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ASSESSING ELECTRICAL AND PHYSICOCHEMICAL PERFORMANCE OF CHEMICALLY MODIFIED PALM OIL AS AN ALTERNATIVE TRANSFORMER LIQUID

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ABSTRACT

Numerous studies have been conducted on enhancing the dielectric properties of palm oil (PO) with the addition of nanoparticles (NPs). However, insufficient emphasis was given to its physicochemical properties, which are also critical for the function of an insulating liquid. The high viscosity of PO is one of the key factors which deteriorates the usage of natural ester in general, and PO in our case. This study was intended to investigate the performance of chemically modified PO by adopting a sequential transesterification process – NPs addition. The present work explored the transesterified PO blended with insulative (SiO_2) and semiconductive (ZnO) NPs at various concentrations (0.1-0.6 g L^{-1}). The modified oils' dielectric strength and physicochemical properties (density, kinematic viscosity, and water content) were measured using standard testing methods. The results showed that the transesterification process effectively reduced the viscosity of PO, and adding ZnO NPs substantially impacted the PO in terms of AC breakdown voltage, with an optimum performance at 0.2 g L^{-1} concentration of 85% improvement. In contrast, while using SiO_2, its breakdown voltage decreased irrespective of the concentration.

Keywords: chemically modification, nanoparticles, physicochemical properties, transesterification.

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INTRODUCTION

For decades, petroleum-based mineral oil (MO) has been utilised conventionally as a transformer insulating liquid. However, the usage of MO derived from non-renewable energy resources is affecting the environment due to its non-biodegradable property. As a result, researchers shifted their interest to biodegradable and renewable alternatives. Most research in biodegradable oils for transformer applications has focused on natural ester oils (NEOs) or vegetable oils (VOs). In the late 1990s, ABB developed the first commercial electrical insulating oil, BIOTEMP®, a sunflower oil-based (Boss and Oommen, 1999). In 2000, McShane *et al*. (2000) of Cooper Industries Inc. introduced Envirotemp FR3™ derived from soybean oil, and later, in 2008, Lion Corporation of Japan successfully developed Palm Fatty Acid Ester (PFAE) with the brand name Pastell Neo®, as potential natural ester (NE) insulating liquids for the transformers. VOs are renewable, cost savings, environmentally friendly, biodegradable, and safer alternative insulating oil (Amin *et al*., 2019). Due to the advantages mentioned above, VO is considered a substitute.

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The wealth of literature conducted with the above NEOs has motivated researchers from other countries to begin researching their plant-based insulating liquids that utilise available and accessible renewable and biodegradable energy resources. Several plant oils, such as palm oil, pongamia pinnata oil, olive oil, marula oil, coconut oil, *etc*., have been used as the raw materials. Their potential suitability as transformer oils has been investigated and examined thoroughly by many researchers (Ariffin *et al*., 2017; Baruah *et al*., 2019; Farade *et al*., 2020; Genga Devi *et al*., 2016; Koutras *et al*., 2020a; Oparanti *et al*., 2020; Samikannu *et al*., 2021). Researchers eventually realised that VO-based liquid insulation needed various modifications to overcome its shortcomings and be employed as the insulating liquid in transformers (Moosasait and Maria Siluvairaj, 2021). One of the issues with VOs is their high viscosity, which undoubtedly reduces their efficacy as liquid insulation, making them unsuitable for cooling purposes (Raeisian *et al*., 2019; Yusof *et al*., 2017).

Over the years, researchers have successfully modified VOs for use as transformer liquid (Menkiti *et al*., 2017). Many studies have recognised the chemical modification of NEOs to lower their viscosities and make them comparable to that of MO for transformer application (Baruah *et al*., 2019). These studies have used various methods and base fluids, as summarised in *Table 1*. These methods are direct purification, esterification, transesterification, and epoxidation-esterification methods. Among all, transesterification is one of the options that has gained popularity, similar to the production of biodiesel as performed by various researchers (Ishola *et al*., 2020; Venugopal *et al*., 2021).

In addition, modifications are attempted on the base fluids to achieve superior thermal and dielectric properties by introducing nanoparticles (NPs), resulting in a nanofluid (NF) mixture. The physical, chemical, and thermal characteristics of dispersed NPs, along with the base fluid, as well as their weight or volume concentrations (Pyrgioti *et al*., 2020), have impacted the improvement and performance of NFs (Hussain *et al*., 2020). The influence of conductive (Fe_2O_3, Fe_3O_4), semiconductive (TiO_2, ZnO, CuO) and insulative (SiO_2, Al_2O_3) NPs on the dielectric and physicochemical properties of biodegradable insulating liquids have been extensively studied in the literature. Koutras *et al*. (2020b) reported that the addition of TiO_2 NPs into FR3 enhanced alternating current breakdown voltage (AC BDV) by 22.40% at 0.02 vol% concentration. Oparanti *et al*. (2021) examined the effects of dispersing TiO_2 and Al_2O_3 NPs into palm kernel oil (PKO) on the physicochemical properties, dielectric response, and BDV. The results showed that the dispersion of these two types of NPs enhanced the physicochemical properties of the PKO. In other studies, for instance, Raj *et al*. (2021) reported the excellent performance of marula oil

TABLE 1. SUMMARY OF LITERATURE RELATED TO METHYL ESTER OILS AS ALTERNATIVE TRANSFORMER LIQUID

Modification method	References	Methyl ester oils	Performance	
			Dielectric strength [kV]	Kinematic viscosity (40°C) [$mm^2 s^{-1}$ or cSt]
Direct purification	Menkiti *et al*. (2017)	Modified *Terminalia catappa* kernel oil (MTCKO)	32.88	15.22
Esterification	Sitorus *et al*. (2016)	Jatropha methyl ester oil (JMEO)	87.00	10.45
Transesterification	Maharana *et al*. (2018)	Karanji oil methyl ester (KOME)	85.40	12.00
	Agu *et al*. (2019)	Modified *T. catappa* kernel oil (MTCKO)	48.55	10.29
	Nkouetcha *et al*. (2019)	Castor oil methyl ester (COME)	74.67	18.42
	Ravulapalli *et al*. (2019)	Methyl ester sesbania seeds oil (MESSO)	n/a	0.98×10^{-11}
	Asse *et al*. (2022)	Palm kernel oil methyl ester (PKOME)	32.22	n/a
	Oparanti *et al*. (2022)	Neem oil ester	n/a	5.17
Epoxidation-esterification	Abdelmalik *et al*. (2011)	Palm kernel oil epoxy methyl ester (PKOEME)	45.58	6.14
	Agu *et al*. (2019)	Modified *T. catappa* kernel oil (MTCKO)	50.05	8.56
Blending with fatty acid or fatty esters	Mohd *et al*. (2021)	Blended RBDPO olein	76.80	2.48 – 5.12 (depends on types of fatty acid or fatty esters)

Note: Recommended specification for natural ester (IEEE C57.147:2018) – Dielectric strength ≥35 kV, and kinematic viscosity ≤50 cSt.
n/a – not available.