



Physico-Chemical Characterization of a Multiparticle Vegetable Oil-Based Nanofluid for High Voltage Application

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ABSTRACT

Among the most significant functional elements of a high voltage system is the transformer oil (TO); usually a mineral-based oil (MO). Nonetheless, most conventional MOs have lower thermal conductivity and therefore present poor cooling performance. Furthermore, they are hazardous to the environment and non-renewable such that they keep depleting with time. The quest for stable and ecofriendly alternative for MOs has attracted lots of research attention in the past few decades. The focus on nanofluids for next generation high voltage (HV) application becomes imminent especially with vegetable oils being ecofriendly. This work focuses on the study of some physicochemical properties of a multi-particles nanofluid for HV application. Groundnut oil was used as the base oil from which a pure methyl ester was extracted. Ester-based nanofluids with varying percentages by weight (0.2 – 1.0 wt. %) of a blend of SiO₂ and TiO₂ nanoparticles were prepared and characterized. Favorable viscosity and density values, i.e. 2.06 mPa-s and 0.5% were recorded for nanofluids at lower loading (0.2 wt. %) and at a higher operating temperature (70 °C) as compared to those of the pure ester. The Average pour point value of -0.2 °C was measured for the nanofluids as against -4.0 °C for pure methyl ester. The obtained values placed the prepared nanofluid as potential candidate to substitute conventional MOs in the insulation and cooling of HV equipment.

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INTRODUCTION

Transmission and distribution network is an imperative but severely overloaded and exclusive constituent of a power generating system. The expansion in the prospect of high voltage (HV) grid has preeminent requirements on the performance and reliability of the transformer to cope with more vigorous and impulse operational conditions (Rafiq *et al.*, 2015). The rapid rise in electricity demand along with the quest for better reliability have attracted emergent concern leading to miniaturization of oil-immersed transformers. One of the most significant component of the transformer responsible for ensuring reliability and safety of operation is the transformer oil (TO) (Rafiq *et al.*, 2026). It is a mineral-based oil (MO) generally executing two concomitant functions; cooling and insulation. However, these MOs usually have low thermal

conductivity which inhibits their cooling performance leading to thermal build-up and eventual damage and/or breakdown of the system (Bertrand & Hoang, 2004). Two main types of transformers had been identified. The oil-filled and dry transformers with the oil-filled being the most commonly used (Wang *et al.*, 2016). In addition to cooling and insulation, oil prevents direct contact of the functional components with atmospheric oxygen due to susceptibility of the transformer to oxidation (Kumar & Singh, 2007). Since transformer winding and the core are immersed in a petroleum-based mineral oil, there are serious concerns regarding fire risk and environmental issues. Hence, the development of high thermal conductivity of transformer oil for critical application is required. One of the initiatives is by implementing nanotechnology with the aim of improving thermal characteristics of the insulating

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oil as well as enhancing its electrical performances (Li *et al.*, 2017). The term nanotechnology has been applied in several science endeavors especially in physics, chemistry, biology, and electronics etc. to offer nano-based solutions of diverse benefits including nanofluids (NFs). Nanofluid is a fluid in which nanoscale particles of a material are suspended in a base fluid to form a colloidal solution of the nanoparticles (NPs). The nanoparticles used in a nanofluid are typically those of metals, oxides and carbides while the base fluids include water, oils and ethylene glycol (Supun *et al.*, 2018). By direct mixing of a base fluid of smaller thermal conductivity with solid NPs of high thermal conductivity such as TiO_2 , SiO_2 , Fe_3O_4 , Al_2O_3 and ZnO etc., a nanofluid having better heat transfer features could be realized (Kumar & Singh, 2013). In this research, the concept of nanotechnology is utilized for the development and characterization of vegetable-based nanofluids (NFs) as the next generation of transformer oils and as alternatives for the conventional mineral oils.

MATERIALS AND METHOD

Purification of base oil

The crude GO was purified in order to remove gum and phospholipids as well as reduce free fatty acids and water content. 600 ml of the crude GO was first heated to a temperature of 60°C and 4.5 ml of citric acid solution was then added and mixed thoroughly using a magnetic stirrer. 12 ml of NaOH solution was then added and stirred for 20 minutes until neutralization. These removes gum, phospholipids and reduces the free fatty acid. The mixture was later dried in a vacuum oven at 70°C for 30 minutes to reduce water content. 6g of silica gel was added and mixed thoroughly for 15 minutes at steady temperature. 12g of fuller earth was finally added and thoroughly mixed for 40 minutes and filtered with a whatman paper.

Transesterification

In order to extract the methyl ester from the purified oil, transesterification was carried out. To achieve this, 203g of the purified oil was heated in a conical flask at temperature 60°C . 2.44g of NaOH was then mixed with 44.05g of methanol inside a beaker stirred for 15 minutes until the NaOH completely dissolved in the methanol

forming sodium methoxide. This mixture was then added into the 203g of purified oil pre-heated at 60°C and mixed thoroughly for 1 hour. The product was then poured into separating funnel mounted on a clamp/stand and allowed to settle down so that a proper separation of ester glycerol is attained. The glycerin is then removed from separating funnel leaving methyl ester in the separating funnel. The ester obtained is then water-washed using warm water to remove excess sodium hydroxide and glycerol. The obtained sample (ester) was then dried in a vacuum oven at 80°C to remove water molecules and methanol.

Functionalization of TiO_2 and SiO_2 nanoparticles

5g each of TiO_2 and SiO_2 nanoparticles were separately dispersed in 100ml of methanol at 60°C and mixed thoroughly for 15 minutes. 0.25ml of oleic acid was then added to each solution and mixed thoroughly for 2 hours. The solution was then filtered with whatman paper No.1 to separate methanol and oleic acid from the nanoparticles. The treated nanoparticles were oven dried to remove any excess methanol at 70°C . This process was carried out in order to functionalize the titanium and silicon oxide nanoparticles so as to prevent any possible agglomeration in the base oil.

Preparation of multiparticle nanofluid

Unlike the single particle types, multiparticle nanofluids utilize more than one type of nanoparticles in the same base oil. The nanoparticles distinctly complement each other in the property enhancement of the base oil. 0.2 wt. % of the nanofluid was prepared by dispersing 0.3g of the functionalized multiparticles (i.e. TiO_2 and SiO_2) directly into 150g of methyl ester and mixed thoroughly 30 minutes for proper dispersion. The process is repeated with 0.6g, 0.9g, 1.2g and 1.5g of multiparticles each dissolved in 150g of methyl ester and mixed thoroughly with a magnetic stirrer for 30 minutes. The result obtained is 0.4wt. % nanofluid. 0.9g of multiparticles is added into 150g of methyl ester and mixed thoroughly with magnetic stirrer for 30min. This produced nanofluids with 0.4, 0.6, 0.8 and 1.0 wt. % loadings respectively.

Viscosity measurement were conducted using a digital viscometer, model RSDV-1 in the Materials Physics Research Laboratory, ABU, Zaria. The rotor speed was selected to be 50rpm and the viscometer was made to stand on its support while the rotor speed was fixed in between the protection rack. 50ml of various samples, i.e. crude groundnut oil, purified oil, ester and the nanofluids of different wt. %, were respectively put under the protection rack and the viscometer was made to move vertically downward along its column so that they are immersed into the sample container. The oil inside the container is surrounded by water bath in order to adjust its temperature. The viscosity (η) value of each sample was recorded off the viscometer and the procedure was repeated for temperature ranges of 30 °C to 70 °C.

For the density measurement, an empty measuring cylinder was weighed and filled with the various samples (crude oil, purify oil, ester and Nanofluid of different wt. %) in succession and at

temperatures ranging from 30 °C to 70 °C. The mass of each sample was recorded along with its volume from which respective densities were calculated and recorded accordingly.

Direct method, with the aid of thermocool refrigerant, was used to determine the pour point of the samples. In this method, an empty container was filled with 20ml of each sample and placed inside a cooling stage along with a thermometer and inspected at different but short time intervals. The inspection takes the form of removing and tilting the container from the cooling apparatus for any surface movement from the samples. The lowest temperature at which each sample loses its flow is visually observed and recorded as the pour point.

RESULTS AND DISCUSSION

The dynamic viscosity (η) values for the crude groundnut oil, purified oil and ester at varying temperatures are shown in table 1.

Table 1: Dynamic viscosity values for the crude groundnut oil (GO), purified oil (PO) and ester at varying temperatures.

S/N	Temp. (°C)	η for GO, (mPa-s)	η for (PO), (mPa-s)	η for ester, mPa-s
1	30	23.48	17.84	4.41
2	35	19.92	15.92	4.38
3	40	16.14	13.79	3.45
4	45	13.63	11.50	2.84
5	50	12.31	10.34	2.69
6	55	11.72	10.12	2.53
7	60	7.92	7.26	2.37
8	65	7.27	7.04	2.23
9	70	7.20	6.40	2.05

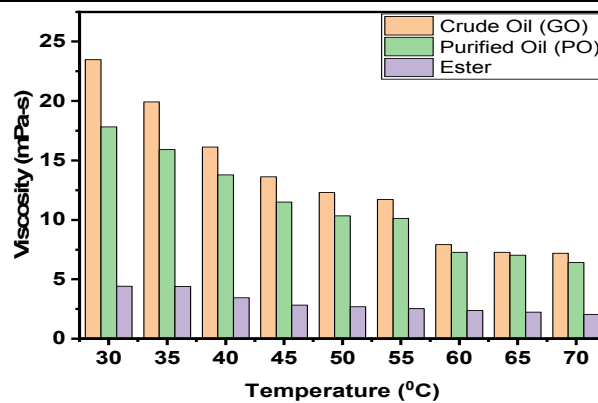


Figure 1: Temperature effect on viscosities of crude, purified and ester base oils.

Figure 1 depicts how the viscosity of the crude groundnut oil reduces after purification and transesterification. The viscosity of GO was observed to be 23.48 mPa-s at 30 °C but reduces to 17.84 mPa-s and 4.41 mPa-s, respectively after purification and transesterification processes. The reduction in viscosity is due to the removal of phospholipids and gum components from the crude groundnut oil due to purification and the chemical modification on purified oil, where

glycerol-which initially bonds the fatty acid together-was removed to obtain clean ester. The percentage decrease in the viscosity of the purified oil was found to be 32.3% which shows the effectiveness of the purification method.

Table 2 shows the effect of incorporating multiparticles (TiO₂ and SiO₂) on the viscosity of the methyl ester (nanofluid) at varying loadings, in relation to that of pure ester both observed at varying temperatures.

Table 2: Dynamic viscosity (η) values for pure ester against nanofluids (NFs) with different loadings and varying temperatures.

S/N	Temp. (°C)	Viscosity, η of pure ester (mPa-s)	Viscosity, η of nanofluids at varying nanoparticle loadings (mPa-s)				
			0.2 wt. %	0.4 wt. %	0.6 wt. %	0.8 wt. %	1.0 wt. %
1	30	4.41	3.90	4.43	4.46	4.50	4.53
2	35	4.38	3.45	3.84	3.92	4.27	4.30
3	40	3.45	3.26	3.58	3.81	3.88	3.90
4	45	2.84	2.56	2.57	2.79	2.82	2.88
5	50	2.69	2.50	2.54	2.72	2.78	2.81
6	55	2.53	2.44	2.47	2.53	2.60	2.69
7	60	2.37	2.37	2.39	2.42	2.47	2.43
8	65	2.23	2.24	2.26	2.29	2.38	2.20
9	70	2.05	2.07	2.10	2.14	2.25	2.16

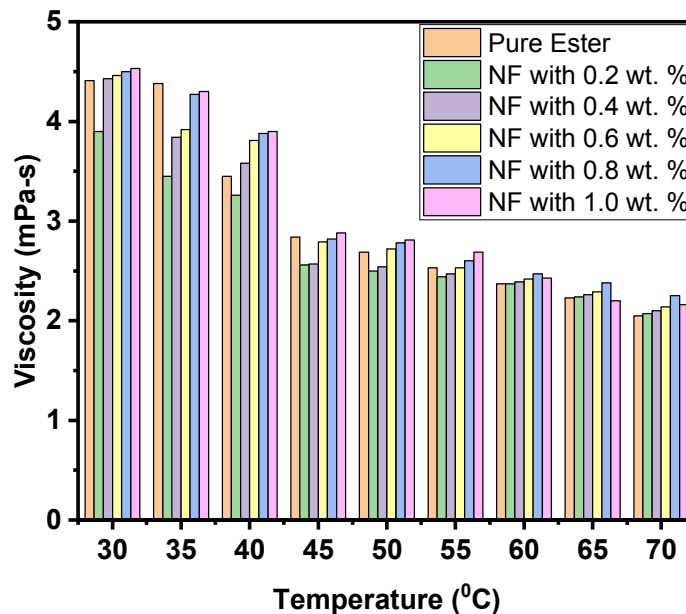


Figure 2: Temperature effect on viscosities of pure ester and various nanofluids.



Figure 2 depicts the viscosity comparison for pure ester and its associated nanofluids. It was observed that the viscosity of pure ester first increases at lower loading of nanoparticles (i.e. 0.2 wt. %) but decreases appreciably at higher loadings from 0.4 – 0.6 wt. % with varying temperature. Clearly, the viscosities of multiparticle nanofluids as well as that of methyl ester do not vary much at higher temperatures. This indicates that the addition of multiparticles has a significantly less effect on the viscosity of the oil at 60 °C and above. It can therefore be deduced that the decrease in nanofluid viscosities with increasing temperature

is as a result of the gradual decrease in the magnitude of intermolecular forces acting between the layers of the oil due to the influence of the TiO₂/SiO₂ nanoparticles. The density of crude groundnut oil was initially measured to be 0.91 gcm⁻³ which reduces to 0.89 gcm⁻³ after purification. This reduction was as a result of decrease in the molecular weight of the oil due to esterification/transesterification. The density values can clearly be seen to be almost stable despite the incorporation of the nanoparticles. Table 3 presents density values of the various samples under consideration.

Table 3: Density of pure ester and various nanofluids.

S/N	Temp. (°C)	Density (ρ) of pure ester (gcm ⁻³)	Density (ρ) of nanofluids at varying nanoparticle loadings (gcm ⁻³)				
			0.2 wt. %	0.4 wt. %	0.6 wt. %	0.8 wt. %	1.0 wt. %
1	30	0.860	0.862	0.865	0.865	0.867	0.870
2	35	0.858	0.857	0.863	0.860	0.864	0.862
3	40	0.853	0.854	0.857	0.855	0.860	0.859
4	45	0.850	0.850	0.851	0.852	0.858	0.852
5	50	0.847	0.848	0.848	0.849	0.851	0.848
6	55	0.844	0.846	0.844	0.846	0.848	0.845
7	60	0.841	0.840	0.842	0.844	0.842	0.841
8	65	0.837	0.836	0.838	0.840	0.839	0.831
9	70	0.833	0.831	0.835	0.837	0.834	0.837

The pour point values for crude groundnut oil, purified oil, ester and multiparticle nanofluids are respectively shown in table 3.

Table 3: Pour point values for ester and various nanofluids.

S/N	Oil Sample	Pour point (°C)
1	Crude groundnut oil	4.0
2	Purified oil	0.0
3	Methyl ester	-4.0
4	Nanofluid with 0.2 wt. %	-3.0
5	Nanofluid with 0.4 wt. %	-3.0
6	Nanofluid with 0.6 wt. %	-2.8
7	Nanofluid with 0.8 wt. %	-2.5
8	Nanofluid with 1.0 wt. %	-2.0

Fluids intended for use in high voltage insulation are often expected to be able to flow under extremely cold weather conditions, at least, to maintain their liquid form for optimum insulation performance. The lowest temperature at which the

movement of the fluid is visually observed is its pour point. As a critical parameter, pour point should be minimized in order that the nanofluid is used in environments of relatively low temperature. It can be seen from Table 3 that the



pour point of crude groundnut oil was initially obtained as 4 °C, which is higher than that of purified oil (0 °C). This is because upon transesterification of the oil, the triglyceride structures form mono-glycerides and thus assist in the flow property of the fluid. The measured pour point of pure ester was significantly below that of purified oil (-4 °C) but gradually appreciates (increases) with the loading of multiparticles from 0.2 to 1.0 wt. %. Although the pour point of pure ester stands lower, the nanofluid with 1.0 wt. % has the highest pour point compared to others (a disadvantage) while nanofluids with 0.2 and 0.4 wt. % have the lowest pour points (an advantage). The low pour point values can be attributed to the nanoscale dimension of the suspended nanoparticles, having high mass-surface ratio, which create strong intermolecular interaction within the molecules (Oparanti et al., 2021)

CONCLUSION

This research focused on the improvement of certain physicochemical properties, of groundnut oil-based ester nanofluids loaded SiO₂ and TiO₂ nanoparticles. The viscosity of multiparticle-filled ester nanofluid was observed to have improved which favored the fluid's applicability as coolant in high voltage equipment. The nanofluids were also observed to have lower viscosity values at operating temperature which is a desired property for insulating oil. An increase in pour point with reduction in density were both observed for the multiparticle NFs which is a clear indication that groundnut oil-based ester multiparticle nanofluid is a promising dielectric liquid as future alternative to conventional mineral oils.

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