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Investigations On Breakdown Voltages In Chemically Treated Natural Esters When Used As Liquid Dielectric

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Abstract

Most commonly used liquid insulators like mineral oil and silicone fluid serve dual purpose of insulation and cooling in electrical apparatus, particularly transformers. Mineral oil is neither bio-compatible nor biodegradable and this may lead to health hazard. While silicone fluid is biocompatible, it is only partly bio-degradable. Each of these has certain drawbacks particularly with respect to environmental impact and biodegradability. Thus, search for a suitable dielectric fluid to replace the mineral oil and expensive silicone fluid is of importance in the present scenario. This paper presents assessment of dielectric properties of natural esters as compared to mineral oil and silicone fluid. The natural esters, due to their superior environmental safety and bio-degradability can be considered as liquid dielectrics. This paper presents the performance study on Indigenous natural esters as liquid dielectric codenamed as IO-18 and IO-19. The effect of temperature is investigated on the samples before and after chemical treatment. Three food grade anti-oxidants are added to the samples in different concentrations. The study shows that there is significant improvement in the dielectric properties of the samples.

Keywords: ***Insulation, Liquid Dielectric, Breakdown Voltage, Dissipation Factor, Permittivity.***

1. Introduction

Mineral oil and silicone fluid are in wide use as dielectric liquids in electrical power apparatus, air-borne systems and defense application. Mineral oil is neither biodegradable nor bio-compatible but silicone fluids are biocompatible but not completely bio-degradable. Also these are non-renewable [1]. In case of an accidental spill, it can be hazardous to the surrounding environment due to contamination of soil and waterways. Therefore, this is considered of utmost importance to develop a suitable natural ester, to reduce future reliance on fossil products [1].

Natural vegetable seed oils are renewable, require simple apparatus for their extraction, and have excellent fire safety characteristics i.e., high flash and fire point. This ensures better safety in operation, handling, storage and transportation. They generally have a higher relative permittivity (approximately 3, as compared to mineral oil which is around 2.2) and thus dielectric mismatch with paper (about 5) is lower. Vegetable oils / poly esters have 97% bio-degradability, whereas mineral oil has only 30% bio-degradability and high temperature mineral oils have much poorer bio-degradability of about 20% [2, 3].

Mineral oil is a type of complex mixture of hydrocarbon compounds and generates short

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chain organic acids while natural esters produce long chain fatty acids. The primary components of natural ester are triglyceride esters of fatty acids and free fatty acids. Fatty acid groups in a triglyceride structure are different for different natural esters which results in different type of behavior for different oils [4]. These attribute to higher values of permittivity but poorer oxidation stability compared to mineral oil.

1.1Esters

Natural esters (Vegetable seed oils) are water-insoluble substances of plant origin which consist predominantly of long-chain fatty acid esters of glycerol (HOCH2CHOHCH2OH), and are known as 'glycerides'. Oils are composed of low-melting fatty acids (mostly unsaturated) such as oleic, linoleic and linolenic acids, while fats are formed from high-melting fatty acids (mostly saturated) such as lauric, palmitic and stearic acids. Vegetable oils are essentially glycerides (esters of glycerol). The non-ester portion is usually less than 2% of the total oil. The glycerides themselves contain about 95% fatty acid and 5% glycerol. Since the amount of glycerol is the same in all vegetable oils, it follows that the differences in properties of different oils are largely determined by the variations in the fatty acid structure. The formulas of various fatty acids are shown below [5].

Name	Formula
Oleic acid	$C_{17}H_{33}COOH$
Linoleic acid	$C_{17}H_{31}COOH$
Linolenic acid	$C_{17}H_{29}COOH$
Lauric acid	$CH_3(CH_2)_{10}COOH$
Palmitic acid	$CH_3(CH_2)_{14}COOH$
Stearic acid	$CH_3(CH_2)_{16}COOH$

The minor (non-ester) components of fats are phospholipids (or phosphatides), sterols, vitamins and their precursors, antioxidants, pigments, free fatty acids and some impurities. These components affect the colour, odour and other qualities of the oil, hence require purification [5].

1.2 Purification process

In order to remove the non-ester (minor) components purification processes followed are:

i) Degumming -to remove some natural gums and phosphatides.

ii) Deacidification-to remove free fatty acids in the oil by treating the oil with a base.

Iii) Deionization or bleaching- removes coloring matter in the oil. By using bleaching earth, such as fuller's earth and active carbons bleaching can be done.

iv)Deodorization-to remove odiferous substances and substances with peculiar tastes.

1.3 Physical and Chemical properties of Natural Esters

The physical properties of natural esters include: melting point, specific gravity, refractive index, viscosity, colour, surface tension, solubility. The chemical constants are: acid number, iodine value, saponification value, etc. Iodine number is a measure of the degree of unsaturation of oil. The greater the total unsaturation, the higher, in general, is the iodine value [5].The chemical and physical properties of oil play an important role in their performance when used as liquid dielectric.

1.4 Esters as Liquid Dielectrics

The following are the important electrical properties and other properties of a liquid dielectric:

Breakdown Voltage, Dissipation Factor, Oxidation Stability, Permittivity, Thermal conductivity, viscosity, flash point, Pour point. The natural esters when used as liquid dielectrics have to match to certain extent with the properties of the existing liquid insulators. The natural esters have some disadvantages like lower oxidation stability and high viscosity. Hence antioxidants are added to overcome this potential handicap. However high flash point (about 300˚C compared to about 150˚C of mineral oil and to about 200˚C of silicone fluid) is an added advantage of these natural esters. Permittivity of all natural esters is between 3-3.5 which is closer to that of paper (about 5) compared to mineral oil.

2 SAMPLE DETAILS

The Experiments were carried out on a number of natural esters. Based on the analysis of results, pertaining to the dielectric properties like Breakdown Voltage, Tan (delta), permittivity etc. two oils were short listed and are codenamed as IO-18 and IO-19.

2.1Fatty acid composition

The details of degree of saturation and un-saturation, fatty acid composition of the samples considered for study is shown in table1 & table 2 respectively. It depicts the amount of anti-oxidant that can be added in various concentrations to improve the dielectric properties of the samples considered.

Table1. Degree of saturation & un-saturation

Oil type	mono-unsaturated fatty acids	poly-unsaturated fatty acids	saturated fatty acids
IO18	39%	35%	20%
IO19	42%	43%	15%

Table2. Fatty acid composition

Sample	Stearic Acid – $C_{18}H_{36}O_2$ (%)	Linoleic acid- $C_{18}H_{32}O_2$ (%)	Linolenic acid- $C_{18}H_{30}O_2$ (%)
IO-18	1.83	5.92	26.36
IO-19	5.49	2.4	37.5

The chemical constant (saponification value and iodine value) also contributes towards the performance of the liquid as dielectric. These values for the samples selected are given in table3.

Table3. Chemical Constants

Sample	Saponication values	Iodine value
IO-18	181 - 189	99 - 108
IO-19	95-105	100-110

2.2 U-V Absorbency spectrum

The U-V spectrum Absorbency graph for the selected samples before and after neutralization is shown in figure1&2.The Peaks show presence of free fatty acids between 400 nm to 600nm wavelength. The peaks shown after 600nm is the fatty acid composition of the sample selected.

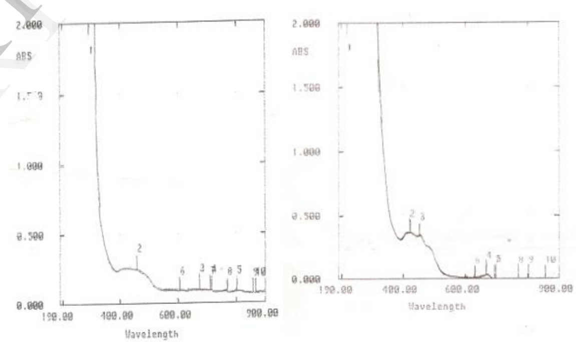

Fig1. IO-18 U-V spectrum Absorbency graph before Neutralization

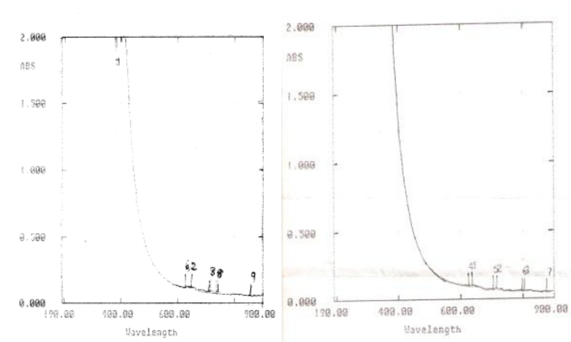

Fig2. IO-19 U-V spectrum Absorbency graph after neutralization

In Fig2 a smooth curve upto 600nm wavelength depicts removal of free fatty acids after neutralization [4].

2.3 Breakdown Voltage in Natural Esters

In practical applications, liquids are normally used at voltage stresses of about 50-60kV/cm when the equipment is continuously operated.

Its causes and effects vary with voltage stresses and temperatures. The Mechanism of breakdown in liquids may be Electronic breakdown or due to Suspended solid particle. Breakdown Voltage may occur due to presence of moisture, liquid temperature or applied voltage duration. Since Breakdown Voltage is the most important dielectric property in liquid insulators, it is measured in a range of room temperature to 90ºC [6].

2.3.1 Improvement in breakdown voltages

It can be achieved by enhancing the liquid quality by liquid filtering, moisture free, dust proof and degassing, using insulation covers and barriers over the liquid and prohibiting occurrence and development of Bridge [6].

2.3Dissipation Factor in Natural Esters

Dissipation factor is another important dielectric parameter which affects the operation of the liquid insulator. The dissipation factor or Loss Factor tanδ is a measure of dielectric loss rate. It consists of conductive losses and polarization losses. Electronic and atomic polarization are temperature independent, but oriental polarization, depending on the extent to which the applied field can orient the permanent dipoles against the disordering effect of the thermal energy of their environment and varies inversely with absolute temperature. This results in energy loss in the dielectric which is nothing but dielectric loss and dissipation factor is a measure of dielectric loss. Voltage stresses and temperature are the main factors influencing the dissipation factor [6].

3 EXPERIMENTAL DETAILS

The parameters like Breakdown Voltage, Dissipation Factor and Relative Permittivity which asses the dielectric property of a liquid is done for the following:

i) Samples in 'as received' condition.

ii) Samples after chemical treatment.

Also experiments were carried out on Mineral Oil and Silicone Fluid for comparison. The free fatty acids present in the 'as received' samples contribute to a lower value of Breakdown Voltage and loss factor. This aspect is addressed by neutralizing the samples using NaOH by following the standard procedure. To improve the properties, different antioxidants such as BHT (Butylated Hydroxyl Toluene), TBHQ (Tertiary Butyl hydroquinone) and PG (Propyl gallate) were added for various concentrations.

3.1 Neutralization: 90ml of NaOH solution is added to 2 litres of sample and mixed thoroughly for 20 minutes (speed of 200-250rpm) and allowed to settle. The oil layer is then separated from the bottom aqueous layer; the top oil layer is washed 3 times with 500ml of distilled water.

The antioxidants BHT, TBHQ were added to the sample with 0.02%, 0.2%, 1% and 2% [7] by weight.

Experiments were carried out on the selected samples for the following cases:

1. Mineral oil.
2. Silicone fluid
3. Samples in 'as received' condition
4. Samples with the following concentrations of additives:

   a) 0.02% b) 0.2%
   c) 1% d) 2%

4. RESULTS AND DISCUSSIONS

4.1 Breakdown Voltage

Breakdown Voltage (BDV) measured as per the standard IS 6792).The graphs of Breakdown Voltage as function of temperature are shown in Figs 3& 4.

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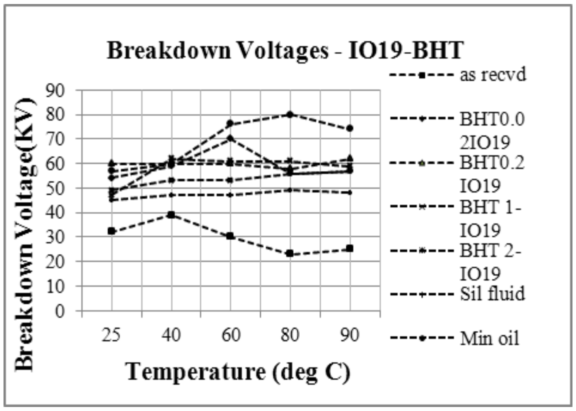

Fig3a: Breakdown voltage Vs. Temperature

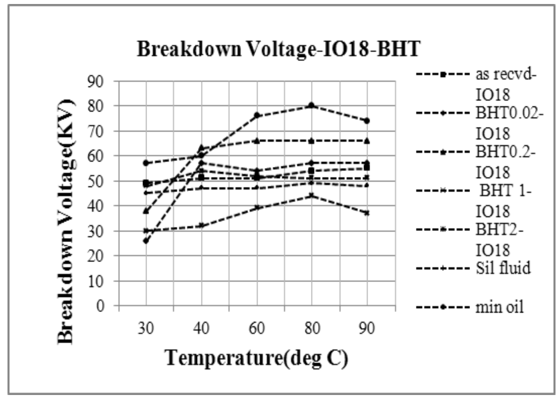

Fig4a: Breakdown voltage Vs. Temperature

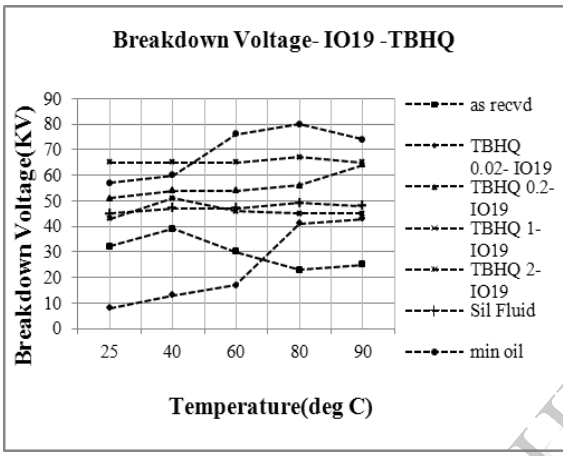

Fig3b: Breakdown voltage Vs. Temperature

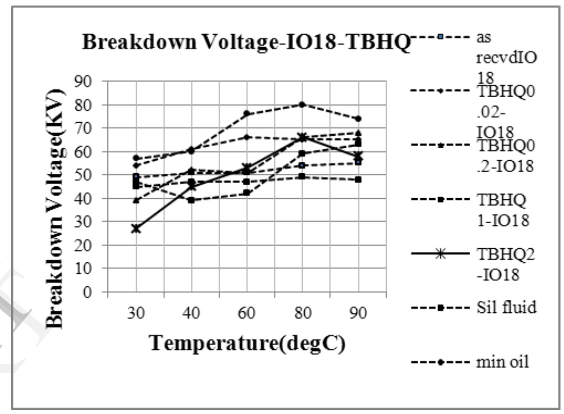

Fig4b: Breakdown voltage Vs. Temperature

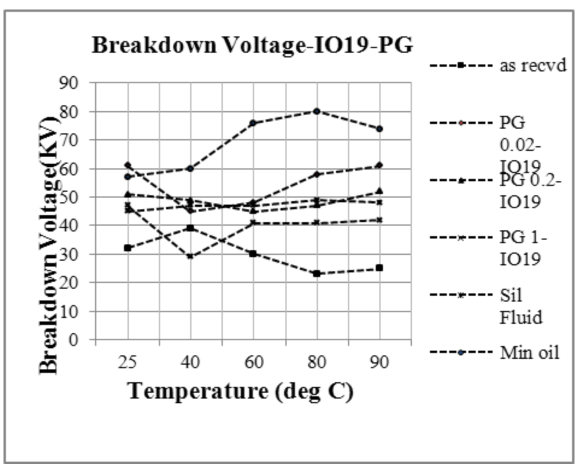

Fig3c: Breakdown voltage Vs. Temperature

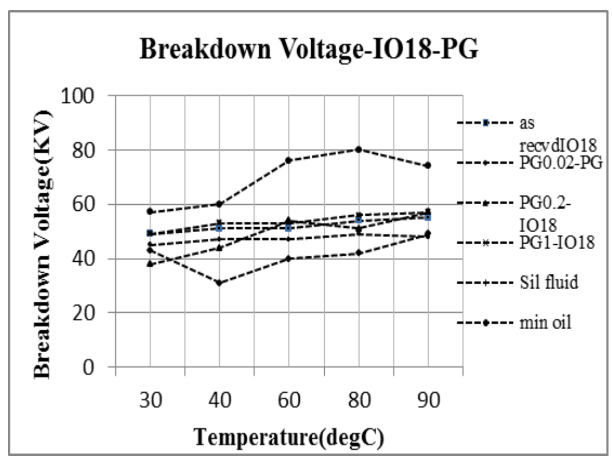

Fig4c: Breakdown voltage Vs. Temperature

The range of Breakdown voltages is summarized as given in table4:

Table 4

Sl.no	Samples	BDV Range
1.	Mineral oil	45kV-80kV
2.	Silicone fluid	40kV-45kV
3.	IO-18 i)'as received' ii)BHT (0.02% - 2%) iii)TBHQ(0.02% - 2%) iv)PG(0.02% - 1%)	 45kV-50Kv 55kV-66kV 60kV-65kV 50kV-60kV
4.	IO-19 i) 'as received' ii)BHT(0.02% - 2%) iii)TBHQ(0.02% - 2%) iv)PG(0.02% - 1%)	 25kV-35kV 60-kV-65kV 60kV-67kV 55kV-60kV

From table 4 it may be seen that Breakdown Voltage is comparable with the standards of mineral oil and silicone fluid. Only IO19 'as received' has poor breakdown which may be attributed towards its chemical composition. With addition of antioxidants there is a significant increase in the Breakdown Voltage. This may be due to the antioxidant acting as a moisture proof and dust proof layer.

The operating temperature being much higher than the room temperature, all dielectric parameters like Dissipation Factor, Permittivity and Oxidation stability are studied at high temperature, particularly at 90ºC [8]. Hence it becomes significant to test the Breakdown Voltages at 90ºC. The values are tabulated in table 5 & 6

Table5-IO-19-BDV values at 90 degC

Sample IO-19	BHT	TBHQ	PG
'as received'	25	25	25
0.02%	57	43	61
0.2%	62	64	52
1%	59	65	42
2%	57	45	--

Table 6-IO-18-BDV values at 90 degC

Sample IO-18	BHT	TBHQ	PG
'as received'	55	55	55
0.02%	57	65	49
0.2%	66	68	57
1%	37	63	57
2%	51	48	--

The Breakdown Voltage has improved significantly with increase in antioxidant concentration when compared with 'as received' (table 5) for sample IO-19 whereas a marginal improvement is seen (table 6) for sample IO-18.

Even though there is a slight reduction in BDV with increase in concentration, it is well within the permissible limit of the required range of 50-60kV. Moreover oxidation stability (standards of AOCS Cd 12B-92 and ISO 6886) and Dissipation Factor (as per IS6262, IEC-60247 and ASTM D-1169 standards) has shown very good improvements with increase in the antioxidant concentrations. Investigations are continued in the same direction.

4.2 Dissipation factor:

Since Breakdown Voltage with TBHQ has given better result at almost all temperatures, Dissipation Factor is measured for the samples with TBHQ of different concentrations and the analysis is shown in Fig 5.

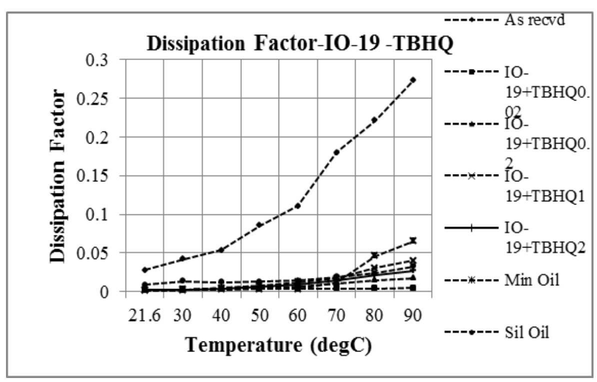

Fig5a: Dissipation factor Vs. Temperature (IO19)

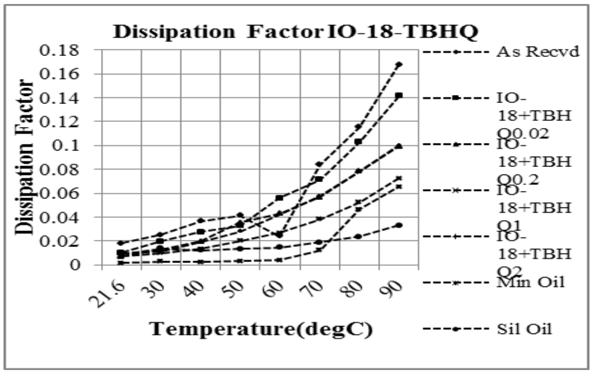

Fig5b: Dissipation factor Vs. Temperature (IO18)

Even though the Dissipation Factor for IO-19 in 'as received' condition is in the range of 0.02-0.27With addition of TBHQ, there is considerable improvement (Fig 5a) in the values and even better than those of mineral oil at all temperatures. The sample IO18 has shown significant decrease after the addition of antioxidants. For TBHQ 1% of IO18 (0.007-0.07) and TBHQ 2% of IO19 (0.0018-0.027), in particular, the Dissipation Factor has reduced to a notable extent.

4.3 Relative permittivity:

The relative permittivity of the oils does not show any significant change either with antioxidant or with temperature. The permittivity is in the range of 3.3 to 2.8 for 'as received' as well as chemically treated samples. Compared to mineral oil & silicone fluid its values are still better.

5. CONCLUSIONS.

i) Increase in additive concentration has shown significant improvement in BDV and marginal improvement in dissipation factor.

ii) There is slight reduction in the Relative Permittivity with increase in the concentration of antioxidants, values still being better than the mineral oil and silicone fluid.

iii) The additive TBHQ has shown better results of breakdown voltage compared to BHT and PG.

On the whole, the addition of antioxidants has shown improvement in various dielectric properties. In particular BDV, with TBHQ, is improved, for both samples. This encourages further studies in the same direction with various concentrations.

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