Analysis Of The Physico-Chemical And Electrical Breakdown Characteristics Of Mucuna Flagellipes Seed Oil As Alternative Insulating Fluid For Power Transformer

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Abstract

Crude Mucuna flagellipes oil have been used to synthesize fluids of natural base esters which are considered as viable alternative to mineral insulating oil. The Physico-chemical properties of the fluid is made easy by the modifications of the chemical contents of the oil. This work gives the physical and chemical analysis of the breakdown characteristics of esters synthesized when compared with the same of crude Mucuna flagellipes oil.The value of the crude Mucuna flagellipes oil direct current conductivity is lower after the impurities have been removed. The purified Mucuna flagellipes oil also showed that its conductivity is relatively higher than that of the mineral oil.There is a significant increase in the mean breakdown voltages in the CMFO, PMFO and PMFOAE and PMFOEAE, where the crude oil have 37.2KV, PMFO have 41.6KV, PMFOAE 43.4KV and the epoxyl oil have 43.7KV.A test cell for small volume samples (10ml) was used to carryout the breakdown test using the American Standard Testing Machine (ASTM)test method standard. In this regard, the results show that the esters from synthesized oil may serve as a viable alternative to electrical insulating oil.

Key words: Mucuna flagellipes oil, esters, mineral insulating oil, Physico-chemical.

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1.0 Introduction:

The increased level of atmospheric carbon (IV) oxide whose primary causes are the burning of fossil fuels such as coal natural gas and petroleum (Mineral oil). As the level of carbon (IV) oxide increases so is it's level of environmental effects causing air pollution. In order to sustain the environment there is a need to search for better substitute as alternative to mineral or fossils fuels. In order to sustain the environment, alternative insulating fluid with high performance are used for power equipment. The products of Crude Mucuna flagellipes oil and its derivative or processed ester is one of the alternatives to high performance insulating fluid.

The production of an insulating oil with a varying temperature usage is one of the heculin task. The crude Mucuna flagellipes oil has 70% saturated fatty acids and 30% unsaturated fatty acids which undergoes extraction, purification, filtration and esterification to reduce the points of pours. The primary purpose of these fluids is to enhance the insulation papers dielectric strength and to protect the seen and unseen parts of power equipment or transformers. They should be able to dissipate heat as well as transfer heat energy by convection and conduction.

Mucuna flagellipes oil is non-toxic, biodegradable, non-flammable and friendly to water-life. These properties are compared to other power equipment oils. According to IEC 61039. Other advantages of Mucuna flagellipes oil for power transformers are limitless to industrial and agricultural sectors.

The exploration of esterification and transesterification methods have been used to remove the value of viscosity in edible oils in order to form esters or methyl esters from the oil and to separate glycerol.[1] The exploitative process advances viscosity and pour points which are the physicochemical characteristics of edible oils as reported by somemany researchers. Mobile ions concentration increase while the viscosity decrease in the oil from the bulk conductivity of edible oil which increases significantly due to the process of transesterification. The suitability of transesterified oil is affected by the breakdown in the system thermally.

The arrangement of apparatus and electrode is highly dependent on the measurement of breakdown strengths. [2]

In this paper, we reported the assessment of the physiochemical properties of Mucuna flagellipes.

1.1 Physio-chemical Processes

The physio-chemical process involves the modification of the physical state of substances or particles using chemicals or re-agents in making them more stable and suitable. The Physio-chemical process edible oils: viscosity and pour point analysis.

1.2 Dielectric features

Non-polar solvents are usually used as dielectric fluids in power equipment's. Sometimes the applied electric field creates induced dipoles. The field may form mobile particles in the form of ions thereby dissociating impurities.[1] The drift of charged particles through conduction leads to the dielectric loss domination at low frequencies. According to Gouy-Chapman model, a dual electrical layer formation at the applied electric field under which there may be an accumulation of mobile charge carriers at the interface between the electrode and liquid surface, thereby the impurity dissociation act as a weak electrolyte in the liquid.[3]

Also according to A.J Bard et al, (2001) the factors on which the thickness of the liquid layer depends are:

i. The liquid temperature
ii. Concentration of particle charge carriers in the liquid
iii. Electric field applied

The process of thermal energy is overcomed by the electrostatic forces which leads to the finite thickness of charge diffused layer. Due to the increase in the mobile charge concentration, the dual electrical layer diffusion reduces in width and at low frequency, the permittivity of the fluid increases.

There is an interface of liquid-electrode layer where charge carrier mobility may accumulate forming a double layer of electrical properties under the field in questions as explained by Gouy-Chapman model. [3]

At low frequencies, the double layer electrical properties which are created by the charges accumulation may result in the relaxation of an interfacial behaviours of dielectric called the Maxwell – Wagner interfacial relaxation. [2]

1.3 Viscosity of the Fluid

The internal friction that exist between the layers of the fluid in motion is the viscosity of the fluid. The resistance to the relative motion of the objects is caused by the fluid in which they are immersed. The kinetic viscosity of the fluid affects the variation of velocities of both the motion of the layers of the liquid and the mobility of ions.[2] The large size of molecular and their composition cause some hinderance to the movement and mobility of ions in most dielectric liquids. [4]

The temperature of the fluids is as a result of the average kinetic energy of the fluid. This means that the viscosity of the fluid and the resistance of the charge carriers to move decreases as the temperature of the fluid increases. The rise in temperature also leads to the loss of dielectric of the fluid increase in the movement of charge carriers mobility and their concentrations and the electrical conductivity increase. [2]

1.4 Electrical Breakdown

The electrical breakdown of fluids most especially dielectric fluids are not understandable nevertheless the dielectric breakdown of liquids is done at high applied electric fluids. The identification of the contribution to breakdown characteristics involves a number of different processes.The geometry complexity of the material interface leads to the breakdown process types and the existence of the field area and spaces. [2]

The measurement of electrical breakdown characteristic of materials gives rise to the values of distribution. The measurements of breakdown number and the voltage breakdowns give the withstand voltage in the American standard of Testing Materials (ASTM) 1816.

2.0 Experimental Procedure

2.1 Materials

In this work, the materials used are Mucuna flagellipes (MF), Methanol, Citric acid, Sodium Hydroxide, Potassium hydroxide, Silica gel, Fuller earth, Tonsil Acidified clay and filter paper.

2.2 Source, Extraction and Processing of Crude Mucuna flagellipes oil

The Mucuna flagellipes seeds were sourced from the river banks of Benue, Abakaliki, Utonkon (Benue) and Yenagoa (Bayelsa State).

The collected samples were cleaned, winnowed and dried under the sun for about 6 days to reduce the content of moisture and dust, and the dirt of the container the sampled seeds were fried, grinded and processed locally by pressing with grinding stone to extract the crude Mucuna flagellipes oil (CMFO).

2.3 Removal of Gum and Acid Neutralization

Gum was removed from the crude Mucuna flagellipes oil (CMFO) when 500ml of (CMFO) was mixed with 3.5ml of citric acid. The treatment citric acid was done at 80^oc in a round bottom flask. For 30 minutes, the (CMFO) and citric acid were stirred continuously. After which sodium hydroxide solution of 6ml was added and stirred for additional 15 minutes for acidic neutralization. In order to remove the water content of the oil and bleach it in the process, 1g of silica gel and 3g of fuller earth were added respectively. [6]

Filtration was carried on the mixture using Whitman filter paper. At 50^oC, transesterification of the purified oil was carried out in order for the oil to flow easily. The quantity of oil transesterified is 100g. Glycerol was separated from the Purified Mucuna flagellipes oil (PMFO) methyl ester using a separating funnel. [5]

Fig. 1 shows the schematic diagram of processing of Mucuna flagellipes oil from its seed.

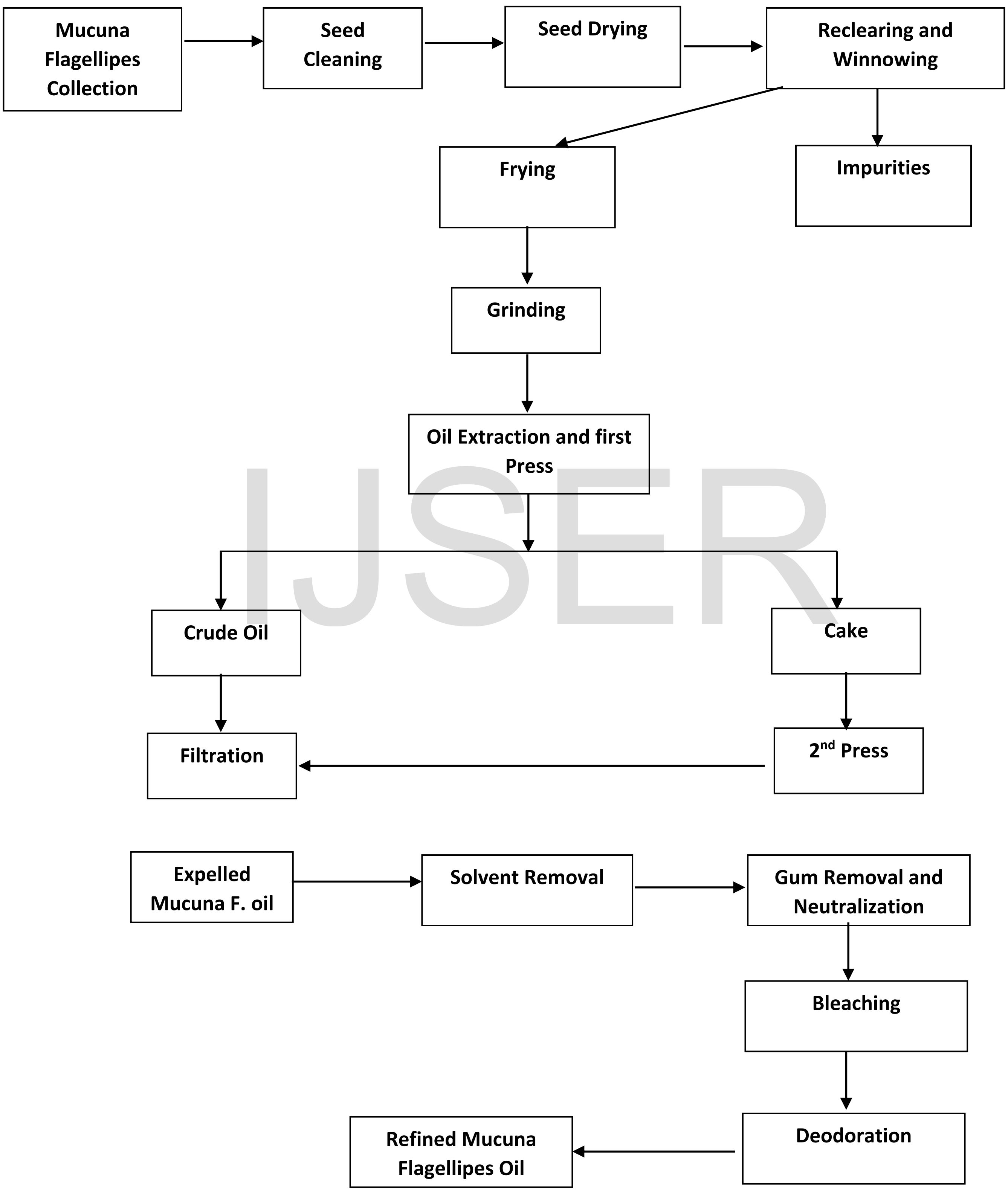

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Fig. 2

Fig. 2a Mucuna Flagellipes Seeds

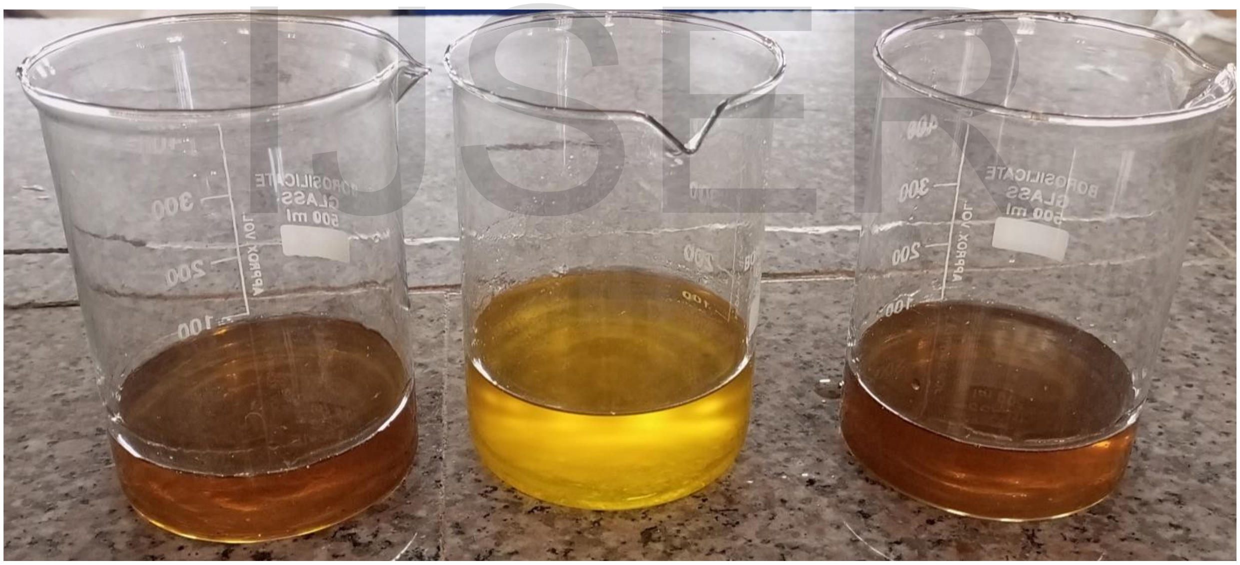


Fig. 2b Crude Mucuna Flagellipes Oil **Fig. 2cPurified Crude Mucuna Flagellipes Oil** **Fig. 2dMineral Oil**

Table 1: Explanation of Samples

CMFO	Crude Mucuna flagellipes oil
PMFO	Purified Crude Mucuna flagellipes oil
PMFOAE	Purified Crude Mucuna flagellipes oil Alkyl ester
PMFOEAE	Purified Crude Mucuna flagellipes oil Epoxyl Alkyl ester
Minoil	Mineral oil

2.4 AC and DC Breakdown Tests

(a) The DC breakdown test was performed on HV DC breakdown equipment set-up where the samples of oil were poured and the electrodes adjustment spacing was 2.5mm from the standard of International Electrochemical Commission (IEC).
At the test cell, the voltage source of high value with a current whose limiting resistance is 1MΩ was used. The measurement of breakdown occur as the voltage was gradually increased at 1KV/s.
The average breakdown value was taken from the breakdown measurement of each sample for three successive times.

(b) Alternatively using the standard of ASTM D1816 for the measurement of AC breakdown the oil samples were subjected to an AC breakdown test, where each oil sample dielectric breakdown were carried out using an automated dielectric strength tester with model FS2080 the breakdown measurement was carried-out as the voltage was gradually increased at 1KV/s and the average breakdown value taken from the measurement of breakdown of each sample for three consecutive times.

2.5 Viscosity Measurement

The viscosity of the oil sample was measured using a viscometer of suspended-level capillarity of 2.518 x 10^{-2} cst/sec. This was done between 15 – 55^{o}c.

2.6 Density Measurement

The determination of the sample densities were carried out using the density meter (Paar DMA 40). This is made up of a capillary U-tube glass where fluid samples are poured into the tube to determine its density and the change in resonate frequency according to Amoka (2012).

2.7 Fourier Transformer Infra-red Spectroscopy

Sample Analysis of Infra-red spectral format were carried out using the FTIR – 8400S Fourier transform infra-red spectrometer in order to get the functional groups of the samples.

The scanning of samples with infra-red radiation was done in the range of 3900cm^{-1} to 390cm^{-1} wave number to get the spectrum.

3.0 Result and Discussion

The table below shows both the AC and DC conductivity response of sample oils and Minoil at 15^{o}c.

As shown in the table below, it was been observed that the value of the crude Mucuna flagellipes oil direct current conductivity is lower after the impurities have been removed. The purified Mucuna flagellipes oil also showed that its conductivity is relatively higher than that of the mineral oil. There is an increased in conductivities of the esters of Mucuna flagellipes oil compared to the purified oil. This is as a result of the presence of charged particles carriers and decreased viscosity of the alkyl esters.[1,2]

Table 2: Features of Viscosity and Conductivities

Samples	Viscosity (pa.s)	Activation Energy for Viscosity (eV)	σ_{AC}	σ_{DC}	Activation Energy for σ_{AC} (eV)
CMFO	37.0	0.260	3.04×10^{-10}	5.30×10^{-10}	0.320
PMFO	36.8	0.258	3.70×10^{-11}	3.20×10^{-11}	0.410
PMFOAE	4.8	0.190	3.92×10^{-10}	1.07×10^{-10}	0.250
PMFOEAE	5.7	0.200	1.73×10^{-8}	1.02×10^{-8}	0.160
Minoil	27.0	0.310	4.4×10^{-12}	2.8×10^{-12}	0.380

Fig. 2: A plot of Viscosity and Activation Energy for Viscosity

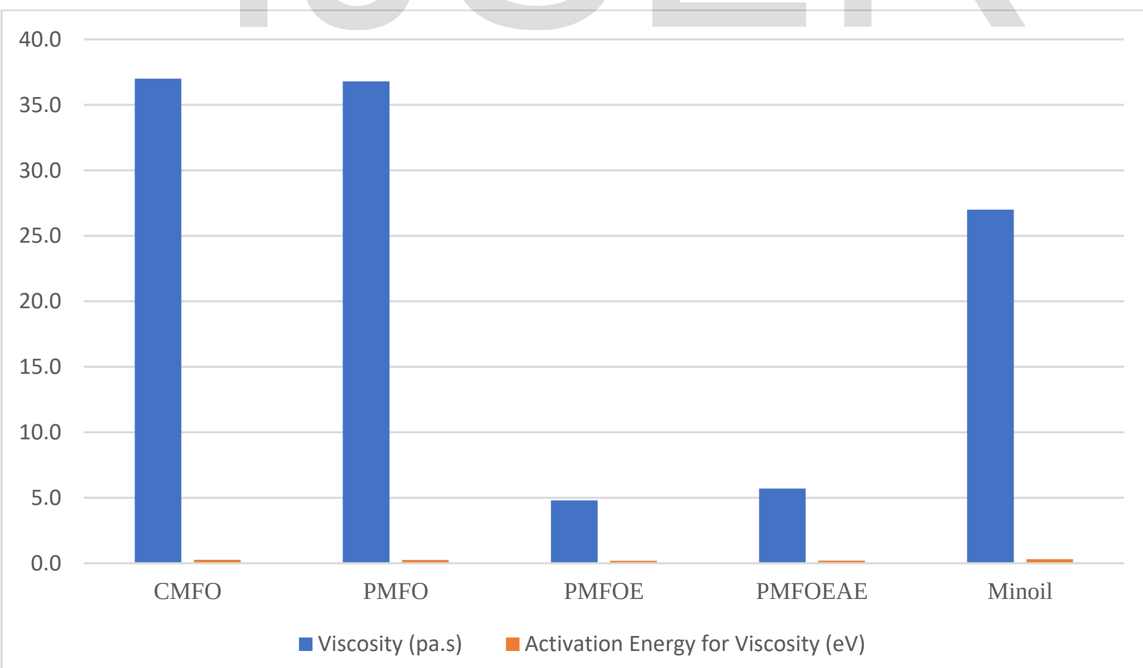
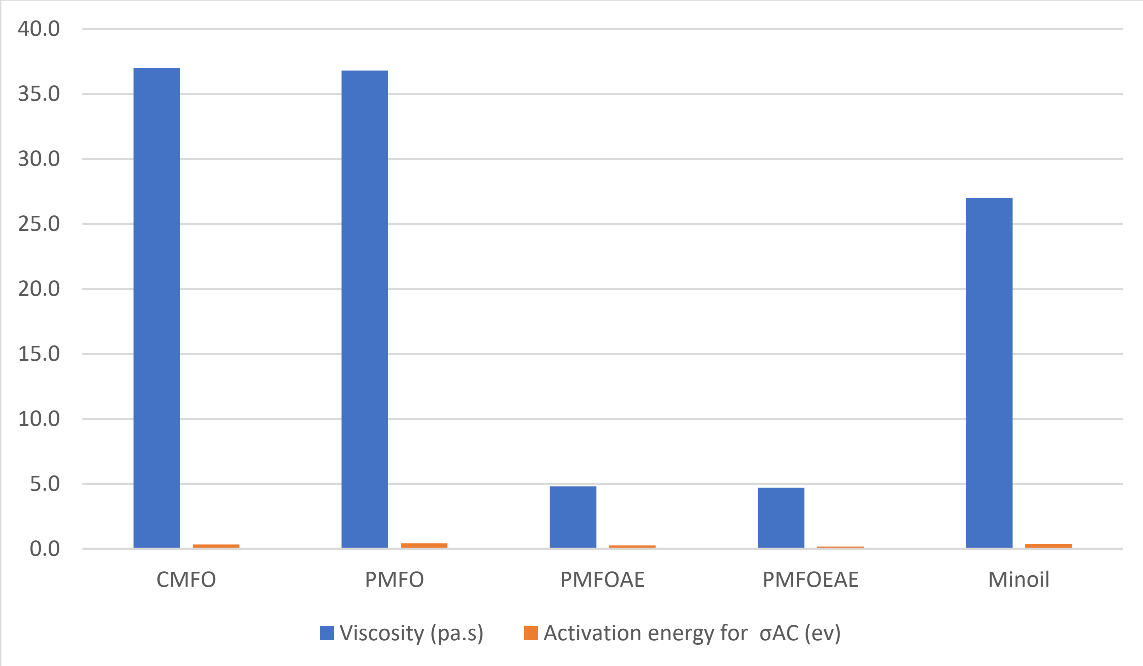


Fig. 3: A plot of Viscosity and Activation Energy for σ_{AC}



3.1 Fourier Transform Infrared Spectroscopy (FTIR)

PMFO FTIR Spectra are shown In Table3

The purified Mucuna flagellipes oil contains alcohol, Amines, Alkenes, Amides,Alkyl halides, and ethers. These materials showed some functional group properties such as O – H, N – H, C – C, C = O, C – F, C – O – C and C – I as shown in table3 below. The presence of stretching and asymmetric stretching was found at the band of 3423.75cm^{-1} for alcohol and amines while alkyl halides and ethers also showed symmetric and asymmetric stretching at the band of 1204.10cm^{-1}.

Table 3: Functional groups for PMFO showing stretching from FTIR

Functional Group	**Wave Number cm^{-1}**	**Mode of Vibration**	**Intensity**
Alcohol	3423.75	O – H Stretching	s
Amines		N – H asymmetric Stretching	W – m
Alkenes	1728.21	C = C Stretching	s
Amides		C = O Stretching	Ms
Alkyl halides	1204.10	C – F Stretching	V_s
Alcohol		C – O Stretching	
Ethers		=C – O – C Symmetric and asymmetric Stretching	ms
Alkyl halides	390.24	C – I Stretching	s

3.2 Breakdown of Dielectric

The analysed breakdown test results for CMFO, PMFO, PMFOAF, PMFOEAE and Minoil samples from normal statistics are shown in table 4.

According to Devvos et al (2005), the breakdown voltage for insulating oil in power equipment is 26KV and its ratings is 345KV. In this work, the breakdown voltage mean is 26.3KV and the deviation is 1.8KV as obtained from the breakdown test cell compared to the reported literature from American Standard Testing Machine Cell.

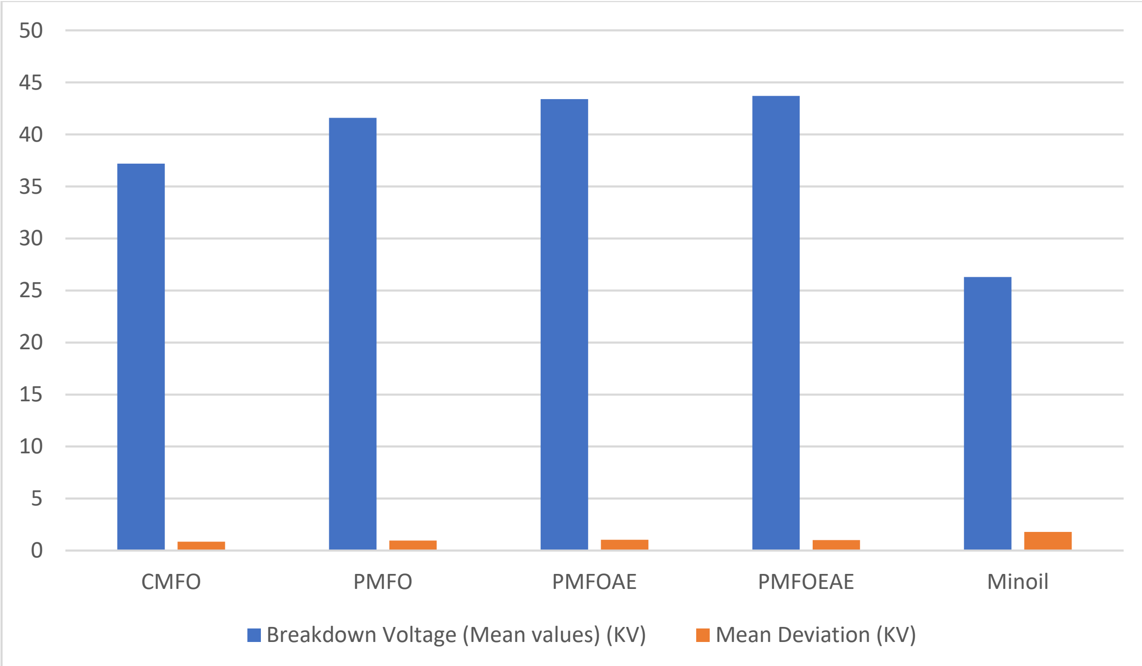
There is a significant increase in the mean breakdown voltages in the CMFO, PMFO and PMFOAE and PMFOEAE, where the crude oil have 37.2KV, PMFO have 41.6KV, PMFOAE 43.4KV and the epoxyl oil have 43.7KV as shown in table 4.

Using the ASTM test standard, the Mucuna flagellipes oil samples breakdown voltage mean were compared to the recommended lowest mean breakdown voltage of mineral oils insulating fluids. The natural Mucuna flagellipes oil ester have the lowest breakdown voltage of mean value of 37KV as recommended.

Table 4: Normal Statistic Values of Breakdown Voltage Test

Samples	**Number of Breakdown**	**Breakdown Voltage (Mean values) (KV)**	**Mean Deviation (KV)**
CMFO	7	37.2	0.85
PMFO	7	41.6	0.96
PMFOAE	7	43.4	1.04
PMFOEAE	7	43.7	1.01
Minoil	7	26.3	1.80

Fig. 4: A plot of Breakdown voltage mean values and Mean Deviation



Conclusion

There is a decrease in the loss of dielectric properties in Purified Mucuna flagellipes oil samples compared to the crude sample of the oil. There is also an increase in the electrical resistivity of purified Mucuna flagellipes oil which in turn decreases the electrical conductivity of the purified Mucuna flagellipes oil which is lower than the crude oil by a value of four to five. The mineral oil electrical conductivity is lower than that of the purified oil sample by a value of 5. The result illustrates that esters of mucuna flagellipes oil have good electrical breakdown features and can be considered as a viable alternative insulating oil.

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Reference

[1] Abdemalik, A.A; Abboth A.P; Fothergill, J.C, Dodd, S. & Harris, R.C (2011). Synthesis of a base – stock for electrical insulating fluid based on palm kernel oil. Industrial crops and products, 33(2) 532 – 536.

[2] Abdelmalik, A.A; Fothergill, J.C; Dodd, S.J. (2012). Electrical Conduction and dielectric breakdown characteristic from palm kernel oil. IEE Transaction on Dielectric and Electrical Insulation. 19(5), 1623 – 1632.

[3] A.J Bard, L.R Faulkner. (2001). Electrochemical Methods; Fundamentals and Applications, second Edition, John Wiley & Sons, Inc.

[4] R. Bartnikas. (1987). Alternating – current loss and permittivity measurement in Engineering Dielectric, Vol. IIB. Electrical Properties of Solid Materials: Measurement Techniques. R Bartnikas, pp. 52 – 123 ASTM.

[5] Oparanti, S.O; Khaleed, A.A; & Abdelmalik A.A. (2021). Nanofluid from Palm Kernel oil for High Voltage Insulation. Materials Chemistry and Physics, 259, 123961.

[6] S.O Oparanti, A.A Khaleed; A.A Abdelmalik and N.M Chalashkanov. (2020). "Dielectric Characterization of palm kernel oil ester-based insulating nanofluid" 2020 IEEE Conference on Electrical Insulation and Dielectric Phenomena (CEIDP), pp 211 – 214, doi:10.1109/CEIDP49254.2020.9437477

[7] IEEE std 930 – 2004. (2005). IEEE Guide for the Statistical Analysis of Electrical Insulation Breakdown Data, IEEE.

[8] Nor, S.F.M; Azis, N; Jasni, J; Abkabir, M.Z.A; Yunus R; & Yaakub, Z. (2017). Investigation on the electrical properties of palm oil and coconut oil based T_iO_2 nanofluids. IEEE Transactions on Dielectrics and Electrical Insulation, 24 (6), 3432 – 3442.

[9] C.T. Dervos, C.D. Paraskevas, P. Skafidas, P. Vassiliou, (2005). Dielectric Characterization of Power Oils as a Diagnostic Life Prediction Method, IEEE Insulation Magazine, Vol. 21, No. 1.