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Influence of Aging Derivatives on Properties of Natural Ester Oil

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Abstract*: *Transformers are the critical component in the power system, which is used for transmission and distribution purposes. Traditionally mineral oil has been used as the liquid insulation medium in the transformer. Owing to poor bio - degradability and availability, it has been widely studied to replace mineral oil with natural ester oil. During the service period of the transformer, oil insulation and paper insulation gets degraded due to aging. This aging results in the formation of furanic compounds in the oil insulation, which will affect the performance of oil insulation and thus the transformer life. In this proposed work, an effort is made to analyze the critical parameters before and after the inclusion of an aging derivative of 2–furfuraldehyde (2-FAL). 2-FAL has been added in the proportion of 20 ppm to investigate the oil's properties such as breakdown voltage, viscosity, flash point, fire point, and peak absorbance of the UV spectrum. It is observed that there is a lesser impact on the properties with the addition of 20ppm of 2-FAL. Hence it is suggested that the various concentration of 2-FAL may be added to check the quality of oil for further applications.

Keywords : ***Power transformer; Insulating oil; Natural ester; Furfuraldehyde;***

I. INTRODUCTION

Transformers are one of the essential equipment for the power system network, which helps for uninterrupted power supply in transmission and distribution. In general, transformer life is determined by its insulation systems, which are majorly known as solid insulation and liquid insulation.

The transformer's insulation system is composed of mineral oil as liquid insulation and kraft paper as solid insulation. It contributes better thermal health by liberating the heat in the form of cooling ducts[2]. The impregnated pressboard is widely used between the transformers winding as oil barriers for breaking up significant oil gaps, so the life of the transformer increases. Paper insulation creates thermal stress, oxidation, hydrolysis, etc. which leads to the degradation and reduce its lifetime[14].

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The purpose of oil insulation in the transformer is insulation and also cooling medium. It absorbs the heat from the winding and transmits it to the outer environment. When the oil gets decomposed, the bonding of hydrocarbon molecules is altered, which raises the water content and leads to sludge formation[10].

For several decades, mineral oil is used as a liquid medium. It protects the winding from direct contact with the oxygen and avoids the oxidation reaction[13,17]. Mineral oil is made up of hydrocarbon molecules, which are categorized as naphtha based mineral oil and paraffin-based mineral oil. Naphtha based oil easily gets oxidized when compared to paraffin-based oil.

The sludge formed in the oil is easily soluble within the oil itself. There are several problems that arise with mineral oil, such as low fire point, low biodegradation, and non–renewable resource.

Therefore, these problems lead to think about an alternative fluid among the researches[11]. Considering the human health and environmental conditions, vegetable oil has drawn more attention as an alternative liquid. Fortunately, natural ester oil has better dielectric properties, viscosity, fire point, flash point, etc. Thus the vegetable oil attracts more attention as a substitute for mineral oil[12,16].

As the chemical and physical properties of the oil change, it accelerates the aging of the cellulose paper used in the transformers[1]. The paper gets degrade due to faults, moisture, overheating, stress, etc.

The aging derivative of furanic compounds indicates the level of degradation in the insulation system. During the degradation process, four prevalent derivatives of furan are produced. They are 5 – HMF, 2 – FAL, 2 – ACF, etc. The stable product formed during the time of cellulosic aging is 2 – FAL. It will be the key indicator of the aging examination[5,8,9].

The main aim of the work is to ensure the impact of the aging derivative in the vegetable oil-based natural ester oil. The aging derivative of 2 – FAL is artificially added in the oil with the proportion of 20 ppm. Various natural ester oil based on fatty acid contents are analyzed for characterization as liquid insulation and for further investigation.

Then the furanic derivative is individually mixed in the oil. The critical properties such as breakdown voltage, viscosity, flash point, fire point, and peak absorbance and bandwidth of UV spectrum are measured. The presence of furanic compounds in natural ester oil is determined using an ultraviolet-visible light spectrometer.

II. SAMPLE DESCRIPTION

A. Oil samples taken for selection

For initial investigation on selected natural ester oil's properties such as breakdown voltage, viscosity, flash point, fire point, pour point, and density are measured as per standards. Oil samples taken for the investigation are given in Table 1.

The oil samples are selected based on the fatty acid compounds.

Table 1. Oil Samples

SAMPLE	FATTY ACIDS	OILS
Sample 1	Saturated oil	Palm oil
Sample 2	Monounsaturated oil	Arachis oil
Sample 3		Sunflower oil
Sample 4	Polyunsaturated oil	Corn oil
Sample 5		Ricebran oil

B. Experimental setup

The standards and experimental setup for the measurement of properties such as breakdown voltage, viscosity, flash point, fire point, pour point, density, ultraviolet-visible spectrophotometer, and magnetic stirrer are listed in Table 2.

Table 2. Measurement of Critical Properties as per Standards

PARAMETER	STANDARDS	MEASURING KIT
Viscosity	ASTM D 445	Redwood viscometer
Breakdown voltage	IEC 60615	Breakdown voltage testing kit
Flash point	ASTM D 93	Pensky – Martin closed cup method
Fire point	ASTM D 93	Pensky – Martin closed cup method
Pour point	ASTM D 5949	Pour point kit
Density	ASTM D 1217	Densometer
Peak Absorbance and bandwidth	NA	UV-1240 spectrophotometer

C. Sample preparation

The sample is prepared by mixing 500ml of oil and 20 ppm of 2 – FAL, and it is stirred for 15 minutes with the help of magnetic stirrer at the speed of 920 rpm, and it was maintained at room temperature. After mixing, the resultant solution was investigated for the critical properties.

D. Methodology

The methodology of the proposed work is shown in Fig 1.

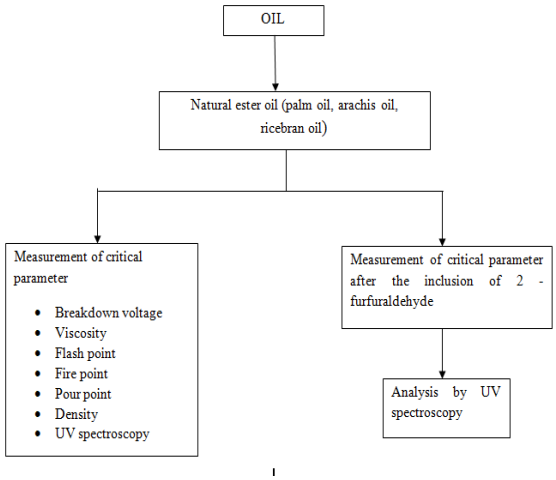

Fig. 1. Proposed Work Methodology

III. EXPERIMENTAL RESULT S

Values of properties of various natural ester oils such as palm oil, arachis oil, sunflower oil, ricebran oil, corn oil are listed in Table 3.

Table 3. Properties of various natural ester oil

PARAMETERS	PALM OIL	ARACHIS OIL	SUNFLOWER OIL	RICEBRAN OIL	CORN OIL
Viscosity (cSt)	182	167	148	174	136
Breakdown voltage (kV)	34	25	30	34	35
Flash point (°C)	335	320	280	320	275
Fire point (°C)	345	340	290	335	290
Pour point (°C)	+5	-8	-14	-7	-6

From the experimental results of properties of natural ester oil, the following inferences are made by comparing results with IEEE Standards.

- **Viscosity**: The maximum allowable range for the viscosity value of natural ester oil is 50 cSt. From the above investigation, it was observed that all the oil samples have a higher value than the specified range.
- **Breakdown voltage**: In the analysis of the selected natural ester, the palm oil, sunflower oil, ricebran oil, and corn oil have a better minimum breakdown voltage between 30 - 35 kV except the arachis oil.
- **Flashpoint**: As per IEEE Guide, natural esters should possess a minimum flash point temperature of 275°C, whereas the palm oil, arachis oil, and ricebran oil have a good range of flashpoint when compared to sunflower oil and corn oil.
- **Pour point:** As per IEEE Guide, the maximum pour point temperature of natural ester oil is -10°C. From the above investigation, it was found the ester oil has the pour point range from +5 to -14°C.

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- **Density: As** per IEEE Guide, the specified value of density is 0.96 g/cm3.All the natural ester oils have a density value lower than the specified value.

From the investigation and observation of properties of oil such as breakdown voltage, viscosity, flash point, fire point, pour point, and density it was found that palm oil, arachis oil, and ricebran oil have the better characteristics when compared to the sunflower oil and corn oil. Hence these three oil samples only considered for the investigations.

By comparing the spectrum, the absorption spectrum range of 190 - 400 nm is shown in Fig. 2. It is evident that there is a presence of more spikes in sample 1 from sample 3 due to the carbon double bond.

- Maximum absorbance value for palm oil is 0.8 a.u
- Maximum absorbance value for arachis oil is 1.2 a.u.
- Maximum absorbance value for ricebran oil is 1.1a.u

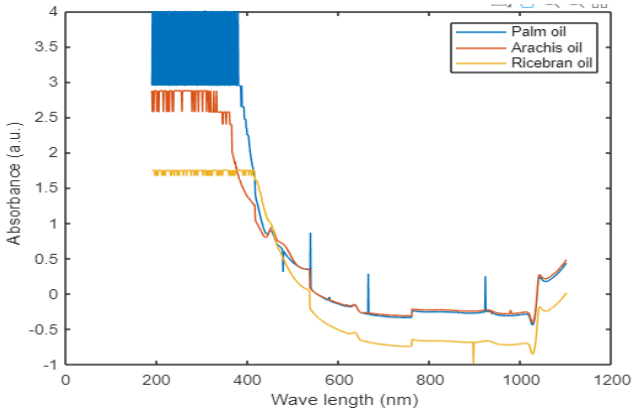


Fig. 2. Absorbance spectrum of taken sample before addition of 2 furfuraldehyde

A.Measurement of Critical Parameters for Natural Ester Oil Added with 2 –Furfuraldehyde

For further investigations on natural ester oil after the addition of 2 - FAL, properties such as breakdown voltage, viscosity, flash point, fire point are measured as per standards. The values of properties of selected natural esters oils are listed in Table 4.

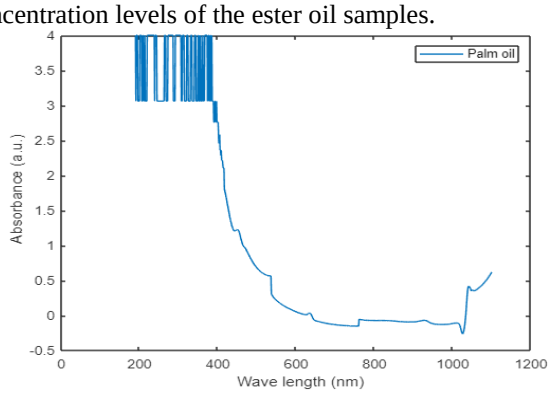
Table 4. Parameters of natural ester oil added with 2 – FAL

Parameters	Palm oil	Arachis oil	Ricebran oil
Viscosity (cSt)	122	111	153
Breakdown voltage (kV)	29	19	27
Flash point (°C)	250	240	260
Fire point (°C)	270	260	280

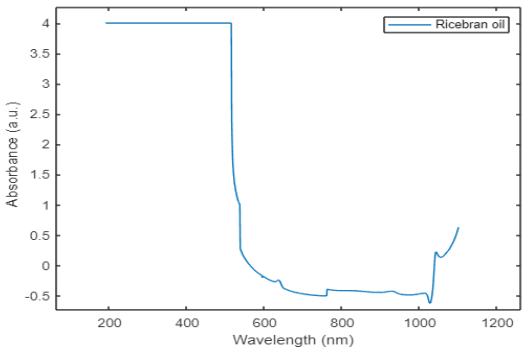
The properties of the selected oil such as viscosity, breakdown voltage, flash point, and fire point get decreases. Although, the ricebran oil gives the better result after the inclusion of 2 -FAL.

B.Furan measurement by UV- Spectrophotometer After the Addition of 2 – FAL

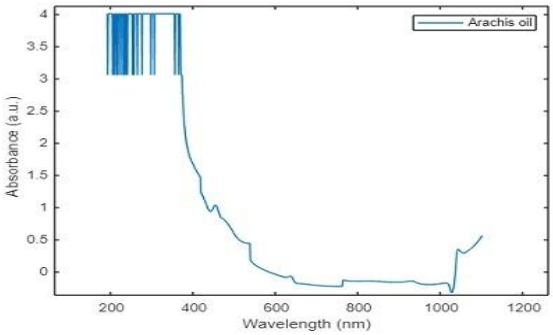
The spectral response of the natural ester oil was analyzed. From the Figures 3 (a), 3 (b) and 3 (c), it is inferred that the spectral response of oil before and after the addition of 2 – FAL was in the similar range except for the palm oil because there is a drastic increase of absorption rate. Determination of bandwidth and peak absorbance helps to estimate the furan concentration in natural ester oil. Table 5 shows the furan concentration levels of the ester oil samples.



(a)



(b)



(c)

Fig. 3. Absorption spectrum of oil with 20 ppm concentration of 2 – FAL (a) Palm Oil (b) Ricebran Oil (c)Arachis Oil

Table 5. Absorption spectral response of the samples

SAMPLES	BANDWIDTH (nm)	PEAK ABSORBANCE (a.u.)
PALM OIL	455	1.191
ARACHIS OIL	449	1.01
RICEBRAN OIL	536	1.012

From the Table 6, it is observed that, there is a slight decrease in the properties of the oil after the inclusion of 2 -FAL at 20ppm. But when it was investigated under UV – VIS, the selected oil shows the various absorbances.

The palm oil has a greater absorbance rate when compared with the refined oil, whereas the arachis oil, and ricebran oil does not show much effect.

Table 6. Percentage Changes in Properties

Oil	Percentage (%)			
	BDV (Kv)	Viscosity (Cst)	Flash Point (°C)	Fire Point (°C)
PALM OIL	14.71	32.97	25.37	21.74
ARACHIS OIL	24	33.78	25	23.53
RICEBRAN OIL	20.58	12.13	18.75	16.42

IV. CONCLUSION

Traditionally used mineral oils in transformers have poor biodegradable nature and less availability. Hence there is a need for the development of alternate natural ester based insulation oils for such applications with good dielectric properties and compatible for use without any risk. The use of natural esters has been demonstrated to extend research related to the above said issue. From the results of this research work, it is observed that natural ester oil (palm oil, arachis oil, ricebran oil) have better breakdown voltage, viscosity, flash point and fire point. It is also observed that the use of natural ester oil leads to improved performance of insulation with retarding the rate of degradation with minimum deterioration in the presence of 2-FAL mixed in ester oil. Methodology has been framed to estimate the peak absorbance and bandwidth by using its spectral response for verifying the obtained results. Further, it is mandatory to investigate the natural esters with different concentration of 2-FAL for analyzing the impact on properties for the inclusion of ageing derivatives.

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