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An Overview on Making a Nanofluid from Vegetable Oil and Researching its Insulating Qualities

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Abstract - The use of vegetable oil as an insulating fluid is becoming increasingly popular due to the mineral oil's qualities, which were first shown by researchers in 1995 [1]. Subsequent studies have demonstrated that a few nanoparticles, including graphene, hexagonal boron nitride (h-BN), titanium oxide (TiO2), aluminium oxide (Al2O3), and aluminium nitride (AlN), can increase the thermal conductivity of mineral transformer oil [2–8]. However, it is also recognised that there is a strong demand for mineral oil these days because it is used as a lubricating fluid in other industries including transportation. Mineral oil poses a threat to the environment and is a non- renewable resource that is running out every day and is predicted to run out entirely in a few decades [1]. In response to this issue, researchers are constantly testing vegetable oil as a mineral oil substitute for transformer insulation [9]. Due to their high flash point and renewable nature, vegetable oils were initially suggested as a liquid for transformer insulation [10]. Researchers also switched the foundation oil of the nanofluid from mineral oil to vegetable oil in accordance with the advances in nanotechnology [11–12]. Just one of the 29 research articles published in 2012 on the issue of nanofluids as transformer insulation liquids employed vegetable oil as the base fluid, according to the statistical analysis from Scopus (Figures 1 and 2). This demonstrates that in 2012, there was little interest in using vegetable oil-based nanofluid as a liquid for transformer insulation. According to the statistics, only three of the more than 60 works published in 2018 on the subject of nanofluid as transformer oil used vegetable oil-based nanofluid as the research material. This indicates that the field of study on this topic is still in its infancy and that its popularity is growing annually.

Keywords - Vegetable oil, Transformer insulation, Mineral oil, Nanofluids, Thermal conductivity.

I. INTRODUCTION

The preparation process for nanofluids based on vegetable oil is reviewed in this research.

The methods used to prepare nanofluids still vary because the use of nanotechnology in transformer insulating oil is still relatively new in the industry. To determine the most effective technique for creating nanofluids, researchers are always conducting experiments.

This report also discusses the findings from testing on vegetable oil-based nanofluids that have been carried out in other studies. Last but not least, this study made a number of additional recommendations for the experimental projects utilising nanofluids based on vegetable oil.

Fig.1 and 2 shows that research works published from the past ten years on mineral oil and vegetable oil nanofluids as transformer insulation liquids and research works published from the past ten years on the topic vegetable oil-based nanofluids.

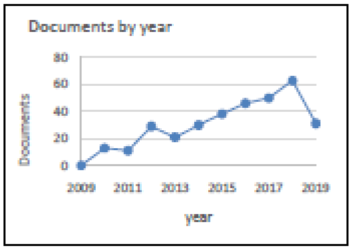

Fig. 1 - Research works published from the past ten years on mineral oil and vegetable oil nanofluids as transformer insulation liquids.

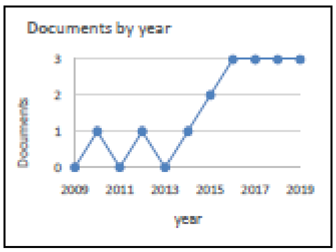

Fig. 2 - Research works published from the past ten years on the topic vegetable oil-based nanofluids

II. MAKING NANOFLUIDS BASED ON VEGETABLE OIL

Types of vegetable oil

Different types of vegetable oil are used by each researcher in their work. This is because the molecular structures of various vegetable oils vary, resulting in variations in their insulating qualities. Jian Li et al., for instance, used three distinct kinds of vegetable oil: RDB, which is derived from rapeseed oil; Cooper Power Systems' natural esters FR3; and ABB's BIOTEMP [14].

RDB, or refined, deodorised, and bleached oil, is a type of vegetable oil that is produced by three methods: vacuum distillation, bleaching, and alkaline refinement [15–16].

Types of nanoparticles used

TiO2 and ferrous ferric oxide (Fe3O4) are the most widely utilized nanoparticles by researchers globally, followed by silicon dioxide (SiO2), Al2O3, and zinc oxide (ZnO), according to a study by Z. Huang et al., which is statistically analyzed in Figure 3 [1].

Numerous studies have demonstrated that Al2O3, TiO2, Fe3O4, ZnO, and copper (II) oxide (CuO) nanoparticles can raise the base transformer oil's breakdown voltage under switching impulse voltage, both positively and negatively [17–22].

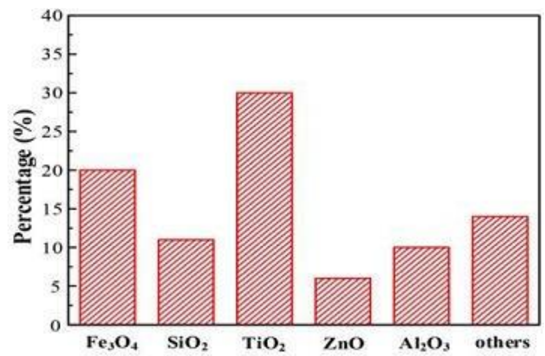

Fig. 3 - Types of nanoparticles used in transformer oil [1].

Preparation of stably dispersed nanofluids

As of right now, there are just two ways to prepare nanofluids: the one-step method and the two- step method. Since the one-step procedure combines the production of nanofluids with the fabrication of nanoparticles, surface modification of the nanoparticles did not occur [23]. The one-step method avoids the storing, drying, and transportation of the nanoparticles by directly preparing the nanofluids using the liquid chemical method or the physical vapour deposition technique (PVD) [23]. The advantage of using one-step method is that agglomeration of nanoparticles in the base oil is minimized. However, this method's application is limited because it only works with fluids with low vapour pressure.

In their investigation, Eastman et al. employed a one-step process to create the nanofluids, in which ethylene glycol, a flowing low vapour pressure liquid, condensed the copper vapor into nanoparticles [24].

By chemically reducing copper nanoparticles in a water-base fluid, Liu et al. created the nanofluids [25].

The copper nanofluids were also made using a chemical reduction procedure in another study by Zhu et al., where CuSO4●5H2O was reduced with NaH2PO2●H2O in ethylene glycol while being exposed to microwave radiation [26]. It is not appropriate to apply the one-step approach to vegetable oils that are high in saturated fatty acids, such as coconut oil and palm oil RDB, because only low vapour pressure fluids, like water and ethylene glycol, can be employed as the base fluid. It is also important to note that no surfactant was employed in any of the studies that created the nanofluid using the one-step technique because the nanofluid was made directly without the agglomeration of nanoparticles.

Nanoparticles are dispersed in the base fluid using the two-step approach, which often involves adding surfactants to the fluids or ultrasonic agitation to reduce agglomeration in the nanoparticles-base fluid mixture [23]. Agglomeration of nanoparticles in the base fluid will reduce the nanofluid's thermal conductivity, according to Y. Li et al. [23]. The nanoparticles are first subjected to surface modification using a surface modifier or surfactant, followed by magnetic stirring and ultrasonic dispersion to create a nanofluid with improved dispersion stability [2,13,27]. M. Taro et al. used SiO2 nanoparticles at a variety of concentrations to successfully create mineral oil-based nanofluids and ester oil-based nanofluids [28]. Initially, they used SiO2, TiO2, CuO, and ZnO nanoparticles as distinct sample variations to create the nanofluids.

However, only the nanofluids containing SiO2 nanoparticles were found to be stably distributed because of the sedimentation and agglomeration of the nanoparticles in the base oil. It should be mentioned that M. Taro et al. used an ultrasonic equipment to create the nanofluids in their investigation in two steps. However, they did not employ any surfactants in the process. This could be the cause of the instability of the dispersion of the nanofluids containing TiO2, CuO, and ZnO. Their investigation did not go into detail as to why, across a range of concentrations, only the SiO2 nanofluid was effectively disseminated.

However, the SiO2 particle bonds may be more easily broken and combined with the base oil's carbon-hydrogen molecule. Because of their surface and interface energies, nanoparticles tend to aggregate in base oil, which impairs the dielectric characteristics of the fluid and prevents it from being evenly distributed [1].

Dispersed in the base fluid, nanoparticles will be exposed to a variety of forces, including gravity, solvation power, electrostatic force, and Van der Waals force [1]. According to the DVLO hypothesis, which was proposed by B. Derjaguin, E. Verway, L. Landau, and T. Overbeek, Van der Waals attractive forces and electrical double layer repulsive forces govern the stability of nanofluids [29–30]. According to DVLO theory, a stable dispersed nanofluid will form if the attractive forces are less than the repulsive forces.

Experimental results

Breakdown voltage studies on SiO2 nanofluids based on mineral oil and synthetic ester oil (MIDEL 7131) were carried out by M. Taro et al. [28]. In the corresponding base fluids, the SiO2 nanoparticle concentration was adjusted to 0.1, 0.3, 0.5, 0.7, and 1.0% volume fraction. According to the study, the breakdown voltage of the nanofluids was almost 12% more than that of the base oils, which included both mineral and ester oil [28]. Figure 4 below illustrates how M. Taro et al. demonstrated that SiO2 nanoparticles may boost the dielectric strength of both vegetable and mineral oils when exposed to impulsive voltages.

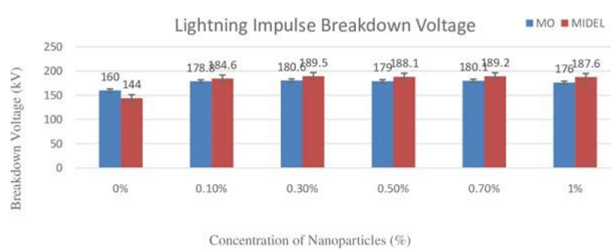

Fig. 4 - Impulse breakdown voltage test result of mineral oil-based SiO2 nanofluids and ester oil-based SiO2 nanofluids in a sphere-sphere electrodes at 3mm gap spacing [28].

Jian Li et al. experimented with Fe3O4 nanoparticles in a study on rapeseed oil RDB and its nanofluid [13]. In compliance with the IEC 60156 standard, the AC breakdown voltage test was carried out using sphere-sphere electrodes spaced 2.5 mm apart. According to their research, the nanofluid sample's average breakdown voltage was 20% greater than the rapeseed oil RDB's [13]. The polarized nanoparticles' ability to capture free electrons may be the cause of the rise in breakdown voltage value [31].

According to additional research by Jian Li et al., the average negative lightning impulse breakdown voltage of a natural ester-based nanofluid sample, as shown in table 2, is 12% higher than that of the natural ester sample, while the average positive lightning impulse breakdown voltage of a natural ester (camellia oil)-based Fe3O4 nanofluid, as shown in table 1, is 37% higher than that of the camellia oil sample [32]. The natural ester and Fe3O4 mixture were ultrasonically dispersed after the Fe3O4 surface was modified to create the nanofluid sample. Camellia oil ester and its nanofluid's lightning impulse breakdown voltage was determined in accordance with IEC 60897. It was demonstrated by the results that the surface-modified Fe3O4 nanoparticles could raise the natural ester insulating liquids' lightning impulse breakdown voltage.

Table 1 Positive lightning impulse breakdown voltage of camellia oil ester and its nanofluid32

Sample	Breakdown Voltage (kV)					
	1	2	3	4	5	Average
Oil	77.8	73.4	74.5	70.2	73.4	73.9
Nanofluids	104.8	99.4	99.4	702.6	101.5	101.5

Table 2 Negative lightning impulse breakdown voltage of camellia oil ester and its nanofluid32

Sample	Breakdown Voltage (kV)					
	1	2	3	4	5	Average
Oil	85.3	84.2	84.2	82.1	84.2	83.8
Nanofluids	96.1	94.0	92.9	96.1	89.6	93.7

III. CONCLUSION

Since vegetable oil is not a low vapour pressure liquid, it is not appropriate to generate vegetable oil-based nanofluids using a one-step process. Instead, researchers often employ a two-step procedure to create these fluids. Other studies have demonstrated that nanoparticles can improve vegetable oil's insulating qualities. Both in theory and in practice, the nanofluids' breakdown voltages are larger than those of their corresponding base fluids. But because there are still a lot of issues that need to be resolved before using vegetable oil-based nanofluids entirely in place of traditional mineral transformer oils, their usage as transformer insulation liquids is still restricted and not common in industries. The majority of recent studies generate transformer oil nanofluids using a two-step technique that requires a lot of time to complete: surface modification of the nanoparticles, magnetic stirring, and sonication. Therefore, it is advised for the future.

According to studies, scientists should create a novel, time-saving, and less expensive method of preparing transformer oil-based nanofluids than the one-step and two-step approaches currently in use. Additionally, as different nanoparticles have varying impacts on the insulating qualities of the base transformer oil, it is worthwhile to conduct study on the material selection for the nanoparticles.

Table3 Physical, chemical and electrical properties of three types of vegetable oil13

Property	RDB		FR3		BIOTEMP	
	Value	Test method	Value	Test method	Value	Test method
Appearance	Light yellow	IEC 61099	Light green	ASTM D1524	Clear & bright	ASTM D1524
Density ($kg \cdot m^{-3}$)	0.90/20°C	ISO 3675	0.92/25°C	ASTM D1298	0.91/25°C	ASTM D1298
Kinematic viscosity ($mm^2 \cdot s^{-1}$)	43/40°C	ISO 3104	34/40°C	ASTM D445	45/40°C	ASTM D445
Pour point (°C)	−18	ISO 3016	−21	ASTM D97	−15 to −25	ASTM D97
Flash point (°C)	325	ISO 2592	316	ASTM D92	330	ASTM D92
Acid value ($mgKOH \cdot g^{-1}$)	0.03	ISO 660	0.04	ASTM D974	0.075	ASTM D974
Interfacial tension ($mN \cdot m^{-1}$)	30	ISO 6295	24	ASTM D971	—	ASTM D971
Breakdown voltage (kV)	73	IEC 60156	56	ASTM D1816	65	ASTM D1816
Dissipation factor (%)	2/90°C	IEC 60247	3/100°C	ASTM D924	2/100°C	ASTM D924
Relative permittivity	2.9/90°C	IEC 60247	3.2/25°C	ASTM D1169	3.2/25°C	ASTM D1169
Volume resistivity ($\Omega \cdot m$)	1×10^{10}/90°C	IEC 60247	2×10^{11}/25°C	ASTM D924	1×10^{11}/25°C	ASTM D924

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