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Assessment of Dielectric Loss and AC Breakdown Voltages of Jatropha-Neem Nanofluid for Insulation in Oil-Filled Equipment

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Abstract
The toxicity, non-renewability, and non-biodegradability of mineral oil-based insulating fluids to the environment brought about the search for superior alternative renewable insulating fluids. This paper examined the possibility of developing alternative insulating fluid from a mixture of Jatropha and Neem oils with the dispersion of titanium oxide nanoparticles (TiO_2). The dielectric loss and the AC breakdown strength were examined. The dielectric loss of the samples at various frequencies was examined. The dielectric loss (tan δ) of Jatropha oil was found to be lowered from 0.2 to 0.004witha dispersion of 1.0 wt. % of titanium oxide nanoparticles (TiO_2). Neem oil and its nanofluid have a higher dielectric loss when compared with the fluids from Jatropha oil. But the mixture of the Jatropha and Neem oil produced an intermediate result and the dielectric loss of the nanofluid with 1wt% was obtained as 0.012.Meanwhile, the developed insulating fluid from Jatropha and Neem mixture with 1wt% nanoparticles recorded the highest characteristic breakdown field strength of 43.34 kV/mm, a value higher when compared with insulating mineral oil (MO) with characteristic breakdown field strength of37.84 kV/mm. There appears to be a considerable improvement in the characteristic breakdown strength of the oil samples due to the dispersion of Titanium oxide (TiO_2) nanoparticles. The results demonstrated that with possible further purification of the Neem oil component, the nanofluid from Jatropha-Neemoil mixture is a potential alternative insulating oil for use in oil-filled equipment.

Keywords: Dielectric Loss, AC Breakdown Voltages, characteristic life, Shape parameter, and Nanofluid.

Introduction
A power transformer is a vital component of electricity generation, transmission and distribution network. Insulating oil is used for electrical insulation in oil-filled power transformers. Insulation liquid transfers heat from the power equipment beside its function of preventing arcing and corona discharge in the transformer system. More importantly, regular checking of the condition of electrical equipment over its service life is performed

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through the liquid. 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 Mehta *et al. (*2016). And about 60% to 75% of high voltage transformer damage was due to dielectric insulation issues Wenxia*et al*. (2016). An effective functioning and lifetime performance of power equipment depend mainly on the quality of insulation materials. An assay of the amount of energy dissipated in form of heat is known as dielectric loss or tan delta. It is a factor that influences to determine whether the oil sample is more resistant to loss of insulation or no. Dielectric breakdown is one of the most vital properties of real dielectrics; however, for any material, there is a limit of field intensity beyond which damage could occur resulting in conduction, sparking and other break down phenomena Wenxia *et al.* (2016). At relatively high fields, the electrons in the dielectrics gain sufficient energy to knock other charged particles thereby making them available for conduction. In the insulating material, this multiplying process happens along the paths in which local heating occurs and may result in permanent damage to oil-filled equipment. All electrical equipment contains a judicious and sensible arrangement of the conductive material used to transport electrical energy, and insulating materials to prevent short-circuits between conductors (Li *et al*. 2012; Zaharadden *et al*. 2013; Evangelista Jr. *et al.*2017). The failure of oil-filled transformers and their oil leakage results to contact with some aquatic life. The toxicity of mineral oil makes it dangerous to the environment. Vegetable oil is then identified as an environmentally friendly alternative. However, it was reported that natural esters have high viscosity which reduces the easy flow of insulating oil in power equipment Abdelmalik (2015) Suwarno *et al*. (2018). Dispersion of nanoparticles in these oils has been found to reduce the viscosity and improve other electrical properties such as the dielectric loss and breakdown field. Electrical insulating nanofluid is used to insulate the high and low voltage parts of oil-filled power equipment such as transformers, switchgear, pipe type cables and circuit breakers among other equipment Mansour *et al.* (2012). In a similar way, mineral-based insulating nanofluids have been reported to have attained high electrical insulation Sanchez and Rodriguez (2016). Despite that, the thermal conductivity of the oils was reported not to have produced desirable characteristics on the insulating properties of the mineral-based fluid Thanigaiselvan *et al.* (2015).In a point of fact, enhancement reported on the part of seed-based nano-insulating oils have shown that these oils with desirable properties can be an alternative to mineral-based insulating nanofluid in power equipment Wei Yao *et al.* (2018). 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 in the oils making the oil milky. This causes the particles to settle at the bottom of the neat fluids within a short period of time after dispersion Sayanta and Paria (2013). Du *et al.* (2015) conducted research on AC breakdown voltages of mineral-based insulating oil where titanium oxide nanoparticles were dispersed. The results have indicated that there was an increment of AC breakdown strength due to the dispersion of nanoparticles in the based-oil. It will be a very good idea to assess the insulation characteristics of Jatropha and Neem oil mixture fluid and the influence of (TiO_2) nanoparticles suspension on the properties of the mixed fluid. This paper presents the dielectric loss (tan δ) and AC breakdown voltage of insulation nanofluid prepared from Jatropha oil, Neem nanofluid, and functionalized nanoparticles.

Materials and Methods

Jatropha curcas and Neem seed-based oils were procured from National Research Institute for Chemicals Technology (NARICT), Zaria. Citric acid, Silica gel, Tonsil Fuller's earth, Magnetic stirrer, KOH solution, Oleic acid, Ethanol, and Titanium oxide nanoparticle (TiO_2) of 99.5% purity of size 10-30 nm were used. Dijkstra and Opstal procedure was adopted for the purification of oils, a small quantity of crude Jatropha curcas and Neem oils was purified in a conical flask with Citric acid and KOH solution in which metal salts were decomposed. 0.5 g of Silica gel was added to the oil at 70ºC and then agitated for 30 minutes at 1200 rpm. 2.5 g of Tonsil Fullers' earth was then added and swirled with a magnetic stirrer for 30 minutes at a constant temperature, the oils were then filtered with hand filtering instrument and re-filtered in a vacuum oven at 80°C that reduced the water content of the oils. The mixture of the oils samples are carried out with a magnetic stirrer for 2 hours and at a rotation speed of 1200 rpm and miscibility was achieved. The ration of the mixture of Jatropha oil, Neem oil was mixed in a precise amount. 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. TiO_2nanoparticles were functionalized with oleic acid. A centrifuge machine was used in the separation of coated TiO_2 from ethanol. Nanofluid was prepared by adding 0.2 wt. % 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. A scanning electron microscope was used to determine the level of dispersion of the nanoparticles in the base ester fluid. The dielectric loss and AC breakdown strength of the samples were measured using programmable HAMEG H8118 programmable LCR Bridge {A Rohde and Schwarz Company, H8118} in figure 1 and FS2080 Dielectric Strength Tester respectively.

Figure 1: LCR Measurement of Dielectric loss

Results and Discussion

SEM Image Analysis

The SEM image of one of the oil samples containing 0.2% and 1% nanoparticles in figure 2 and it can be seen from the image that the nanoparticles were dispersed in the fluid.

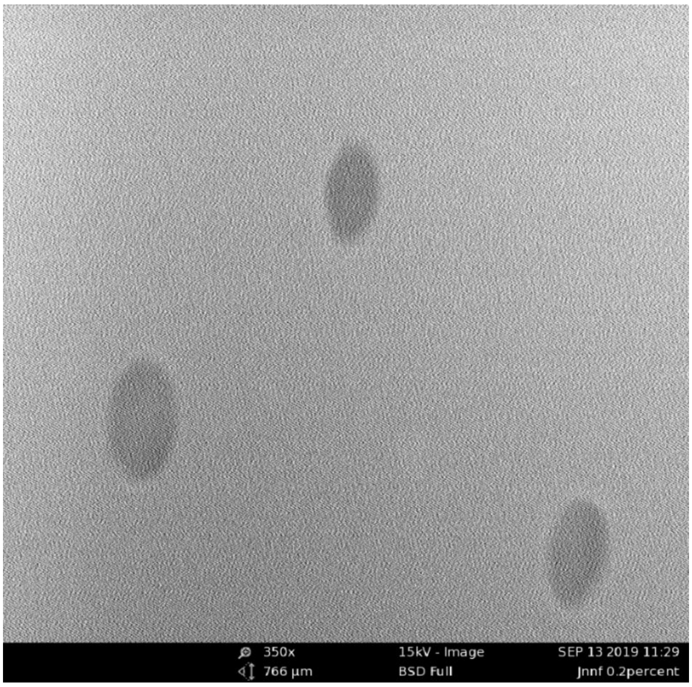

Figure 2: SEM of 0.2 wt. % of Jatropha-Neem Nanofluid (JNNF) sample

Dielectric Loss Analysis

The measured Tan delta (dielectric loss) at various compositions for Jatropha nanofluid (JNF) is plotted in figure 3. Dielectric loss is referred to as the amount of energy dissipated in form of heat. It is also known as dissipation factor, tan delta (tan δ), or loss tangent. An insulating material is meant to be a perfect insulator. The tan δ is a measure of oil resistance to loss of insulation caused by the presence of conductive contaminants. The neat Jatropha oil sample has a dielectric loss behaviour that decreases from 0.26609 at 200 Hz to 0.16129 at 10 kHz. An increase in dielectric loss to 0.28644 was then observed at 90 kHz. The increasing dielectric loss is due to the dielectric phenomenon in the oil sample at higher frequencies. The dispersion of nanoparticles in the oil resulted in a decreasing dielectric loss. There was a continuous decrease with an increase in the percentage weight of the nanoparticles in the base oil. When an alternating voltage was applied to an insulating medium the charging current led the voltage by 90°. The presence of impurities such as moisture, contaminants or oxidation by-products within the insulating medium can lead to dipolar relaxation. Such dipolar relaxation and the transport of the mobile charge carriers in the oil could lead to dielectric losses. A resistive current is introduced which causes the current to shift from the ideal degree phase deviate from the applied voltage. The nanofluid samples with 1.0 wt. % of the nanoparticles hada tan δ value of 0.00508 at 200Hz. The value decreases steadily to 0.002482 at 90 kHz.

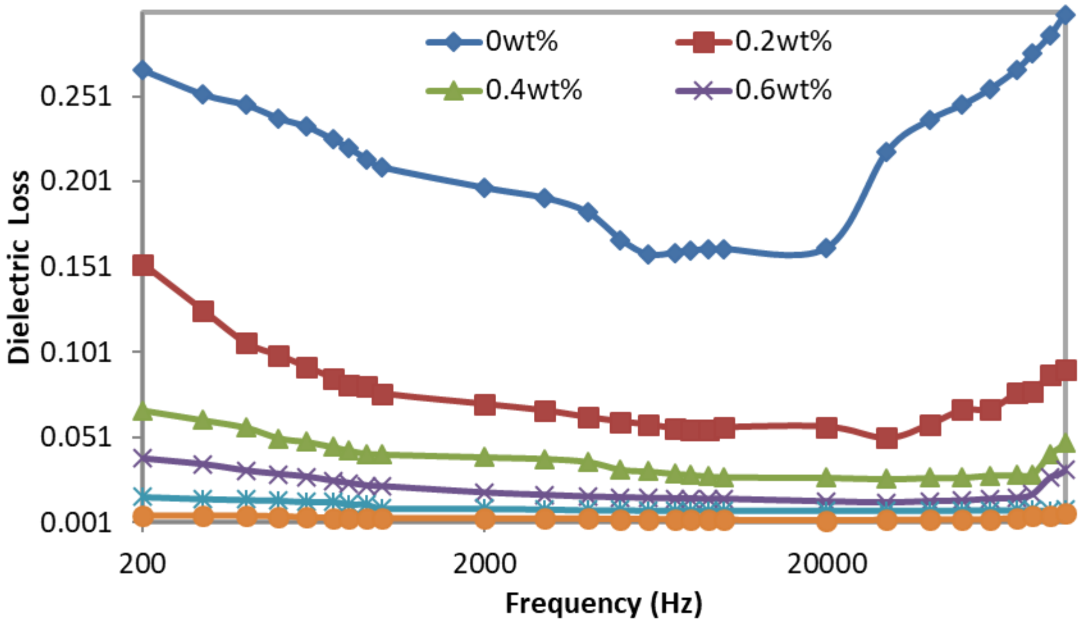

Figure 3: Dielectric Loss vs. Frequency (Hz) for Jatropha Nanofluid (JNF)

Similar to the neat samples, a sharp rise in tan δ was observed from 100 kHz to 200 kHz.The decrease in the dielectric loss with an increase in the content of the nanoparticles can be linked to the trapping of charge carriers by the nanoparticles. This led to the restriction of charge transport in the nanofluid. Figure 4 shows the plot of dielectric loss of neat Neem oil and Neem-based nanofluid (NNF). The tan δ spectra of Neem fluid samples are similar to that of Jatropha. The loss tangent of the neat Neem oil was measured to be 0.75104 at 200 Hz, and reduced to 0.01957 at 200Hz with the dispersion of 1 wt. % of nanoparticles in the oil. The dispersion of nanoparticle influences the decrease in the dielectric loss but at the level higher than that of Jatropha oil.

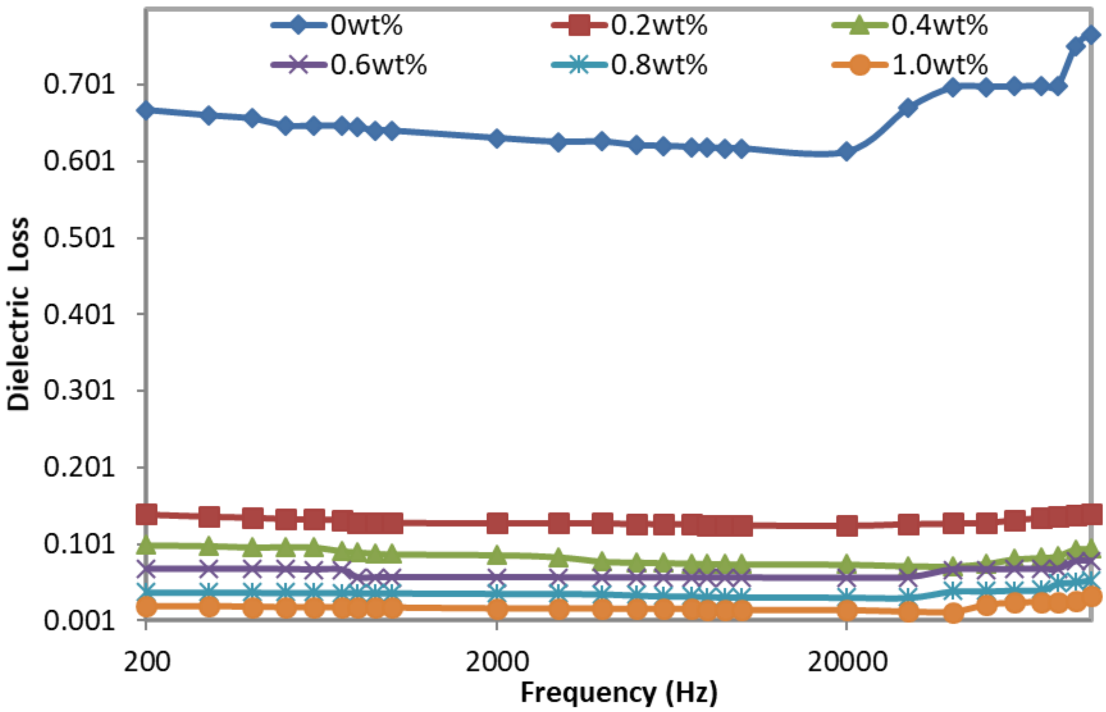

Figure 4: Dielectric Loss vs. Frequency (Hz) for Neem Nanofluid (NNF)

Figure 5 shows the dielectric loss (tan δ) spectra of the composite nanofluid from Jatropha and Neem oil samples. The spectra followed the trend of figures 3 and 4. The tan δ of the neat oil mixture was measured to be 0.39057 at 200Hz. There was a gradual steady change in tan δ as the frequency increases and a value of 0.25444 was recorded at 20 kHz similar to Neem and Jatropha oil samples, increasing the concentration of nanoparticles in the composite liquid led to a decrease in tan δ of the samples. This could be due to electrons trapping within high field regions of the oil in the system. This result is in conformity with Mehta *et al*. (2016). At the highest nanoparticle loading of 1.0 wt. %, tan δ value of 0.01555 was obtained at 200 Hz. There was no significant change in the tan δ as the frequency increases as a value of 0.01224 were obtained at 20 kHz. This may be attributed to the addition of titanium oxide nanoparticles that is efficient in the trapping of electrons in the system.

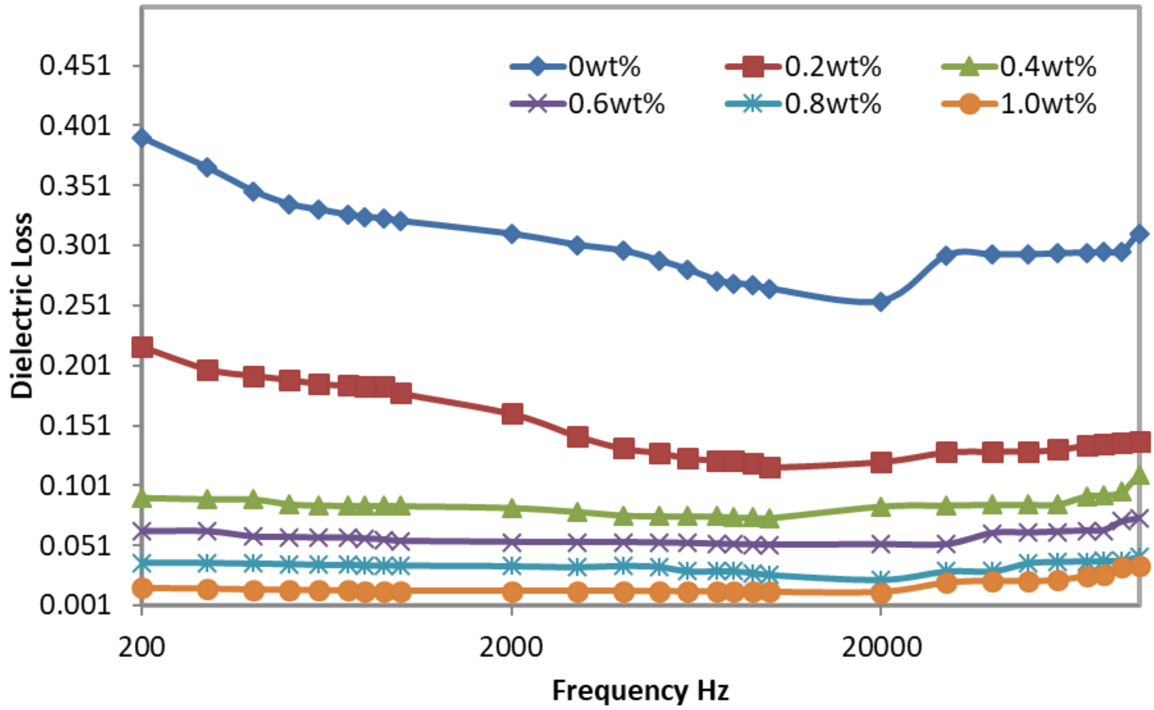

Figure 5: Dielectric Loss vs. Frequency (Hz) for Jatropha-Neem Nanofluid(JNNF)

Figure 6 shows a comparative chart of the tan delta of the samples at 1 kHz. It is clear from the chart that the sample with 1.0 wt. % of titanium oxide nanoparticles had the lowest dielectric loss. Meanwhile, Jatropha nanofluid had the lowest dielectric loss of 0.004. This is an indication that the level of restriction to charge flow increases as the percentage on the insulating nanoparticles increases within the composition studied.

Breakdown strength Analysis

The measured AC breakdown strength of the oil samples was analysed using FS2080 Dielectric Strength Tester. Twelve (12) breakdown tests were examined in every sample. The sample was stirred after every breakdown experiment. The obtained data were plotted in Weibull plots. Figures 7 to 9 show the typical Weibull plot for the samples. The Weibull distribution plots are preferred to 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. When a single statistical distribution is needed the Weibull is preferred because of its ability to represent skewness. The Weibull distribution gives room for small data analysis and it fails when the weakest link fails.

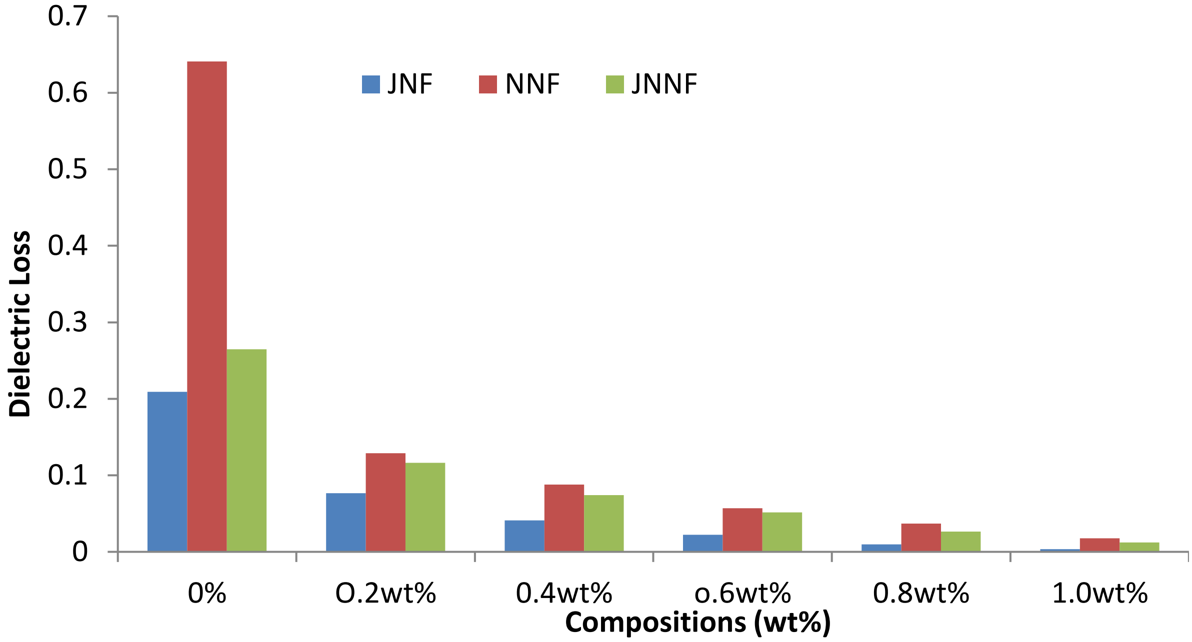

Figure 6: Dielectric Loss vs. Compositions of Titanium Oxide Nanoparticles.

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 1 shows the characteristic values (α) and the shape parameters (β). The Weibull distribution describes the statistical distribution of the samples in which a straight line was displayed on a Weibull plot. Linear regression was used to numerically assess goodness of fit and estimated the parameters of the Weibull distribution. And 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 indicates the hazard function or failure rate beta or Gamma (β or ϒ) of the samples under study.

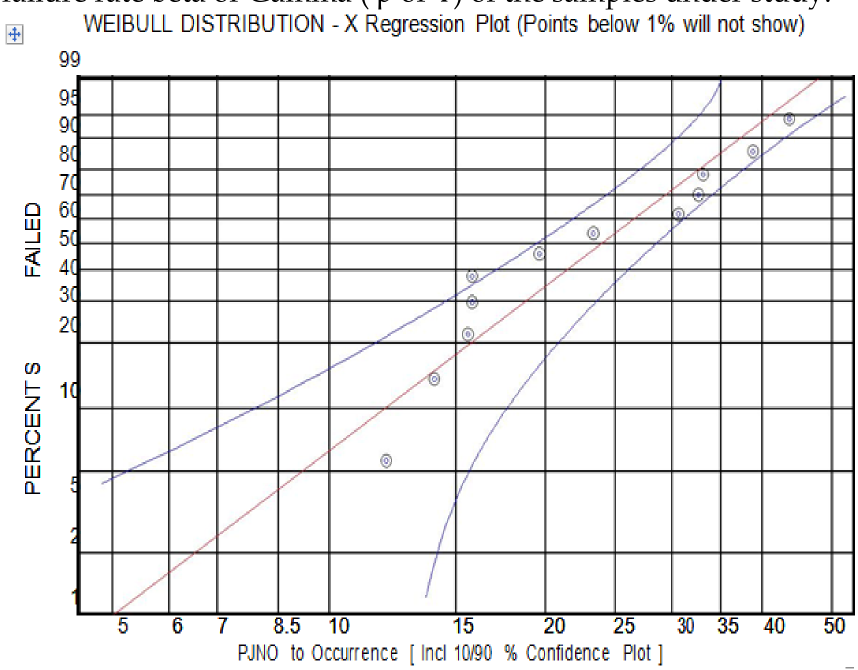

Figure 7: Weibull plot for Jatropha and Neem oil mixture (JNNF) Sample

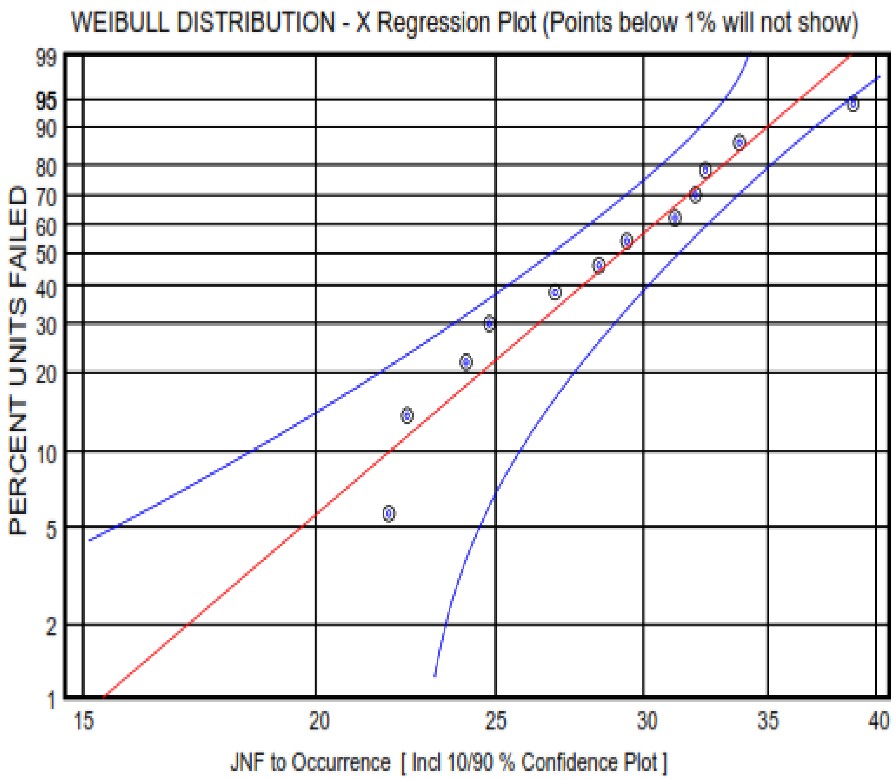

Figure 8: Weibull plot of Jatropha nanofluid (JNF)

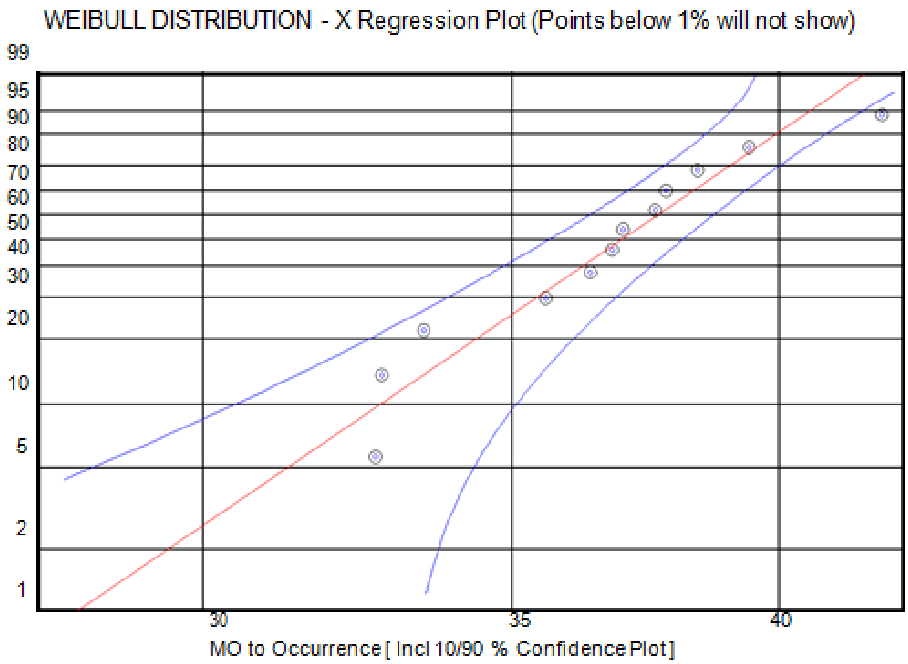

Figure 9: Weibull plot of AC breakdown field data for Mineral oil (MO)

Table 1: Weibull parameters of ac breakdown field data for purified oils, nanofluid, and mineral oil samples

Samples	N	Characteristic value α, (kV/mm)	The shape parameter, β	correlation
PJO	12	28.13	9.831	0.9285
PNO	12	21.09	2.547	0.9768
PJNO	12	27.32	2.715	0.9451
JNF	12	30.81	6.607	0.9700
NNF	12	31.31	2.885	0.9280
JNNF	12	43.34	7.155	0.8761
MO	12	37.84	15.613	0.9610

It can be observed from the Table 1 that the characteristic breakdown field strength of purified Jatropha oil (PJO) was higher than of purified Neem oil (PNO) and was slightly different compared to the purified Jatropha-Neem oils mixture PJNO sample. But with the dispersion of Titanium oxide nanoparticle, the characteristic breakdown strength improved as compared to the base oil. However, the developed Jatropha-Neem oils mixture based nanofluid recorded characteristic breakdown field strength that was much higher compared to the base fluid and also that of the mineral oil (MO) sample. This observation is in close agreement with previously reported results Henry *et al.* (2017). The JNNF sample possessed the highest characteristic breakdown strength. This could be due to nanofluid had heat transfer potential ability as compared to the neat oil without the nanoparticles. Since (TiO_2) nanoparticles are known to have the capability at trapping of electrons within high field regions of the oil hindering the breakdown processes.

The characteristic breakdown strength of the oil samples appears to have improved considerably with the dispersion of Titanium oxide nanoparticles. And shape parameter, β which is also known as the Weibull slope, its value is equal to the shape of the line in a probability plot and different values of it can have marked effects on the behaviour of the distribution in the samples. The breakdown field of the samples was observed to have narrow distribution owing to the slight high values for the fitted shape parameter, β

Conclusion

Nanoparticles of TiO_2 were dispersed in the Jatropha and Neem oils and their mixture to improve its dielectric and electrical characteristics. An increase in the concentration of TiO_2 nanoparticles caused dielectric loss to decrease significantly. The dielectric loss (Tan δ) of Jatropha decrease from 0.2 to 0.004 at 1 kHz with 1 wt. % nanoparticles, which is within the standard ASTM D924 and IEC 60247 that for very good insulating oils with low decimal values below 0.005 is preferred. The result also shows that characteristic values of the neat oil samples and its mixture has lower values than the synthesized nanofluids. A sample of JNNF recorded the highest characteristic value among all the prepared samples and that of Mineral oil (MO),Hence, the synthesized nanofluid from Jatropha and Neem oils could be a viable insulation fluid for use in oil-filled equipment.

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