Renewable and Sustainable Energy Reviews 65 (2016) 784–799

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

A critical review on the characteristics of alternating liquid dielectrics and feasibility study on pongamia pinnata oil as liquid dielectrics

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ARTICLE INFO

Article history:
Received 28 April 2015
Received in revised form
23 May 2016
Accepted 8 July 2016

Keywords:
Distribution Transformer
Mineral oil
Pongamia pinnata oil
Electrical property
Physical property
Chemical property
XRD
SEM

ABSTRACT

Green insulating fluids are playing a vital role in insulation design of the distribution transformers. Traditionally used mineral oil has lesser biodegradable and low fire resistant characteristics. Hence, it does not satisfy the new environmental regulation. Besides that, the availability of fossil fuels is also going to run out. These negative aspects motivate to search for an alternate insulating oil. This research has been proposed for feasibility study on non - edible pongamia pinnata oil as an alternate liquid dielectric which can be used in Distribution Transformers. The paper also reviews the alternate insulating oil, electrical, physical and chemical properties. Subsequently, Pongamia Pinnata Oil's electrical properties (Dielectric Strength, Dielectric Constant, Dielectric Dissipation Factor and Specific Resistance), chemical properties (Water content, Acidity) and physical properties (Viscosity, Flash Point, Interfacial Tension) have been estimated according ASTM and IEC for comparing the Pongaima Pinnata oil with conventional mineral oil. Alongside, solid insulating material deterioration, both in pongamia pinnata oil and mineral oil, using XRD and SEM was carried out. The experiments are encouraging. If the oil suited for these characteristics the value addition has been made from this oil which leads to waste land utilization and rural development.

Contents

Abbreviations: IEC, International Electrotechnical Commission; ASTM, American Society for Testing And Materials; IEEE, Institute of Electrical and Electronics Engineers; IS, Indian Standard; ISO, International Organization for Standardization; DC, Dielectric Constant; DDF, Dielectric Dissipation Factor; DLF, Dielectric Loss Factor; BDV, Breakdown Voltage; PCB, Polychlorinated Biphenyl; VO, Vegetable Oil; MO, Mineral Oil; HONE, High Oleic Natural Ester Oil; SHO, Sunflower High Oleic; PPO, Pongamia Pinnata Oil; RSO, Refined Soybean Oil; RRO, Refined Rice Bran Oil; SRO, Sunflower Refined Oil; HSO, High Oleic Sunflower Oil; PPO, Pongamia Pinnata Oil; RSF, Refined soybean oil; RBDPO, Refined Bleached Deodorized Palm Oil; H_2, Hydrogen; CO, Carbon monoxide; CO_2, Carbon dioxide; XRD, X-ray powder diffraction; SEM, Scanning Electron Microscope

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http://dx.doi.org/10.1016/j.rser.2016.07.036
1364-0321/

1. Introduction

Distribution Transformer is the most significant component in power system. The life time of transformer strongly depends on life time of the insulation to be used. Commonly, oil-impregnated distribution transformer is used in power system since its life cycle is higher than that of others. Transformer operating condition and mechanical-, electrical- and thermal-stresses are occurring during routine service; it accelerates the ageing rate of the insulation system. The deterioration of insulation is strongly dependent on its operating temperature. In transformers, 70% of the failures are due to liquid insulation, whereas 50% of them are due to tensile strength of solid insulation [1,2].

The liquid dielectrics used in distribution Transformers perform two important functions. That is, it acts as an insulation medium and maintains the transformer operating temperature within limits. Over 100 years, mineral oils are used as the liquid dielectrics in transformers, since its physiochemical and electrical properties are suitable for the transformer; also, it is said to be of low cost. However, the negative aspects of mineral oils are low flashpoint, fire point and dielectric strength. Adding all these aspects with mineral oils are extracts from fossil fuel, nowadays fossil fuels are being rapidly decreased. As the mineral oil is less biodegradable, it doesn't satisfy new environmental laws [3,4].

The low fire and flash point and breakdown strength can be rectified by using a Higher Molecular Weight of Hydrocarbon, but its viscosity is high and so the capacity of heat transfer is low. In Later years, biodegradable synthetic ester, developed by organic components, is synthesized from organic acids and alcohols. But, it has higher viscosity and cost wise higher. In 1970's, silicone oil was developed which has high fire point, very low pour point and not affected by oxidation. But, it has higher viscosity at low temperature. Also, Silicone oil contains methylpoly siloxanes which can generate formaldehyde at around 300 °F, which causes cancer to living organisms [5–7].

Since 1990's, the vegetable oils are the commonly used liquid dielectrics in Distribution transformers, as its physical, chemical and electrical properties satisfy the required standard. The vegetable oils are band triglyceride structures, which can be classified according to their fatty acid composition like saturated and unsaturated (mono, Di and Tri). These fatty acids are the deciding factors of physiochemical and electrical properties of the oil. The saturated fatty acid oils are having higher viscosity, higher freezing point and pour point; but they have low oxidation stability and low dielectric strength. The Triple unsaturated fatty acids exhibit a lower viscosity, and consequently, it has an unstable property, while the poly unsaturated fatty acids oils have good oxidation stability [8].

In recent years, highly biodegradable insulation fluids, such as Environtemp FR3 and Biotemp, are developed and successfully used in distribution transformers in USA. Apart from these oils, several researchers are investigating sunflower oil, coconut oil, canola oil, palm oil, rapeseed oil, soybean oil and olive oil properties according international standards. Results show that, except for viscosity, sunflower, soybean, rapeseed and canola oil perfectly satisfies the liquid dielectric standards [9]. These oils are obtained from edible oil. This increases the competitions between food and insulating oil. This research work has been proposed for feasibility study on non - edible Pongamia Pinnata Oil as an alternate liquid dielectric which can be used in Distribution Transformers. Furthermore, deteriorations of solid insulating materials were investigated using XRD and SEM.

2. Breakdown strength

Abdi et al. conducted accelerated thermal aging test on transformer oil at temperature ranges of 80 °C, 100 °C, 120 °C and 140 °C for 5000 h of the aging period. For every 500 h of sampling interval, Breakdown strength of oil sample was measured as per IEC 60156 for accessing the electrical characteristics of transformer oil under elevated temperature. Initially, the breakdown strength of oil was 80 kV, which was reduced 50% at the temperature ranges 80 °C and 100 °C for end of aging periods, where it is reduced to 80% when thermally aged at 120 °C. Further raise in temperature dropped the BDV of transformer oil to a critical value after 3000 h of sampling periods. Because of overheating of oil, water molecule was developed, which motivates the formation of gas bubbles in the oil. Due to these impurities, a streamer phenomenon occurs in the gas bubbles. It is propagating during application of voltage. This process expands, consequently leading to breakdown [10].

Al-Eshaikh et al. analyzed corn's oil electrical property and its viability as a liquid dielectric. The breakdown strength of the oil samples is measured as per IEC-60156 by using Foster type 60A automatic oil tester. The mean BDV of mineral oil is 33.9 kV with a standard deviation of 3.96, whereas for corn oil, BDV was 46.1 kV, with a standard deviation of 4.7 kV. However, mineral oil sample has a moisture content of 15 ppm, and corn oil is having moisture content of 127 ppm. It is inferred that the breakdown strength of corn oil is not affected by moisture content because corn oil has more than 70% unsaturated fatty acids [11].

Liao et al. conducted accelerated thermal aging test for catalytic added vegetable (BIOTEMP) oil at 170 °C for 216 h which measures BDV of oil samples as per ASTM D1816. The BDV of oil sample depends on the moisture furfural concentration at the initial stage and acid content at the later stage. The acid content is higher in natural ester oil when compared to mineral oil, but it does not affect the breakdown strength of Natural Ester oil, because, during thermal aging of natural ester oils, mild long chain fatty acids are generated, which are not corrosive. Furthermore, it generates peroxide, which has a high affinity to hydrogen gas and reduces formation of bubbles in the oil [12].

Singh et al. investigated 10 different transformer oil's BDV for evaluating the influence of the aging factor into oil electrical property. The oil sample's BDV has been measured as per IS 335 using a 12.5 mm sphere electrode with 2.5 mm gap spacing. From the experimental results, the BDV of transformer oil decreases gradually, and it bears a nonlinear relationship with aging. During transformer operating condition, an electrochemical stress occurs inside transformer, which degrades the transformer insulation. These effectively increase the number of conducting particles, which are rapidly increased with aging. Hence, the BDV of oil samples is strongly affected by these impurities [13].

Abderrazzaq et al. evaluated the breakdown strength of olive oil as per the IEC 60156 standard, and the test results were compared with mineral oil. The breakdown strength was performed at