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Investigation on Critical Property of *Pongamia pinnata* Oil as Liquid Dielectrics for Distribution Transformers

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Distribution Transformers are one of the imperative equipment used in the power system. The insulation design of the transformer plays an important role, because it is continuously energized in a day. Due to the electro mechanical stresses, the operating temperature of the distribution transformer will be increased and it is also maintained within the limit using liquid dielectrics. Traditional mineral oil is the one which is used as the liquid dielectric in the Distribution Transformers. Due to its limited fire resistant characteristics, lesser biodegradability characteristics and also due to the lack of fossil fuels, the alternate liquid dielectrics are very important in an insulation design of the Distribution Transformers. This research work has been proposed on non edible Pongamia Pinnata Oil as an alternate liquid dielectric which can be used in Distribution Transformers. This paper Pongamia Pinnata Oil (PPO) Electrical, Physical and chemical properties has been estimated according to Indian standard to study the feasibility of alternating liquid dielectrics. The experiments results are compared with traditionally used mineral oil. It has been found that PPO has better Electrical, physicochemical characteristics than that of mineral oil.

Key words: Distribution Transformers, Dielectric Material, Biodegradability, Mineral oil, Electrical property, Physiochemical property.

Distribution transformers are one of the key components in power systems. It distributes the electrical energy from suppliers to consumers. It's not only performing a distribution action also acts as isolation between high voltages to the low voltage side. The insulation design has an important role because it continually energizes in a day. The life of the transformer strongly depends on its insulation life. During transformer operating condition, mechanical, electrical and thermal stresses are occurring which accelerates the ageing rate of the insulation system[1]. The deterioration of insulation is strongly depends on its operating temperature. In transformers 70% of the failures depend on liquid insulation, whereas 50% depend on tensile strength of solid insulation[2,3].

Conventionally mineral oil is used as a liquid dielectric in Distribution transformers, because it has good physical and dielectric properties as well as cost wise low. However, mineral oils are extracted from fossil fuels, which are nonrenewable sources. In future, fossil fuels are going to run out. Also, it has lesser biodegradable and fire resistant characteristics. So that if accidently spill to soil and water, which is affecting the ecosystem[4-6].

These negative aspects of mineral oil, several researchers have been involved in alternating liquid dielectrics for many years. The

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impact of this effort, Synthetic Insulating Liquids, hydrocarbon based Liquids, Silicone oil, Synthetic and natural ester oils etc., are developed. The hydrocarbon based synthetic insulating fluids have non flammable characteristics while it is only 30% biodegradable where natural and synthetic ester oil have less flammable characteristics than mineral oil however higher biodegradable characteristics than mineral oil, hydrocarbon based. Consequently, silicone oil fire resistant characteristics are higher than natural and synthetic ester but it has low biodegradable characteristics[7].

Now a day's highly biodegradable Environtemp FR3, BIOTEMP insulating liquids are developed which is successfully used in Power, Distribution Transformer in United States of America[8]. Although, few researchers has been investigates properties of sunflower oil, Coconut oil, Canola oil, Palm oil, Rapeseed oil Soybean oil and Olive oil. Apart from viscosity, the sunflower, soybean, rapeseed and canola oil perfectly satisfy the liquid dielectric standards[9].

Formerly pongamia pinnata oil, water content analysis performed by weight balance method and viscosity, dielectric strength of oil has been measured according to international standards. The result shows that it is satisfying the international standard requirement as liquid dielectrics for Distribution transformer[10]. But weight balance method not accurate. Due to during measuring time it is easily absorbed moisture content from the atmosphere. The moisture is the first enemy of insulation liquids. The formation of water content in liquid dielectrics is oxidation and thermal degradation of cellulosic type insulating materials. This is significantly reduced dielectric property of insulating oil and increases the conductivity, dissipation factor[11]. Also, the acidity is the main causes of transformer solid insulation failure. As well as it is a good indicator for access the condition of the oil[12]. The electrical and physicochemical property of oil samples were measured according to Indian standard.

Characteristics of Pongamia Pinnata

Pongamia Pinnata is a medium sized evergreen tree, belonging to the family Fabaceae, subfamily is Papilionaceae. The origin of the tree is India and its subcontinents; also it is successfully introduced in humid tropical region of the world such as Australia, Newland China and USA etc. A single tree can produce 9-90kg seeds per year, the yield potential of tree is 900-9000kg/ha. The oil content which is ranging between 30 to 40 wt% .It is a nitrogen fixing plant, hence it improves the soil. It is a drought resistant (500-2500mm rainfall per year), heat resistant (-1 to 50 °C), synchronized flowering and harvesting, tolerates saline conditions and alkaline soils. From an environmental point of view, the CO_2 sequestrating of the perennial tree is estimated at 30 tons/ha/a. Historically, this plant has been used in India as medicines, especially in Ayurveda and Siddha system. Also crude oil used for tumors, piles, skin diseases, abscess, animal fodder, green manure, timber, water-paint binder, pesticide, fish poison. Recently, pongamia pinnata oil has been recognized as a viable source of oil for bio fuel the industry[10,13-15].

Basically India is an agro based country. The total graphical area of India is 328.73 million hectares. Among this land 12.66million hectare of land is lying as cultivable waste land[16]. Utilize this land for cultivating Pongamia Pinnata tree which is providing employment to 300-320 persons per day for plantations, collecting seeds and production of oil. This is improving the livelihood of remote village people[14].

From the literature review none of the researchers focus about on Pongamia Pinnata Oil as a viable source of liquid dielectric for Distribution transformer[10]. Therefore, in this research work has been proposed non edible Pongamia Pinnata Oil as liquid dielectrics for distribution transformers.

Sample preparation

The mineral oil is obtained from associate transformers. Whereas PPO oil is obtained from local market. These samples are filtered, dehydrated and degassed for minimizing the influence the moisture content on the experimental results. Then the oil sample is poured into a separate vacuum box which is heated to 80 ºC for 48 hours, subsequently, it allowed to cooling for 24 hours under vacuum conditions. Then the moisture content of the oil samples is measured, it is 5mg/kg for mineral oil and 17.8mg/kg for PPO respectively[17].

Measurement methods

The Breakdown strength of oil sample is measured according to IS: 6792-2008. It was conducted by using Nutronics oil test kit, which consists of two hemispherical electrodes with 2.5mm gap spacing. Before pouring the oil into test cell, it will be properly clean. The fresh oil sample was poured into oil test cell subsequently in order to check whether any air bubbles are present in it or not. When the air bubbles are expelled, voltage was applied to the oil samples through the electrode. The rate of rise of voltage is 2kV/Sec. This voltage is applied to the oil sample automatically by means of switching ON the automatic test switch. When the breakdown occurred inside the oil corresponding reading will be measured. The measurements were conducted 5 times with 2 minutes of time delay between consecutive measurements[18, 19].

The moisture content of oil sample is measured according to IS: 6262-20001 using coulometrically generated Karl Fischer reagent. It is suitable for measuring the lower water content of oil samples. This is injected into coulometrically generated Karl Fischer titration test cell. The required titration is generated electrochemical process in the titration cell[20, 21].

The Dielectric dissipation Factor is measured according to IS: 6103-2006 using Schering circuit test and null indicator oscilloscope. The oil sample is poured into three terminal test cell, it is from a capacitance where oil is act as a dielectric medium. Initially operating temperature is raised up to 100°C then it let go down to 90°C corresponding measurement is made. It is also used to measure the specific resistivity of oil samples[22-24].

Specific Resistance of oil samples is measured according to IS:6103-2006. It is a measure of resistance between two opposite sides of one cm^3 block of oil; the standard unit is taken as ohm cm at a specific temperature[25,26]. The acidity of oil sample measured according to IS: 1448 (P: 2)-2007 which is measured in terms of total acid number. It is measure of amount of KOH required to neutralize the acids in one gram of oil[27].

The interfacial number is measured according to IS: 6104-2006 using Ring Method. It is measuring the force required to remove a planner ring of platinum wire from the surface of liquid of higher surface tension that is upward from the water oil interface. The measurement was carried out rigidly standard non equilibrium conditions. So that measurement completed within one minute after that formation of interference[28].

The Flash point of oil sample is measured according to IS: 1448 (P: 2)-1992 using Pensky Martens Closed cup Test Method. The oil sample is poured into a brass test cup and it is covered. The temperature is amplified by energy regulator. Regular interval the test flame is introduced into test cup. At a particular movement, the vapor formed inside test cup mixed with air to motivate or promotes temporary fire on the oil surface less than one second [29]. The Density of oil sample is measured according to IS: 1448 (P: 16) -2002 using Hydrometer method[30].

The Viscosity of oil sample is measured according to IS: 1448 (P: 25)-1976 using red wood Viscometer. It is a measure of time required to flow of a given quantity of oil under controlled conditions. Redwood Viscometer have a silver plated oil cup with opening called an orifice of standard diameter. The oil sample is filled to the silver plated oil cup and then open the orifice the time required for collecting samples is noted[31]. The sludge content monitored according to IS: 1866:2005. The DGA is performed according to IS: 10593:2006, 9434-1992 using a DGA gas analyzer with multiple gas extractor[32,33].

Breakdown strength

The breakdown strength of an insulating oil refers to its ability to withstand voltage stress without failure. Which , depending on physical chemical properties of insulating oil and impurities presents in the oil also arrangement of electrodes[12]. The average breakdown strength of PPO is higher than that of mineral oil shown in table 2. Due to it having a higher amount of unsaturated fatty acids as shown in table 1. Since it has a high viscosity, density[34]. Which restricting particle movement inside the oil[35].

Dielectric Dissipation Factor

It is the measure of dielectric loss of an insulating fluid due to application of alternating electric field. The energy dissipated as a heat in electric field. The Dielectric Dissipation factor of both oil samples has increased with temperature rises as shown in Table 2. The operating temperature causes dissociation of oil molecules and decreased the oil viscosity. Therefore, dissociation of oil molecules easily moves in the oil, which increased conductivity of oil samples[23].

For all sampling temperatures, the DDF of mineral oil is higher than that of the PPO shown in table 2. Since the mineral oils are mainly composed of hydrocarbon molecules with 15 to 40 carbon atoms per molecules. These molecules are having C-C and C-H bonds. Due to thermal stress, the chemical bonds between atoms are broken[36]. Whereas in PPO has triglyceride structure. It has more than 70% unsaturated fatty acids and so the viscosity of PPO oil is high compared to mineral oil[16]. This is the fact restricting the movement of dissociation of oil molecules in the in PPO oil. So that conductivity of oil is low, consequently DDF of oil

Water Content Analysis

The water content has highly influenced factor for electrical characteristics of insulating oil also it deteriorates cellulosic materials, copper, transformer metal parts[37, 38]. For all sampling temperatures, moisture content of Pongamia Pinnata oil is higher than the mineral oil as shown in table 2. Even though, it does not affect the electrical characteristics of PPO. Since the electrical characteristics of oil samples is depends on relative water content. It is very low in vegetable oil on compared to mineral oil[6].

Specific Resistivity

It is the ratio between the direct potential gradient in volts/centimeter (V/cm) paralleling the current flow within the sample to the current density in amperes/square centimeter (A/cm^2), at a given instant of time and under prescribed conditions[26]. The specific resistivity of oil is gradually decreased with temperature raises. It has a direct relationship with interfacial tension and the dielectric loss factor[37]. When, oil has low resistivity, which increases the conductivity of oil which reduces the breakdown strength of oil. Here PPO has a much higher resistivity than mineral oil as shown in table 2. Which infers that contamination rate is low as compared to mineral oil for same sampling temperature.

Acidity

It is the measure of acidic element of the insulating liquids[26]. Acidity is the best indicator to assess the condition of the oil. The acidity of PPO is higher than that of mineral oil as shown in table 2. Due to PPO has the saturated, unsaturated (mono, poly) fatty acids as shown in table 1. Among these it has a higher amount of un saturate double bonds in fatty acids which is limiting oxidation stability of oil. Moreover, PPO undergoes hydrolysis reaction in the presence of moisture whereas in mineral oil there are no hydrolysis reactions. In contrast, Acid formation in mineral oil is occurring in the following ways chain off, chain continuity and chain breaking out. Mineral has the Lower Molecular Acids such as formic, acetic and levulinic acids. Whereas PPO has higher amount of oleic acid, linoleic acid these are higher molecular fatty acids. These acids are not accelerating aging rate of paper, but lower molecular acids react with paper so it is influencing paper aging[38, 39].

Interfacial Tension

It is the measure of the molecular attractive force (oil and water) between their unlike molecules at the interface. It is used to detect the soluble polar contaminations, oil deterioration and oxidation products[26,40]. The PPO has higher acidity content than mineral oil as shown in table 2. So the polar contents are higher than that of mineral oil. Hence interfacial tension of PPO is lower than that of mineral oil in same sampling temperature[37].

Table 1. Fatty Acid Profile of PPO [10], [13]-[15]

Fatty Acid	Molecular Formula	Percentage	Types
Palmitic acid	CH3(CH2)14COOH	3.7-7.9	Saturated Fatty Acids
Stearic acid	CH3(CH2)16COOH	2.4-8.9	Saturated Fatty Acids
Oleic	CH3(CH2)14(CH=CH)COOH	44.5-71.3	Unsaturated Fatty Acids
Linoleic acid	CH3(CH2)12(CH=CH)2COOH	10.8-18.3	Poly Unsaturated Fatty Acids
Eicosenoic	CH3(CH2)18COOH	2.4	Mono Unsaturated Fatty Acids
Arachidic	C20H40O2	5.3	Saturated Fatty Acids
Lignoceric acid	CH3(CH2)22COOH	1.1-3.5	Saturated Fatty Acids

Table 2. Comparison of Critical Properties of PPO Oil And Mineral Oil

SL.No	Test Parameter	Standard	Limit	PPO	MO
1	Breakdown strength RH:49%	IS 6792-2008	Min 60	67	63
2	Dielectric Dissipation Factor at 25 ºC			0.00139	0.005
	at90ºC	IS 6262-20001	0.002	0.00156	0.009
	RH:50%				
3	Moisture Content in ppm at 25 ºC			17.8	10
	at 40 ºC	IS 13567-1992	50	13	7
	at 90ºC			8	5
	RH:48%				
4	Specific Resistivity in ohm-cm, at 90ºC RH:47%	IS 6103-2006	35×10^{12}	12×10^{13}	10^{13}
5	Acidity in mg KOH/g	IS 1448(P:2)-2007	0.1 - 5	0.5	0.01
6	Flash Point in ºC	IS 1448(P:2)-1992	Min. 140	245	165
7	Sedimentation/Sludge % by weight	IS 1866:2005	Max. 0.05	ND	ND
8	Interfacial tension in mN/m	IS 6104-2006	0.04	11	42
9	Density in g/cm^3 at 29.5°C	IS 1448(P:16)-2002	0.8-1.6	0.924	0.85
	at 90 °C			0.872	0.76
10	Kinematic Viscosity in cSt at 27°C			40	12
	at 40°C	IS 1448(P:25)-1976	2 – 50	27	8
	at 90°C			11	3
11.	Dissolved Gas Analysis in ppm	IS	50		
	Methane in ppm	10593:2006&9434-	50	NA	NA
	Ethylene in ppm	1992	50	NA	NA
	Ethane in ppm		5	NA	NA
	Acetylene in ppm		200	NA	NA
	Carbon monoxide in ppm		5000	12	40
	Carbon-di-oxide in ppm		100	98	120
	Hydrogen in ppm			ND	ND

Flash Point

It is the lowest temperature at which the vapour pressure is sufficient to from a flammable mixture with air near the surface of the liquids[26]. The flash point is the best indicator of quantity of volatile contamination presents in the insulating oil. If the flash point is low, it has a higher amount of volatile contaminations[12]. The Flash point of PPO is much higher than that of mineral oil as well as minimum requirement according to IS 1448 (P: 2) -1992.

Density

It is the ratio between the equal volume of oil and water. This is used to infer that the chemical composition of substances in insulating oil[26]. Also quality of oil can be evaluated by density. The density of PPO is 0.924 at 29.5°C which is reduced to 0.872 at 90°C while the density of mineral oil changed from 0.85 at 29.5°C to 0. 76 at 90°C shown in table2. This is indicating that PPO oil has a little higher density than the mineral oil, but it is significantly reduced when sampling temp. rises.

kinematic Viscosity

It is the measure of the fluid resistance to flow. It is the ratio between the viscosity of the fluid and its density[26]. The cooling capacity of oil is highly depended on the oil viscosity. If the oil has a high viscosity it reduces the fluid flow and heat transfer ability of the oil. The aging by products and oxidations are increases with the oil viscosity[8]. PPO viscosity is higher than that of mineral oil for all sampling temperature as shown in table 2. Similarly to the mineral oil, the viscosity of Pongamia pinnata oil decreased with increasing oil with the temperature.

Dissolved Gas Analysis

Dissolved Gas analysis is cheapest, effective method for predicting the status of the transformer using analyze dissolved gases in the insulation liquids. When the electro mechanical stresses are exceeding its threshold limit insulating oil degrades which is producing the combustible gases, which are hydrogen (H_2), Methane (CH_4), Ethane (C_2H_6), ethylene (C_2H_4) and acetylene (C_2H_2). The oil samples are exhibits significant amount of CO and CO_2 since these have hydrocarbon molecules. The PPO exhibits lower quantity of CO than mineral oil. But it exhibits higher amount of CO_2 than that of others [41]. Also the ratio of CO/CO2 is low as shown in table 2.

CONCLUSION

Based on the experimental results critical properties of Pongamia Pinnata oil has satisfied the Indian standard requirements as a liquid insulating material. From the experimental analysis the electrical and physicochemical properties are better than the conventionally used mineral oil. The results are encouraging for use of pongamia pinnata oil in distribution transformers. Since micro grids are growing in country like india, the finding of alternate liquid dielectrics for distribution transformer is the need. From this experiments pongamia pinnata oil is very good substitution for liquid dielectric in distribution transformer. This also enhances the cultivation of non edible oil plant in uncultivable waste lands in India. The waste land development will lead to the raise the income of rural people and their livelihood. In future the Non edible pongamia pinnata oil is loaded to distribution transformer for assessing the performance of the oil.

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