Investigative Study On The AC And DC Breakdown Voltage of Nanofluid From Jatropha –Neem Oils Mixture For Use In Oil-Filled Power Equipment.

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Abstract

This paper investigated the feasibility of developing alternative insulating nanofluid from a mixture of Jatropha and Neem oils into which compositions of 0.2wt% to 1.0wt% of titanium oxide nanoparticles were dispersed. FTIR, SEM-EDX and XRD analysis of Titanium oxide nanoparticles were carried out. The DC and AC breakdown voltages were measured and analysed using Weibull statistical tool. In the Weibull statistical analysis, it was observed that the characteristic breakdown field strength of PJO is higher relative to PNO and has slight differences compared to the PJNO sample. With the dispersion of TiO_2 nanoparticles, the characteristic breakdown strength improved as compared with the base oil. Furthermore, the developed Jatropha-Neem mixture nanofluid recorded characteristic breakdown field strength that is much higher compared to that of the mineral oil sample. The JNNF sample possessed the highest characteristic breakdown strength among prepared nanofluids which indicates that the characteristic breakdown strength of the oil samples has been improved considerably with the dispersion of TiO_2 nanoparticles. The results have shown the viability of Jatropha-Neem nanofluid as insulating oil for use in oil-filled power equipment.

Introduction

Insulating oil is used in oil-filled power transformers for electrical insulation and cooling. It transfers heat away from power equipment at the same time; it stops arcing and corona discharge in the transformer system. More importantly, they provide a suitable way of routine examining the condition of electrical equipment over its service life [1]. The expected life span of transformers ranges from 35 to 40 years, but available transformer failure statistics have shown that the typical service life of transformer failure nowadays is 18 years, owing to insulation problems [2]. An effective functioning and lifetime of power equipment depend mainly on the quality of insulation materials. Conventional mineral oil has been used as an insulating and cooling material since the 1900s because of its good ageing property, low viscosity, availability and low cost [3]. At a particular period, the use of nanoparticles in improving the insulating properties of the mineral oil was introduced by the researchers in the year 1995. Despite the aforementioned merits, the demerits of the mineral-based insulating fluids such as its high fire risk, low biodegradability potential couple with its scarcity in the near future because the oil resources will run out and there is an increase in electric power consumptions across the globe, particularly, Nigeria [4–5]. Also, transformers failure and leakage of their oil are toxic to the aquatic life and not friendly to the environment. This provided an impetus to scientists to focus and search for a superior alternative to mineral-based insulating fluid from renewable energy sources such as vegetable oil from a plant seed.

Vegetable oil is identified as an environmentally friendly alternative. However, it was found that they have high viscosity which reduces the easy flow of insulating oil in power equipment [6–7]. Dispersion of nanoparticles in these oils has been found to reduce the viscosity and improve other electrical properties such as dielectric constant and AC breakdown voltage. Similarly, mineral-based insulating nanofluids has been reported to have attained high electrical insulation [8]. Interestingly, the enhancement reported on the part of seed-based nano-insulating oils shows that these oils can replace the mineral-based insulating

nanofluid in power equipment [9]. But there is still an issue with the stability of particles in the insulating nanofluids. Poor cohesion between the nanoparticles and the base fluid has been reported to occur soon after the nanoparticles were dispersed into the oil. This causes the particles to settle at the bottom of the base fluids within a short period after dispersion [10]. This paper presents the synthesis of a stable nanofluid through functionalization of the nanoparticle with the aid of oleic acid. Furthermore, the effect of the coated nanoparticle on DC and AC breakdown voltage of Jatropha –Neem nanofluid were studied.

Materials And Method

2.1 Materials

Jatropha curcas and Neem seed-based oils were procured from National Research Institute for Chemicals Technology (NARICT), Zaria, Nigeria. Citric acid, Silica gel and Fuller earth, Magnetic stirrer, KOH solution, Oleic acid, ethanol and Titanium oxide nanoparticle were used in this work.

2.2 Methods

Dijkstra and Opstal procedure was employed for purification of oils, a small quantity of crude Jatropha curcas and Neem oils was purified in a conical flask. Citric acid was used as a catalyst in the company with KOH solution. 0.5 g of Silica gel was added to the oil at 70°C and then agitated for 30 minutes at 1200 rpm. 2.5 g of Fullers' earth was then added and swirled with a magnetic stirrer for 30 minutes at a constant temperature. The oils were then filtered with a hand filtering instrument and re-filtered in a vacuum oven at 80°C.

A sample of purified Jatropha and Neem seed oils in equal ratios was poured into a conical flask and heated to 80°C for one hour. The functionalization method by [11] was adopted where 10 g of TiO_2 nanoparticles were dispersed in 200 ml of ethanol followed by the addition of 0.5 ml of oleic acid. Nanofluid was prepared by adding 0.2wt % to 1.0wt % concentration of titanium oxide (TiO_2) nanoparticles to the oil. The sample was swirled with a magnetic stirrer at the rate of 1200 rpm for 25–30 minutes to disperse the nanoparticles and prevent agglomeration. Nicolet 6700 FTIR spectrometer was used to perform the Fourier transforms infrared analysis of the Oleic acid-coated particles. The surface morphology of the nanoparticle was studied using SEM – EDX analysis while the crystallite size was determined using X-ray Diffraction. AC and DC breakdown voltage measurements were performed on the samples in accordance with the guidelines of ASTM D1816 [13]. AC breakdown voltage was conducted using an automatic breakdown kit while the DC breakdown test was conducted with the test set shown in Fig. 1.

Table 1
Description of samples.

Sample code	Description
MO	Mineral oil
PJO	Purified Jatropha oil
PNO	Purified Neem oil
PJNO	Purified Jatropha-Neem oil
JNF	Jatropha nanofluid
NNF	Neem nanofluid
JNNF	Jatropha-Neem nanofluid

Results And Discussion

3.1 Nanoparticles Analysis

3.1.1 SEM – EDX analysis

The surface morphology and elemental composition, the SEM – EDX analysis were done on TiO_2 nanoparticle. Figure 2a shows the micrograph image of TiO_2 nanoparticle with an abundance of quasi-spherical shaped particles. The elemental composition of the nanoparticle in Fig. 2b showing the peak of Ti and O is evidence of the purity of the nanoparticles.

3.1.2 XRD analysis

X-ray pattern of TiO_2 nanoparticles was used to determine the average crystallite size. In Fig.3, the diffraction peaks can be attributed to TiO_2 nanoparticles and the two intense peaks of 2θ at 25.26° and 47.84° can be attributed to the anatase phase (JCPDS file no.21–1272) [11]. The mean crystallite size of the nanoparticles was calculated using the Debby-Scherer equation and the average particle size of TiO_2 is 11 nm.

3.1.3 Fourier Transform Infrared Spectroscopy

The result of pure and coated TiO_2 nanoparticles can be seen in Figs. 4a and 4b. At 3235 cm^{-1} , an asymmetric and symmetric stretching is observed which is related to the hydroxyl group (Ti-OH). Also, at 1636 cm^{-1} , deformation vibration of Ti-OH bending mode is observed which implies these two observed peaks are characteristic of O-H bending modes of adsorbed water and hydroxyl groups on the TiO_2 surface. The band from 1000 cm^{-1} to 400 cm^{-1} is the fingerprint of Ti-O stretching and Ti-O-Ti bridging stretching modes. The peak at 650 cm^{-1} is within the range of anatase Titania is an indication that the titanium oxide nanoparticle used is anatase. An absorption peak of CH_2 at 2926 cm^{-1} was

observed in the spectrum of the coated TiO₂ which does not reflect in pure TiO₂ nanoparticles. The CH₂ peak in the coated TiO₂ is an indication that oleic was successfully coated on the TiO₂ nanoparticle. The peak at 1461 cm⁻¹ is a fingerprint of carboxylate which proves the combination of oleic acid and nanoparticle surfaces.

3.2 Nanofluid Samples Analysis

3.2.1 *Basic properties oil samples*

The basic properties of the Mineral oil (MO), purified Jatropha Oil (PJO), Purified Neem Oil (PNO), Purified Jatropha and Neem mixture (PJNO), Jatropha nanofluid (JNF), Neem nanofluid (NNF) and the mixture of Jatropha and Neem oils nanofluid (JNNF) at 1 wt.% and power frequency 60 Hz is shown in Table 2.

Table 2
Basic properties of purified oil and 1wt. % TiO₂ nanofluid (27°C)

Sample	Dielectric Constant at 60 Hz	Dielectric loss at 60 Hz	Viscosity(mPa.s) at 40°C	Flash point at 40°C
MO	2.21	0.00225	9.82	140
PJO	3.58	0.0551	11.07	245
PNO	3.44	0.0244	11.10	242
PJNO	3.63	0.02365	11.41	238
JNF	7.26	0.002151	10.01	256
NNF	6.78	0.00208	9.930	248
JNNF	8.36	0.001862	9.874	261

From Table 2, the loading of TiO₂ nanoparticle leads to an increase in the relative permittivity of the base fluid. This can be attributed to an increase in the polarization rate of the mixture which is caused by the TiO₂ nanoparticle. Dielectric liquid with high permittivity is desired when it comes to insulation in high voltage equipment. In this regards, the Jatropha-Neem nanofluid with the highest permittivity at 1 wt. % can be considered as an insulating liquid. Also, a decrease in the dielectric loss was observed after the loading of the nanoparticle and this can be attributed to nanoparticle obstructing the charge transport in the base fluid which consequently, decreases the conductivity. Eq. 1 shows the relationship between dielectric loss and conductivity.

$$\sigma = \omega \epsilon''$$

The viscosity of the purified oil was found to be slightly higher than that of mineral oil but still within the range of the recommended value by IEC 60296 and ASTM D3487. The addition of the nanoparticle to the base oil slightly reduces the viscosity at 1wt. %. The decrease in viscosity of the base fluid after the loading of the nanoparticle can be attributed to the reduction in the frictional force that exists between

the molecules of the oil. The low viscosity value in high voltage insulation is the desired one as it helps in proper cooling and prevents localized heating and hotspot formation.

Furthermore, the flash point of the purified Jatropha oil, Neem oil and the mixture is 75%, 72.8% and 70% greater than the flash point of mineral oil. The loading of the nanoparticle at 1 wt. % increases the flash point of the base fluid. The flash point of JNF, NNF and JNNF is 82.8%, 77.1% and 86% greater than that of conventional mineral oil.

3.2.2 High Voltage Analysis.

The high voltage DC properties of the samples with 1 wt. % nanoparticle was studied in a hemisphere-sphere electrode test cell using a high voltage test setup with a 35 kV DC source. HVDC was applied through the samples to determine the leakage current. The voltage was supplied by increasing the voltage by 0.5 kV at 0.5 steps to record the leakage current and determine the voltage at which breakdown occurs. This was performed on Mineral oil (MO), purified Jatropha Oil (PJO), Purified Neem Oil (PNO), Purified Jatropha and Neem mixture (PJNO), Jatropha nanofluid (JNF), Neem nanofluid (NNF) and the mixture of Jatropha and Neem oils nanofluid (JNNF). The average HVDC leakage current flowing through the samples was calculated using Ohm's law through the measured output voltage and the measuring resistor. The plot of the measured HVDC leakage current against the applied voltage for MO, PJO, PNO and PJNO samples is displayed in Fig. 5. The characteristic curves for MO, PJO, PNO and PJNO oil shows that the DC leakage current increases almost linearly with the applied voltage. For all the oil sample, the HVDC leakage current is ionic and increase linearly with the applied voltage. It's imperative to notice that the samples PJO, PNO and PJNO without TiO_2 nanoparticles were observed to have an HVDC leakage current that is comparable with the mineral oil sample (MO) as illustrated in Fig. 5. The lower the volume resistivity, the higher the leakage current and the more conductive the material is, but good oil for oil-filled power equipment, the resistivity should be high. Insulating oil with lower resistivity indicates the presence of moisture and conductive contaminating agents.

In the case of pure oil samples, the characteristic curve depicts that the current increases slightly with applied voltage, though, the graph do not display an absolute saturation value but a small rise in current with increasing applied voltage. Therefore, Fig. 5 displayed a linear growth. The TiO_2 nanoparticles in the oil act as electron traps by slowing down the streamer transport which contributes to improving dielectric strength. Oil having nanoparticles has a more efficient heat transfer capability as compared to oil without nanoparticles. The breakdown voltages of the prepared nanofluids were observed to be higher when compared with the purified oil samples. The breakdown voltage of JNF and NNF was recorded to be 25 kV and 24 kV respectively. The nanofluid from the mixture of the two seed oils produced a composite material with a breakdown voltage of 26 kV at 1wt. % loading. The DC electrical strength of the seed oil-based nanofluids is better than that of seed-based oil samples without the addition of TiO_2 nanoparticles.

Meanwhile, the recorded leakage current shows a nearly ohmic relationship. The leakage current through the nanofluids was observed to be higher than that of the purified oil samples, an indication that the nanofluids have slightly lower DC resistance. This revealed an indication that DC breakdown does not rely

completely on the resistance of the material. Charge injection from the electrodes may have played a greater role in the breakdown of the samples. The obtained result indicates that the dispersion of nanoparticles enhanced breakdown voltage, this finding could be explained by the fact that the polarized TiO_2 nanoparticles can act as electron traps to catch the free electrons released from oil molecules under a high electric field and that would otherwise cause a breakdown. It could also be related to the higher chance of electron scattering in nanofluids due to the high specific surface area of nanoparticles. Therefore, adding TiO_2 nanoparticles to base oil have improved breakdown voltage at the optimum concentration of 0.6wt% loading. This is in close agreement with Given *et. al.*, (2011) and Khedkar *et.al.*, (2016) results [16–17]. The nanofluid from the mixture of Jatropha and Neem appeared to have positively influenced the breakdown strength and this signifies nanofluid samples prepared can be suitable for electrical insulation. This result complies with a fixed standard and in conformity with that obtained by [2].

3.2.3 Weibull Analysis

The Weibull distribution plots were used instead of normal distribution, though normal distribution is a very important and well-known probability distribution for dealing with problems in scientific data. However, there are numerous situations when the assumption of normality is not validated by the data. Weibull provides better goodness of fits than the generalization of the normal distribution. Weibull parameters of the breakdown strength data for purified Jatropha oil(PJO), purified Neem oil (PNO), purified Jatropha-Neem oil mixture (PJNO), Jatropha nanofluid (JNF), Neem nanofluid (NNF), Jatropha-Neem nanofluid(JNNF) and Mineral oil (MO) samples were extracted from the plots. Table 2. Shows the characteristic value (α) and shape parameter (β). The Weibull distribution describes the statistical distribution of the samples in which a straight line is displayed on a Weibull plot. Linear regression is used to numerically assess the goodness of fit and estimated the parameters of the Weibull distribution. The gradient informs one directly about the characteristic life or scale factor known as scale parameter or Weibull modulus alpha (α) and shape parameter which is the cumulative probability of function or failure rate beta or Gamma (β) of the samples studied.

Table 3 shows the Weibull parameters of AC breakdown strength of mineral oil (MO), Jatropha-Neem oil (JN), and Jatropha-Neem nanofluid (JNNF) samples. Mineral oil has the highest breakdown field strength followed closely by Jatropha-Neem nanofluid. Both the characteristic breakdown field strength and the shape parameter of Jatropha-Neem oil improved considerably with the addition of nanoparticles. The breakdown field of Jatropha-Neem nanofluid (JNNF) has narrow distribution as indicated by the values for the fitted shape parameter, β as seen in Figs. 6, 7 and 8. This observation is in close agreement with the previously reported result by [15].

The characteristics breakdown strength of oil samples for the selected probability of failures can be seen in Table 4. There is a situation where failure occurs at low voltage, therefore breakdown voltage at the lowest probability (1%) for each sample was also considered. It was observed that the breakdown strength of the prepared JNNF at the lowest probability is better than all the prepared oil including mineral

oil. Therefore, the obtained result at 1% probability demonstrates the high operating reliability of the JNNF insulating fluid.

Table 3

Weibull parameters of AC breakdown field data for purified oils, nanofluid and mineral oil samples

Samples	Number of Readings (N)	Characteristic Breakdown Strength (kV/mm)	95% Confidence Bound for α (kV/mm)	Shape parameter β , (kV/mm)	95% Confidence Bound for β , (kV/mm)	Correlation Coefficient
MO	6	36.8	37.03–43.17	12.80	7.29–30.71	0.855
PJO	6	28.7	29.10–40.10	6.13	3.49–14.70	0.933
PNO	6	15.1	15.53–29.17	3.12	1.77–7.48	0.940
PJNO	6	15.8	15.95–19.07	11.00	6.26–26.38	0.959
NNF	6	18.5	18.65–23.41	8.63	4.91–20.71	0.932
JNF	6	25.7	25.93–31.12	10.77	6,13-25.84	0.937
JNNF	6	35.6	35.64–37.35	41.81	23.81-100.31	0.981

Table 4

Weibull probability of the AC breakdown voltage for all oil samples at 1%.

Weibull probability (%)	MO	PJO	PNO	PJNO	JNF	NNF	JNNF
1	25.67	13.54	3.45	10.42	16.78	10.83	31.86
5	29.16	17.67	5.82	12.03	19.52	13.09	33.12
10	30.84	19.87	7.33	12.90	20.87	14.22	33.70
30	33.93	24.24	10.85	14.41	23.37	16.38	34.69
63.2	36.77	28.68	15.10	15.83	25.72	18.46	35.56

Conclusion

In this work, jatropha and Neem oils were purified and titanium oxide nanoparticles were functionalized with oleic acid. The stability of the prepared nanofluid was observed to have enhanced. The dielectric constant values of the PJO, PNO, PJNO JNF, NNF and JNNF were found to have increased linearly with an increase in the concentration of titanium oxide nanoparticles (TiO₂). The results also show that characteristic values of the purified oils samples and their mixture has lower values than the synthesized nanofluids. A sample of JNNF recorded the highest characteristic value among all the samples prepared and that of Mineral oil (MO). As such, the developed nanofluid with the precise amount mixture from Jatropha and Neem oils could be a viable insulation fluid for use in oil-filled power equipment.

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Figures

Figure 1

35 kV High Voltage DC Breakdown Test Setup

Figure 2

a SEM micrograph of TiO₂ nanoparticles. b. EDX of TiO₂ nanoparticles.

Figure 3

XRD spectrum of TiO₂ nanoparticles

Figure 4

a. FT-IR of Pure TiO₂ nanoparticles b. FT-IR of Oleic-coated TiO₂ nanoparticles.

Figure 5

Current against Applied voltages

Figure 6

Weibull plot of AC breakdown field data for MO

Figure 7

Weibull plots of AC breakdown field data for samples PJO, PNO and PJNO

Figure 8

Weibull plots of breakdown strength for NN, JNF and JNNF samples