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Suitability of Alternative Insulating Fluid for Power Transformer: A Laboratory Investigation

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Abstract**—**Power transformer is a vital element in a power system as it continuously regulates power flow, maintaining good voltage regulation. The working of transformer much depends on the oil insulation, the oil insulation also decides the aging of transformer and hence its reliability. The mineral oil based liquid insulation is globally accepted for power transformer insulation; however it is potentially hazardous due to its non-biodegradability. In this work efficient alternative biodegradable insulating fluid is presented as a replacement to conventional mineral oil. Dielectric tests are performed as distinct alternating fluid to evaluate the suitability for transformer insulation. The selection of the distinct natural esters for an insulation system is carried out by the laboratory investigation of Breakdown voltage, Oxidation stability, Dissipation factor, Permittivity, Viscosity, Flash and Fire point. It is proposed to study and characterize the properties of natural esters to be used in power transformer. Therefore for the investigation of the dielectric behavior rice bran oil, sesame oil, and sunflower oil are considered for the study. The investigated results have been compared with the mineral oil to validate the dielectric behavior of natural esters.

Keywords**—**Alternative insulating fluid, dielectric properties, natural esters, power transformers.

I. Introduction

POWER transformers are very widely used in the electrical power sector, the intention of a power transformer is to alter the voltage from unusable rate for a specific application to a lower utilization level. Power transformers are the most fundamental equipment in most industrial and commercial electrical systems. The energized parts of power transformers are normally immersed in oil which acts as an insulating medium and cooling agent.

The insulating oil of power transformer provides efficient cooling and dielectric strength to the transformer insulation system. It protects the transformer core and coil assembly from chemical degradation and prevents the formation of sludge in the transformer tank. Insulating oil may degrade due to accidental leakage of water, chemical decomposition and oxidation products, contamination by gases and also due to the electrical and thermal stresses on the transformers. Mineral oils, natural esters, aromatic hydrocarbon liquids are the insulation liquids which are branched out into different groups based on their chemical composition and properties [9], [10]. Mineral oils are extracted by petroleum distillation process and other treatments.

Mineral oil as a liquid dielectric has higher insulation properties and beneficially lower cost [11]. The flash point of mineral oil is about 160 °C, with higher fire safety hazards but biological degradation of the mineral oil will be less than 30% in natural environment, could be a threat to pollution to nature. An accidental spill or leakage of mineral oil results in contamination of soil and water and is of serious concern [1], [2]. With the advantage of renewability, higher biological degradation rate and high flash point of about 300 °C [3], natural ester based insulating oil is considered as an ecofriendly insulating oil.

The non-biodegradability nature of mineral oil necessitates it to be replaced by natural ester oils in distribution transformers [14], the difficulty lies in extending their use to HV power transformers, where operation and maintenance are of utmost importance [4]. However, natural ester oils' availability is rich in nature, and they are biodegradable, biocompatible and bio-friendly, require simple arrangement for their extraction. The present paper deals with the comparison of main dielectric properties of selected oils such as sesame oil, sunflower oil, rice bran oil along with mineral oil based on the experimental investigations on as received (untreated) conditions. The work analyzes especially the laboratory investigation of the distinct natural esters.

II. Sample Details

Natural esters have attracted considerable attention with particular reference to 50 Hz application. Investigations on some of the bio-friendly oils such as sesame oil, sunflower oil, rice bran oil along with mineral oil for more important dielectric properties namely Breakdown voltage, Oxidation stability, Dissipation factor, Permittivity, Viscosity were carried out on a selected indigenous natural esters.

III. Experimental Details

Experiments were conducted for all the samples in "as received" condition. According to the standards the following dielectric tests were carried out [5]-[7].

A. Breakdown voltage was measured at power frequency using W.S Test Systems set-up (measured as per Standard IS 6792/IEC 60156) having a standard oil cell consisting

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of 2.5 mm gap in a standard oil cell [12].

B. Dissipation factor and relative permittivity were measured using impedance analyzer- model WK-4300 of Wayne Kerr Electronics. Frequency range was from 500 Hz to 500 kHz.

C. Oxidation stability of the samples was determined using Rancimat 743. The measuring standards were as per Active Oxygen Method, AOCS Cd 12B-92 and ISO 6886 [8].

D. Viscosity was measured using Saybolt viscometer, ASTM D2161.

E. Flash and fire point were determined using Pensky-Martens flash point apparatus, ASTM D93-18 [13].

IV. Results and Discussion

The investigations carried out on "as received" samples of the oil sunflower oil, sesame oil, rice bran oil and mineral oil showed the improvements in dielectric properties of natural esters when the results were compared with mineral oil. The results are discussed in the below section.

A. Breakdown Voltage (BDV)

The BDV was measured for the selected samples in as received condition at room temperature for 2.5 mm spacing. From Fig. 1 it is observed that sunflower oil has poor BDV, 21 kV to 24 kV. The sesame oil when measured showed a bit better result, 29 kV to 31 kV, than the sunflower oil, the oil forms a carbonized channel at 28 kV. Rice bran oil when measured showed the result of 50 kV to 53 kV and mineral oil showed 44 kV to 46 kV. On the whole, rice bran oil has shown the best results from the point of BDV.

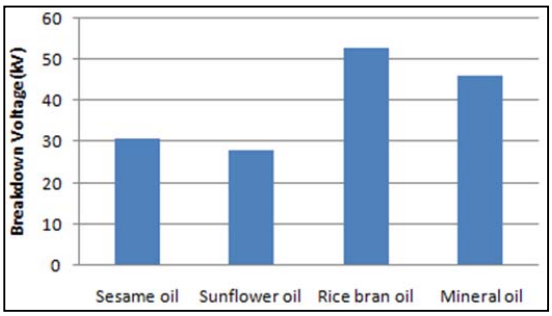

Fig. 1 BDV of selected oils

B. Dissipation Factor

Theoretically, dissipation factor (tanδ) should be as minimum as possible for better insulating condition. For mineral oil, the dissipation value was very low, below 0.005. The dissipation factor for all the samples in as received condition were measured at room temperature (26 ºC) and at 50 Hz. From Fig. 2, sesame oil has a dissipation factor of 0.0231, which results in greater power loss. In the case of sunflower oil, the dissipation factor was 0.0032 which was considerably higher than mineral oil. But rice bran oil showed better result of 0.0011 when compared with other selected samples.

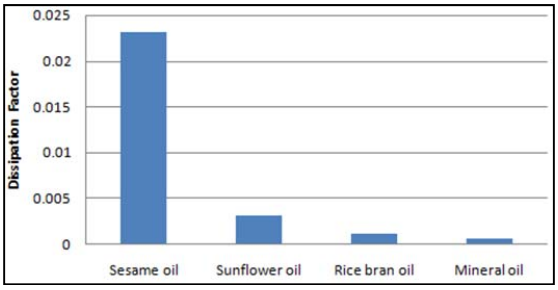

Fig. 2 Dissipation factor of selected oils

C. Relative Permittivity

Relative permittivity of transformer insulation oil is greater than 1 and in vacuum it is equal to 1. The relative permittivity is the capability of the dielectric oil to polarize and to gain electrical capacity. Higher relative permittivity would be an advantage. The relative permittivity for all the samples in as received condition has been measured at room temperature and at 50 HZ frequency. As seen from Fig. 3, the investigated sesame oil has permittivity in the range of 3.3 to 3.6. The sunflower oil has permittivity in the range 3.5 to 3.6. The relative permittivity of rice bran oil is in the range 3.6 to 3.7. The relative permittivity of transformer oil is approximately 2.2 to 2.4. From the investigations, it was seen that the relative permittivity of rice bran oil is well above the permittivity values of other natural esters and mineral oil.

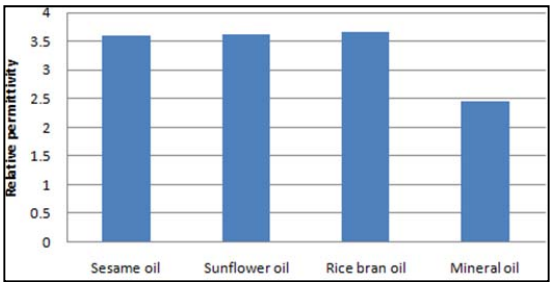

Fig. 3 Relative permittivity of selected oils

D. Oxidation Stability

Since the selected samples for investigation are of plant origin, they are more prone to oxidation. Hence the study of oxidative stability is of prime importance, which was carried out at a temperature of 110 ºC. Oxidation stability of mineral oil expressed in hours was found to be greater than 160 hours. The determined induction times for selected samples are given in Table I.

TABLE I
Oxidation Stability of Selected Samples

Oil samples (as received)	Induction time in hours
Sesame oil	6.80
Sunflower oil	12.23
Rice bran oil	20.19

E. Viscosity

Viscosity is a measure of a fluid's resistance to flow and thereby heat conduction. Viscosities of selected oil samples in as received condition are given in Table II.

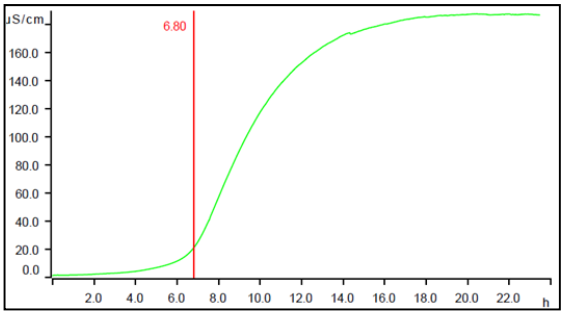

Fig. 4 (a) Oxidation stability of sesame oil

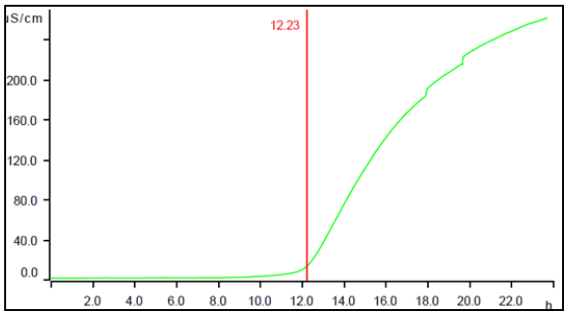

Fig. 4 (b) Oxidation stability of sunflower oil

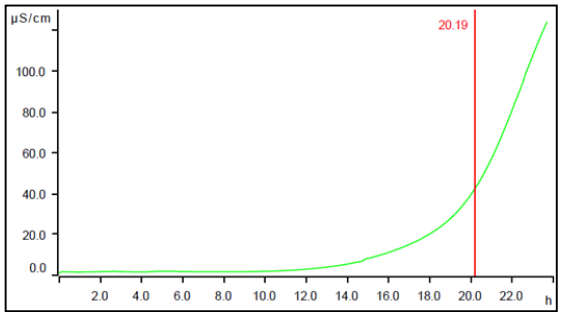

Fig. 4 (c) Oxidation stability of rice bran oil

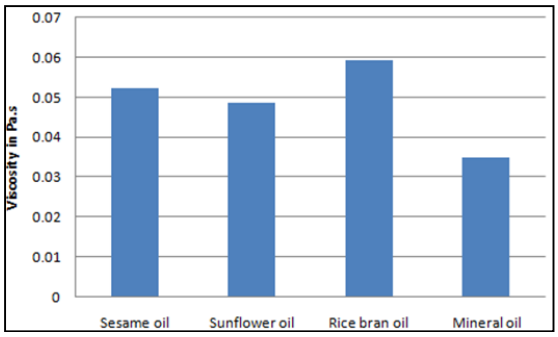

Fig. 5 Viscosity of selected samples

TABLE II
VISCOSITY OF SELECTED SAMPLES

Oil samples (as received)	Viscosity in Pa.s
Sesame oil	0.0525
Sunflower oil	0.0488
Rice bran oil	0.0593
Mineral oil	0.0351

F. Flash and Fire Point

Fresh mineral oil and natural esters have to satisfy the IEC60296, IEC 62770 standards respectively for fire safety. The flash point is the crucial property of mineral insulating oils, mainly in certain locations, such as those at higher risk of fire.

TABLE III
FLASH AND FIRE POINT OF SELECTED SAMPLES

Oil samples	Flash point (ºC)	Fire point (ºC)
Sesame oil	315.2	371.0
Sunflower oil	318.9	360.0
Rice bran oil	323.8	368.3
Mineral oil	160.1	185.2

V. CONCLUSION

The laboratory investigations were carried out on the selected oil samples viz sesame oil, sunflower oil, Rice bran oil and mineral oil in 'as received' condition. It has shown that the selected oil showed different values of dielectric parameters- BDV, dissipation factor, permittivity, oxidation stability and viscosity.

The behavior of the selected oils showed the following result:

- Among the selected natural esters, rice bran oil withstands the high voltage even greater than mineral oil.
- Dissipation factor of sesame oil was very high which results in greater power loss among the selected samples, the rice bran oil showed better result.
- Relative permittivity of rice bran oil was higher than mineral oil.
- The oxidation stability of selected natural esters was lower than mineral oil. Hence there is scope for further improvement in oxidation stability.
- The oil samples having higher flash points help in reducing the fire risk.

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REFERENCES

[1] Patric Mc Shane. C, Relative Properties of the New Combustion-Resistant Vegetable-Oil-Based Dielectric Coolants for Distribution and Power Transformers, 1132 IEEE transactions on industry applications, vol. 37, NO. 4, July/August 2001, pp1132-1139

[2] Md. Amanullah, Syed M. Islam, Sameer Chami, Gary Ienco, Evaluation of Several Techniques and Additives to De-moisturise Vegetable Oils and Bench Mark the Moisture Content Level of Vegetable Oil-based Dielectric Fluids, Dielectric liquids.ICDL-2008,IEEE International Conference on June 30 2008-July 3 2008,pp1-4.

[3] M. Mazzaro, D. De Bartolomeo, L. Calcara, M. Pompili, F. Scatiggio,

A. Vailant, M. Rebolini, E. Bemporad, S. Berardi, A. Ledda, M. Falconi, A. Vecchio, A. Sturchio, M. Salvadori, F. Mauri, "Power Transformer Fire and Environmental Risk Reduction by Using Natural Esters", International Conference on Dielectric Liquid (ICDL), Manchester (UK), 2017

[4] T.V Oommen, "Vegetable Oils for LiqUid Filled Transformers", IEEE Electrical Insulation Magazine, Vol 18, No.l, Jan/Feb 2002, pp.6-11.

[5] IEEE Guide for Acceptance and Maintenance of Insulating Mineral Oil in Electrical Equipment, IEEE Std C57.106™-2015 (Revision of IEEE Std C57.106-2006)

[6] IEEE Guide for Acceptance and Maintenance of Natural Ester Fluids in Transformers IEEE Std C57.147™-2008

[7] IEC 60076-3:2002, Power Transformers. Insulation Levels, Dielectric Tests and external clearances in air.

[8] Yang Xu, Sen Qian et.al., Oxidation Stability Assessment of a Vegetable Transformer Oil under Thermal Aging, IEEE Transactions on Dielectrics and Electrical Insulation Vol. 21, No. 2; April 2014, pp683-692

[9] C. Perrier, A. Beroual “Experimental Investigations on Mineral and Ester Oils for Power Transformers”, IEEE transactions 2008, pp 178-183.

[10] Shah. Z.H and Tahir. Q.A, Dielectric Properties of Vegetable Oils, Journal of scientific research, J. Sci. Res. 3 (3), 2011,pp481-492

[11] C. Perrier, A. Beroual, J.-L. Bessede, Improvement of power transformers by using mixtures of mineral oil with synthetic esters, IEEE Trans. Dielectr. Electr. Insul. 13 (3) (2006) 556e564.

[12] Bertrand Y, Hoang LC. Vegetable oils as substitute for mineral insulating oils in medium-voltage equipments. D1-202, CIGR´E Session, 2004.

[13] ASTM D 93. Standard Test Methods for Flash Point by Pensky-Martens Closed Cup Tester, 2012.

[14] Jeong J-I, An J-S, Huh C-S, Accelerated aging effects of mineral and vegetable transformer oils on medium voltage power transformers. IEEE Transactions on Dielectrics and Electrical Insulation 2012; 19(1):156–161.