Preparation of vegetable oil-based nanofluid and studies on its insulating property: A review

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Abstract: The application of vegetable oil as an insulating fluid is gaining a lot of interest from researchers all over the world because of the fact that it is a renewable source and is easily available. This paper reviews and compares the preparation methods of vegetable oil-based nanofluids that have been used by many different authors. The experimental results obtained by previous researchers on the insulating properties of the vegetable oil-based nanofluids are also analysed and discussed in detail. In addition, future improvements for experimental works with insulating nanofluids are also proposed.

Keywords: Vegetable oil, Insulating fluid, Nanofluids, Transformer oil, Nanoparticle.

1. Introduction

Transformer is a device that plays an important role in the electrical system. For hundred years, mineral oil have been used as an insulating fluid inside the transformer. The mineral oil also serves as a coolant for the transformers. Later then, the use of nanoparticles in improving the insulating properties of the mineral oil was introduced by the researchers in year 1995 \[1\]. Other research works after that have proved that aluminium oxide(Al2O3), aluminum nitride (AIN), titanium oxide(TiO2), hexagonal boron nitride (h-BN), graphene and few other nanoparticles are able to improve the thermal conductivity of mineral transformer oil\[2–8\].

But it is also known that nowadays, the demands for the mineral oil is high since it is also needed in other sectors such as transportation, which it is processed as a lubricating fluid. Mineral oil is hazardous to the environment and it is a non-renewable resource that is continuously depleting by each day and is estimated to completely run out several decades in the future\[1\]. Reacting to this problem, researchers are continuously experimenting on vegetable oil as the alternative to mineral oil in the application of transformer insulation\[9\].Vegetable oils are first proposed as a transformer insulation liquid because they are a renewable source that are environmentally friendly and has high flash point\[10\].Following the nanotechnology trends, researchers also changed the base oil of nanofluid from mineral oil to vegetable oil \[11-12\].

The statistical analysis from Scopus (Figure 1 and Figure 2) shows that there were 29 research articles published in the year 2012 related to the topic nanofluids as transformer insulation liquids, but in the same year, only 1 of them used vegetable oil as the base fluid. This shows that back in 2012, the research interest in vegetable oil based nanofluid as transformer insulation liquid is not widely attractive to researchers. The statistics also show that recently in year 2018, there are over 60 works published on the topic related to the nanofluid as a transformer oil, but only 3 from the works are using vegetable oil-based nanofluid as the research material, proving that the vegetable oil based nanofluid is still in the early research stage and its popularity is increasing by each year.
This paper reviews the preparation method of vegetable oil-based nanofluids. Since the application of nanotechnology in the transformer insulating oil is still new in the industries, the preparation methods of nanofluids are still varies. Researchers are constantly experimenting in order to find the most efficient method for preparation of nanofluids. The results for the tests conducted on the vegetable oil-based nanofluids that have been done in other research works are also discussed in this paper. Lastly, this paper also suggested several further improvements for the experimental works involving vegetable oil-based nanofluids.

2. Preparation of vegetable oil-based nanofluids

Types of vegetable oil
Every researchers use different vegetable oil in their works. This is because different vegetable oils have different molecular structures, which means that their insulating properties are also different. For example, Jian Li et al.[13] used three different types of vegetable oil which are RDB made from rapeseed oil, and natural esters FR3 manufactured by Cooper Power Systems and BIOTEMP[14] manufactured by ABB. RDB is a name stands for refined, deodorized and bleached oil, which is a type of vegetable oil that is obtained by using three processes called alkaline refinement, vacuum distillation and bleaching[15-16]. Basically, all processed vegetable oil that has refined label on it is called RDB. The choosing factors for types of vegetable oil used in the research works depend on the availability of the vegetable oil and their basic physical, chemical and electrical properties. Figure 3 shows some of the properties for RDB, FR3 and BIOTEMP.

Types of nanoparticles used
Figure 4 shows the statistical analysis from a study by Z. Huang et al. reporting that TiO2 and ferrous ferric oxide (Fe3O4) are the most common nanoparticles used by researchers worldwide, followed by silicon dioxide (SiO2), Al2O3 and zinc oxide (ZnO) [1]. It was proven in many different research works that Al2O3, TiO2, Fe3O4, ZnO and copper (II) oxide (CuO) nanoparticles can increase both positive and negative breakdown voltage of the base transformer oil under switching impulse voltage [17–22].
Preparation of stably dispersed nanofluids

Until this day, there are only two methods of nanofluids preparation exist which are one-step method and two-step method. In one-step method, the surface modification of the nanoparticles did not take place since it is a process where the preparation of nanoparticles and synthesis of nanofluids is combined [23]. One-step method is a process in which the nanofluids are directly prepared by physical vapour deposition technique (PVD) or liquid chemical method so that the storage, drying and transportation process of the nanoparticles are avoided [23]. The advantage of using one-step method is that agglomeration of nanoparticles in the base oil is minimized. However, only a low vapour pressure fluid are compatible with this method, making its application limited.

Eastman et al. in their study, used one-step method to prepare the nanofluids where the copper vapour was condensed into nanoparticles by a flowing low vapour pressure liquid, ethylene glycol [24]. Liu et al. prepared the nanofluids by chemical reduction process of copper nanoparticles in the water-base fluid [25]. In other research work by Zhu et al., the copper nanofluids was also prepared by chemical reduction process where CuSO₄ • 5H₂O was reduced with NaH₂PO₄ • H₂O in ethylene glycol under microwave irradiation [26]. Only low vapour pressure fluids such as water and ethylene glycol are suitable to be used as the base fluid in one-step method, meaning that the one-step method is not a suitable method to be applied to vegetable oils that are high in saturated fatty acid like coconut oil and palm oil RDB. It is also noteworthy that there was no surfactant used in any of the works that prepared the nanofluid by one-step method, since the nanofluid was directly produced without nanoparticles agglomeration.
The two-step method is a process of dispersing nanoparticles in the base fluid, where the ultrasonic agitation or adding of the surfactants to the fluids are usually used in order to minimize the agglomeration in the nanoparticles-base fluid mixture [23]. Y. Li et al. stated that the agglomeration of nanoparticles in the base fluid will decrease the thermal conductivity of the nanofluid[23]. To prepare a nanofluid with a better dispersion stability, first, the nanoparticles are put through the surface modification process by using surface modifier or surfactant, then magnetic stirring and ultrasonic dispersion are performed [2,13,27].

M. Taro et al. successfully prepared mineral oil-based nanofluids and ester oil-based nanofluids by using SiO2 nanoparticles at several different concentrations[28]. Originally, they prepared the nanofluids using SiO2, TiO2, CuO and ZnO nanoparticles as a separate variation of samples. However, due to sedimentation and agglomeration of the nanoparticles in the base oil, only the nanofuids with SiO2 nanoparticle was found to be stably dispersed. In their study, M. Taro et al. prepared the nanofluids by two-step method using ultrasonic device, but the point to be noted is that they did not use any surfactant during the nanofluid preparation process. This might be the reason why the nanofuids with TiO2, CuO, and ZnO were unable to be stably dispersed. The reason as for why only the SiO2 nanofluid was successfully dispersed even with several different concentrations was not elaborated in their study. But it might be that because of the particle bonds in the SiO2 is easier to break and combine with the carbon-hydrogen molecule of the base oil.

Nanoparticles have a tendency to agglomerates in the base oil due to the surface energy and interface energy causing the nanofluid to be not stably dispersed and affecting its dielectric properties [1]. Nanoparticles that are dispersed in the base fluid will be subjected to many different forces such as Van der Waals force, electrostatic force, solvation power and gravity [1]. A theory suggested by B. Derjaguin, E. Verway, L. Landau and T. Overbeek (DVLO theory) stated that the stability of nanofluids is determined by Van der Waals attractive forces and electrical double layer repulsive forces [29-30]. DVLO theory suggests that if the attractive forces is lower than the repulsive forces, a stably dispersed nanofluid will be produced.

3. Experimental results

M. Taro et al. conducted the breakdown voltage tests on mineral oil-based SiO2 nanofluids and synthetic ester oil (MIDEL 7131)-based SiO2 nanofluids [28]. The concentration of SiO2 nanoparticles in the respective base fluids was varied to 0.1, 0.3, 0.5, 0.7 and 1.0% volume fraction. In the study, they found that the breakdown voltage of the nanofluids was about 12% higher than the breakdown voltage of the base oils (both mineral oil and ester oil) [28]. M. Taro et al. proved that the SiO2 nanoparticles are able to increase the dielectric strength of the mineral oil and vegetable oil under impulse voltages which is shown in figure 5 below.

![Lightning Impulse Breakdown Voltage](image-url)

Figure 5. 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].
In a study conducted by Jian Li et al., they experimented on the rapeseed oil RDB and its nanofluid with Fe₃O₄ nanoparticles [13]. The AC breakdown voltage test was conducted in accordance with the IEC 60156 standard where the electrodes used were sphere-sphere electrodes at 2.5mm gap spacing. It was recorded in their study that the average breakdown voltage of the nanofluid sample was 20% higher than that of the rapeseed oil RDB [13]. The increase in breakdown voltage value may be due to the trapping of free electrons by the polarized nanoparticles[31].

Other research work also by Jian Li et al. recorded that the average positive lightning impulse breakdown voltage of a natural ester (camellia oil)-based Fe₃O₄ nanofluid as in table 1 is 37% greater than that of camellia oil sample while the average negative lightning impulse breakdown voltage as in table 2 of the natural ester-based nanofluid sample is 12% greater than that of the natural ester sample [32]. The nanofluid sample was prepared by first, Fe₃O₄ surface modification and then the ultrasonic dispersion of the natural ester and Fe₃O₄ mixture. The lightning impulse breakdown voltage of camellia oil ester and its nanofluid was measured following the IEC 60897 standard. Based on the result obtained, it was proven that the surface-modified Fe₃O₄ nanoparticles are able to enhance the lightning impulse breakdown voltage of natural ester insulating liquids.

| Table 1. Positive lightning impulse breakdown voltage of camellia oil ester and its nanofluid [32]. |
|---------------------------------------------------------------|
| **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  | 102.6 | 101.5 | 101.5       |

| Table 2. Negative lightning impulse breakdown voltage of camellia oil ester and its nanofluid [32]. |
|---------------------------------------------------------------|
| **Sample** | **Breakdown voltage (kV)** |
| **1** | **2** | **3** | **4** | **5** | **Average** |
| Oil       | 85.3  | 84.2  | 83.2  | 82.1  | 84.2  | 83.8        |
| Nanofluids| 96.1  | 94.0  | 92.9  | 96.1  | 89.6  | 93.7        |

4. Conclusion

The vegetable oil-based nanofluids are not suitable to be prepared with one-step method since vegetable oil is not a low vapour pressure liquid, thus making the two-step method as the common method used by researchers to prepare the vegetable oil-based nanofluids. Based on other research works, nanoparticles have been proven able to enhance the insulating properties of vegetable oil. The breakdown voltage of the nanofluids are theoretically and proven practically higher than the breakdown voltage of their respective base fluids. However, the application of vegetable oil based-nanofluids as a transformer insulation liquid is still limited and not widely used in the industries, since there are many problems need to be explored before completely applied them in place of the conventional mineral transformer oils. Most of the recent research works use the two-step method to prepare the transformer oil nanofluids which the nanoparticles surface modification, magnetic stirring and sonication process takes a lot of time to be conducted. Hence, it is recommended for the future studies that researchers should develop a new method of preparation for transformer oil-based nanofluids which is time saving and at the same time, lower in cost compared to the existing methods, one-step method and two step-method. Besides, selection of the nanoparticles material is also worth to be researched, because different nanoparticles cause different effects on the insulating properties of the base transformer oil.
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References

[1] Huang Z, Li J, Yao W, Wang F, Wan F, Tan Y and Mehmood M A 2019 Electrical and thermal properties of insulating oil-based nanofluids: a comprehensive overview IET Nanodielectrics 2 27–40

[2] Choi C, Yoo H S and Oh J M 2008 Preparation and heat transfer properties of nanoparticle-in-transformer oil dispersions as advanced energy-efficient coolants Curr. Appl. Phys. 8710–712

[3] Naddaf A and Zeinali S 2018 Experimental study on thermal conductivity and electrical conductivity of diesel oil-based nanofluids of graphene nanplatelets and carbon nanotubes Int. Commun. Heat Mass Transf. 95 116–122

[4] Bian W, Yao T, Chen M, Zhang C, Shao T and Yang Y 2018 The synergistic effects of the micro-BN and nano-Al2O3 in micro-nano composites on enhancing the thermal conductivity for insulating epoxy resin Compos. Sci. Technol. 168 420–428

[5] Asadi A, Asadi M, Rezaniakolaei A, Rosendahl L A and Wongwises S 2018 An experimental and theoretical investigation on heat transfer capability of Mg(OH)2 / MWCNT-engine oil hybrid nano-lubricant adopted as a coolant and lubricant fluid Appl. Therm. Eng. 129 577–586

[6] Kiran M R and Babu S R 2018 Experimental investigation on natural convection heat transfer enhancement using transformer oil-TiO2 nanofluid IRJET5 1412-1418

[7] Maharana M, Baruah N, Nayak S K and Sahoo N 2018 Effect of oxidative ageing on the thermophysical and electrical properties of the nanofluid with statistical analysis of AC breakdown voltage IET Sci. Meas. Technol. 12 1074-1081

[8] Liang N, Liao R, Xiang M, Mo Y and Yuan Y 2018 Effect of nano Al2O3 doping on thermal aging properties of oil-paper insulation Energies 11 1–12

[9] Wilhelm H M, Tulio L and Postal C 2011 Aging markers for in-service natural ester-based insulating fluids IEEE Trans. Dielectr. Electr. Insul. 18 714–719

[10] Oommen T V 2002 Vegetable oils for liquid-filled transformers IEEE Electr. Insul. Mag. 18 6–11

[11] Yao W, Huang Z, Li J, Wu L and Xiang C 2018 Enhanced electrical insulation and heat transfer performance of vegetable oil based nanofluids J. Nanomater. 2018

[12] Sulemani M S, Majid A, Khan F, Ahmad N, Abid M A and Khan I U 2018 Effect of nanoparticles on breakdown, aging and other properties of vegetable oil 2018 1st Int. Conf. Power, Energy Smart Grid (ICPESG) 1–6

[13] Li J, Zhang Z, Zou P, Grzybowski S and Zahn M 2012 Preparation of a vegetable oil-based nanofluid and investigation of its breakdown and dielectric properties IEEE Electr. Insul. Mag., 28 43–50
[14] Oommen T V, Claiborne C C and Walsh E J 1998 Introduction of a new fully biodegradable dielectric fluid IEEE Annu. Textile, Fiber Film Ind. Tech. Conf.

[15] Li J, Grzybowski S, Sun Y and Chen X 2007 Dielectric properties of rapeseed oil paper insulation Annu. Rep. - Conf. Electr. Insul. Dielectr. Phenomena, CEIDP 500–503

[16] Li X, Li J and Sun C 2006 Properties of transgenic rapeseed oil based dielectric liquid Conf. Proc. IEEE SoutheastCon 81–84

[17] Coulibaly M L, Perrier C, Marugan M and Beroual A 2013 Aging behavior of cellulosic materials in presence of mineral oil and ester liquids under various conditions IEEE Trans. Dielectr. Electr. Insul. 20 1971–1976

[18] Du B X and Li X L 2017 Dielectric and thermal characteristics of vegetable oil filled with BN nanoparticles IEEE Trans. Dielectr. Electr. Insul. 24 956–963

[19] Hwang J G, O’Sullivan F, Zahn M, Hjortstam O, Pettersson L A A and Liu R 2008 Modeling of streamer propagation in transformer oil-based nanofluids Annu. Rep. - Conf. Electr. Insul. Dielectr. Phenomena CEIDP 361–366

[20] Torshin Y V 2009 Schlieren registration of electrohydrodynamics phenomena in dielectric liquids under lightning impulse IEEE Trans. Dielectr. Electr. Insul. 16 470–474

[21] Liu R, Pettersson L A A, Auletta T and Hjortstam O 2011 Fundamental research on the application of nano dielectrics to transformers Annu. Rep. - Conf. Electr. Insul. Dielectr. Phenomena CEIDP 423–427

[22] Liu Q and Wang Z D 2011 Streamer characteristic and breakdown in synthetic and natural ester transformer liquids with pressboard interface under lightning impulse voltage IEEE Trans. Dielectr. Electr. Insul. 18 1908–1917

[23] Li Y, Zhou J, Tung S, Schneider E and Xi S 2009 A review on development of nanofluid preparation and characterization 196 89–101

[24] Eastman J A, Choi S U S, Li S, Yu W and Thompson L J 2001 Anomalously increased effective thermal conductivities of ethylene glycol-based nanofluids containing copper nanoparticles Appl. Phys. Lett. 78 718–720

[25] Liu M S, Lin M C C, Tsai C Y and Wang C C 2006 Enhancement of thermal conductivity with Cu for nanofluids using chemical reduction method Int. J. Heat Mass Transf. 49 3028–3033

[26] Zhu H, Lin Y and Yin Y 2004 A novel one-step chemical method for preparation of copper nanofluids J. Colloid Interface Sci. 277 100–103

[27] Viali W R, Alcantara G B, Sartoratto P P C, Soler M A G, Mosiniewicz-Szablewska E, Andrzejewski B and Morais P C 2010 Investigation of the molecular surface coating on the stability of insulating magnetic oils J. Phys. Chem. C114 179–188

[28] Taro M, Shill D, Das A K and Chatterjee S 2017 Experimental investigation of transformer oil based nanofluids for applications in distribution transformers 3rd Int. Conf. Condition Assessment
Techniques in Electrical Systems (CATCON) 2017  367-370

[29] Missana T and Adell A  2000  On the applicability of DLVO theory to the prediction of clay colloids stability  J. Colloid Interface Sci.230  150–156

[30] Popa I, Gillies G, Papastavrou G and Borkovec M 2010 Attractive and repulsive electrostatic forces between positively charged latex particles in the presence of anionic linear polyelectrolytes J. Phys. Chem. B114  3170–3177

[31] Hwang J G, Zahn M, O’Sullivan F M, Pettersson L A A, Hjortstam O and Liu R  2010  Effects of nanoparticle charging on streamer development in transformer oil-based nanofluids  J. Appl. Phys.107

[32] Li J, Liao R and Yang L  2012Investigation of Natural Ester Based Liquid Dielectrics and Nanofluids  2012 Int.Conf. High Volt. Eng. Appl.  56  16–21