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 with in 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 are 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 is 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 9.9and 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 Envirotemp 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 Envirotemp 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. Ata 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 L/h 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 EnvirotempFR3 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. Pongmia Pinnata

Pungamia 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 hardly and highly tolerant of sanity. Historically, this plant has been used in Indian and neighboring regions as a source of traditional medi-cines, 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 pongama 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 are 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 pungamia 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.

| 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               |

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 pogamia 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.
Table 2. Water content analysis of pongamia pinnat oil

| Date       | weight of oil before testing in mg/kg | weight of oil after Testing in mg/kg | %W=((w1-w2/w2)*100) Water content in ppm |
|------------|---------------------------------------|-------------------------------------|------------------------------------------|
| 8/2/2014   | 20.0004                               | 20.0001                             | 0.00149999                               |
| 9/2/2014   | 20.001                                 | 19.9998                             | 0.00150002                               |
| 10/2/2013  | 19.9998                               | 19.9995                             | 0.00150004                               |
| 11/2/2013  | 19.9995                               | 19.9993                             | 0.00100004                               |
| 12/2/2014  | 19.9993                               | 19.9987                             | 0.00300002                               |
| 13/2/2013  | 19.9987                               | 19.9986                             | 0.00150012                               |
| 14/2/2014  | 19.9986                               | 19.9982                             | 0.00200018                               |
| 15/2/2014  | 19.9982                               | 19.9979                             | 0.00150016                               |
| 16/2/2013  | 19.9979                               | 19.9976                             | 0.00150018                               |
| 17/2/2014  | 19.9976                               | 19.9973                             | 0.00150021                               |
| 18/2/2014  | 19.9973                               | 19.997                              | 0.00150023                               |
| 19/2/2014  | 19.997                                | 19.9967                             | 0.00150025                               |
| 20/2/2014  | 19.9967                               | 19.9965                             | 0.00100018                               |
| 21/2/2014  | 19.9965                               | 19.9962                             | 0.00100019                               |
| 22/2/2014  | 19.9962                               | 19.996                              | 0.0010002                               |
| 23/2/2014  | 19.996                                | 19.9957                             | 0.00100021                               |
| 24/2/2014  | 19.9957                               | 19.9955                             | 0.00100023                               |
| 25/2/2014  | 19.9955                               | 19.9954                             | 5.0E-04                                  |
| 26/2/2014  | 19.9954                               | 19.9953                             | 5.0E-04                                  |
| 27/2/2014  | 19.9954                               | 19.9953                             | 5.0E-04                                  |
| 28/2/2014  | 19.9954                               | 19.9953                             | 5.0E-04                                  |
| 1/3/2014   | 19.9954                               | 19.9953                             | 5.0E-04                                  |
| 2/3/2014   | 19.9954                               | 19.9953                             | 5.0E-04                                  |
| 3/2/2014   | 19.9954                               | 19.9953                             | 5.0E-04                                  |
| 4/3/2014   | 19.9954                               | 19.9953                             | 5.0E-04                                  |
| 5/3/2014   | 19.9954                               | 19.9953                             | 5.0E-04                                  |
| 6/3/2014   | 19.9954                               | 19.9953                             | 5.0E-04                                  |
| 7/3/2014   | 19.9954                               | 19.9953                             | 5.0E-04                                  |

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                    |
5.3.1. Result and Discussion:

From the experimental results the average breakdown strength of pongamia pinnata 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, Ambiant prime insulating fluid as shown Table 4.

6. Conclusions

From the experiment it is concluded that

Appendix 1

| Oil name | Testing standard | Operating Temperature | Viscosity | Refered by |
|----------|------------------|-----------------------|-----------|------------|
| High oleic natural oil | ASTM D445 | At 40 °C | 40 cSt | [7] |
| Mineral oil | | At 0°C | 9.8 cSt | |
| HOSO | | At 40 °C | 40 mm²s⁻¹ | |
| FR3 | | At 40 °C | 33 mm²s⁻¹ | |
| | | At -20 °C | App. 500 mm²s⁻¹ | |
| MideL eN | | At 40 °C | 37 mm²s⁻¹ | |
| | | At -20°C | 1485 mm²s⁻¹ | |
| MideL 7131 | | At 40 °C | 28 mm²s⁻¹ | |
| | | At -20°C | 1400 mm²s⁻¹ | |
| Olive oil | | At 40°C | 9.9/11.6 cSt | [9] |
| Filtered new/old | | | | |
| Olive oil Un filtered oil new/old | | | | |
| 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 | |

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 | |

[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 have 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 is the 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 matches with liquid dielectrics properties it can replace the traditional used mineral oil in Distribution Transformer
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|                | ASTM D445 and ISO 3104 | At 40°C | [12] |
|----------------|------------------------|---------|------|
| 100% MO        |                        |         |      |
| 100% RBDPO     |                        |         |      |
| 20% RBDPO/80% MO|                       |         |      |
| 90% RBDPO/10% MO|                       |         |      |

|                | ASTM D 445 | At room temperature | [13] |
|----------------|-------------|---------------------|------|
| Sunflower Oil  |             | 132 cSt             |      |
| Rice Bran Oil  |             | 154 cSt             |      |
| Soya bean Oil  |             | 140 cSt             |      |
| Corn Oil       |             | 134 cSt             |      |
| 1gm of BHT with Sunflower Oil | | 109 cSt | |

|                | ASTM D445 | At 30 °C | [13] |
|----------------|-----------|----------|------|
| 0.5gm of BHT + 0.5gm of CA9 with sunflower oil | | 109 cSt | |
| 1gm of BHA with Rice Bran Oil | | 143 cSt | |
| 5gm of BHA with Rice Bran Oil | | 143 cSt | |
| 5gm of BHT with Soya bean Oil | At 30 °C | 103 cSt |
| 0.5gm of BHT + 0.5gm of CA with Soyabean oil | | | |
| α-T + CA with soyabean oil | | | |
| 0.5gm of BHT + 0.5gm of CA with sunflower oil | | | |
| α-T + CA (0.5:0.5) with corn oil | | 105 cSt | |

|                | ASTM D445 | At 20°C | At 40°C | At 100°C | [14] |
|----------------|-----------|---------|---------|----------|------|
| EnvirotempFR3  | At 20°C   | 82 cSt  |         |          |      |
| At 40°C        |           |         | 40 cSt  |          |      |
| At 100°C       |           | 9 cSt   |         |          |      |
| Biotemp        | At 20°C   | 77 cSt  |         |          |      |
| At 40°C        |           | 36 cSt  |         |          |      |
| At 100°C       |           | 8 cSt   |         |          |      |

|                | At 30°C   | At 40°C | At 50°C | At 60°C | At 70°C | At 80°C | [16] |
|----------------|-----------|---------|---------|---------|---------|---------|------|
| Soybean oil    | 78.38 cSt | 62.21 cSt | 48.20 cSt | 38.20 cSt | 32.34 cSt | 26.28 cSt |

|                | At 30°C   | At 40°C | At 50°C | At 60°C | At 70°C | At 80°C | [16] |
|----------------|-----------|---------|---------|---------|---------|---------|------|
| Sesame oil     | 68.79 cSt | 62.41 cSt | 53.38 cSt | 46.10 cSt | 41.92 cSt | 28.30 cSt |

|                | At 30°C   | At 40°C | At 50°C | At 60°C | At 70°C | At 80°C | [16] |
|----------------|-----------|---------|---------|---------|---------|---------|------|
| Coconut oil    | 76.98 cSt | 62.21 cSt | 48.20 cSt | 38.20 cSt | 32.34 cSt | 26.28 cSt |

|                | At 30°C   | At 40°C | At 50°C | At 60°C | At 70°C | At 80°C | [16] |
|----------------|-----------|---------|---------|---------|---------|---------|------|
| Sunflower oil  | 500 cSt   | 300 cSt | 48 cSt  | 30 cSt  | 15 cSt  |         |
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