AC Analysis of Synthesized Nanofluids from Palm Kernel Oil for Transformer Insulation

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ABSTRACT

This work presents the effect of insulating (Al_2O_3) and semiconductive (TiO_2) nanoparticles on methyl ester oil synthesized from palm kernel oil. The surface of the nanoparticle was coated with oleic acid before dispersion into the methyl ester to modify the stability of the mixture. The preparation of nanofluids was achieved through the dispersion of 0.2, 0.4, 0.6, 0.8 and 1wt% of nanoparticle into the methyl ester. The effect of this nanoparticles on loss tangent, conductivity and AC breakdown strength of the synthesized methyl ester was studied. It was observed that the two nanoparticles reduces the loss tangent and conductivity of methyl ester with an increasing concentration of nanoparticles. The Weibull statistical analysis of the breakdown data shows that the dispersion of the nanoparticles in the base fluid increases the characteristic breakdown strength of methyl ester with an optimum performance at 0.6 wt%. The result revealed that Al_2O_3 nanofluid possesses the highest dielectric properties with low loss, low conductivity and high characteristic breakdown strength.

INTRODUCTION

In high voltage engineering, transformer cooling and insulation are imperative to avoid a breakdown in generation and distribution system which can lead to an interruption in power supply, breakdown of transformer and high cost of repair. The oil (mineral oil) which is the passive component of transformer serves as a coolant and as well as an insulator in high voltage engineering. However, this oil is not environmental friendly and non renewable. Therefore, there is a need for alternative oil. Research reveals that methyl ester can serve well as an alternative insulating oil. However, there is still a problem of high dielectric loss and high conductivity which can lead to overheating in the system and cause thermal breakdown and electric breakdown. In this work, the effect of insulating and semiconductive nanoparticle on the dielectric properties of the palm kernel oil methyl ester were studied

SAMPLE PREPARATION

Synthesis Process

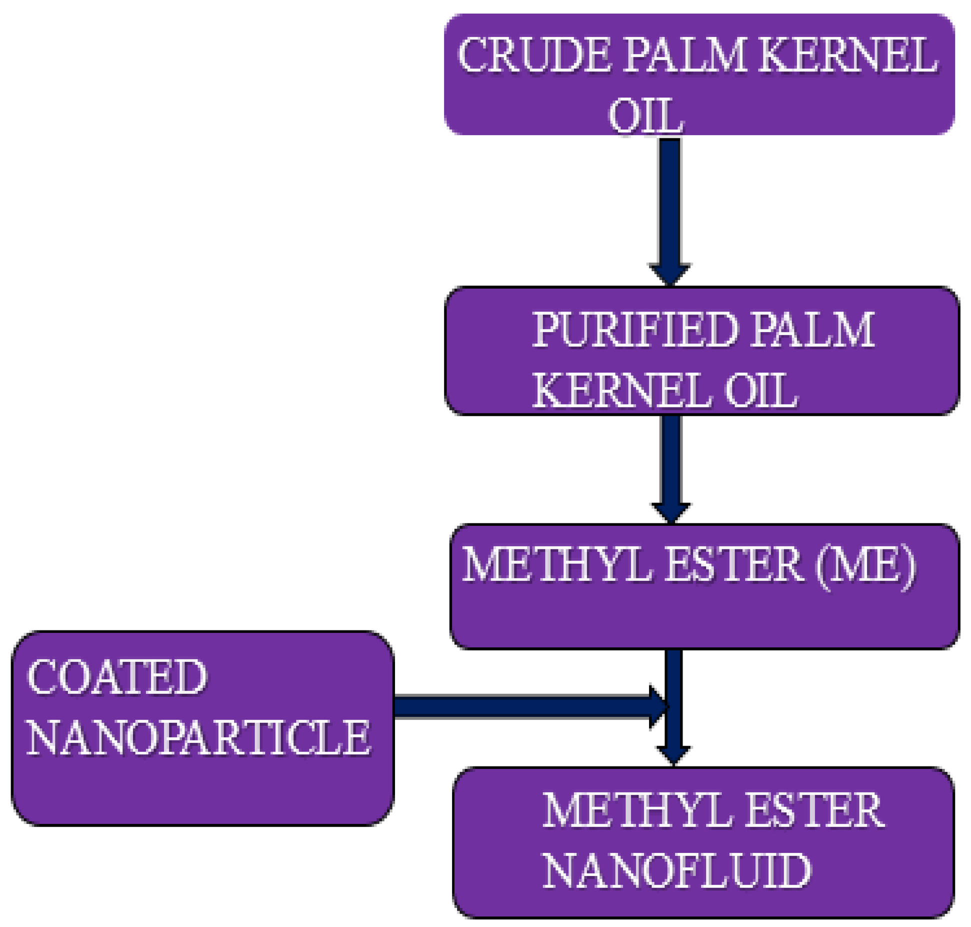

Table 1.Sample Description

Sample code	Description	Sample code	Description
MO	Mineral oil	MET1	Ester + 0.2wt% TiO_2 NP
PPKO	Palm kernel oil	MET2	Ester + 0.4wt% TiO_2 NP
ME	PPKO Methyl ester	MET3	Ester + 0.6wt% TiO_2 NP
MEA1	Ester + 0.2wt% Al_2O_3 NP	MET4	Ester + 0.8wt% TiO_2 NP
MEA2	Ester + 0.4wt% Al_2O_3 NP	MET5	Ester + 1wt% TiO_2 NP
MEA3	Ester + 0.6wt% Al_2O_3 NP		
MEA4	Ester + 0.8wt% Al_2O_3 NP		
MEA5	Ester + 1wt% Al_2O_3 NP		

EXPERIMENTAL

Dielectric Properties Test

The dielectric loss of mineral oil, palm kernel oil, ester and ester-based nanofluids were measured using Rohde & Schwarz HM8118 Programmable LCR BRIDGE at 60Hz. The gap between the two electrodes was kept at 2.5 mm according to the ASTM D1531 standard. The electrical conductivity of the samples was determined using the equation;

$\sigma_{ac} = \omega\varepsilon_o\varepsilon''$. Where σ is the conductivity in Sm^{-1}, ω =2πf is angular frequency, ε_o is the permittivity of free space, ε'' is the dielectric loss factor.

AC Breakdown Test

The dielectric breakdown strength of the samples was measured in accordance with the ASTM D1816 standard. The test was performed by increasing the supply voltage step-wisely at a rate of 1 kV/s until breakdown occurs. The test was repeated 12 times and the AC breakdown strength of the samples was analyzed using Weibull statistics.

RESULTS

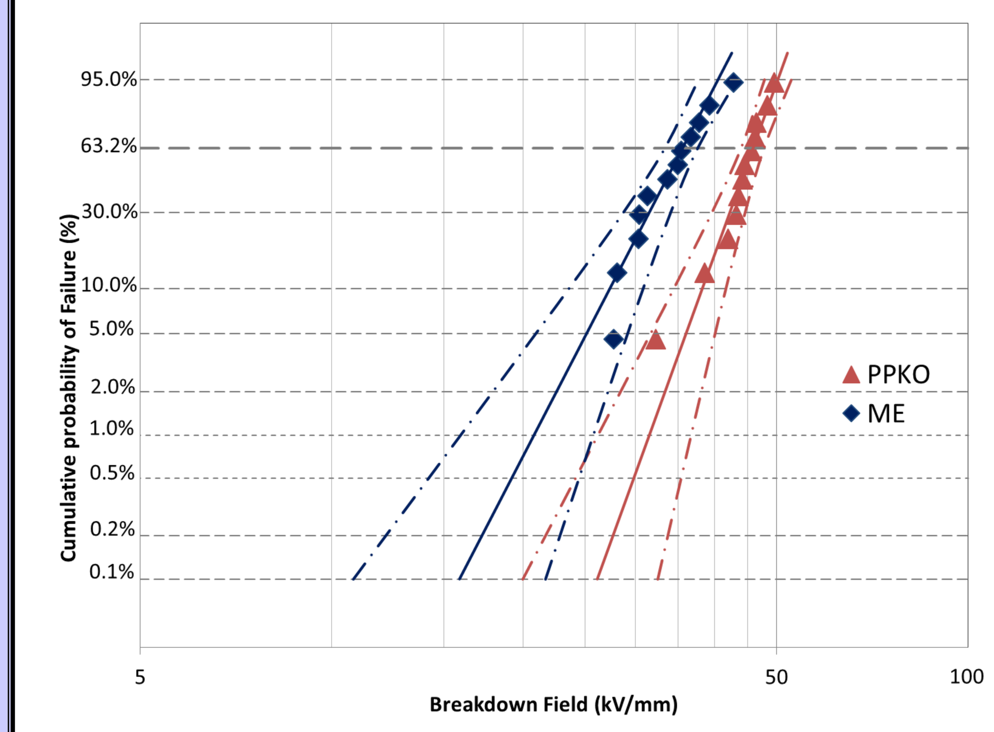

Fig. 1: Weibull plot of the AC breakdown strength for PPKO and ME

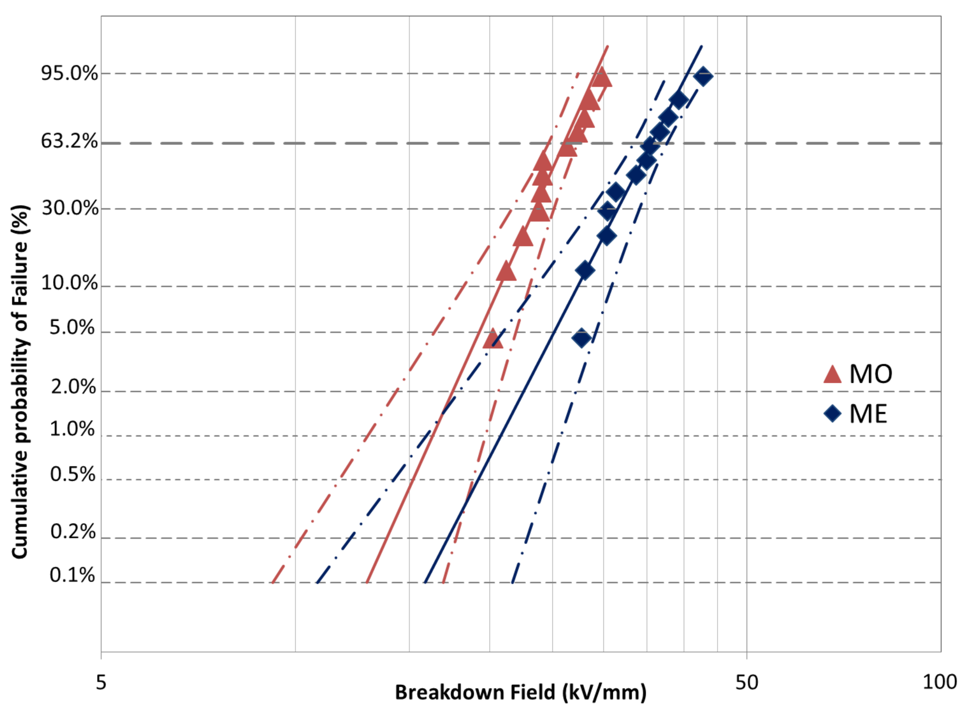

Fig. 2: Weibull plot of the AC breakdown strength for MO and ME

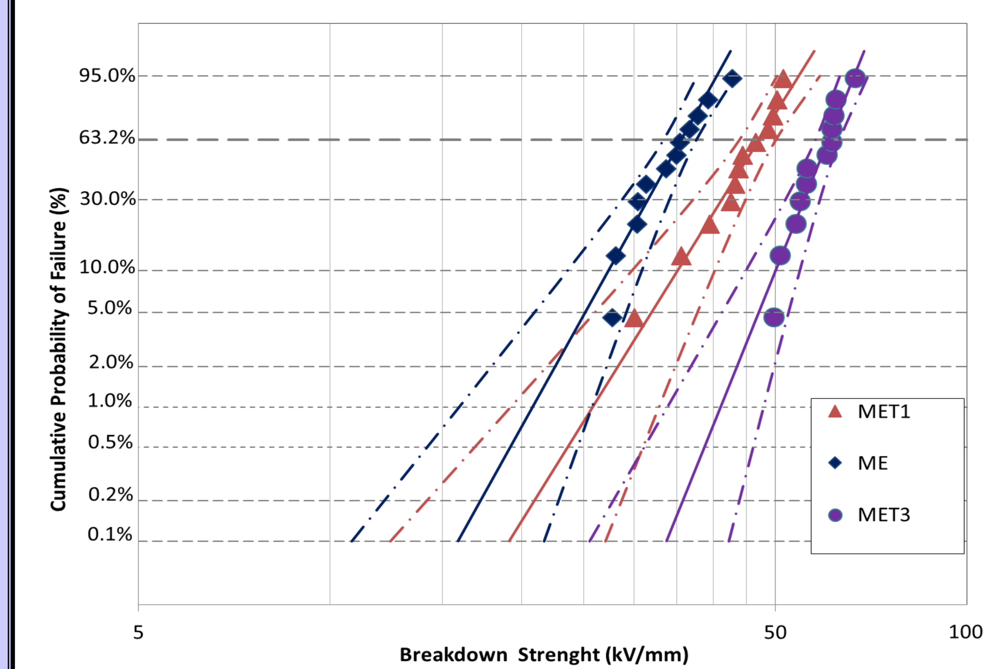

Fig. 3: Weibull plot of the AC breakdown strength for ME and TiO_2 nanofluids

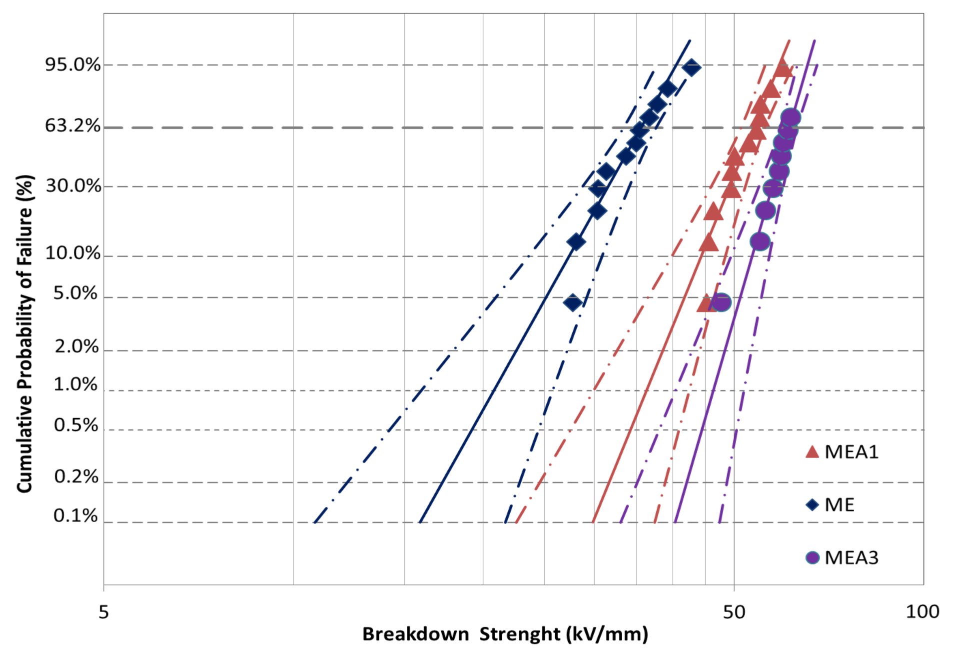

Fig. 4:Weibull plot of the AC breakdown strength for ME and Al_2O_3 nanofluid

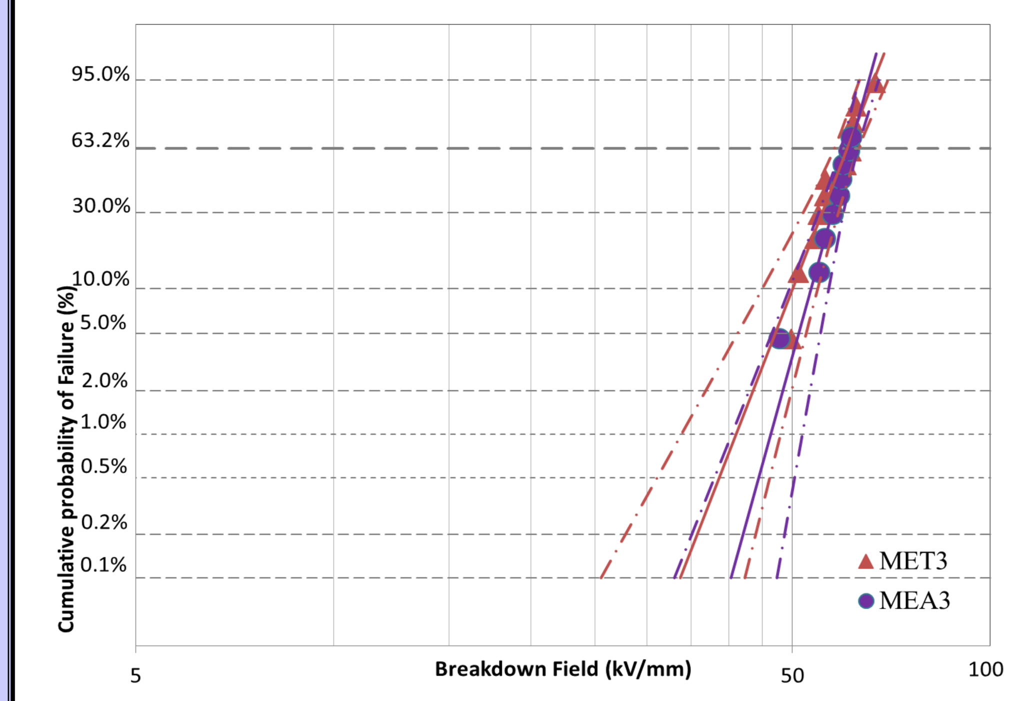

Fig. 5: Weibull plot of the AC breakdown strength for 0.6wt.% of TiO_2 and Al_2O_3 nanofluids

Table 2. Characteristic breakdown strength

Samples	N	Characteristic value, α (kV/mm)	95% Confidence bound for α (kV/mm)	β shape parameter	95% Confidence bound for β	ρ Correlation Coefficient
MO	12	26.0	24.64 – 27.32	9.83	6.41 – 16. 97	0.959
PPKO	12	45.9	43.94 – 47.72	12.26	7.99 – 21.16	0.963
ME	12	35.6	33.40 – 37.59	8.56	5.58 -14.77	0.944
MEA1	12	53.7	51.27 -55.88	11.76	7.66- 20.29	0.927
MEA2	12	58.2	55.78 – 60.33	12.90	8.41 – 22.26	0.964
MEA3	12	64.1	59.57 – 68.32	7.38	4.81 – 12.74	0.970
MEA4	12	61.1	59.19 – 62.92	16.57	10.80 – 28.59	0.971
MEA5	12	60.5	57.21 – 63.56	9.62	6.27 – 16.60	0.979
MET1	12	47.1	43.92 – 50.12	7.65	4.98 – 13.20	0.988
MET2	12	58.4	55.08 – 61.49	9.19	5.99 – 15.87	0.946
MET3	12	60.6	57.86 – 63.03	11.81	7.69 – 20.38	0.954
MET4	12	45.0	43.65 – 46.19	17.87	11.64 – 30.84	0.966
MET5	12	36.0	34.05 – 37.78	9.73	6.34 – 16.80	0.990

Table 3. The dielectric loss of MO, PPKO, ME and nanofluids 60 Hz

Sample	MO	PPKO	ME	MEA1	MEA2	MEA3	MEA4
Dielectric Loss (tan δ)	0.00115	0.00631	0.044	0.00221	0.00152	0.00129	0.00083
Sample	MEA5	MET1	MET2	MET3	MET4	MET5	-
Dielectric Loss (tan δ)	0.00051	0.00432	0.0034	0.00264	0.00212	0.00144	-

Table 4. AC conductivity of MO, PPKO, ME and nanofluids at 60 Hz

Sample	MO	PPKO	ME	MEA1	MEA2	MEA3	MEA4
AC Conductivity (S/m)	7.78×10^{-12}	7.46×10^{-11}	4.71×10^{-10}	2.97×10^{-11}	2.35×10^{-11}	2.24×10^{-11}	1.65×10^{-11}
Sample	MEA5	MET1	MET2	MET3	MET4	MET5	-
AC Conductivity (S/m)	1.11×10^{-11}	6.35×10^{-11}	5.77×10^{-11}	5.32×10^{-11}	4.93×10^{-11}	3.71×10^{-11}	-

DISCUSSION

Dielectric Response

From table 3, the dispersion of nanoparticles in the oil was observed to have led to a reduced dielectric loss in the methyl ester. A similar observation was made for the two nanoparticles in the methyl ester. The progressive loading of nanoparticles from 0.2wt% - 1wt% led to a reduction in conduction rate by trapping and de-trapping of the dissociated electron in the methyl ester by the nanoparticles and consequently reduce the dielectric loss.

Since the conductivity is having a direct relationship with dielectric loss, a corresponding decrease in the conductivity of the ester was observed across the loading of nanoparticles, see table 4. The obtained data revealed that Al_2O_3-nanofluid will likely serve better as an insulating fluid for oil-filled power equipment when considering the loss and the conductivity.

AC breakdown Strength

The addition of nanoparticles both semiconducting and insulating nanoparticle was observed to have increased the AC breakdown strength of the base oil with optimum performance at 0.6wt.% as shown in table 2 based on Weibull probability of 63.2%. It is worthwhile noting that after 0.6wt.% a reduction in the breakdown voltage was observed for the two nanoparticles. This can be attributed to the decrease in inter-particle distance and a reduction in the potential width of the double layers. At the observed optimum performance for both nanofluids, the TiO_2 and Al_2O_3 nanoparticles increases the AC breakdown strength of methyl ester by 41.3% and 44.5% respectively. This indicates that Al_2O_3 nanoparticle increases the AC breakdown strength more than TiO_2.

CONCLUSION

- The study of the influence of semiconductive and insulating nanoparticles on the dielectric response of palm kernel oil methyl ester was successfully performed.
- At every loading of nanoparticles, it was observed that the dielectric loss and the conductivity reduces. This may be attributed to the trapping and de-trapping of the mobile electron and ions in the oil
- Form 0.2wt% - 0.6wt% loading of nanoparticle, an increase in AC breakdown strength was observed with an optimum performance at 0.6wt% for both TiO_2 and Al_2O_3 nanoparticle. The reduction in the value of AC breakdown strenght after 0.6wt% may be due to the higher percentage of nanoparticle which causes a reduction in inter-particle distance and consequently, leads to conduction which eventually reduces dielectric breakdown strength. From the result , it is revealed that TiO_2 and Al_2O_3 nanofluid from palm kernel oil ester will likely serve better as an insulating liquid with better performance in Al_2O_3 nanofluid.

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