Pongamia Pinnata as Alternate Liquid Dielectrics in Distribution Transformer: A Critical Study on the Property of Viscosity

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Abstract Distribution Transformers are one of the imperative equipment in power system. The insulation design has an important role because it continuously energizes in a day. Due to electro mechanical stresses the operating temperature of distribution transformer will be increased which maintains within limit using liquid dielectrics. Traditional mineral oil is used as liquid dielectrics in Distribution Transformer. Due to lack of fossil fuels and lesser biodegradability characteristics of mineral oil, the alternating liquid dielectrics are important. In this research work viscosity of pongamia pinnata oil is measured using PLINT TE 62 Bench Viscometer as per ASTM D445 standard. Water content analysis of the oil sample has to be measured by weight balance method and Breakdown strength of oil sample was measured by Nutronics oil test set as per IEC 60156. From the experimental analysis, the viscosity of pongamia pinnata oil is low as compared to RBDPO, Soyabean oil, Coconut oil and Sunflower oil. The moisture content of pongamia pinnata oil is significantly reduced during aging period and the average breakdown strength of pongamia pinnata oil is higher than that of conventionally used mineral oil.

Keywords Distribution Transformer, Alternating Liquid Dielectrics, Pongamia Pinnata Oil (Karanja Oil), Viscosity, Water Content Analysis, Breakdown Strength

1. Introduction

The first oil cooled Transformer was introduced by Brown of Germany in the year 1890 [1]. In power system Transformers play a significant role [2]. The main classification of Transformers are Distribution Transformers (50–2500 kVA) and Power Transformers (above 2500 kVA) [3]. The insulation is playing an important role in the life time estimation of transformer. The main causes of Transformers failure are insulation degradation [4,5]. There

are two types of insulation medium used in Transformer solid and liquid insulation medium. The solid insulation is made up on cellulose materials and liquid insulation is from mineral oil. Several decades in the transformer mineral oil is used heat transfer and insulation medium, for the reason that of its physical and chemical properties is suitable for use as a liquid dielectrics also availability and low cost of mineral oil. But now a day's several researchers are focused on alternating liquid dielectrics.

There are two important factors alternating liquid dielectrics are quite most important. First availability of fossil fuels because mineral oil is extracted from fossil fuels; now a day's natural resources of petroleum products are rapidly decreased. Secondly it has lesser biodegradability characteristics [6]. Because of mineral oils are made upon hydrocarbon components with different molecular structure which resists degradation behaviors of mineral oil. Due to such phenomenon several recharges are involves vegetable oils is used as a liquid dielectric in transformers. In this recharge work to examine pongamia pinnata oil (Karanja oil) is suitable for Distribution transformer or not?.

In this paper investigate the viscosity of pongamia pinnata oil as per ASTM D445 standards. Because vegetable oils are more viscous than the conventionally used insulation oil. This is used in reducing the fluid flow in the windings, cooling ducts and increases the operating temperature of the transformer. It has effectively reduced transformer life. So that investigation of any alternating liquid dielectrics viscosity is very essential. Also the water content of oil is deciding factor for quality of the insulating property of the oil. This analysis is performed by weight balance method. The efficiency of the oil is determined by its dielectric strength. Any new insulating oil requires at least 30kV dielectrics strength. So that breakdown strength test is conducted and compared with traditionally used mineral oil.

2. Literature Review

Santanu singe et al investigates viscosity of mineral oil as

per ASTM D445 at 40°C comparing with High Oleic Natural Ester. Earlier than 1500hrs of operation the viscosity of natural and HONE oil is not stable. Up to 3500 hrs of operation the viscosity of high oleic natural ester and mineral oil almost no change. Because of the test is conducted under nitrogen atmosphere which limiting the influences of oxygen with ester oil. So that high oleic natural ester oil viscosity is highly suitable for hermetically sealed transformer applications [7]. Stefan tenbohlen et al study effects of oxygen on viscosity of oil. Natural ester oil viscosity is strongly increased with influence of oxygen present in the air. The molecules of ester oils are divided into small element due to oxidation process where remaining molecules of ester oils involve a polymerization process; it strongly increases the viscosity of oil. So that to maintain ester filled transformer without contact with air. The mineral oil viscosity is affected by oxidation is very less as compared to ester oil [8].

M.H abderarazzaq et al measures various types of olive oil viscosity. The viscosity of new and old olive oils is 9.9 and 11.6 cSt respectively. Also the viscosity of naturally grown tree oil is 8.43cSt and irrigated Olive oil tree is 8.5cSt respectively. If temperature of oil increases it reduces the oil viscosity and increases the pressure inside the transformer. Hence viscosity of oil depends on temperature and pressure [9].

IL Hosier et al measures the viscosity of oil using physical reolabmcl at room temperature with and without catalyses added. The sunflower oil viscosity is significantly increased for all sampling periods where DDb, environment temp and olive oil viscosity has no significance difference after aging. The corn oil and rapeseed oil viscosity is slightly increased when catalysis add in these oil. Here a copper wire is acted as a catalytic [10].

R karthic et al evaluates viscosity of mixing insulating liquids at 60°C. The viscosity of ester oil, mineral oil and synthetic ester oils are 17.2cSt, 5.72cSt and 289.74 cSt respectively. It infers that mineral oil have low viscosity than natural and synthetic ester oil. While synthetic ester oil viscosity is much higher than mineral oil and ester oil. The viscosity of 80% mineral oil mixing with 20% of synthetic ester oil is 16.92cSt while viscosity of 80% mineral oil is mixed with 20% of ester oil is 6.82cSt. Hence the viscosity of synthetic ester, natural ester oil has to be significantly reduced by it mixing with mineral oil [11].

Yuvsnidan et al measuring the viscosity of mixed insulating fluid at 40°C. The viscosity of mineral oil is 8.33cSt where viscosity of RBDPO is 37.95 cSt. From this measurement RBDPO have a much higher viscosity than mineral oil. If the concentration of RBDPO increases it decrease the overall viscosity [12].

A Raymon et al studies the effect of antioxidants mixing with vegetable oil. The viscosity of sunflower oil, Rice Bran oil, Soya bean oil and corn oils are 132, 154, 164, and 134cSt respectively this higher viscosity of oils is reduced by adding different quantities of antioxidants. After adding antioxidants Viscosity of Rice bran oil to reduced very little

quantity only. In soya bean oil the viscosity of considerable decreased expect 5g of butylated Hydroxyl and 5g of acidic acids [13].

H. M. Wilhelm, L. Thalia et al measures the viscosity of Enviromtemp FR3 and Biotemp liquid at the temperature ranges of 20°C, 40°C and 100°C as per ASTM D445 standard. In general viscosity of vegetable oil is 4 times higher than mineral oil. As the 20°C operating temperature viscosity of Enviromtemp FR3 oil is 77cSt which is lower than bitmap it has 82cSt. Initially the vegetable oil viscosity is very high which is gradually decreased after 100°C of operating temperature [14].

Kailas M. Talkit et al. measures the viscosity of soyabean, sesame, coconut and sunflower oil using Redwood Viscometer No.1. Also author measures the viscosity of the soybean oil mix together with various proportions of sesame oil, coconut oil and sunflower oil. Up to 30°C of operation the viscosity of vegetable oils is very high. While beyond 80°C operating temperature the viscosity of vegetable oils significantly decreased. The mixing ratio of 10% soya bean oil with coconut oil has 18.18CST which is the minimum value as compared to all other combinations. The mixing of 90% soya bean with 10% coconut oil has a higher viscosity than all other combinations of oil mixing [15]. S M Bashi et al measures the viscosity of RBDPO oil as per ASTM D88 and D445 Standard. Initially RBDPO oil viscosity is 500cSt when the operating temperature to reach a 40°C the viscosity of RBDPO oil is significantly reduced to 48cSt. At 100°C operating temperature the viscosity of oil to reach 15°C St [16].

H.M Wilhelm et al conducted an accelerated thermal aging test under oxygen flow rate 1 Lh-1 in a thermo-stabilized bath. The viscosity of Biovolt A and Refined vegetable oils are measured with and without adding antioxidants. At 40°C the viscosity of Biovolt A is 36.1×10^{-6} m²/s which is rapidly decreasing at 100°C. At 40°C Sunflower oil have higher viscosities than refined soya oil, rice oil where at 100°C rice bran oil has a lower viscosity than others. Before adding antioxidants Refined soya oil, rice oil to reach a viscosity limit value after 2 hrs while rice oil to reach a critical value after 10 hrs of aging. After adding antioxidant refined soya oil, Sunflower reaches a limited value after 69hrs. Where Refined rice oil to take 64 hrs, it infers that AD-4 antioxidants could be maintains the viscosity of vegetable oil within limits during the aging process [17].

From the literature review viscosity of vegetable oil is higher than that of mineral oil. At 40°C operating temperature the viscosity of all types of olive oils, High oleic natural ester oil and the blending combination of 80% of mineral oil with 20% ester oils are significantly decreased. At 100°C operating temperature EnviromtempFR3 and biotemp has the lower viscosity. From the above review it was found that even after the increase of operating temperature viscosity doesn't reduce below the level of viscosity of mineral oil. The various vegetable oil viscosity with different compositions are shown in appendix 1.

3. Pongamia Pinnata

Pongamia pinnata is a medium sized evergreen tree which grows in Indian subcontinent and south east Australia...etc It's a nitrogen fixing plant. A single tree can produce 9-90kg seeds per year. The yield potential of tree is 900-9000kg/ha. The seed oil content range between 30-40 wt% This tree is fast growing, drought resistant, moderately frost hardy and highly tolerant of salinity. Historically, this plant has been used in Indian and neighboring regions as a source of traditional medicines, animal fodder, green manure, timber, water-paint binder, pesticide, fish poison and fuel. Recently, Pongamia pinnata has been recognized as a viable source of oil for the biofuel industry. Since In 2003 the Himalayan Institute of Yoga Science and Philosophy was started campaign of education and public awareness to rural people related to extract Bio fuel from ponga oil. Due to this program at least 200 million pongamia pinnata trees has been planted by 45,000 farmers. In power transformer Soya bean, Sun flower oil, Palm oil, Rice bran oil is also used as a liquid dielectric. These are the edible oil so research work focus on the non-edible oil as a liquid dielectrics [18, 19].

4. Fatty Acids

Vegetable oils have a triglyceride structure. It has different types of fatty acids which are saturated, monounsaturated and poly unsaturated fatty acids. These fatty acids decides the physical and chemical property of the oil. A few vegetable oils are having higher saturated fatty acids; these vegetable oils are has higher viscosity while some vegetable oils are have higher un saturated fatty acids, it having lower viscosity. The pongamia pinnata 79.4% mono unsaturated fatty acids and 20.5% saturated fatty acids [19,20].

5. Experimental Analysis

5.1. Viscosity Measurement

Viscosity of pongamia pinnata oil was measured using PLINT TE 62 Bench viscometer as per ASTM D445 standard. A 40ml of oil sample is poured into oil chamber of viscometer and press the start button. The viscosity of pongamia pinnata oil is measured against the operating temperature rise. The measurement has been made between room temperature 32°C to 90°C.

5.1.1. Result and Discussion

At 32°C operating temperature the viscosity of pongamia oil is 75 cSt. The operating temperature of viscometer is increases this will decreases viscosity of pongamia pinnata oil as shown in table 1 and figure 1. The viscosity of oil sample to be reached 17 cSt at 90°C.

Table 1. Viscosity of pongamia pinnata oil

Temperature in °C	Viscosity in cSt
32	75
34	65
36	53
38	45
40	38
50	33
60	27
70	23
80	19
90	17

Figure 1. Viscosity (cSt) Vs Temperature in °C

5.2. Water Content of Pongamia Pinnata Oil

The water content of insulating oil significantly affects physical and chemical property of the oil. Initially weight of pongamia pinnata oil sample is measured using fourth decimal accuracy weight balance meter. Later that pongamia pinnata oil sample is kept placed in Hot Air Oven at 100°C for 8 hours. After eight hours of oil sampling periods it allows cooling for 8 hours and then the oil mass is measured for the thermal and electrical degradation. The same oil is put into same aging process for 30 days. The mass of oil is tabulated and is converted to ppm value.

Figure 2. Aging vs Water content

Table 2. Water content analysis of pongami pinnat oil

Date	weight of oil before testing in mg/kg	Testing duration			weight of oil after Testing in mg/kg	%W=((w1-w2/w2)*100)	Water content in ppm
		Starting Time in hrs	Ending Time in hrs	Total Time in hrs			
8/2/2014	20.0004	9am	5pm	8	20.0001	0.00149999	15.00
9/2/2014	20.0001	9am	5pm	16	19.9998	0.00150002	15.00
10/2/2014	19.9998	9am	5pm	32	19.9995	0.00150004	15.00
11/2/2013	19.9995	9am	5pm	48	19.9993	0.00100004	10.00
12/2/2014	19.9993	9am	5pm	64	19.9987	0.0030002	30.00
13/2/2043	19.9987	9am	5pm	80	19.9986	0.00150012	15.00
14/2/2014	19.9986	9am	5pm	96	19.9982	0.00200018	20.00
15/2/2014	19.9982	9am	5pm	112	19.9979	0.00150016	15.00
16/2/2013	19.9979	9am	5pm	128	19.9976	0.00150018	15.00
17/2/2014	19.9976	9am	5pm	144	19.9973	0.0015002	15.00
18/2/2014	19.9973	9am	5pm	160	19.997	0.00150023	15.00
19/2/2014	19.997	9am	5pm	176	19.9967	0.00150025	15.00
20/2/2014	19.9967	9am	5pm	192	19.9965	0.00100018	10.00
21/2/2014	19.9965	9am	5pm	208	19.9962	0.00100019	10.00
22/2/2014	19.9962	9am	5pm	224	19.996	0.0010002	10.00
23/2/2014	19.996	9am	5pm	240	19.9957	0.00100021	10.00
24/2/2014	19.9957	9am	5pm	256	19.9955	0.00100023	10.00
25/2/2014	19.9955	9am	5pm	272	19.9954	5.00E-04	5.00
26/2/2014	19.9954	9am	5pm	304	19.9953	5.00E-04	5.00
27/2/2014	19.9954	9am	5pm	320	19.9953	5.00E-04	5.00
28/2/2014	19.9954	9am	5pm	336	19.9953	5.00E-04	5.00
1/3/2014	19.9954	9am	5pm	352	19.9953	5.00E-04	5.00
2/3/2014	19.9954	9am	5pm	368	19.9953	5.00E-04	5.00
3/2/2014	19.9954	9am	5pm	384	19.9953	5.00E-04	5.00
4/3/2014	19.9954	9am	5pm	400	19.9953	5.00E-04	5.00
5/3/2014	19.9954	9am	5pm	416	19.9953	5.00E-04	5.00
6/3/2014	19.9954	9am	5pm	432	19.9953	5.00E-04	5.00
7/3/2014	19.9954	9am	5pm	448	19.9953	5.00E-04	5.00
8/3/2014	19.9954	9am	5pm	464	19.9953	5.00E-04	5.00

5.2.1. Result and discussion

At the first sampling period the water content of pongamia pinnata oil is 14.99993ppm. After 16 hours of sampling period the water content of oil is increased to 0.0022ppm. After 64 hours of sampling time the moisture content of oil reaches 30.00195013ppm which is the maximum value. Up to 272 hrs of sampling period the water content of pongamia pinnata oil is not stable. Above 272 hrs of sampling periods the water content of pongamia pinnata oil has reached a stable value as shown in Table2, Fig 2 ,.

5.3. Breakdown Strength of Pongamia Pinnata Oil

The breakdown strength of Pongamia pinnata oil was measured as per IEC 60156. The test was conducted by nutronics oil test kit, it having 0-80kv capacity. At first the

test cup was washed by pongamia pinnata oil. After cleaning the oil is poured into test cup. The test cup has 2.5mm gap spacing between two electrodes. After 5 minutes of pouring the oil, the supply mains are switched on. The applied voltage will be increasing at the rate of 2kV/s. The voltage will be rising until breakdown occurs inside the oil sample. Five consecutive measurements are made for accuracy.

Table 3. Breakdown strength

SL.No	Pongamiapinnata oil BDV in kV	Mineral oil BDV in kV
1	77	67
2	73	63
3	59	52
4	54	48
5	51	42

Figure 3. Comparison between Breakdown strength (BDV) of Pongamia pinnata oil(P.O) Vs Mineral oil(M.O)

5.3.1. Result and Discussion:

From the experimental results the average breakdown strength of pongamia pinnta oil is higher than the conventional used mineral oil. This satisfies the requirement for the breakdown strength of insulating liquid as per IEC standard. Also breakdown strength of pongamia pinnata oil is much higher than vegetable oils like sunflower oil, soya bean oil, coconut oil, corn oil and natural ester like BIOTEMP, ambient insulating fluid, Ambient prime insulating fluid as shown Table 4.

6. Conclusions

From the experiment it is concluded that

[1]. 40°C operating temperature the viscosity of pongamia pinnata oil is low as compared to RBDPO, Soya bean oil, Sesame oil, Coconut oil and sunflower oil. Also it has higher amount of mono unsaturated fatty acids. Due to this pongamia oil has low viscosity.

[2]. Water content of pongamia pinnata oil has to be significantly reduced which satisfies the basic property of insulating oil

[3]. Average better breakdown strength is higher than the conventional used mineral oil.

In future, other physical and chemical properties are tested as per ASTM and IEC standard. If test results match with liquid dielectrics properties it can replace the traditionally used mineral oil in Distribution Transformer

Table 4. Breakdown strength comparison

Name of oil	BDV in kV	Referred by
Sunflower Oil	34	13
Rice Bran Oil	39	
Soya bean Oil	27	
Corn Oil	32	
coconut oil	60	21
Ester oil		
BIOTEMP	45	
Ambiant insulating fluid	55	
Ambiant prime insulating fluid	51	

Appendix 1

Oil name	Testing standard	Operating Temperature	Viscosity	Referred by
High oleic natural oil Mineral oil	ASTM D445	At 40 °C	40 cSt 9.8cSt	[7]
HOSO		At 40 °C At -20 °C	40 mm ² s ⁻¹	[8]
FR3		At 40 °C At -20 °C	33 mm ² s ⁻¹ App. 500 mm ² s ⁻¹	
Midel eN		At 40 °C At -20 °C	37 mm ² s ⁻¹ 1485 mm ² s ⁻¹	
Midel 7131		At 40 °C At -20 °C	28 mm ² s ⁻¹ 1400 mm ² s ⁻¹	
Olive oil Filtered new/ old		At 40°C	9.9/11.6 cSt	[9]
Olive oil Un filtered oil new/old			9.9/11.6 cSt	
Naturally grown olive trees			8.43 cSt	
Irrigated olive trees			8.52 cSt	
Synthetic Ester oil		At 60 °C	289.74 cSt	[11]
Ester oil		At 60 °C	17.2 cSt	
80 % mineral oil with 20 % Ester oil		At 60°C	6.82 cSt	

100% MO	ASTM D445 and ISO 3104	At 40°C	8.33 cSt	[12]
100%RBDPO			37.95 cSt	
20%RBDPO/80%MO			11.86 cSt	
90%RBDPO/10%MO			33.65 cSt	
Sunflower Oil	ASTM D 445	At room temperature	132 cSt	[13]
Rice Bran Oil			154 cSt	
Soya bean Oil			140 cSt	
Corn Oil			134 cSt	
1gm of BHT with Sunflower Oil		At 30 °C	109 cSt	
0.5gm of BHT + 0.5gm of CA9 with sunflower oil		At 30 °C	109 cSt	
1gm of BHA with Rice Bran Oil			143cSt	
5gm of BHA with Rice Brann oil			143 cSt	
5gm of BHT with Soya bean Oil			103cSt	
0.5gm of BHT + 0.5gm of CA with Soyabean oil α -T + CA with soyabean oil			103cSt	
α -T + CA(0.5:0.5) with corn oil			105cSt	
EnvirotempFR3	ASTM D445	At 20°C At 40°C At 100°C	77 cSt 36 cSt 8cSt	[14]
Biotemp		At 20°C At 40°C At 100°C	82cSt 40cSt 9cSt	
Soybean oil		At 30°C At 40°C At 50°C At 60°C At 70°C At 80°C	78.83 cSt 62.21 cSt 48.20 cSt 38.20 cSt 32.34 cSt 26.28 cSt	[16]
Sesame oil		At 30°C At 40°C At 50°C At 60°C At 70°C At 80°C	74.38 cSt 57.48 cSt 42.60 cSt 33.54 cSt 28.29 cSt 25.30 cSt	
Coconut oil		At 30°C At 40°C At 50°C At 60°C At 70°C At 80°C	68.79 cSt 62.41 cSt 53.38 cSt 46.10 cSt 41.92 cSt 28.30 cSt	
Sunflower oil		At 30°C At 40°C At 50°C At 60°C At 70°C At 80°C	76.98 cSt 62.21 cSt 48.20 cSt 38.20 cSt 32.34 cSt 26.28 cSt	
RBDPO	ASTM D88 and D445	At 0 At 25°C At 40°C At 60°C At 100°C	500 cSt 300 cSt 48 cSt 30 cSt 15 cSt	[17]

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