systems because of their significant impact on improving the coefficient of performance of these systems as well as thermophysical properties of pure lubricating oils and thus reducing energy consumption. In this study nanoparticles were synthesis in an easy and cheap way and from materials available in chemistry laboratories to overcome the cost barrier that is the main obstacle to the use of nanoparticles in most applications as following copper oxide, cerium oxide, mixture1 consisted of 50% copper oxide with 50% cerium oxide, mixture2 consisted of 60% copper oxide with 40% cerium oxide, mixture 3 consisted of 70% copper oxide with 30% cerium oxide, mixture 4 consisted of 40% copper oxide with 60% cerium oxide, and mixture5 consisted of 30% copper oxide with 70% cerium oxide to study their effectiveness on enhancing the viscosity and density of polyolester (POE) lubricating oil using mathematical equations available from previous studies.

Keywords: Nanolubricants; Nanoparticles; Coefficient of Performance; Viscosity; Density

Introduction

Currently, most studies focus on enhancing the efficiency of refrigerating and air conditioning systems to reduce power consumption caused by the poor thermal properties of working fluids in these sectors. In 1873 Maxwell diffused very small particles with diameters of millimeters to micrometers, into working fluids to enhance their thermal properties. Unfortunately this attempt failed due to some problems such as instability of these particles inside the fluids. At the end of the last century Choi added nanoparticles to primary fluid to enhance its thermal properties that is known as nanofluids [1,2].

Nanofluids are produced by dispersing nanoparticles with a diameter size of 1 to 100 nm into a base fluid, where nanoparticles have highest thermal properties compared to pure fluid. The nanofluids are classified into different categories (i) mono-nanofluids that contain the similar nanoparticles, (ii) hybrid nanofluids that contain different nanoparticles, and (iii) hybrid nanofluids that contain composite nanoparticles [1]. Success of nanofluids preparation requires the following conditions (i) dispersability and stabilization of nanoparticle (ii) Nanoparticle must be chemically compatible (iii) nanofluid must be thermally stable. All the mentioned circumstances produce nanofluids with the best thermal properties due to increase the surface area of nanoparticles, and Brownian's predominant movement will also contribute to a better diffusion of the nanoparticles, which leads to less accumulation of particles and reducing power pump compared to the base fluid [3]. Recently, new concepts of nanofluids technology have been developed, where nanoparticles are dispersed into the refrigerant, which is known as nanorefrigerant, or nanoparticles are dispersed with lubricating oils, which is known as nanolubricant. Two methods to produce nanofluids, one step method and two step method. Two step method is considered the mostly using for preparing nanorefrigerants, where nanoparticle is synthesized as a powder and mixed with a pure fluid to form a mixture, after that use the dispersion technologies, which include ultrasound devices, excitation using magnetic field, and homogenization to diffuse nanoparticles inside the pure fluids. In the one step method nanoparticles are manufactured using a physical or chemical method, where the condensation processes is carried out on a vapor nanophase powder to convert it into a liquid under lower pressures, and then is dissolved it in a liquid instantly. Using nanorefrigerant enhances COP and reduces compressor work as a result of improving thermal properties of refrigerants [4,5]. While using nanolubricant improves the tribological properties such as lubrication, wear properties, high pressure conditions, COF, which achieves a good wear properties, thus extending the life of mechanical parts of the system [6]. The previous studies are categorized into two parts, the first part is a study of refrigerating systems that operate using nanolubricants, and the second part is a study the thermophysical properties of nanolubricants. Vijaya Kumar., *et al*. 2021 investigate the influences of Al_2o_3 added to POE oil on COP of refrigerators. A result confirmed improvements in refrigeration effects and COP by 6.09%, and 20.09%, while the power consumption decreased by 15.78% [7]. Tae Jong Choi., *et al*. 2021 investigate the influences of MWCNTS added to POE oil on COP of refrigerators. The results showed that the energy consumed decreased by 17% [8]. A. Senthil Kumar., *et al*. 2021 investigate the influences of Al_2o_3/Sio_2 hybrid nanoparticles on COP of refrigeration system. A result confirmed improvements in COP and refrigeration loads by 30 and 25%, whereas energy consumed decreased by 80 W [9]. A.Senthil Kumar., *et al*. 2021 investigate the influences of CuO/Sio_2 hybrid nanoparticles on COP of refrigeration system. A result confirmed improvements in COP and refrigeration loads by 35% and 18%, whereas energy consumption decreased by 75 W [10]. A. Senthil Kumar., *et al*. 2021 investigate the influences of Sio_2 distributed inside POE oil on COP of refrigeration system. The results showed that 0.4 g/L Sio_2 carried out the highest refrigeration effects and improvements in COP by 1.7, while the reduction in energy consumption was 80 W [11]. A. Senthil Kumar., *et al*. 2021 investigate the influences of ZnO/Sio_2 hybrid nanoparticles on COP of refrigeration system. A result confirmed 0.6 g/L ZnO/Sio_2 carried out the highest refrigeration loads by180 W, and improved COP by 1.7, whereas the lowest energy consumption was 78 W [12]. A. Senthilkumar., *et al*. 2021 investigate the influences of CuO/Al_2O_3 hybrid nanoparticles on COP of refrigeration system. A result confirmed improvements in COP and refrigerating loads by 27% and 20% whereas energy consumed decreased by 24% [13]. Farhood Sarrafzadeh Javadi., *et al*. 2021 investigate the influences of Al_2O_3 on COP of refrigerators. The results showed that energy consumed decreased by 2.69% [14]. Jatinder Gill., *et al*. 2019 investigate the influences of TiO_2, distributed inside Capella D oil on COP of a domestic refrigerator and 40 to 70 g of LPG were charged as an alternative to R134a. A result confirmed improvements in refrigerating loads and COP by 18.74-32.72 and 10.15-61.49%, higher than, while energy consumption was less than R134a by 3.20-18.1 [15]. Munuswamy Karthick., *et al*. 2020 investigate the influences of four samples on COP of VCRS as follows, No.1 (MO+ 0.02 vol% Al_2O_3 + 0.01 vol% TiO_2), No. 2 (MO + 0.01 vol% Al_2O_3 + 0.005 vol% TiO_2), No.3 (MO + 0.05 vol% Al_2O_3), and No. 4 (MO + 0.02 vol% Al_2O_3 + 0.02 vol% ZnO. A result confirmed improvements in COP by 14.61%, [16]. Damola S. Adelekan., *et al*. 2019 investigate the influences of TiO_2 added to mineral oil on COP of refrigerators and. The results showed that for above concentrations energy consumed decreased by 14%, 9%, and 8% [17]. Dattatraya G. Subhedar., *et al*. 2020 investigate the influences of Al_2O_3 added to mineral oil on COP of refrigerators. A result showed that 0.075 vol% carried out the improvements in COP by 85%, and redoes 27% of energy consumed [18]. T. O. Babarinde., *et al*. 2019 investigate the influences of TiO_2 distributed inside mineral oil on COP of a refrigerators. The results confirmed that 0.4 g/L TiO_2 carried out the maximum COP and minimum energy consumed [19]. F. Selimefendigil., *et al*. 2019 investigate the influences of TiO_2 added to PAG oil on COP of refrigeration system,. The results indicated that 0.5vol%, 0.8vol%, and 1vol% carried out enhancements in COP by 1.43%, 15.72%, and 21.42%, and 1vol% decreased power consumption by 15% [20]. S. Sundararaj., *et al*. 2020 investigate the influences of Au, HAuCl4, and CNTs, mixed with PAG oil on COP of VCRS. The results showed that 0.2vol% Au and 0.02vol% CNTs carried out the minimum energy consumed, the maximum refrigeration effects, and the maximum COP compared to another composition [21]. Anusha Peyyala., *et al*. 2020 investigate the influences of Al_2O_3 added to mineral oil on

COP of refrigeration system. The results indicated that 0.2 vol % Al_2O_3 carried out the maximum value of COP [22]. T.O. Babarinde., *et al*. 2019 investigate the influences of graphene distributed inside mineral oil on COP of refrigeration system. The results showed that 0.2 g/L graphene achieved minimum energy consumed, and maximum COP [23]. D.S Adelekan., *et al*. 2019 investigate the influences of TiO_2, added to mineral oil on COP of a refrigerator. A result confirmed that the best values of COP and refrigeration loads were 4.99 and 290.83 kJ/kg [24]. Oluseyi O. Ajayi., *et al*. 2019 investigate the influences of Al_2O_3 added to Capella D oil, on COP of VCRS. The results indicated that nanolubricants improved both of refrigeration capacity and COP, while power consumed decreased [25]. A. Senthil kumar., *et al*. 2020 investigate the influences of Sio_2, distributed inside POE oil on COP of VCRS. A result confirmed that 0.4 g/L Sio_2 increased both of refrigeration capacity and COP, while power consumed decreased [26]. A. Senthilkumar., *et al*. 2020 investigate the influences of Al_2o_3/Sio_2 added to mineral oil on COP of refrigeration system. A result confirmed that nanolubricant achieved a higher refrigerating loads and COP by 25%, and 30%, and a minimum compressor work [27]. M.A. Kedzierski., *et al*. 2017 investigate the influences of Al_2O_3 and ZnO respectively, with diameters of 127 nm and 135 nm added to POE oil at 288 to 318 K. on thermophysical properties of nanolubricants. A result confirmed improvements in viscosity, density, and thermal conductivity with increasing nanoparticle concentrations however viscosity and density reduced with increasing temperatures [28]. S.S. Sanukrishna., *et al*. 2018 investigate the influences of TiO_2 mixed with PAG at 20°C to 90°C on the thermophysical properties of nanolubricants. The results indicated that improvements in thermal conductivity and viscosity with increasing nanoparticles concentration [29] N.N.M. Zawawi., *et al*. 2018 investigate the effects of Al_2O_3/SiO_2, Al_2O_3/TiO_2, and TiO_2/SiO_2 added to PAG oil at 303 to 353 K on the thermophysical properties of nanolubricants. The results indicated that 0.1vol% Al_2O_3/TiO_2 increased the viscosity by 20.50% at 303 K. While 0.1vol% Al_2O_3/SiO_2 increased the thermal conductivity by 2.41% at 303 K [30] R. Harichandran., *et al*. 2019 studied the effect of h-BN on thermophysical properties of nanolubricant. A result confirmed improvements density and viscosity with increasing nanoparticles concentration, whereas the viscosity reduced with increasing temperature. Additionally the viscosity of nanolubricants at 0.4 vol% was 14% more than that lubricant [31]. Munuswamy Karthick., *et al*. 2020 investigate the influences, of the four samples as No.1 (MO + 0.02 vol% Al_2O_3 + 0.01 vol % TiO_2), No. 2 (MO + 0.01 vol % Al_2O_3 + 0.005 vol % TiO_2), No.3 (MO + 0.05 vol% Al_2O_3), and No. 4 (MO + 0.02 vol% Al_2O_3 + 0.02 vol % ZnO) on thermal conductivity of nanolubricants. The results indicated that mineral oil containing of 0.05vol% Al_2O_3 achieved a maximum increase in thermal conductivity, and mineral oil containing of 0.01 vol % Al_2O_3 and 0.005 vol % TiO_2 achieved a minimum increase in the thermal conductivity. Additionally sample 1 achieved a maximum viscosity compared to other samples [16]. Ravinder Kumar., *et al*. 2018 investigate the influences of CuO on the viscosity of nanolubricants. A result confirmed that 0.2–1.0 wt % CuO increased viscosity by 17%, whereas decrease it with increase temperatures [32]. Gill Jatinder., *et al*. 2019 investigate the influences of TiO_2 on thermophysical properties of nanolubricants. A result confirmed that thermal conductivities were more than that of pure lubricant of approximately 14.37-41.25%, while the viscosity was more than that of pure lubricant of approximately 2-6%. [33]. M.Z. Sharif., *et al*. 2016 investigate the influences of Al_2O_3 added to PAG at 303.15 to 353.15 K on thermophysical properties of nanolubricants. A result confirmed improvements in thermal conductivity with increasing nanoparticles concentration and viscosity increases for concentrations higher than 0.3vol%, but decreased with temperature [34]. Mark A. Kedzierski 2012 studied the effect of spherical CuO with diameters of 30 nm, at 288 K to 318 K added to POE oil on thermophysical properties of nanolubricant. A result confirmed improvements in viscosity and density with increased nanoparticles concentration [35]. N.N.M. Zawawi., *et al*. 2017 investigate the influences of Al_2O_3/SiO_2 hybrid nanoparticles at 303 to 353 K on thermophysical properties of nanolubricants. The results indicated that the maximum values of thermal conductivity and viscosity were by 2.41% and 9.71% [36]. Amin Asadi., *et al*. 2016 investigate the influences of MWCNTS/MgO hybrid nanoparticles added to engine oil at 25°C to 50°C on the viscosity of nanolubricants. A result indicated that viscosity decreased with increasing temperatures while the increasing nanoparticle concentrations led to increasing the viscosity. The maximum increase in viscosity was by 65% at 2 vol % and 40°C while the minimum increase was by 14.4% at 0.25 vol % and 25°C [37]. A.A.M. Redhwan., *et al*. 2017 studied the effect of SiO_2 added to PAG at 303 to 353 K and compared them with nanolubricants based on Al_2O_3 on the thermophysical properties of nanolubricants. A result indicated that improvements in viscosity and thermal conductivity with increasing concentrations and thermal conductivity based on 1.0 vol% SiO2 was higher than thermal conductivity based on Al_2O_3 [38]. Sanukrishna S. S., *et al*. 2017 investigate the influences of CuO added to PAG oil on thermal conductivity of nanolubricants. A result confirmed that thermal conductivity ratio increases linearly with increasing concentrations and 0.1 vol% achieved the highest value in the thermal conductivity by 12.67% [39]. Ravinder Kumar., *et al*. 2017 evaluated the viscosity of mineral oil with and without ZnO. The results showed that 0.2 wt% and 60 °C improved the viscosity by 7.7%, whereas, 0.4, 0.6, 0.8 and 1.0 wt %, improved the viscosity by 15.87, 21.45, 22.9 and 25.1% respectively., however viscosity decreased with increasing temperature [40]. S.S. Sanukrishna., *et al*. 2018 investigate the thermophysical properties of nanolubricants depending on PAG/ Al_2O_3 at 20 to 90°C. A result indicated that the maximum thermal conductivities ratio and maximum viscosity ratio were 1.48 and 18.42 at 0.6 vol % and temperature 20°C respectively [41]. Subramani Narayanasarma., *et al*. 2019 investigate the thermophysical properties of nanolubricants depended on POE/ SiO_2 at 25 to 85 °C. The results indicated that improvements in thermal conductivity with increase concentrations and temperature, its maximum value was 1.109, at (0.2 wt % and 85°C). Additionally the viscosity improved with increase concentrations but reduced with temperature [42]. Dattatraya G. Subhedar., *et al*. 2020 investigate the influences of 0.05 vol%, 0.075vol%, 0.1 vol%, and 0.2 vol% Al_2O_3 on the viscosity of nanolubricant. The results indicated that an increase concentration of Al_2O_3, led to increase in the viscosity compared to pure lubricant [18]. Mohammad Hemmat Esfe 2020 studied the effect of (20% MWCNTS/80% ZnO) hybrid nanoparticles on the viscosity of nanolubricants based on SAE 50 engine oil at 25 to 50°C. A result confirmed improvements in viscosity with increasing concentrations, while the viscosity decreases with increasing temperature [43]. N. N. M. Zawawi., *et al*. 2019 investigate the thermophysical properties of nanolubricants of 20:80, 40:60, 50:50, 60:40 and 80:20 Al_2O_3/SiO_2 hybrid nanoparticles at concentration 0.1% vol added to PAG oil at30 to 80°C. The results indicated that thermal conductivity improved by 2.41% at 80°C, while the highest an improvement of dynamic viscosity, was 9.34% at 70°C. Improvements in both parameters were observed for 50:50 nanoparticle ratios [44].

Through the previous studies that were presented, it appears clearly that the addition of nanoparticles to lubricating oils enhances its thermophysical properties and thus enhances the performance of refrigeration system.

Materials and Methods

In this section of the research, it will be divided into two paragraphs, first, the proposed method for preparing nanoparticles, and secondly, calculating the viscosity and density of polyolester oil (POE) using numerical equations available from previous studies.

Synthesis of nanoparticles

This paper proposes the preparation of nanoparticles as oxides or as mixtures of oxides based on a solution of nitrate, which is dissolved in distilled or deionized water. Distilled water was used because it is a good and cheap solvent, so that the mixture undergoes a series of chemical reactions until the oxide is obtained. The preparation process is summarized as follows:

- The solution should be heated to a temperature of 80°C, keep the mixer speed at 375 rpm and the time is one hour;
- Add ammonia at 60°C, and keep both mixer speed at 375 rpm, and PH at 10 ± 1;
- Raise temperature to 90°C to obtain the oxides;
- The solution should be cooled at normal temperature;
- Using the filtration system that was designed in the lab to complete the filtration process;
- Use the electric oven to complete the drying process at 110°C;
- Grinding;
- Sifting and
- Save until use.

As shown in Eq (1) the method of manufacturing nanoparticles relied on converting the weights of the materials into moles and that is done by dividing these weights by molecular weights. As shown in Eq (2) molar concentrations were obtained using moles and volume of solvent, the results of synthesis nanoparticles including obtained amount of oxides as well as some important properties of prepared materials are included in table 1 and table 2 [45-48].

$$\text{Mole} = \frac{Weight}{Molecular\ weight} \quad \text{---------} \ (1)$$

$$\text{Mole concentration} = \frac{Number\ of\ moles}{Volume} \quad ---------\ (2)$$

The molecular weights of the reactants are as following

Copper nitrate = 241.606

Cerium nitrate = 434.22

Copper oxide = 79.5

Cerium oxide = 172.12

No	Proportion		Molar concentration		Molar concentration of the mixtures	The quantities (g)
	Copper oxide %	Cerium oxide %	Copper nitrate	Cerium nitrate		
1	Fifty	Fifty	0.20867	0.09673	0.1527	12.67
2	Sixty	Forty	0.250408	0.07753	0.181258	11.44
3	Seventy	Thirty	0.300075	0.05834	0.21530	10.97
4	Forty	Sixty	0.16694	0.11622	0.13651	13.07
5	Thirty	Seventy	0.125687	0.135569	0.13260	13.85

Table 1: The results of synthesis of mixtures [45-48].

No	Nanoparticle	Mw	τ	K	Cp
1	Copper oxide	79.55	6320	32.9	536
2	Cerium oxide	172.115	6100	11.715	352
3	50% Copper oxide +50% Cerium oxide	125.833	6210	22.31	444
4	60% Copper oxide +40% Cerium oxide	116.576	6232	24.43	462.4
5	70% Copper oxide +30% Cerium oxide	107.32	6254	26.54	480.8
6	40% Copper oxide +60% Cerium oxide	135.089	6188	20.19	425.6
7	30% Copper oxide +70% Cerium oxide	144.346	6166	18.07	407.2

Table 2: Some properties of nanoparticles [49].

Viscosity and density of polyolester (POE) with nanoparticles

Viscosity is one of the most important thermophysical properties of lubricating oil because the thickness of a lubricant film is a function of the viscosity and its dependences with pressure and temperature, which has impact on the equipment performance. A decrease of viscosity will cause thinning of the lubricant film and may cause equipment failure if the viscosity is too low, while an excessively large viscosity can lead to increased motor loading and higher power consumption. These characteristics are paramount considerations when choosing the viscosity grade of a lubricant [50]. POE are synthetic lubricants with high chemical and thermal stability. Due to their good miscibility with refrigerants they are the best choice for refrigeration system. There are many numerical equations of calculating the viscosity and density of nanofluids. Brinkman model shown in Eq (3) was chosen to calculate viscosity and Eqs (4) was chosen to calculate density of POE based on 0.05 to 0.33 wt % of nanoparticles [51]. The results are indicated clearly in tables 3 to 4.

$$\mu_{nr} = \mu_r \frac{1}{(1-\emptyset)^{2.5}} \qquad \text{--------------} \ (3)$$

$$\rho_{eff} = (1-\emptyset)\,\rho_f + \emptyset\,\rho_{np} \qquad -\,-\,-\,-\,-\,-\,-\,-\,-\,- \ (4)$$

The viscosities (mm²/s)	Mass fractions						
	0.05	0.09	0.1	0.2	0.24	0.28	0.33
	52.29	58.23	59.86	80.36	91.35	104.57	125.19

Table 3: The viscosities of POE with nanoparticles.

The densities (kg m^{-3})	Mass fractions						
	0.05	0.09	0.1	0.2	0.24	0.28	0.33
CuO	1208.05	1423.29	1477.1	2015.2	2230.44	2445.68	2714.73
CeO_2	1197.05	1403.49	1455.1	1971.2	2177.64	2384.08	2642.13
50%CuO+50%CeO_2	1202.55	1413.39	1466.1	1993.2	2204.04	2414.88	2678.43
60%CuO+40%CeO_2	1203.65	1415.37	1468.3	1997.6	2209.32	2421.04	2685.69
70%CuO+30%CeO_2	1204.75	1417.35	1470.5	2002	2214.6	2427.2	2692.95
40%CuO+60%CeO_2	1201.45	1411.41	1463.9	1988.8	2198.76	2408.72	2671.17
30%CuO+70%CeO_2	1200.35	1409.43	1461.7	1984.4	2193.48	2402.56	2663.91

Table 4: The densities of POE with nanoparticles

Results and Discussion

The results of this research involve specifications of nanoparticles, and viscosity and density of POE based on different mass fractions of nanoparticles using some numerical equations.

Specifications of nanoparticles

The properties of the prepared nanoparticles were verified by sending samples to Huazhong University of Science and Technology in China on September 24, 2019 as shown in figure 1, where XRD analysis was used and scanned from 20deg to 80 deg to examine the samples. The results showed all of the peaks agree with database standard (JCPDS 00-045-0937) of face centered cubic CuO. All of the peaks agree with database standard (JCPDS 00-004-0593) of face centered cubic CeO_2. SEM images showed that the samples were spherical with diameters of 78.95 nm, 79.9 nm, 44.15 nm, and 63.3 nm for CuO, CeO_2, fifty % CuO + fifty % CeO_2, and sixty % CuO + forty % CeO_2 respectively, as shown in figure 2. The nanoparticles preparation method in succeeded in obtaining suitable diameters. This study gives a significantly indication for future researchers to be interested in preparing nanoparticles as a mixture and focuses attention on CeO_2, which does not use before within a vapor compression refrigerating system, an attempt to reveal the most important properties and its effective to enhance the efficiency of refrigerating system and whether it will be effective while it was mixed with other oxides [45-48].

Figure 1: (a) CuO (b) CeO2 (c) 50% CuO + 50% CeO2 and (d) 60% CuO + 40 % CeO2 Nanoparticles [45-48].

Viscosity and density of POE based on numerical equations

The results of the numerical equations that were chosen to determine the viscosity and density of (POE + CuO), (POE+ CeO_2), (POE + mixture No1), (POE + mixture No.2), (POE+ mixture No3),

Figure 2: (a) CuO (b) CeO2 (c) 50% CuO+50% CeO2 and (d) 60% CuO+40% CeO2 [45-48].

(POE + mixture No4), and (POE + mixture No 5) for mass fractions by 0.05 to 0.33 wt %, showed that these properties increase linearly with nanoparticles, where CuO/POE achieved the best results among other types of nanoparticles as shown in figure 3.

Conclusions

The first barrier that prevents the uses of nanoparticles in many applications is the cost. This research presents a new method for preparing nanoparticles as oxides and a mixture of different oxides, the method by which nanoparticles were prepared was simple, easy and inexpensive, and from materials available in every laboratory. Thus the cost barrier that prevented the use of nanoparticle on a large scale in refrigeration systems was broken. Moreover, the materials that were prepared were characterized by good thermal properties In addition, the cost of nanoparticle rises as it has better thermal properties will this method succeed in producing nanoparticles with a high thermal conductivity so that the door of research remains open to answer these questions. The second barrier is to maintain a nanoparticle attached to refrigerant or lubricant for as long as possible time, as the deposition of nanoparticle is considered one of the most problems and this is known as stability. Recently the concept of using nanoparticles as a hybrid began to appear an attempt for solving the problem of stability. Will the mixtures that were mentioned in this research succeed in achieving best results, With regard to the study of the thermophysical properties; the results were in agreement with the literature review, whether these studies were experimental or theoretical or using numerical equations. The results of this research indicated that the viscosity and density of Polyol ester oil increase with increasing proportion of nanoparticles within the mixture.

Figure 3: a) The effects of nanoparticles on viscosity of POE oil b) The effects of nanoparticles on density of POE oil.

Nomenclature

Vapor compression refrigeration system	VCRS
Coefficient of performance	COP
Coefficient of friction	COF
X-ray diffraction	XRD
Scanning electron microscopy	SEM
Polyol ester oil	POE
Poly Alkylene Glycol	PAG
Mineral Oil	MO
Liquefied Petroleum Gas	LPG
Mass fraction	Wt
Volume fraction	Vol
Thermal conductivity	K (W m^{-1} K-1)

Density	ρ (kg m^{-3})
Specific heat	Cp (J kg^{-1} K-1)
Mole	M (g/mol)
Weight	W (g)
Molecular weight	Mw (mol)
Mole concentration	C (mol/L)
Number of moles	n (-)
volume	V (L)
volume fraction	Φ (-)
Dynamic viscosity of nanorefrigerant	(mPa.s)
Dynamic viscosity of refrigerant	(mPa.s)
Density of refrigerant and nanoparticles	(Kg/m^3)

Table a

Chemical symbols	
Copper Oxide	CuO
Tanium Dioxide	TiO_2
Aluminum Oxide	Al_2O_3
Zinc Oxide	ZnO
Silicon Dioxide	SiO_2
Hexagonal Boron Nitride	h-BN
Tetrachloro (hydrido) gold	HAuCL4
Gold	Au
Carbon NanoTubes	CNT
Multiwall Carbon Nanotubes	MWCNTS
Magnesium Oxide	MgO

Table b

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