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ORIGINAL ARTICLE

An experimental investigation on composite methyl ester as a solution to environmental threat caused by mineral oil in transformer insulation

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Abstract

The quest for green alternative insulating oil in high-voltage equipment has been the desire of researchers for over decades. Vegetable oil has been considered as alternative insulating oil; this oil contains two different fatty acids, saturated and unsaturated. However, this fatty acid contains two opposing properties. In this work, physicochemical and dielectric properties of methyl ester from neem, yellow oleander and palm kernel oil were measured. The pour point of palm kernel oil methyl ester and the mixture of palm kernel oil methyl ester with yellow oleander methyl ester were obtained to be -9 °C and -2°, respectively. The viscosity of mineral oil is 9.5 mPas, that of palm kernel oil methyl ester, and mixture of palm kernel oil methyl ester and yellow oleander oil methyl ester were obtained to be 4.14 mPas and 4.38 mPas, respectively. A good dielectric loss relatively close to the dielectric loss of mineral oil was obtained for the mixture of palm kernel ester and yellow oleander ester. The mixture of the three methyl esters has the highest dielectric breakdown result of 26 kV better than the breakdown result of mineral oil. However, the optimization of all the parameters reveals that the mixture of palm kernel ester and yellow oleander ester has the desired property that can serve as an alternative for mineral insulating oil. Also, aging of the samples confirmed that mixture of palm kernel methyl ester and yellow oleander methyl ester has the potential to replace mineral oil.

Keywords Palm kernel oil methyl ester · Neem oil methyl ester · Yellow oleander oil methyl ester · Viscosity · Pour point · Dielectric loss · Breakdown voltage · Aging

1 Introduction

One of the most vital high-voltage equipment in the transmission network is the power transformer; it enables proper energy flow and has the highest asset in project accomplishment for electric utility [1]. The durability and stable functionality of transformer mainly depend on dielectric material used for insulation and cooling purposes as it prevents its potential failure which can result into economic losses during a power outage [2]. The mineral oil having high stable temperature properties and good oxidative stability has over time proved itself as an outstanding insulating oil for indoor and outdoor applications because of its cooling and electrical insulating properties. It has good dielectric properties and facilitates electrical power transfer capacity [3–5]. When there is a spillage, petroleum-based mineral oil which is a common effective insulating oil has proved to be environmentally unfriendly because of its poor biodegradability and its low affinity for water. As a result, a green alternative consideration is essential. This consideration has led to the discovery of vegetable seed oil which has received great attention over the years because it is friendly to the ecosystem [6–8]. It has shown to be a promising oil for insulation because of its hydrophilicity which helps in protecting the quality of paper insulating materials whenever there is leakage of water molecules into the system [9–11]. Abeysundra worked on the insulation property of coconut oil, and they reported low viscosity which made it a good oil for cooling [12]. Abdemalik worked on palm kernel oil ester and compared the breakdown voltage with that of petroleum mineral oil; the ester of palm kernel oil shows a relatively high breakdown voltage [13]. Amannullah worked on

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vegetable oils as a substitute to mineral oil. They analyzed the electrochemical characteristics of vegetable oils and revealed that these oils can be considered as alternative transformer fluid as it shows characteristics that can be compared with that of mineral oil [14]. Neem, an evergreen tree that grows in different parts of Nigeria, belongs to the family of Meliaceae; botanical name is Azadirachta Indica. The oil gotten from its seed has been established to have about 40% oil, and this made it easier to be used in biodiesel production [15]. Yellow oleander scientifically called Thevetia peruviana is a non-edible fruit whose seed has high biodiesel potential containing up to 67% seed oil [16]. Palm kernel with the scientific name Elaeis Guineans has proven to have seed oil up to 30% which can be used in producing biodiesel [17]. These three non-edible seed oils are potential insulating oil for transformers [9, 16, 18]; however, some negative setbacks are affecting these oils. The advantage of oils with a higher percentage of unsaturated fatty acid is low pour point and low melting point which can be attributed to the difficulty in the formation of crystals in the oil due to bend and kinks caused by double bonds [13]. The low pour point of unsaturated oil makes them suitable for use in a low temperature region. However, due to the presence of double bonds or triple bonds in the unsaturated fatty acids, they exhibited poor oxidative stability. Contrary to the properties of unsaturated fatty acids, saturated fatty acids have good thermo-oxidative stability but have a high pour point and melting point [7]. Due to these contrary characteristics between unsaturated and saturated fatty acids, their mixture is considered in this work to optimize the properties to meet up with the mineral oil standard. In this work, three oil were selected, one saturated (Palm kernel) and two unsaturated (Yellow oleander and Neem oil). The choice for selecting these oils is because they are not edible. Yellow oleander and neem oil with higher percentage yield are non-edible and palm kernel oil edibility also varies due to location. With this combination, using vegetable oil as the base fluid for transformer insulation will not place pressure on food materials, whereas it will increase rural development and job opportunity in the agriculture system. The mixture of palm kernel oil methyl ester and neem oil methyl ester, palm kernel oil methyl ester and yellow oleander oil methyl ester, and a mixture of the three oils have been considered.

This study highly investigated the position and chances of using a composite mixture of saturated and unsaturated methyl ester as a replacement for standalone vegetable oil which has one or more drawbacks.

2 Materials and methods

2.1 Material

The oils were gotten from the National Research Institute for Chemical Technology, NARICT, Zaria, Nigeria. Sodium hydroxide, potassium hydroxide, phenolphthalein, methanol, citric acid, silica gel, Tonsil supreme fuller's earth, and Whatman No. 5 and No. 1 were other materials used in this work. Figure 1 shows the seed of neem, palm kernel and yellow oleander, respectively.

2.2 Purification and transesterification of the vegetable oils

The purification method by Oparanti et al. 2021 was selected for the purification of the three oils and these purification processes were achieved in stages [7]. For each sample of the oil, 1.5 ml of the prepared aqueous citric acid was gently poured into 200 ml pre-heated oils and allowed to mix thoroughly with the aid of a magnetic stirrer for 20 min at a steady temperature of 70 oC to degum and remove phospholipids in the oils. 4 g of aqueous sodium hydroxide solution (8%w/w) was used for alkali neutralization of 200 ml of oil and the solution was allowed to stir for 30 min. The oils were oven dry to eliminate the water content but in case there exist some traces of water in the oils, 2 g of silica gel was added and stirred for another 15 min. 5 g of fuller's earth was added to the oil solution and stirred for 45 min. This serves as bleaching clay and helps in bleaching the oils, removing colored compound, metals, and oxidation products. The mixtures were then filtered in an oven with Whatman No. 5 and

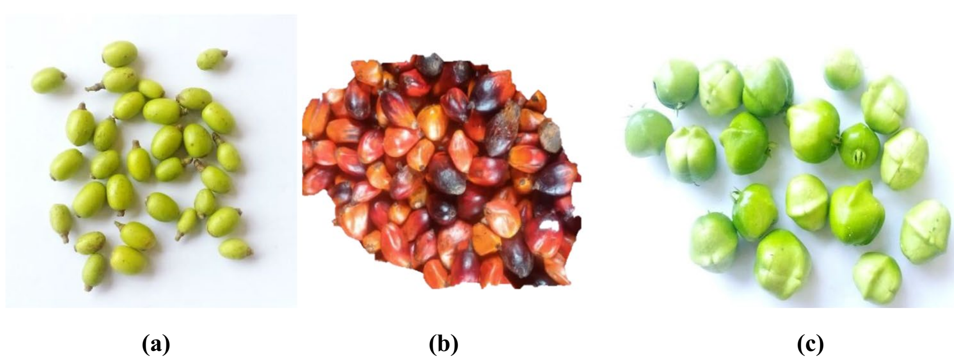

Fig. 1 (**a**) Neem seeds; (**b**) Palm kernel seeds; (**c**) Yellow oleander seeds

Whatman No. 1. The purified oils were heated to 60 oC and sodium methoxide solution was prepared from anhydrous sodium hydroxide being dissolved in methanol. The sodium methoxide solution was then added to the pre-heated purified oils at the same temperature of 60 °C and stirred for an hour. Water washing of the separated methyl esters with warm distilled water was done to remove excess sodium hydroxide and other traces of dissolved impurities. After washing with warm water, the esters were transferred into a vacuum oven operating at temperature of 80 °C for 5 h to remove traces of moisture. The mixed samples were prepared by mixing equal volume of each methyl ester (100 ml). The mixture was stirred for 1 h at 60 °C for homogenous blending. Table 1 shows the description of the sample accordingly.

2.3 Pour point

The pour point which is defined as the minimum temperature at which a fluid loses its fluidity was examined according to Ref [19, 20]. The temperature of the ester was slightly increased to 48 °C in the sample container. The container was immediately transferred to ice bath and the flow property of the sample was monitored by sight. The temperature at which the oil starts forming a semi-solid was recorded as the pour point [21].

2.4 Viscosity

Dynamic viscosity which is a crucial physical property of dielectric fluid is related to the frictional force that exists among moving close-by molecules of fluid at different velocities [22]. Using ASTM D445 standard, the viscosities of the samples were determined at ambient temperature using RVDV-1 digital viscometer [23, 24].

2.5 Dielectric loss

Rohde & Schwarz HM8118 Programmable LCR Bridge at 1 kHz was connected to a test cell at ambient temperature. The gap between electrodes was permanently set to 2.5 mm, and the sample was gently filled into the test cell using a syringe [25]. The dissipation factor of the samples at frequency and temperature of 1 kHz and 30 °C, respectively, is noted. The relationship between conductivity and dielectric loss is shown by Eq. (1), and this validates that frequency is inversely proportional to dielectric loss [26, 27].

$$\sigma = \omega\varepsilon'' \tag{1}$$

where σ is the conductivity, $\omega = 2\pi f$ is the angular frequency, f is the frequency and ε'' is the relative imaginary part that is related to the dielectric dissipation factor.

2.6 Breakdown voltage

The breakdown voltage of the prepared samples was measured according to ASTM standard D 1816 [28]. Prior to the filling of the test cell, the prepared oil samples were degassed using a vacuum oven. The test cell with a sphere mushroom-like electrodes and 2.5 mm apart was filled with approximately 250 ml oil sample. Five-minute waiting time was observed so that the air bubbles resulting from oil filling will be eliminated. The test cell was connected to a 35 kV DC source and a bench top multimeter was used to pick the voltage across the measuring resistor. The voltage was steadily applied at the rate of 0.5 kV/s to the sample until the breakdown occurred. The leakage current was obtained through the output voltage and the measuring resistor of 50 kΩ using ohm's law. The breakdown test was performed six times for accurate readings.

3 Results and discussion

3.1 Pour point

A good dielectric fluid is determined by its ability to retain its degree of fluidity across the whole temperature range it may encounter while in service [29]. Therefore, the lowest temperature of flow at which the oil is observed at the standard test is the pour point of the oil [17]. Under low temperatures, insulating oil is often expected to flow to serve as good

Table 1 Description of samples

Sample code	Description
MO	Mineral oil
PE	Palm kernel oil methyl ester
NE	Neem oil methyl ester
YE	Yellow Oleander oil methyl ester
PNY	Palm kernel oil methyl ester + Neem oil methyl ester + Yellow oleander oil methyl ester
PN	Palm kernel oil methyl ester + Neem oil methyl ester
PY	Palm kernel oil methyl ester + Yellow oleander oil methyl ester

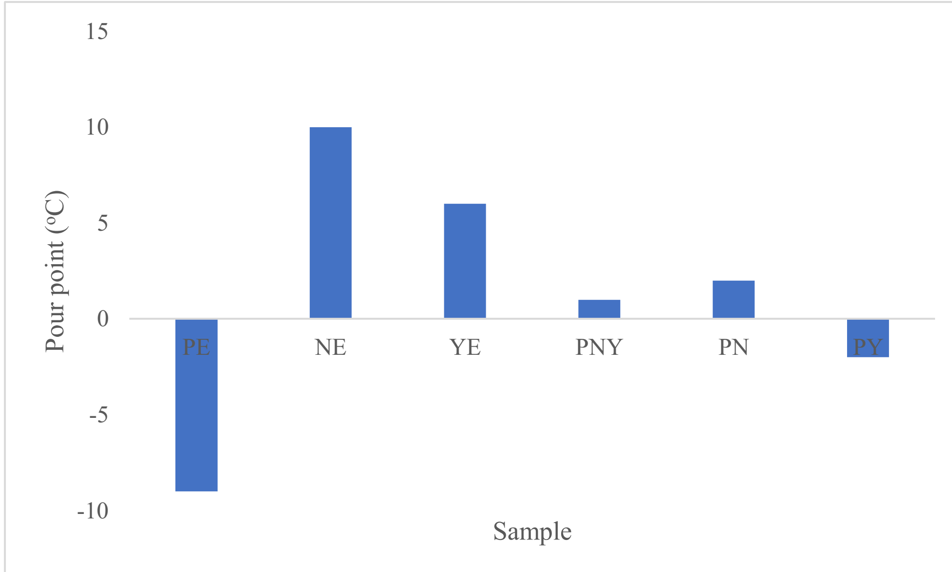

Fig. 2 Pour point of esters and their various blends

cooling oil. Figure 2 shows the graphical representation of the results obtained by taking the pour point of the blends. -9 oC, 10 oC and 6 oC were observed to be the pour point of PE, NE and YE, respectively. Also, for the mixtures, the pour point of PNY, PN and PY were observed to be 1 oC, 2 oC and -2 oC, respectively. It is important to notice that a contradicting behavior was observed in the oil after their transesterification. Palm kernel oil is known to be dominated by high percentage of saturated fatty acid, 48.7% lauric acid, but neem oil and yellow oleander oil have unsaturated fatty acid with 62% oleic and 41% oleic, respectively [30–33]. It is expected that oil dominated with saturated fatty acid should have a high pour point and a reverse condition for unsaturated [13, 17]. However, after the transesterification through the removal of glycerol, palm kernel oil was observed to have the lowest pour point followed by yellow oleander and neem oil. The blending of three esters gives a unique pour point; however, the mixture of palm kernel oil and yellow oleander oil gives the best result that can be considered in a negative temperate region when considering blending methyl esters from edible and non-edible oil. Therefore, in low-temperature regions, PY can be considered for use as insulating oil for effective cooling. Samples pour points are shown in Fig. 2.

3.2 Viscosity

In high-voltage equipment, low viscous liquids perform better in cooling process which is achieved through convection [12]. In this regard, the viscosity which is one of the physical properties of the insulating oil is pertinent for study as it is related to the flow of the oil. The study of viscosity does not only elaborate on the effect of heat transfer capacity of the oil but also on its electrical behavior. The loss generated in the transformer oil gives rise to heat, and it is reported that 6 °C rise in the temperature of the windings can reduce the life span of a transformer by 50% [34]. The generated heat in the transformer gets dissipated faster with the aid of low viscous insulating oil. This helps in reducing the temperature of transformer parts to a reasonable level for a smooth operating condition [28, 35]. The viscosity of PE, NE and YE was recorded to be 4.14 mPas, 5.17 mPas and 4.44 mPas, while for PNY, PN and PY, the viscosities were recorded to be 4.74 mPas, 4.64 mPas and 4.38 mPas, respectively. Following the IEC 60,296 requirement for the viscosity of good transformer oil, 12 mPas was noted to be the maximum value [18]. Therefore, the viscosity results of the samples are compared with the requirement, and the samples' viscosities meet up with the standard. Each sample viscosity is presented in Fig. 3. The heat transfer coefficient is inversely proportional to the dynamic viscosity as seen in Eq. 2 [18]; therefore, since the samples have viscosity lower than mineral oil, it might serve better as a coolant in the dissipation of heat in the transformer and will, consequently, prevent hot spot generation in the transformer.

$$h = C \times \left(\frac{\Delta T_{oil}}{\mu(T)} \right)^n \quad (2)$$

h is the heat transfer coefficient, C is dependent on density, thermal conductivity, thermal expansion coefficient and specific heat of the oil, μ is the dynamic viscosity of the oil, ΔT is the temperature difference of the oil, n is an empirical constant which is a function of oil circulation be it laminar or turbulent, and T is the temperature in kelvin.

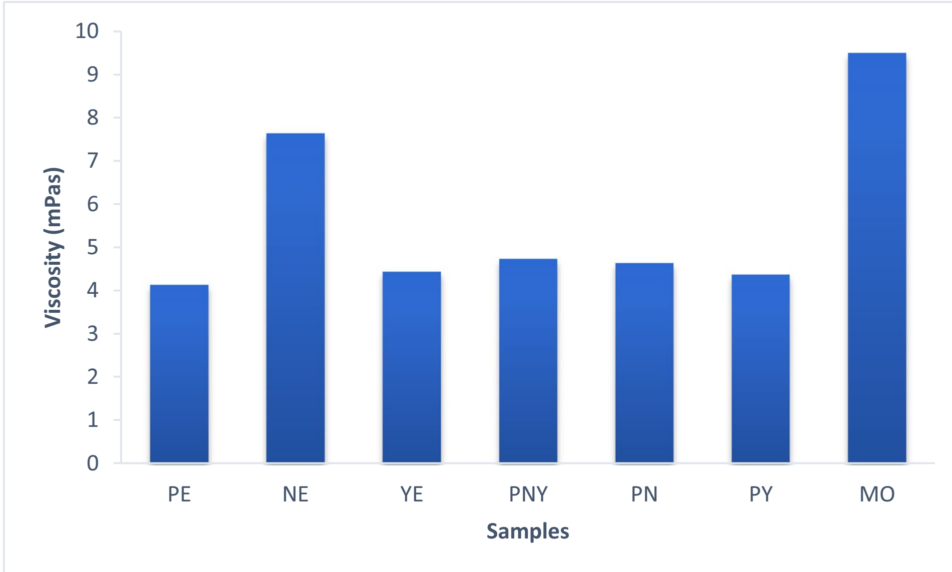

Fig. 3 Dynamic viscosity of oil samples at room temperature

3.3 Dielectric loss factor

The two major factors that determine the dielectric loss in a dielectric material are conduction and polarization. These two processes cause the motion of charged particles in the dielectric liquid and increase the loss factor [36, 37]. Due to the low viscosity of the oil after the removal of glycerol, there will be easy charge transport in the liquid which leads to an increase in the dielectric loss of methyl ester. In mineral oil, the only contributing factor to the dielectric loss is the loss due to conduction since the oil is non-polar [38]. However, in methyl ester, the contributing factor to the dielectric loss is loss due to polarization and conduction. Therefore, the loss in the methyl ester is relatively higher than the loss in the mineral oil. Among all the methyl esters, yellow oleander methyl ester has the least dielectric loss. This could be because of the molecular arrangement of the methyl ester of yellow oleander which helps in electron trapping in the oil. The strong molecular attraction between the molecules of the oil can reduce the streamers' transport which consequently enhances the dielectric properties of the oil. Since the mixture of methyl esters is the objective of this work, it is important to notice the dielectric properties of the mixed ester. From Fig. 4, the dielectric loss of the palm kernel ester and yellow oleander ester gives the least dielectric loss amidst the mixed ester. The dielectric loss of palm ester and yellow oleander ester at 1 kHz is 0.00074, and the dielectric loss of mineral oil is 0.000656.

The results of the composite mixture obtained show a slight decrease in the dielectric loss which proves that

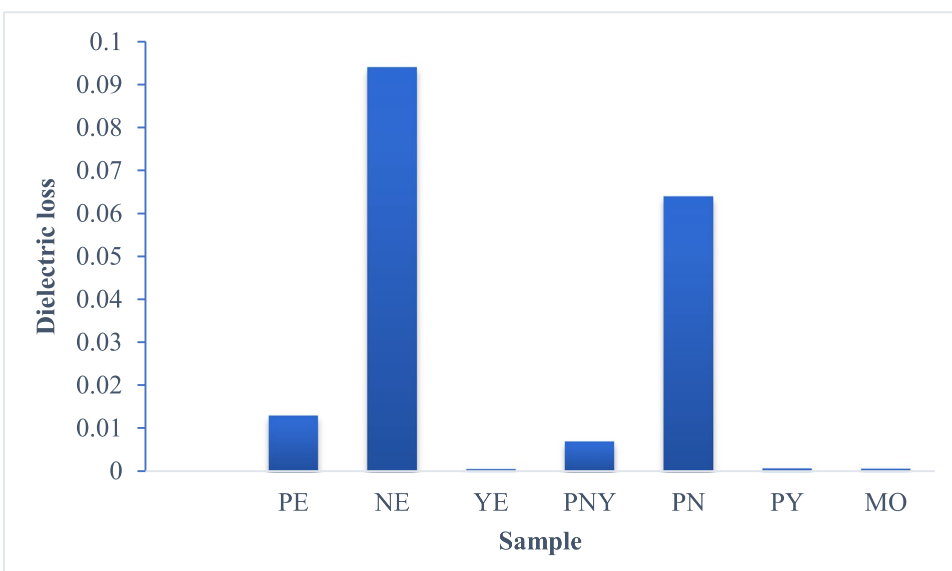

Fig. 4 Dielectric loss of the oil samples at room temperature and 1 kHz

velocity of the dissociated fast-moving electrons which could have developed into streamer growth is captured by the ester molecules or by the interfacial force between the liquids. The percentage difference in the dielectric loss of PY and mineral oil is 11.43% which might be considered negligible.

3.4 Breakdown voltage

Dielectric strength also known as breakdown voltage which is one of the vital parameters in insulating liquid is the greatest value of electric field strength that a sample can resist without experiencing failure of its insulating parameters. The progressive creation of streamers between the upper and lower electrodes is a major determinant of electrical breakdown in dielectric fluids as the introduction of an electric field will lead to the formation of ions and electrons [39]. The ground electrode being the lowest potential area received the streamers from the source and this caused a connection between the two electrodes leading to the formation of an arc flow, thereby causing an electrical breakdown of the dielectric fluid [40].

The mean value of the breakdown voltage with a standard deviation was recorded as the procedure was done six times on each sample. Two minutes minimum stirring time interval was considered to normalize the increased temperature in the oil. The increase in temperature is because of charge transport which can cause an increase in streamers velocity and thus lead to a faster breakdown. The samples breakdown voltages and the I-V curve are shown in Table 2 and Fig. 5.

The breakdown voltage of the composite mixtures was observed to have improved compared to the single methyl esters. The increase in the breakdown properties of this composite could be because of molecular bonds between different ester molecules which helps in delaying or obstructing the propagation of streamers in the oil. The mixture of palm kernel, yellow oleander and neem ester gives the highest breakdown voltage of 26 kV higher than the breakdown voltage of mineral oil. In this regard, the composite mixtures have shown a good dielectric property showing a promising property for the replacement of mineral oil. The transport of the electron can be pictured in the current–voltage plot in Fig. 6. Electrons ejected from the electrode due to electrochemical reaction collide with the molecules of the oil and get them ionized, this leads to charge transport of ions and electrons in the oil down to the ground of the electrode. The movement of the charged particles in the electric field leads to current generation. It can be observed from the graph that the ionization rate of mineral oil molecules is low which is the cause of the low current in mineral oil. Yellow oleander and the mixture of yellow oleander and palm kernel oil show the lowest current value close to mineral oil among the

Table 2 DC Breakdown results of methyl esters

Samples	Mean breakdown voltage (kV)	Standard Deviation (kV)
PE	22	1.14
NE	23	0.84
YE	23	1.14
PNY	26	0.89
PN	25	1.52
PY	25	1.14
MO	24	0.71

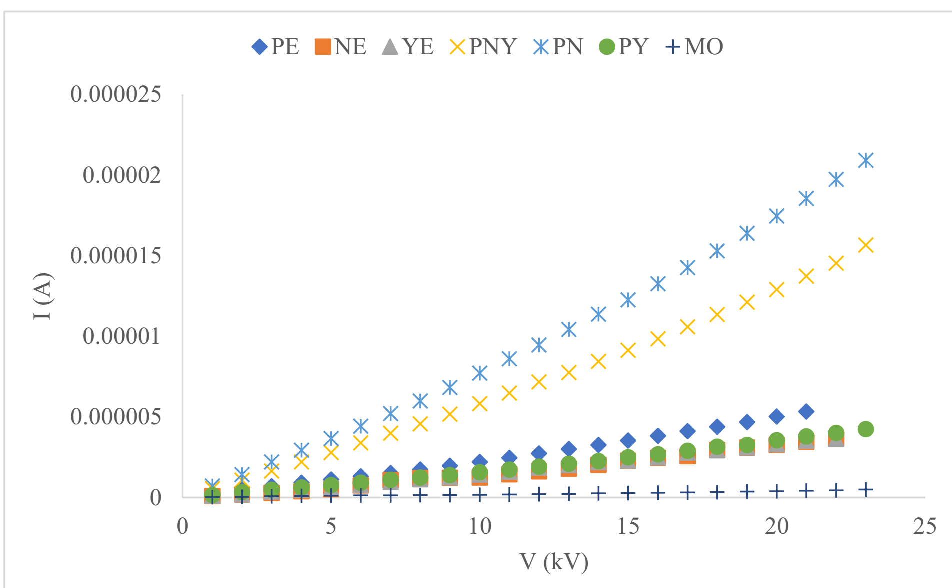

Fig. 5 I-V characteristics curve of methyl ester dielectric fluid

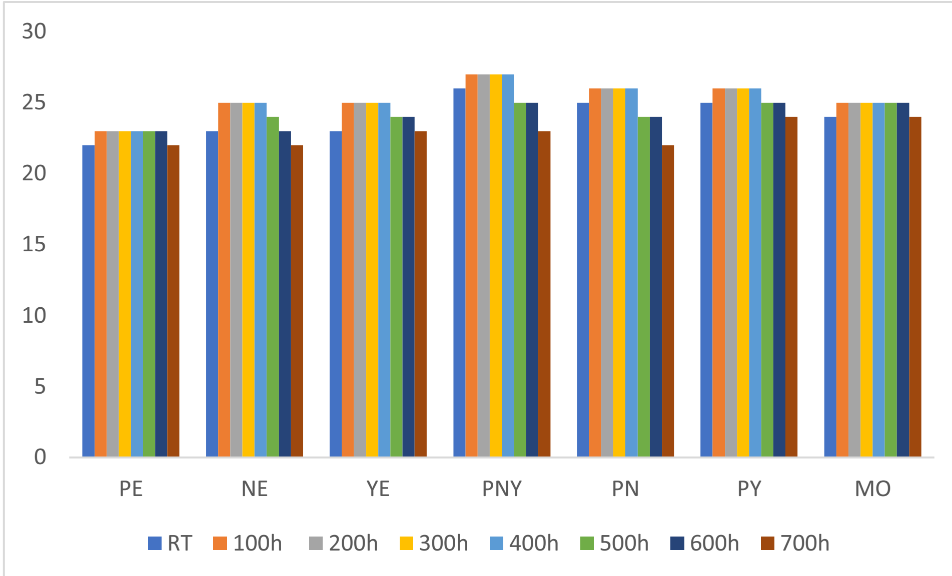

Fig. 6 Dielectric breakdown voltage of thermally aged methyl esters and mineral oil

Table 3 Pour point of esters before and after aging

Sample	Pour point before aging (°C)	Pour point after aging (°C)
PE	-9	-6
NE	10	11
YE	6	8
PNY	1	2
PN	2	4
PY	-2	-1

Table 4 Viscosity of esters before and after aging

Sample	Viscosity before aging (mPas)	Viscosity after aging (mPas)
PE	4.14	5.06
NE	7.64	8.24
YE	4.44	5.18
PNY	4.74	6.01
PN	4.64	5.48
PY	4.38	5.32
MO	9.5	9.92

natural esters. It is an indication that the mixture of yellow oleander methyl ester and palm kernel methyl ester has the potential of replacing mineral oil in green technology.

3.5 Effect of thermal aging on pour point and viscosity of methyl ester and its composite

Evolutionary study on the physical and chemical properties of insulating oil is an important study that cannot be overlooked. Since transformer operations last for several years, it is important to study the aging behavior of the insulating material. The prepared methyl esters and MO were subjected to aging for 700 h in an open glass beaker placed inside an oven controlled at 110 °C. Tables 3 and 4 show the flow properties of the oil after the accelerated thermal aging. Table 3 shows pour point results after aging, and Table 4 shows the viscosity of the esters and the composite after aging. A slight increment in the pour point of all the samples was observed which may be attributed to the formation of some high molecular aging product which, consequently, increases the rate of crystallization of the wax component of the oil. From Table 4, the composite oil with the best pour point after aging is the mixture of palm kernel oil and yellow oleander oil. This could possibly serve well as an insulating oil for a long time without losing its flow. In addition, the cooling behavior of insulating oil which is a function of viscosity is imperative to study to see the effective cooling properties of the oil over time. From Table 4, a slight increase in the viscosity of the esters including the composite was observed after the aging period. The increase in the viscosity can be attributed to an increase in the high molecular aging product in the oil and this is a similar trend to the report by Ref [17, 41]. The equation relating the dynamic viscosity and molecular weight M can be seen in Eq. 3 [18]. The increase in the dynamic viscosity connotes an increase in the molecular weight of the oil. However, despite this increase, the viscosity of esters and ester composites is lower than the viscosity of mineral oil. Since oil with lower viscosity is desired for proper cooling in a transformer, the aged methyl esters with lower viscosity should perform well as a cooling oil in a transformer.

$$[\mu] = K\overline{M}^{\alpha} \tag{3}$$

where μ is the dynamic viscosity, $\overline{M}$ is the average molecular weight, and K and α are constant which directly depends on the temperature and the solvent.

3.6 Dielectric properties of aged methyl ester

The dielectric loss is the ratio of active power to reactive power, the active power comprises the power loss due to conduction and the one due to polarization. Equation 4 can be used to express the relationship between the imaginary part of complex permittivity which is related to energy loss in the system, and both conductivity and polarization [42].

$$\varepsilon'' = \varepsilon_p + \frac{\sigma}{\omega\varepsilon_o} \tag{4}$$

where ε_p is the loss due to polarization, $\frac{\sigma}{\omega\varepsilon_o}$ is the loss due to conduction, ε'' is the total loss, σ is the conductivity, ω is the frequency and ε_o is the permittivity of free space. Table 5 shows the dielectric loss of the esters and composite after aging. The dielectric loss of the insulating oils increases after the aging period as seen in Table 5. Thakur et al. reported that thermal aging results in the formation of high concentration of ions which, consequently, increases the conductivity of the liquids [43]. Also, because of thermal degradation, the formation of polymeric materials in the oil increases. The dielectric loss due to orientation of dipoles in the polar molecules formed also contributes to the total loss. The increase in dielectric loss observed after aging is also similar to the report made by Ref [41] where it was reported that, the increase in dielectric loss after aging could be related to oxidation products present in the oil. The dielectric loss of PY after aging is close to the dielectric loss of mineral oil. This is a promising property for the composite of palm kernel methyl ester and yellow oleander methyl ester.

Table 5 Dielectric dissipation factor (DDF) of the aged methyl ester at 1 kHz

Sample	Dielectric Dissipation factor before aging	Dielectric Dissipation factor after aging
PE	0.013	0.023
NE	0.094	0.143
YE	0.006	0.013
PNY	0.007	0.015
PN	0.064	0.082
PY	0.0007	0.0013
MO	0.000656	0.00080

3.7 Dielectric breakdown voltage of the aged ester and its composites

The effect of accelerated thermal aging on ester and its composite will give more information on the evolutional behavior of this propose insulating oil, especially the dielectric breakdown property. The average breakdown properties of methyl ester measured at room temperature (RT) and every 100 h are shown in Fig. 6.

The behavior of all the esters over the aging time follows the same trend because an increase in the breakdown voltage of the oil was initially observed, thereafter, the breakdown value started depreciating. The initial increase in the breakdown voltage can be attributed to the reduction in moisture content in the oil sample during thermal aging. High moisture content in an insulating oil is detrimental to the good insulation properties [17, 41]. After some hours of aging, the dielectric strength of the oils starts depreciating and this could be attributed to the formation of oxidation product and increase in acidity which, consequently, enhance the streamer propagation in the oil from the point of inception to the grounded electrode. From Fig. 6, the breakdown voltage of palm-yellow oleander oil after aging has the same value as mineral oil. The failure rate of the aged oil was characterized by two parameters Weibull plot. The characteristic breakdown voltage and Weibull plot of PY and the mineral oil can be seen in Table 6 and Fig. 7, respectively. It can be seen from Table 6 that mineral oil has a shape parameter greater than PY oil; however, their characteristic breakdown voltage has almost the same value. Also, the plot of the oils in Fig. 7 shows a similar trend. This is an indication that PY oil is a promising green alternative insulating oil for the power industry.

4 Conclusion

The novel research work on the properties of composite methyl esters from edible and non-edible oil as insulating oil in high-voltage equipment was examined. The dielectric loss factor, dielectric strength and some notable physicochemical properties were examined. The blending

Table 6 Two-parameter Weibull plot data

Sample	β (Shape parameter)	α (Characteristic breakdown voltage, kV)	ρ (Correlation coefficient)
PY	20.76	24.5	0.982
MO	26.45	24.6	0.926

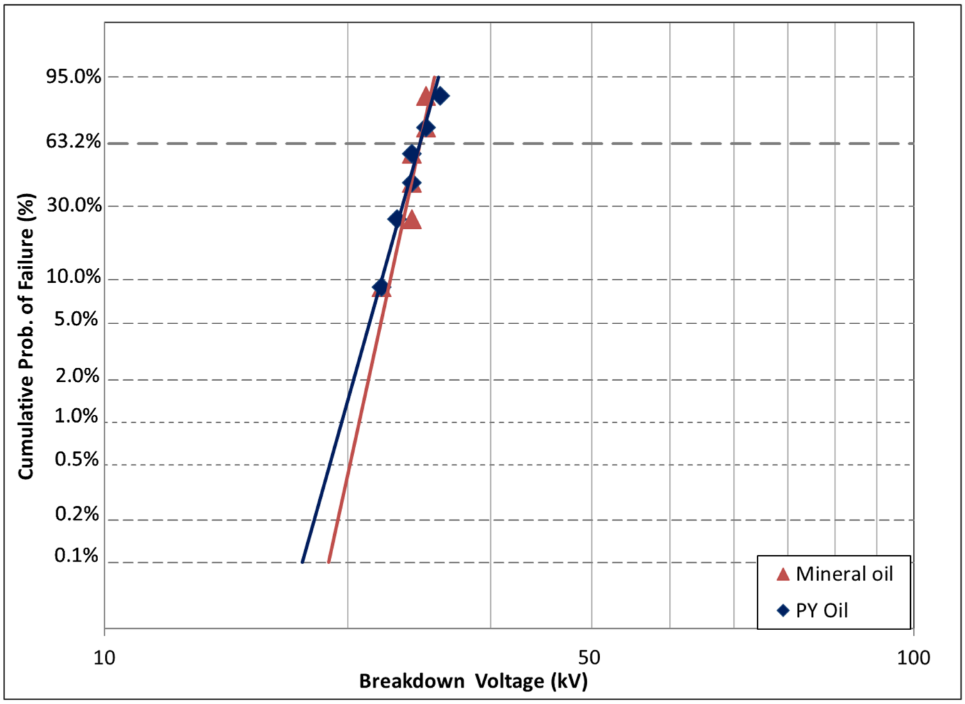

Fig. 7 Weibull plot of Mineral oil and Palm-Yellow oleander oil

of methyl esters from highly unsaturated oil and saturated oil is crucial to augment their deficiencies.

i. The pour point of composite methyl ester obtained reveals that the composite of methyl ester from edible and non-edible oil is a promising alternative insulating oil in a cold temperature region. The composite of yellow oleander and palm kernel oil has pour point of -2 °C; however, this is not up to the pour point of mineral insulating oil. This can be improved through the addition of flow improvers. The low viscosity of the composites and the standalone esters is a good indication that these esters are promising alternatives for mineral oil since oil with low viscosity is desired in transformer for proper insulation.
ii. It was observed that the composite ester has a good dielectric loss with an outstanding value in PY ester. Also, the breakdown voltage of the composite ester shows a good value relatively higher than the breakdown voltage of mineral oil. The mixture of the three esters reveals the highest breakdown voltage of 26 kV which is 8% greater than the breakdown voltage of mineral oil.
iii. The property of the aged oil shows that Palm-Yellow Oleander oil has both physical and electrical properties similar to mineral oil even after aging.
iv. Optimizing all the properties analyzed in this work, it can be concluded that the mixture of palm kernel methyl ester and yellow oleander methyl ester has outstanding properties with pour point of -2, a viscosity of 4.38 mPas, dielectric loss of 0.00074 and a breakdown voltage of 25 kV. The mixture of methyl ester from edible and non-edible oil has shown good physical and dielectric properties; this will tackle the problem of high pour point and poor oxidative stability affecting saturated and unsaturated oil, respectively. Optimization of methyl ester mixing can be done using the design of experiment. It is also recommended that an enhancement of dielectric properties of the composites should be done by the addition of electron scavengers to the insulating oil. In addition, the oxidative properties of the prepared samples should be thoroughly investigated.

Authors' contributions **S.O. Oparanti** contributed to conceptualization, investigation, formal analysis, writing—original draft, and writing—review and editing. **Andrew Adewunmi Adekunle** performed investigation, formal analysis, and writing—original draft. **Victoria Ene Oteikwu** performed formal analysis and writing—original draft. **Abdulsalam Ismaila Galadima** was involved in supervision, project administration, and writing—review and editing. **Abdelghaffar Amoka Abdelmalik** contributed to funding acquisition, supervision, project administration, and writing—review and editing.

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Data availability Not applicable.

Declarations

Ethics approval Not applicable.

Competing interests Not applicable.

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