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Characterization of Variant Vegetable Oil as a Substitute to Power Transformer Coolant

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Abstract

The need to provide an alternative transformer coolant that will be safer, non-flammable and environmentally friendly as a substitute to the petroleum-based oil presently being used as transformer oil necessitated this research. The study explores the potential of variant vegetable oils (melon oil, jatropha oil, coconut oil, and palm kernel oil) as substitutes for petroleum-based transformer oil. In other to find a suitable, non-flammable alternative and biodegradable vegetable oil as alternative to transformer oil, these oils were subjected to dielectric and chemical tests, particularly their insulation breakdown voltage before and after the addition of nanoparticles. The insulation breakdown voltage test results of the vegetable oil samples without nanoparticle addition were Jatropha oil 21 kV, Coconut oil 18 kV, Melon seed oil 15 kV and PKO 25 kV, while with the introduction of nanoparticles, the results became 25 kV, 19 kV, 15 kV and 35 kV respectively. Results obtained from the study show that with nanoparticles, PKO exhibited the highest improvement, reaching 35 kV, making it the most suitable candidate for 11kV/415V distribution transformer. This suggest that PKO, with nanoparticle modification, can be a viable transformer coolant, but further research is needed to optimize oxidation stability and other key properties.

1. Introduction

Petroleum-based oils have been the main insulating liquid in industrial power systems since the 1900's. They have a long and proven track record of their excellent performance and inherent good properties which include good aging behaviour, good viscosity index, ready availability and low cost. These will ensure their continued use for decades to come [1]. Because of these, mineral oils have met with little or no competition till date. However, growing demands for improved fire safety, material sustainability especially transformer cores, environment friendliness and longer asset service duration have driven the development of alternative natural insulating liquids [2]. There are two primary reasons why we should search for substitute natural insulating liquids. Among these are the low biodegradability of mineral oil and the growing demand for petroleum products, which could lead to acute shortages as early as the mid-21st century. Therefore, fully biodegradable oil with superior, more suitable additives will be essential in the future [3]. Vegetable oil requires a major improvement. For any power equipment, a biodegradable insulating liquid's long-term dependability is essential. To guarantee efficiency, it must have a high enough withstand voltage for the equipment's lifetime, say at least 30 years. Different types of liquids are employed as lubricants [4]. These insulating liquids are subdivided into different categories based on their chemical structures or fire points. They are:

Mineral Oils: Mineral oils are complex mixtures of hundreds of different organic compounds consisting of mainly carbon and hydrocarbon. They are made from fractional distillation of petroleum crude stock. There are two main categories of mineral oils, namely paraffin and naphthene [5]. In the early days, paraffin based mineral oils were used. They were later replaced by naphthalene oils because of the high pour point of paraffin oil. Also, paraffin oil contains wax while naphthene oil has very little wax [6].

Synthetic Insulating Liquids: Although mineral oils are crucial to the power sector, synthetic insulating liquids are utilized when specific qualities are required, such as resistance to fire, partial discharge, and negative gassing tendency (gas absorption). Halogenated hydrocarbons/polychlorinated biphenyls (PCBs), synthetic esters, silicone oils, and other substances make up a significant portion of synthetic insulating liquids [7].

Synthetic Esters: Made from organic acids and alcohols, esters are a large family of chemical molecules. When exposed to fire, they have good biodegradability and only produce carbon dioxide and water, not dioxins or other harmful byproducts. Tetra esters and phosphoric esters are two of the many kinds of esters utilized in electro technology [3].

Natural Esters: Since natural oils are easily accessible, they are excellent starting materials for completely biodegradable insulating solutions. Vegetable oils, which are made from plant crops, are used to make natural esters. All forms of natural esters have the drawback of being less oxidation stable than other kinds of insulating liquids, despite their high fire-point and good biodegradability [8]. While a wide range of crop oils can be used to make natural esters, soy, rapeseed, and sunflower oils are the most frequently used to make natural esters for electrical applications. This is because of things like cost, performance, and availability. Triglycerides, the main component of vegetable oil, are naturally produced by esterifying tri-alcohol glycerol with free fatty acids. As a result, many vegetable oils on the market now have chemical additive packages that lower pour points and improve oxidation stability [9]. Adding a polymethyl-acrylate derivative at a concentration below 1% can usually lower the pour point by 10^0C with little impact in electrical conductivity. Occasionally, the products include a copper deactivator or antibacterial agent [10]. Palm fatty ester is a recently proposed novel vegetable-based transformer insulating oil. Its relative permittivity is 30% higher and its dynamic viscosity is 60% lower than that of mineral oil [11 – 13]. Jatropha oil a kind of natural esters from a non- edible seed and therefore does not interfere with foodstuffs. It is widespread in arid, semi-arid and tropical regions of the world. Jatropha curcas is mostly found in northern part of Nigeria states of Sokoto, Zamfara, Kebbi, Kastina and Kano [14]. The Jatropha tree is a highly interesting plant with potential uses, particularly as biofuel to help in eliminating the energy crisis around the global. Jatropha oil is a clean fuel that reduces greenhouse gas emission. It has greater lubricity thereby reducing engine wear as well. The trees grow readily in areas where rainfall levels are significantly low [15, 16].

Several studies have explored vegetable oils, such as soybean oil, rapeseed oil, and sunflower oil, as substitutes for mineral oil, focusing on their high biodegradability, high flash points, and low toxicity [17, 18]. Despite these advantages, challenges such as poor oxidation stability, high viscosity, and suboptimal dielectric properties have hindered widespread adoption [19, 20]. The existing research primarily evaluates individual vegetable oils without systematically addressing the performance gaps, especially in long-term transformer applications. Moreover, while commercial bio-based transformer oils like Cargill’s FR3 have been developed, comparative studies between these and new vegetable oil formulations remain limited. Existing studies have primarily focused on the viability of single vegetable oils as transformer coolants but have not systematically compared multiple variants under uniform testing conditions [21, 22]. Additionally, many studies have not explored the potential of nanoparticle additives to enhance the dielectric properties of vegetable oils [23]. Furthermore, while commercial bio-based oils like FR3 exist, direct comparisons between them and alternative vegetable oil formulations remain scarce.

However, this study differs from the literatures in comparing multiple vegetable oil variants under identical testing conditions to determine their suitability as transformer coolant alternatives, investigating nanoparticle-enhanced formulations to address the dielectric limitations of raw vegetable oils, conducting comparative analysis with commercial bio-based oils to determine whether the proposed vegetable oils offer advantages in cost, performance, or environmental impact, assessing long-term stability through oxidation, moisture absorption, and thermal degradation tests, which are often missing in prior studies. By addressing these critical gaps, this study provides a more comprehensive evaluation of vegetable oils as transformer coolants and proposes solutions to improve their performance, thus enhancing their viability for real-world applications.

2. Methodology

The methodology section is divided in respect to the different kinds of oil used for the analysis.

2.1 Jatropha
Jatropha curcas seeds were obtained from a research institute in Zaria, Kaduna State, Nigeria. The peeled seeds were dried in an oven at temperatures between 60^0C and 80^0C until a constant mass was obtained. Then the extraction step was carried out (mechanical extraction, sohxlet or solvent extraction by direct contact). The extracted oils were processed in three steps: Degumming, neutralization and drying.

2.1.1 Extraction of Jatropha
Using a soxhlet or coming into direct contact with hexane, the resulting press cakes underwent chemical extraction after the peeled seeds had been mechanically extracted as shown in Figure 1. The oils from dried Jatropha carcas peeled seeds were extracted using a manual hydraulic press and the produced oils were filtered under vacuum.

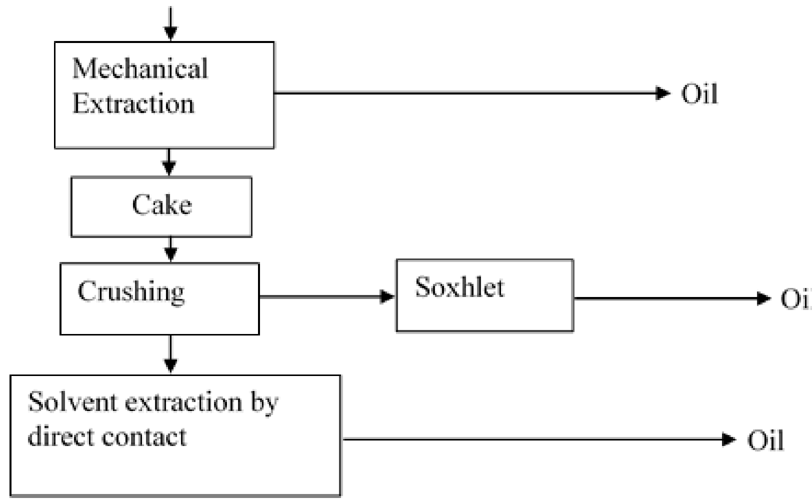

Figure 1: Oil extraction from peeled seeds

2.2 Melon seed, palm kernel and coconut
Melon seed was purchased from a local market in Owerri, Imo State with the identity authenticated by Chemical Engineering Laboratory, Faculty of Engineering, Federal University of Technology Owerri. Moisture was taken away from the seeds by oven drying for few hours. The yield of the dry seeds from the sample was determined. The dry seeds were then ground in some blender, separately and placed in vacuum oven at 60^0C for 6 hours and finally stored in exiccator until analyzed.

Palm kernel was gotten from Abia State in Nigeria as well as coconut. They were extracted at Chemical Engineering Laboratory, Faculty of Engineering, Federal University of Technology Owerri. The palm kernel after husking was crushed to smaller pieces so as to meet the requirements of palm kernel requirements.

2.3 Melon seed oil
Melon belongs to the family of cucurbitaceous. It was investigated for nutritional quality and the oil seed characteristics. They thrive in tropical, subtropical, deserts and temperate locations. Melon is a monoecious, herbaceous, annual plant that creeps rather than climbs [24]. Within three weeks of planting, they totally cover the soil's surface, and flowering begins. Insects are the pollinators. The fruits are frequently ready to be picked 90 - 120 days (3 - 4 months after seeding). The huge, smooth, indehiscent berries can be cleaned and dried once the sound has been eliminated. In West Africa, melon seeds are a major soup ingredient and a common component of daily meals. Melon oil is obtained from either mechanical extraction or by chemical extraction. These melon seeds, on a dry weight basis, consist of testa and kernel. The moisture content in melon seed is very high and it also has mineral constituents. Melon has high oil content ranging from 22.1-53.5% due to the presence of the hulls and crude protein content as well [25, 26].

2.3.1 Extraction
An electric blender was used to grind the seeds after they had been allowed to dry at room temperature. Using a Soxhlet device, 100g of seed samples were extracted using petroleum ether at 40–60^0C for six hours. Lipid samples were obtained as the residue after the extract was deseloventized in vacuo on a rotary evaporator at 35^0C. Physicochemical characteristics of seed oil samples:

The ordinary oil constants, e.g. acid value, iodine, saponification and peroxide values, specific gravity was calculated according to the AOAC method (Official Methods of Analysis of the Association of Official Analytic Chemists AOAC 1998).

2.4 Palm kernel oil (PKO)

Oil palm is the main oil crop in the tropical and sub-tropical region. Palm fruit is the most productive oil in the world. Palm pulp has 46-50% oil and palm kernel have 45-50% of oil [27]. Palm kernel oil (PKO) is the oil that is derived from palm kernels, whereas palm oil (PO) is the oil that is extracted from palm fruit. Both of these oils are unique, and so are the methods used to extract them.

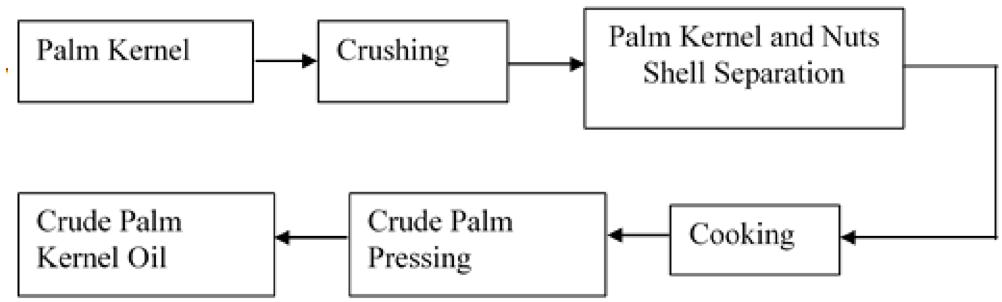

Figure 2: Palm kernel oil processing machine

The full set of palm kernel oil (PKO) processing machine include husking, crushing, cooking, pressing and oil filtration as shown in Figure 2.

2.4.1 Extraction/Pressing

The oil is extracted from pretreated palm kernel via mechanical forces. Palm kernel oil extraction machine is divided into two types: Special palm kernel oil press and conventional oil press.

Palm kernel oil is edible plant oil. It is semi-solid in non-temperature and is more saturated than palm oil and comparable to coconut oil as well. PKO does not contain cholesterol or trans fatty acids. It is packed with lauric fatty acid ($C_{12}H_{24}O_2$) and therefore suitable for the manufacture of soaps, detergents and other personal care products. It is also used in manufacturing both edible and non-edible products. In fact, it has a great application both in food and non-food industry [28]. The palm kernel oil is entirely different from palm oil. The two oils from the same fruit are totally different in fatty acid composition and properties. It can be used alone or blended with other oil for manufacture of cocoa butter substances, confectionary fats, biscuits doughs, caking icing, table margarine etc. Palm kernel oil can be directly combined with petrol diesel or used in making biodiesel for diesel engines. Locally, Africans use the oil to fuel native lamps for lighting in rural communities where electricity is next to nil.

Two methods of oil extraction

Solvent extraction method: This is employed to extract oil either from seed containing about 20% oil or from the pre-pressed expeller cake. This solvent extraction method is divided into three:

i Kernel pre-treatment
ii Oil extraction
iii Solvent recovery

During solvent extraction method, there are three units involved to carry on the operation which include:

i Extraction unit
ii Distillation unit
iii Drying unit

Mechanical extraction of palm kernel oil

The mechanical extraction method uses screw press as the principal means of extracting the oil. The use of screw press for full extraction has increased over the years in the developing countries.

The three basic steps involve:

i Kernel pre-treatment (clearing, size reduction, flaking and then steam conditioning)
ii Screw pressing

iii Oil clarification [29]

2.5 Coconut oil

Coconut oil or copra oil is an edible oil extracted from the kernel or meat of a mature coconuts harvested from the coconut palm (cocos nucifera). It is an important fruit tree in the world, providing food for millions of people, especially in the tropical and subtropical regions. Copra is made by drying coconut oil in the sun or fire after it has been removed from the shell either wetly or dryly. Coconut oil is created by pressing or dissolving the copra with solvents. Wet process: This method makes use of copra and coconut milk [30]. Centrifuges and pre-treatments such as heat, cold, acids, salts, enzymes, electrolysis, steam distillation, or a combination of these are used in modern methods. Wet processing yields a yield that is 10–15% lower than dry processing, despite the many variants and technologies. Hexane is used as a solvent in conventional coconut oil processors to extract up to 10% more oil than would be possible with rotary mills and expellers alone. To lessen the oil's vulnerability to rancidity, it is refined by removing specific free fatty acids. Fresh coconut milk, flesh, or leftovers can all be used to make virgin coconut oil (VCO) [31 – 33].

2.6 Testing the extracted oils for insulation strength and dielectric properties

The variant vegetable oil samples are physically and chemically tested under density, free fatty acid, iodine value, electrical testing and breakdown voltages. To ensure statistical reliability, the dielectric strength and physicochemical properties of Jatropha oil, coconut oil, melon seed oil, and palm kernel oil (PKO) were tested in their raw and nanoparticle-enhanced forms. The breakdown voltage (BDV) was measured using ASTM D-1816 and IEC 60156 standards. Standard deviations and statistical significance tests (ANOVA) were applied to confirm differences among samples.

2.6.1 Physical and chemical testing of variant sample oils

Density
Density was measured using the standard method. Capillary stopper relative bottle density of 50ml capacity was used to determine the density of oil.

Free fatty acid
Almost all vegetable oils contain fatty acid. This is because of the long continuous glycerol chain they possess. A weighted mass of 0.67g of raw vegetable sample was transferred into a beaker and 50ml of ethanol was added to it. The mixture was placed on a hot plate. As the temperature was raised, the mixture started boiling and the ethanol absorbed the free fatty acid on the vegetable sample oil.

Iodine value
Iodine value is the measure of the average degree of unsaturation of a fat or oil. It is also a predictor of its oxidation stability. If the degree of unsaturation is high, it will help in the degradation of the oil which is facilitated by the influence of oxone and oxygen. While the lower the unsaturation of oils and fats, the greater will be its oxidation stability.

Aging Tests

To evaluate long-term performance, the following additional tests were conducted: Oxidation stability test by using ASTM D-2440, the samples were aged at 120°C for 164 hours, and peroxide formation was measured; Moisture absorption test by the relative moisture content of the oils was tested over a 30-day period using Karl Fischer titration; Thermal degradation test done when oils were exposed to cyclic heating (85°C to 150°C) to simulate operational stress.

Electrical testing of the sample oils
In order to investigate the performance of different vegetable oil as an alternative insulating liquid for transformer, several samples of the natural oil were collected from various farms in Nigeria. Jatropha seed oil was obtained from Research Institute of Nigeria, Zaria, Kaduna state. Melon seed was purchased from a local market in Owerri, Imo state and was extracted at Chemical Engineering Laboratory, Federal University of Technology, Owerri. Palm kernel oil (PKO) and coconut oil were collected from processed farm in Imo state. A sample of mineral oil was collected from Egbu transmission station, Owerri, Imo state was also included for comparison. The comparison of the sample was carried out based on the following properties of insulating liquid: breakdown voltage, flash point, pour points, acidity and density.

Breakdown voltage measurement in oil

To determine the breakdown voltage of insulating oil is included in international and national standards on liquid dielectrics. Among the well-known are IEC 60156 and ASTM D -1816. These standards are used to check the oil quantity and to diagnose insulation contaminants and oil degradation. In order to meet the insulation criteria, the oil must have high dielectric strength and low dielectric dissipation factor to withstand the electrical stresses imposed in service. Therefore, high breakdown voltage i.e. BDV is needed. Oil with low dielectric strength indicates the presence of contaminants.

Breakdown voltage testing procedure

The breakdown voltage of a sample of dielectric transformer oil is tested in order to determine the oil's insulating qualities. There is less transformer oil present if the breakdown voltage that results is smaller. The processes adopted are:

- i The testing device's vessel is filled with coolant. The dielectric oil surrounds two standard-compliant test electrodes with a usual clearance of 2.5 mm.
- ii The electrode receives a test voltage, which is gradually raised to the breakdown voltage at a steady, standard-compliant slew rate, such as 2kV/s.
- iii The test voltage collapses when an electric arc breaks down at a specific voltage level.
- iv The test gadget immediately turns off the test voltage as soon as the arc ignites.
- v The mean or average breakdown voltage value is measured and reported by the insulation oil testing apparatus.
- vi The insulation oil is automatically stirred when the test is over, and the test procedure is carried out repeatedly—usually six times, depending on the specification.
- vii Consequently, the average or mean value of the different measurements is used to compute the breakdown voltage.

3. Results and Discussion

The result of aging test between transformer oil and vegetable oils is shown in Table 1, while the comparative results of the properties between transformer oil and vegetable oils without nano-particles are presented in Figures 3 to 11.

Table 1: Aging test results

Property	Standard Transformer Oil	Jatropha	Coconut	Melon Seed	PKO
Moisture Content (mg/kg)	0.00	1.23	1.50	1.26	1.33
Viscosity at 40°C (cSt)	7.90	47.75	37.60	33.24	28.08
Viscosity at 100°C (cSt)	2.30	8.20	8.41	8.00	6.87
Acid Value (mgKOH/g)	0.597	7.966	0.561	3.029	19.747
Free Fatty Acid (mgKOH/g)	0.00	3.983	0.2805	1.5145	9.8735

From Table 1, the moisture content of vegetable oils is slightly higher than standard transformer oil, but still within an acceptable rang. The vegetable oils are within the standard but significantly more viscous than mineral oil while PKO has the highest acid value, which can lead to faster degradation over time.

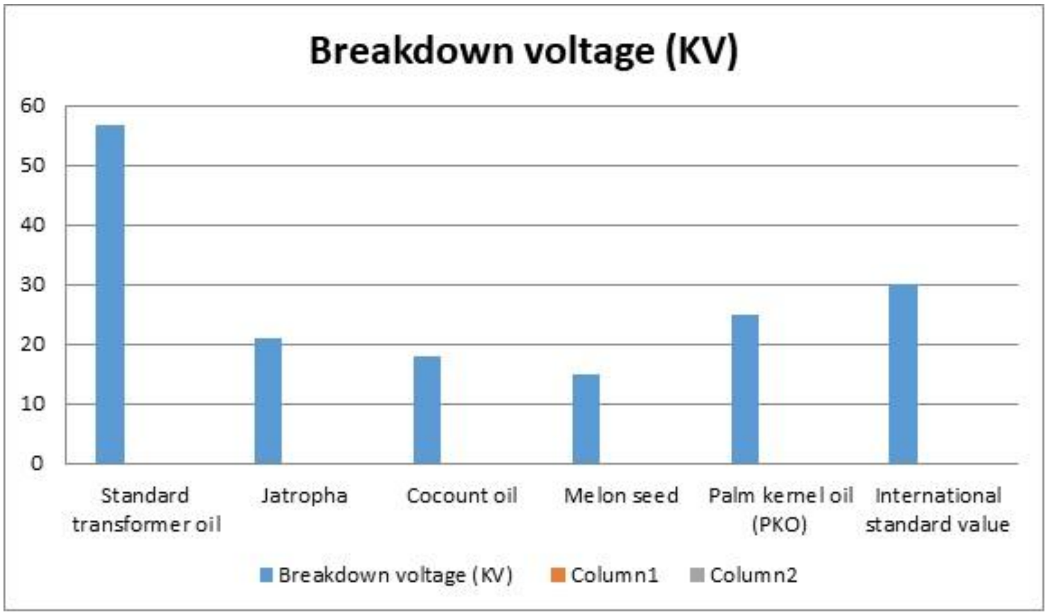

Figure 3: Comparison of breakdown voltage without nano-particle

From the result of Figure 3, the breakdown voltage (BDV) of Jatropha, coconut, melon and PKO without nano-particle are 21 kV, 18 kV, 15 kV and 25 kV respectively. None of them were able to attain the international standard value of ≥ 30kV, as can be observed. The BDV of PKO, which has the highest, is 5 kV lower than the global standard value.

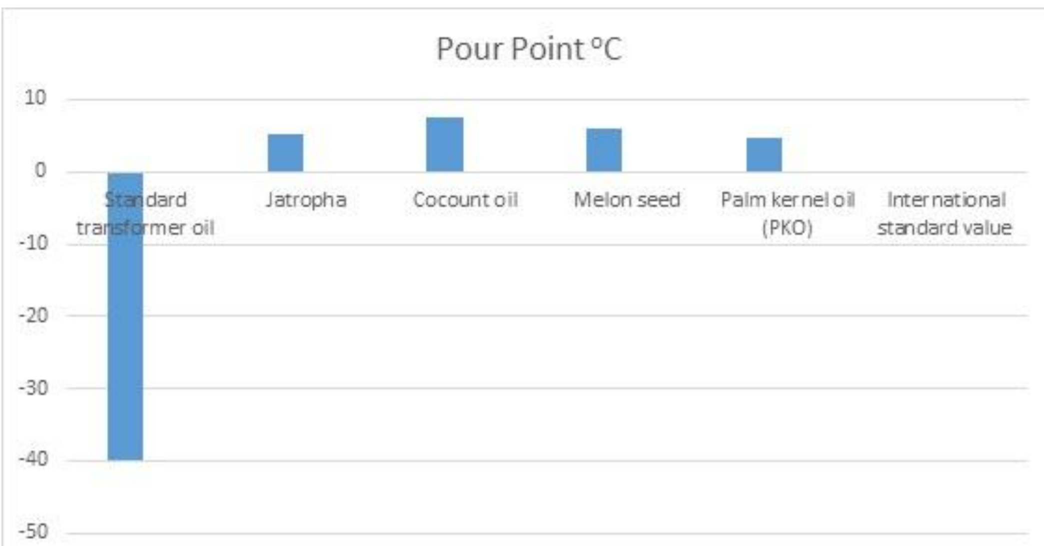

Figure 4: Comparison between standard transformer oil and vegetable oil pour point

From Figure 4, the pour point of standard transformer oil is -40ºC while the pour points of Jatropha, coconut, melon and PKO are 5.3ºC, 7.5ºC, 6.1ºC and 4.8ºC respectively. The pour point international standard value is ≤ -10ºC. The difference between the standard transformer oil and the sample oils is too much. This is one of the major constraints of vegetable oil. Future work has to be done to reduce the pour point level of vegetable oils.

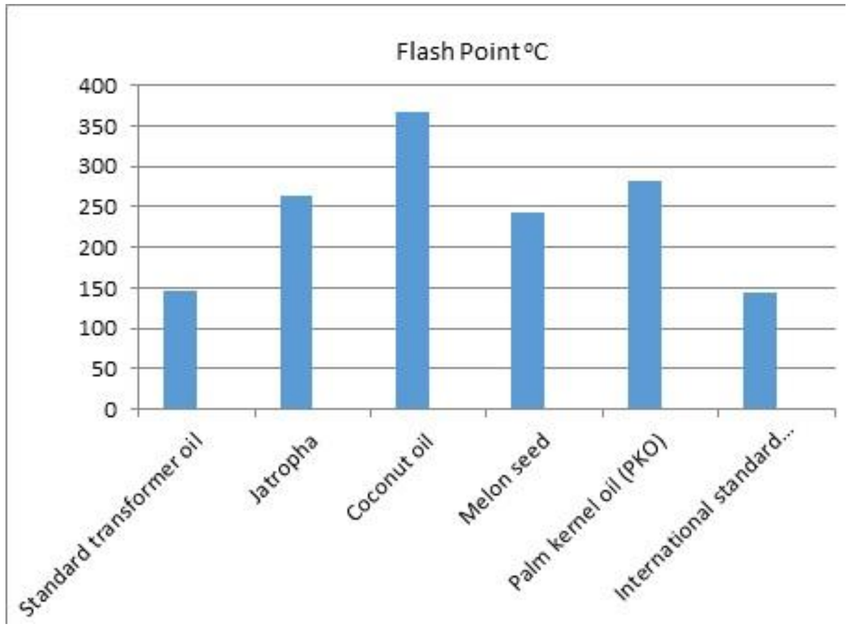

Figure 5: Comparison between standard transformer oil and vegetable oil flash point

From Figure 5, the flash point of standard transformer oil is 146ºC while the flash points of Jatropha, coconut, melon and PKO are 263ºC, 368ºC, 244ºC and 282ºC respectively. It is evident from the results that normal transformer oil is vulnerable to volatile regions due to its low flash point of 146oC. In contrast, the flash points of the samples are about double that of normal transformer oil, with coconut oil having the highest flash point at 368ºC. This further demonstrates why vegetable oil is a perfect substitute for distribution transformers.

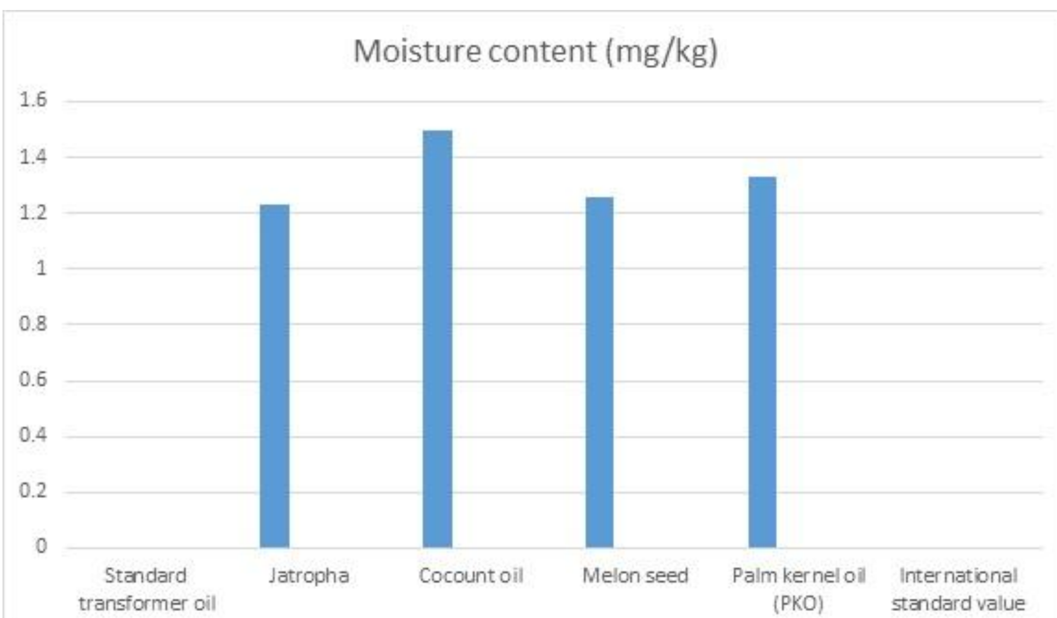

Figure 6: Comparison between standard transformer oil and vegetable oil moisture content

From Figure 6, the moisture content of standard transformer oil is nil while the moisture content of Jatropha, coconut, melon and PKO are 1.23mg/kg, 1.5mg/kg, 1.26mg/kg and 1.33mg/kg respectively. From the results, the disparity between the moisture content of conventional transformer oil and the sample oils is small but still, more work has to be done to bring the moisture content of sample oils next to nil.

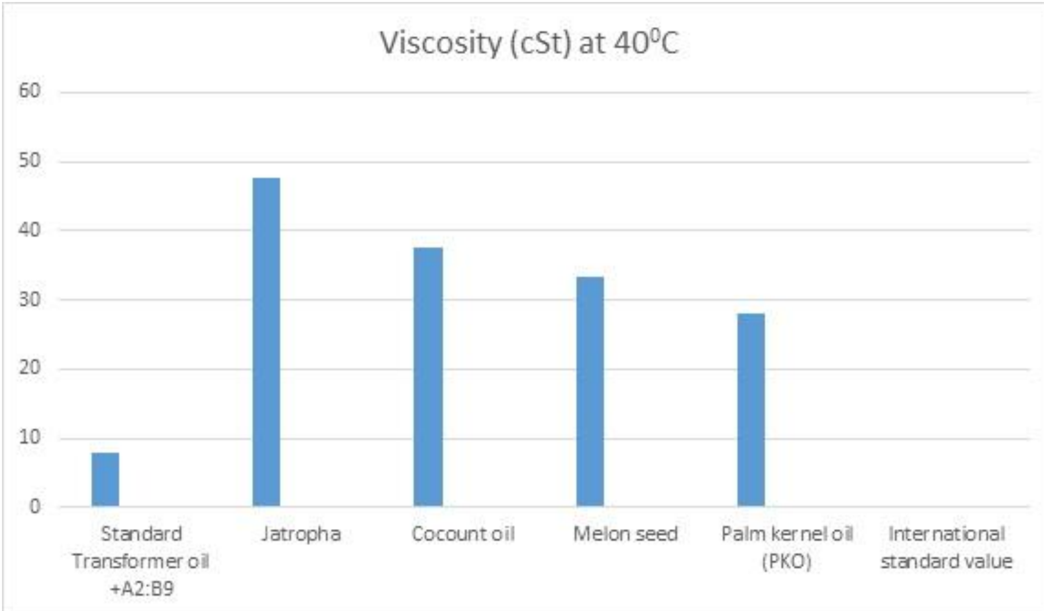

Figure 7: Comparison between standard transformer oil and vegetable oil viscosity at 40ºC

From Figure 7, the viscosity of standard transformer oil at 40ºC is 7.9ºC while the viscosity values of Jatropha, coconut, melon and palm kernel oil are 47.7451ºC, 37.6011ºC, 33.2404ºC and 28.0838ºC respectively. The results show that the viscosity of the sample oils is much higher than standard transformer oil although it stills fall within the range of international value of ≤ 50ºC. More work also has to be done on the sample oils to reduce the viscosity.

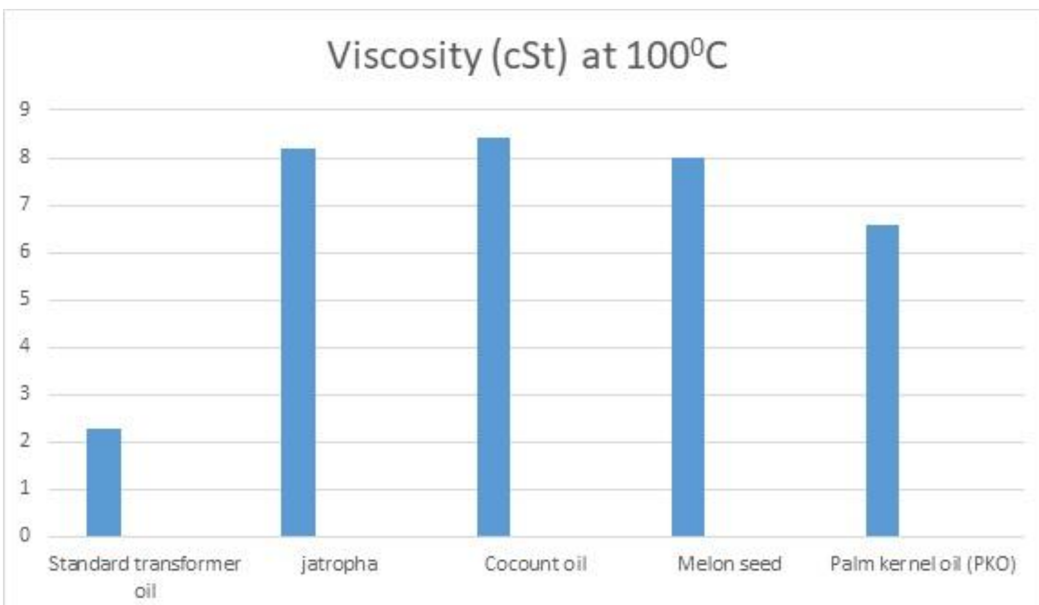

Figure 8: Comparison between standard transformer oil and vegetable oil viscosity at 100ºC

From Figure 8, the viscosity of standard transformer oil at 100ºC is 2.3ºC while the viscosity of Jatropha, coconut, melon and PKO are 8.2ºC, 8.41ºC, 8.0ºC and 6.87ºC respectively. The difference between the viscosity of standard oil and the sample oils is also high. Future work needs to be done to reduce the viscosity of sample oils to a lower level.

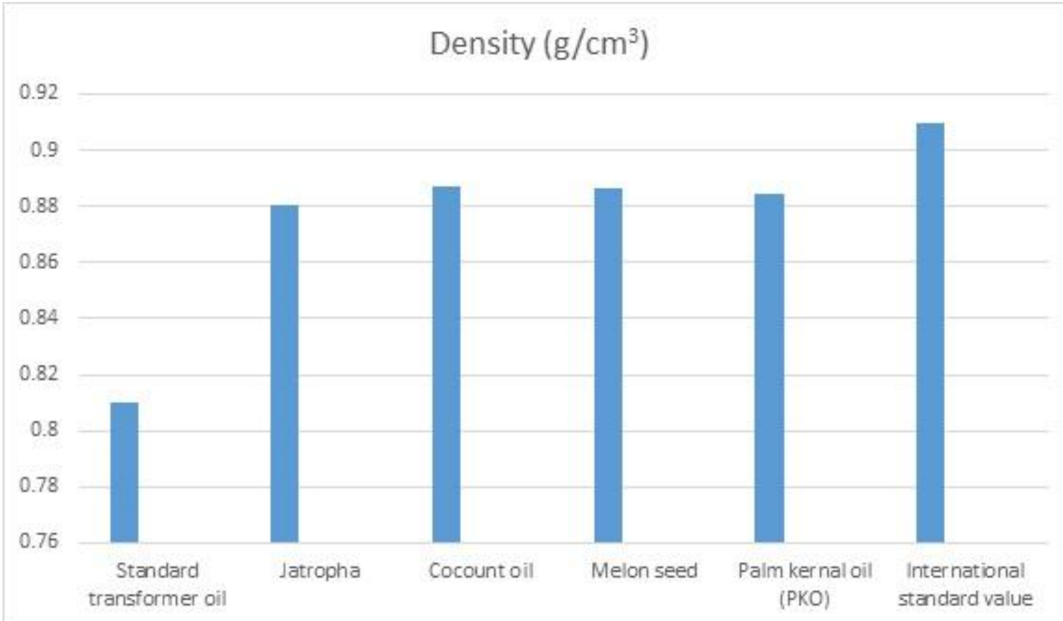

Figure 9: Comparison between standard transformer oil and vegetable oil density

Standard transformer oil has a density of 0.81g/cm^3, whereas the densities of particle-free Jatropha, coconut, melon, and palm kernel oil are 0.8804g/cm^3, 0.8872g/cm^3, 0.8867g/cm^3, and 0.8843g/cm^3, respectively as seen in Figure 9. The density of the sample oils and standard transformer oil differs slightly, but it is still within the international standard limit of < 0.91g/cm^3, according to this comparison.

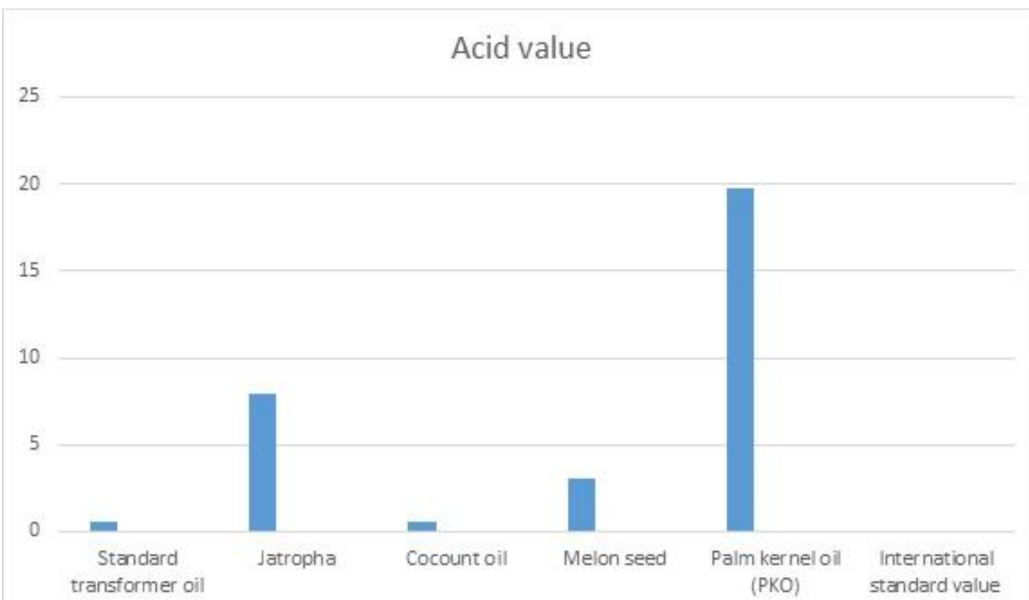

Figure 10: Comparison between standard transformer oil and vegetable oil acid value

From Figure 10, the acid value of standard transformer oil is 0.597 while the acid values of Jatropha, coconut, melon and palm kernel oil are7.966, 0.561, 3.029 and 19.747 respectively. In this case, there is an excessive difference in the acid value of the sample oils and standard transformer oil. This indicates that further effort is needed to lower the acid value of the vegetable oils in the sample.

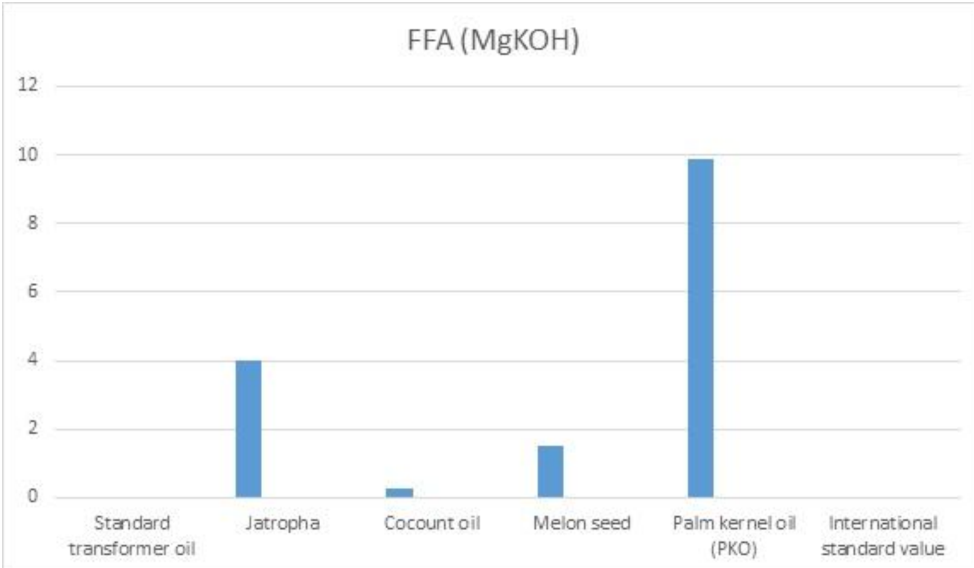

Figure 11: Comparison between standard transformer oil and vegetable oil FFA

From Figure 11, the free fatty acid of standard transformer oil is nil while the free fatty acid of Jatropha, coconut, melon and palm kernel oil are 3.983, 0.2805, 1.5145 and 9.8735. The free fatty acid of palm kernel oil is much higher than the other three samples. More work also has to be done to reduce the free fatty acid of the sample oils since the standard transformer oil does not have. The comparative results of the properties between mineral oil and vegetable oils with and without nano-particles (titanium iv oxide) are presented in Table 2. When nano-particle was added to the oil samples, a considerate rise was seen in the breakdown voltage of sample oils as shown in Table 2.

Table 2: Comparison of (BDV) of conventional transformer and vegetable oils with and without nano-particles

Property	Standard Transformer Oil	Jatropha	Coconut	Melon Seed	PKO
Breakdown Voltage (kV)	56.8	21	18	15	25
Breakdown Voltage with Nanoparticles (kV)	56-60	25	19	15	35

Without nanoparticles, the BDV of Jatropha, coconut, melon, and PKO oils were 21 kV, 18 kV, 15 kV, and 25 kV, respectively, all below the international standard (≥30 kV) as shown in Table 2. However, with the addition of TiO_2 nanoparticles, PKO's BDV increased to 35 kV, surpassing the required standard. The improvement was statistically significant ($p < 0.05$, ANOVA test) making PKO an almost perfect insulating liquid for a distribution transformer. These findings indicate that while raw vegetable oils do not meet industry standards, modified PKO can serve as a viable alternative with proper additives. In comparing with the commercial bio-based transformer oils such as Cargill's FR3 have been successfully implemented in transformers due to their oxidation stability and high BDV (typically 56 kV) [17]. While PKO with nanoparticles achieves the required BDV, its oxidation stability is yet to match FR3 [20, 21]. Additional modifications, such as antioxidant additives, are recommended to enhance PKO's long-term performance.

4. Conclusion

The aim of this paper is to investigate the use of natural oils as a possible replacement for mineral oil transformer coolant as well as a potential feedstock for biodiesel production. The advantages of natural oils can be acknowledged from its performance criteria; good biodegradability characteristic, high flash point, high solubility, lubricity, high solvency, and negative gassing tendency (gas absorption). With these merits, vegetable oil has been conceded as a good alternative material for transformer oil. The drawbacks of natural oils can be solved by introduction of some additives such as antioxidants or metal deactivators to inhibit and restrain chemical or organic reaction as well as enhance oxidation stability. This study confirms that while raw vegetable oils do not meet international standards for transformer coolants, PKO with TiO_2 nanoparticles demonstrates improved dielectric properties, reaching the required BDV of $\geq$30 kV. However, oxidation stability and moisture resistance remain concerns. Future research should focus on: chemical modification (e.g., antioxidants) to improve oxidation resistance, long-term field testing to assess performance under real transformer conditions, comparative testing with commercial bio-based oils to establish competitive advantages.

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