Investigation of Various Natural Esters Insulating Medium for the Applications in High Voltage Machinery

Joeljoshuva.P [1],Prabhu.A[2], Arun Kumar.R [3], Senthil Kumar.S[4]
UG Students [1,2,3],Assistant Professor[4], High Voltage lab, Dept. of EEE,
National Engineering College, Kovilpatti – 628 503, Tamilnadu, India.
Corresponding author [4]:senthilkumarneceee@gmail.com,ssenthil@nec.edu.in.

Abstract — **Oil-based commodities command the whole world's basic power parts applications.The oil-based mineral oil is utilized with the end goal of protection and also a cooling medium in the transformers of energy framework systems. In high voltage transformers, the liquid insulations act as the insulating medium as well as cooling medium. For the past several decades, the mineral based transformer oil is used traditionally for liquid insulations. In the environmental aspect, there are several disadvantages in the mineral oil even though it has improved insulating properties. By thinking about the ecological part of contamination, Future shortage and protecting properties, the scientists tend to locate the other protecting liquids for the high voltage applications. In this work, the suitability of various natural ester-based vegetable oils is investigated to analyze the best performing insulating medium. The different vegetable oils such as corn oil, honge oil, neem oil, mustard oil, punna oil castor oil, olive oil, gingelly oil, groundnut oil, sunflower oil, palm olein oil, rice bran oil, coconut oil and punga oil are investigated with the measurement of properties like breakdown voltage, flash point, fire point and viscosity. Further analysis is also made with the comparison of features, the fatty acid content, and cost of vegetable oils. From the investigations, it is shown that the natural ester-based vegetable oils have the potential to replace the traditional Transformer oil.**

Keywords— ***breakdown voltage; flash point; fire point; fatty acids; natural ester; mineral oil; vegetable oil; viscosity***

I. INTRODUCTION

In the power framework arranges, the power transformers assume an enormous part in the transmission and disseminations side. The transformers are crucial gear in the power framework on the grounds that any disappointments in one transformer on the framework prompts add up to blackout in the customer side. The disappointments in the transformers are for the most part happened because of the protection issues [1, 2].

Transformer is one of the major components in power system equipment. The primary insulations used in transformer system are categorized into solid, liquid and gas. Among them, solid and liquid insulations are indispensably used. The Mineral oil is used as insulating fluids in transformer. The main function of the mineral oil is to provide good insulation, suppress corona, and arcing at very high temperatures. Mineral oils are mainly obtained from further processing of crude petroleum. These mineral oil have been service over 70 years. The use of this petroleum-based product has been justified until now by its wide availability; its functional properties, its right combination with cellulose, and its low cost For the past several decades the transformers are installed with oil filled technology. The liquid insulation used in the transformers is derived from the petroleum products which are also used as cooling or heat transfer medium [2].

The life of transformer is for the most part described by the state of fluid protections. The dependability of fluid protections is fundamental for nonstop administration of transformers. The mineral oil-based transformer oil is utilized as the fluid protection in the transformers alongside some strong protection. The transformer oil is additionally utilized as a part of the high voltage link systems [3].

Notwithstanding the way that the properties of mineral oil based transformer oil are unrivaled, there are a couple of deterrents in the transformer oil, for instance, environmental perils, unsafe and high cost of exchange. It encourages the examiners to find the other liquid securities which are condition sincere. For this vegetable oil may be the fitting other alternative to transformer oil on account of their normally welcoming nature and non-unsafe [4-5].].

In this work with the aim of analyzing the suitability of vegetable oil as liquid insulations, the effort has been made to investigate the natural ester based vegetable oil. The investigations are carried out with corn oil, honge oil, neem oil, mustard oil, punna oil castor oil, olive oil, gingelly oil, groundnut oil, sunflower oil, palmolein oil, rice bran oil, and coconut oil and punga oil. The suitability analysis is conducted with the measurement of critical properties such as breakdown voltage, flash point, fire point and

viscosity of oil samples. Further, the investigation analysis is extended to comparison of different vegetable oil for their properties, fatty acid content and cost. These work activities to develop the environmental friendly products for the high voltage applications.

In this paper, section 2 explains the investigating oil sample details and section 3 describes the importance of critical properties along with the measurement techniques. Section 4 explains the experimental results and analysis in various aspects such as properties, fatty acid content and cost of natural ester-based vegetable oils. Finally, the conclusions are given in the section 5.

II. ESTER OIL SAMPLE DETAILS

In this work, analyze are made with the Natural esters liquid insulation; examination is carried out with some samples natural ester-based vegetable oils. The natural esters based vegetable oils are derived from the plant or seed of plants. The natural esters have the triglyceride esters of fatty acids. The fatty acids are classified as saturated fatty acids and unsaturated fatty acids. The unsaturated fatty acids are subdivided into monounsaturated and polyunsaturated fatty acids [6-9]. The investigating oil samples are listed in the Table 1 along with the percentages of fatty acids content. The oil samples are bought from the available local manufacturers. The fatty acids content of oil is also got from their oil data sheet. The transformer oil is taken as reference samples.

TABLE I. INVESTIGATING OIL SAMPLES WITH THEIR FATTY ACID CONTENTS

Oil Samples	**Fatty Acids Content (%)**		
	Saturated Fatty Acids	***Mono Unsaturated Fatty***	***Poly Unsaturated Fatty***
Corn oil	15	29	56
Honge Oil	2	62	17
Neem Oil	40	21	39
Punna Oil	39	59	2.1
Castor Oil	1.1	98	1.1
Mustard oil	12	60	21
Olive oil	20	45	35
Gingelly oil	22	39	35
Groundnut oil	18	50	32
Sunflower oil	12	28	60
Palm olein oil	45	35	10
Rice bran oil	20	45	35
Coconut oil	21	52	34
Punga oil	12	30	62

III. INVESTIGATIONAL DETAILS

For the investigations of natural ester-based vegetable oils, the breakdown voltage, flash point, fire point and viscosity of oil samples are measured.These properties are considered as important in the aspect of insulation behavior, fire safety and heat transfer ability.

The ability of perfect insulating medium is determined by the breakdown strength of that medium. The breakdown voltage of oil insulation used in the transformer determines the efficiency of oil as ideal insulation. The breakdown voltage of oil depends on the purity of oil.

If any contaminants or moisture present in the oil, the breakdown voltage will reduce [10]. The breakdown voltage of oil insulation is measured according to the standard IEC 60156 [11]. The measurement is carried out with the oil sample filled in the oil test cup. By adjusting the variac, the applied voltage to 2.5mm gap distanced two spherical electrodes in test cup is varied. The breakdown voltage is noted for the samples. The breakdown voltage of oil sample is the mean value of five breakdown voltage which is obtained by the conducting five consecutive measurements with the same oil sample. The test setup for the measurement of breakdown voltage is shown in Fig. 1.

Fig. 1. *Breakdown Voltage measurement kit*

The flash point and fire point are the temperatures which determine the fire safety characteristics of oil [10]. The flash point and fire point temperature are measured according to the standard ASTM D93 [12]. The test is carried out with

the Pensky Martins Flash point setup and heat regulator chamber. The Fig. 2 shows the flash point and fire point measurement setup. The heat regulator chamber is used to heat the oil. The flash point and fire point temperature are indicated by the temporary flame and continuous fire on the surface of heated oil respectively, when the test flame is introduced in the test opening in the apparatus.

Fig 2. *Pensky- Martens Cup.*

Oil viscosity is typically measured and defined in two ways, either based on its absolute viscosity or by its kinematic viscosity. The absolute viscosity of oil is its resistance to flow and shear due to internal friction and it is measured with SI units of Pa·s. In contrast, the kinematic viscosity of oil is its resistance to flow and shear due to gravity and it is measured with SI units of m2/s. The kinematic viscosity of oil can be obtained by dividing the oil absolute viscosity with its corresponding density.The oil flow characteristics are indirectly constituted in the heat transfer ability of oil. The viscosity measurement determines the flow characteristic of oil. The viscosity is the measure of shear resistance offered by oil for the flow on the surface [10]. The viscosity measurement is conducted with the Redwood Viscometer setup and according to the standard ASTM D445 [13]. The flow time for 50ml of oil sample is noted for calculating viscosity of oil sample. The Redwood viscometer is shown in Fig. 3.

Fig 3. *Red Wood Viscometer*

IV. Experimental Results and Discussion

The critical parameters such as breakdown voltage, flash point, fire point and viscosity of different oil samples are measured to find the compatibility of natural ester-based vegetable oil as perfect insulating medium. In this section, the obtained experimental results are analyzed in the different aspects such as properties, fatty acid content and cost[14].

A. Critical Properties

The properties of different oil samples are investigated as per specified standards and procedure as given in the section of experimental details. The breakdown voltage of oil samples is given in the Table 2 and pictorially represented in Fig. 4. The fire safety parameters such as flash point and fire point are tabulated in Table 3. The comparison of flash point and fire point is shown in Fig. 5[15, 16, 17]. The flowing nature of oil is studied with viscosity measurement. The time is taken for 50ml of oil to flow, and the viscosity of the oil is listed in the Table 4. The viscosity of oil samples is given as chart in the Fig. 6.

TABLE II. Electrical Properties OF INVESTIGATING OIL SAMPLES

Oil Samples	Breakdown Voltage (kV)
Transformer oil	32
Corn oil	37
Honge Oil	43
Neem Oil	43
Punna Oil	42
Castor Oil	31
Mustard oil	49
Olive oil	46.2
Gingelly oil	45.6
Groundnut oil	45.3
Sunflower oil	43.6
Palm olein oil	42
Rice bran oil	37.2
Coconut oil	36
Punga oil	26

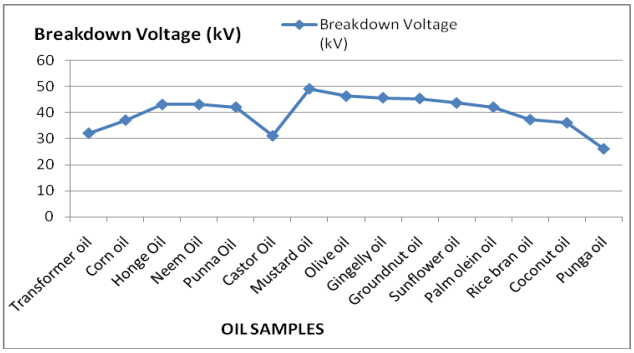

Fig. 4. *Test results for Breakdown voltage variations*

TABLE III. THERMAL PROPERTIES OF INVESTIGATING OIL SAMPLES

Oil Samples	Flash point (^{O}C)	Fire point (^{O}C)
Transformer oil	160	180
Corn oil	258	272
Honge Oil	298	310
Neem Oil	288	297
Punna Oil	289	300
Castor Oil	280	305
Mustard oil	295	315
Olive oil	285	310
Gingelly oil	285	305
Groundnut oil	280	290
Sunflower oil	270	285
Palm olein oil	295	310
Rice bran oil	260	275
Coconut oil	235	270
Punga oil	210	235

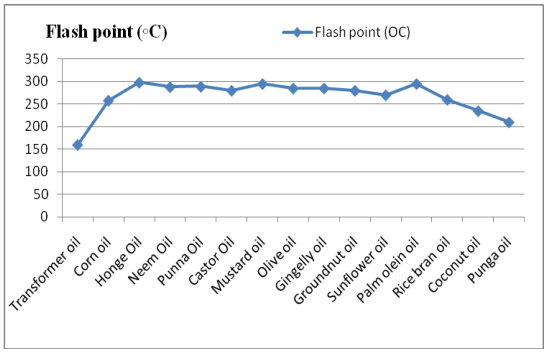

Fig 4. *Test results for Flashpoint variations*

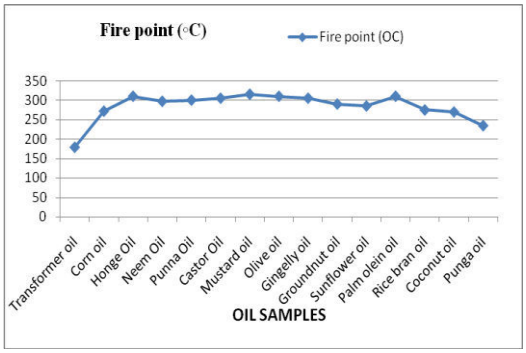

Fig 5. *Test results for Fire point variations*

TABLE IV. Physical Properties OF INVESTIGATING OIL SAMPLES

Oil Samples	Flow Time for 50ml of oil (sec)	Viscosity (cSt)
Transformer oil	152	38.39
Corn oil	290	75
Honge Oil	450	117
Neem Oil	410	109
Punna Oil	500	130
Castor Oil	610	156
Mustard oil	315	81.35
Olive oil	405	104.88
Gingelly oil	450	116.62
Groundnut oil	445	115.31
Sunflower oil	380	98.35
Palm olein oil	500	129.66
Rice bran oil	510	132.26
Coconut oil	310	87
Punga oil	590	143

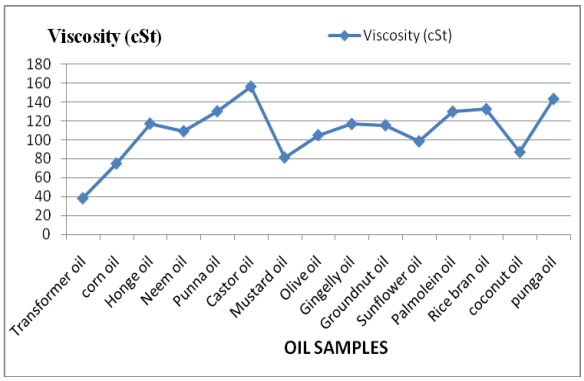

Fig 6. *Test results for Viscosity variations*

B. Analysis based on properties

From the investigations of oil samples, the following outcomes are inferred.

- The breakdown voltage of honge neem, punna, mustard, olive oils, generally all natural ester-based vegetable oils is higher than the existing traditional mineral based transformer oil.
- Among the investigated natural ester-based vegetable oil, mustard oil has higher breakdown voltage, and rice bran oil and punga oil has the lower value.
- Also, the flash point and fire point temperature of vegetable oils are very much higher than that of the transformer oil.

Thus the all investigated vegetable oil samples hav e the high fire safety characteristics.

- Honge, neem punna,Mustard oil, Palm olein oil, olive oil shows better value of flash and fire point temperature. Punga oil has the lowest flash point and fire point

temperature in the investigated natural ester oil samples. The sunflower oil has slightly higher temperature ranges than rice bran oil.

- The viscosity of natural ester oil samples is very much higher than the viscosity of mineral-based transformer oil. These properties show that the time taken for the heat transfer is very high.
- Mustard oil, Coconut oil has lowest viscosity value in the natural esters investigated. Punga oil, Castor oil, Palmolein oil, Rice bran has the highest value of viscosity among the investigated ester oil samples.
- From the overall analysis of natural ester-based vegetable oil, it is evident that all the investigated oil samples show the better properties than the mineral based transformer oil.

C. Analysis based on the fatty acids content of vegetable oil

From the comparison of oil properties and the fatty acid content, the following inferences are made.

- Most of the investigating oil with high monounsaturated fatty acid shows the higher breakdown voltage. Honge, punna, castor Olive oil, mustard oil and groundnut oil have the higher content of monounsaturated fatty acid and higher breakdown voltage.
- The fire safety characteristics of investigating oil show the improved result for the oil with high monounsaturated fatty acid and high saturated fatty acid.
- Rice bran oil has the higher monounsaturated fatty acid, but has lower breakdown voltage and lower fire safety characteristics among the investigating oil.
- The viscosity profile of vegetable oil shows increasing nature for the higher content of monounsaturated fatty acid and saturated fatty acids.
- The viscosity value is low for the oil with high polyunsaturated fatty acid.
- But the viscosity of rice bran oil is very much high, and viscosity of mustard oil, coconut oil, corn oil is low even though both the oils have higher monounsaturated fatty acids.

D. Analysis based on the cost

The cost of the investigating oil samples is given in the Table 5. The price of some of the vegetable oil is higher than the traditional mineral based transformer oil, and some have lower cost.

TABLE V. COST OF INVESTIGATING OIL SAMPLES

Oil Samples	Cost INR – (Rs.)
Transformer oil	110
Corn oil	100
Honge Oil	110
Neem Oil	80
Punna Oil	110
Castor Oil	130
Mustard oil	130
Olive oil	400
Gingelly oil	140
Groundnut oil	160
Sunflower oil	90
Palm olein oil	80
Rice bran oil	107
Coconut oil	110
Punga oil	95

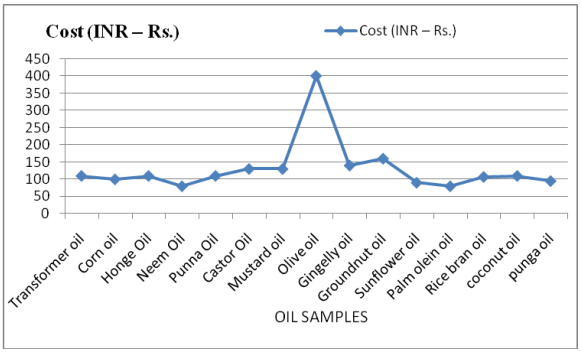

Fig. 6. COST OF INVESTIGATING OIL SAMPLES

By considering the performance as insulating oil and cost, the following points are made.

- The olive oil shows the better properties than the mineral oil, but its cost is very much high.
- The honge oil shows the better properties than the mineral oil, but its cost is slightly high.
- The neem oil shows the better properties than the mineral oil, but its cost is slightly low.
- The punga oil shows the better properties than the mineral oil, but its cost is slightly low.
- The mustard oil has shown the better properties of the vegetable oil, and the cost is slightly higher than the mineral oil. The price of gingelly and groundnut oil is

somewhat higher. They show the considerably better properties.

- The sunflower oil and palm olein oil have the lowest cost and have the better performance than the transformer oil.
- The rice bran oil has the poor characteristics in the investigated vegetable oil samples, but has the better attributes than the transformer oil. The cost and availability of rice bran oil are similar to transformer oil.

V. CONCLUSION

In the principal investigations for finding the suitability of natural ester-based vegetable oil as the liquid insulation for high voltage applications, the oils such as Corn oil, Honge oil, Neem oil, Punna oil, Castor oil, mustard oil, olive oil, gingelly oil, groundnut oil, sunflower oil, palm olein oil, rice bran oil, Coconut oil and Punga oil are investigated. From the overall investigations on the vegetable oils, it is shown that the mustard oil shows the better properties and the punga, rice bran oil shows the lower properties of the vegetable oils. The fatty acid content may also influence in the properties of vegetable oil samples. The investigations reveal that the investigated natural ester-based vegetable oils have the prospective choice of alternate liquid insulations for the high voltage apparatus like transformers. For investigating long-term performance of these oils for the transformer applications, further studies are suggested to analyze with the aging behavior of ester oil by adding the antioxidants additive, nano particles of oil with the solid insulations can be analyzed in future.

REFERENCES:

1] IEEE, Guide for loading Mineral oil immersed Transformer, Annex I: Transformer Insulation Life, IEEE Standard C57.91, 1995.

[2] T.O. Rouse, "Mineral oil in transformers," IEEE Electrical Insulation Magazine, Vol.14, No. 3, pp. 6-16, 1998.

[3]W Young, "Transformer Life Management-Condition Monitoring," Proceedings of the IEEE Colloquium, (Digest) IEE Stevane, England, pp. 1-4, 1998.

[4]T.V.Oommen,C. Claiborne, "Biodegradable Insulating fluid from High- oleic Vegetable Oils," presented at CIGRE 15-302, Paris, France, 1998.

[5] T. V. Oommen, "Vegetable oils for liquid filled transformers", IEEE Electrical Insulation Magazine, Vol. 18, No. 1, pp. 6-11, 2002.

[6] C. P. McShane, "Vegetable oil based dielectric coolants", IEEE Industrial Applications Magazine, Vol.8, No. 3, pp. 34-41, 2002.

[7]Y. Bertrand and L.C. Hoang, "Vegetable Oils as Substitute for Mineral Insulating Oils in Medium-Voltage Equipments", CIGRE, 2004.

[8] Allan Darwin, Perrier. C, Folliot. P, "The use of Natural Ester Fluids in Transformer," Matpost, 2007.

[9]L. Hosier, A. Guushaa, E. W. Westenbrink, C. Rogers, A. S. Vaughan and S. GSwingler, "Aging of Biodegradable Oils and Assessment of their Suitability for High Voltage Applications", IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 18, No. 3, 2011.

[10]Karthik. R and Sree Renga Raja. T, "Investigations of Transformer Oil Characteristics", IEEJ-TEE, Vol. 7, pp. 369-374, 2012.

[11]Insulating liquids – Determination of the breakdown voltage at power frequency –Test method, IEC 60156, Third Edition, 2003-11.

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

[13] Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids and Calculation of Dynamic viscosity), ASTM D 445, 2011.

[14]T. V. Oommen, "Introduction of a new fully biodegradable dielectric fluid", IEEE Annual Textile , Fiber and Film Industry Technical Conf., Charlotte, north California , Vol.3, pp. 1-4,1998.

[15] A. U. Biermann and J. O. Metzger, "Application of Vegetable Oil Based-Fluids as Transformer Oils" Faculty of Mathematics and Natural Sciences, Carl Von Ossietzky University, Oldenburg, Germany, 2007.

[16]D. Martin, N. Lelekakis, W. Guo and Y. Odarenko, "Further Studies of a Vegetable-Oil-Filled Power Transformer", IEEE Electr. Insul. Mag., Vol. 27, No. 5, pp. 6-13, 2011.

[17] S.Senthil Kumar, M.Willjuice Iruthayarajan, M. Bakrutheen," Analysis of Vegetable Liquid Insulating Medium for Applications in High Voltage Transformers", IEEE International Conference on Science Engineering, pp. 1-5, 2014.