Thermal Aging Effects on the Electrical Breakdown Voltage of TiO_2 and MWCNT Nanofluids Based on POME

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***Abstract*—In this work, the aging behavior of liquid insulation in transformers using chemically modified refined, bleached, and deodorized palm oil (RBDPO) olein is investigated. The transesterification process is used to modify RBDPO olein to produce palm oil methyl ester (POME), which is used as a base fluid for nanofluid (NF) preparation. The performance of POME with the dispersion of semiconducting titanium oxide (TiO_2) and conducting multi-walled carbon nanotube (MWCNT) nanoparticles (NPs) at different concentrations on the AC breakdown voltage (AC BDV) as insulation in transformers is evaluated for their aging behavior. The accelerated aging was conducted under sealed conditions at a temperature of 130°C for 1000 hours. The results show that incorporating TiO_2 and MWCNT NPs into POME did not have an adverse effect on the BDV, regardless of the doping concentrations. Notably, POME-based TiO_2 NFs exhibited the highest AC BDV after thermal aging, specifically at a concentration of 0.05 g/L. Anderson-Darling goodness-of-fit statistics were performed on the experimental data to verify their agreement with the Normal and Weibull distributions.**

***Index Terms*—Dielectric liquids, nanofluids, palm oil methyl ester, statistical analysis, thermal aging.**

I. INTRODUCTION

ONE of the promising and directly relevant initiatives in supporting the United Nations (UN) Sustainable Development Goal (SDG)-7, which is to facilitate access to affordable, clean, and modern energy services, has greatly benefited from the shift of researchers' interest from conventionally non-biodegradable mineral oil (MO) to biodegradable and renewable alternatives. Most biodegradable research for transformer applications is done on natural ester oils (NEOs) or vegetable oils (VOs).

The first industrial insulating dielectric oil, BIOTEMP®, extracted from sunflower oil, was commercialized by ABB in 1999 [1], followed by Environtemp FR3® made from soybean oil in 2000 by Cooper Industries Inc. [2]. Later, in 2008, the Lion Corporation of Japan successfully developed a palm fatty acid ester (PFAE) as a potential substitute for dielectric liquid in the transformers. Numerous studies conducted using the commercial NEOs have consequently inspired some scholars in Southeast Asian countries, especially in Indonesia, Malaysia, and Thailand, to start exploring their plant-based insulating liquids utilizing widely available and accessible feedstock, particularly palm oil (PO). Most researchers give preference to investigating refined, bleached, and deodorized palm oil (RBDPO) olein over other PO forms in their studies. Abdullahi *et al*. [3] are among the pioneers who explored the effectiveness and suitability of PO as an oil insulation replacement. Since then, the study has evolved tremendously. Previous empirical data from various studies have demonstrated that the PO should be given preference for biodegradable oil insulation.

However, there are substantial limitations that continue to prevent the broader usage of VO as a replacement for dielectric liquid in high-voltage (HV) applications [4]. Chemical modification of VOs represents an attractive alternative route for producing potentially usable oils to replace oil insulation. Chemical modification studies have been used to obtain derivative esters with low viscosities and melting points and make them coincide closely with MO for transformer applications. Moreover, the advances in nanotechnology have provided a new perspective and opportunities for better properties and performances of VO-based as well as PO-based transformer liquid insulation, resulting in a mixture called nanofluids (NFs). For the purpose of synthesizing NFs, many studies have been done using PO, RBDPO, or its methyl ester (also known as palm oil methyl ester, or POME) as the base fluid and blending it with different nanoparticles (NPs). According to recent review articles by [5], [6], the most commonly investigated NPs in PO insulating liquids include titanium dioxide (TiO_2) by Nor *et al*. [7], Makmud *et al*. [8] and

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