Comparative Study of AC and DC Breakdown Voltages in Jatropha Methyl Ester Oil, Mineral Oil, and their Mixtures

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ABSTRACT

This paper is aimed at the comparison of breakdown voltage (BDV) of oil mixtures consisting of Jatropha curcas methyl ester oil (JMEO) extracted from the fruit seeds of jatropha curcas plants, and mineral oil (MO) under AC and DC voltages. Two JMEO/MO oil mixtures were considered: (50% JMEO + 50% MO) and (80% JMEO + 20% MO). The goal was to predict the insulation behavior of power transformers when re-filling with JMEO after they were emptied of mineral oil. The statistical analyses of the experimental data shows that the BDV values conform to normal law. It is shown that the (80%JMEO+20%MO) oil mixture is the most interesting whether under DC or AC as it shows the highest breakdown voltage. The U1% of JMEO under AC voltage is higher than those of the other tested oils. And the U1% of oils mixture (50%JMEO+50%MO) is the lowest one.

Index Terms — **AC and DC breakdown voltages, statistical analysis, Jatropha curcas methyl ester oil (JMEO), mineral oil (MO), JMEO/MO mixtures**

1 INTRODUCTION

THE development of ecofriendly products for high voltage power transmission line and substation applications is encouraged and strongly supported by both national and international policies for more than two decades. And the use of new materials with low impact on the environment as substitutes for gases as sulfur hexafluoride (SF_6) in high voltage apparatus (circuit breakers, gas insulated switchgear, and gas insulated lines) because of its global warming potential (GWP) and its long life in the atmosphere, or substitutes for mineral oils and synthetic ester oils for oil-filled apparatus and especially high voltage transformers because of their poor biodegradability (the biodegradability of typical mineral oils is not more than 30 %) [1, 2] and their impact on aquatic sources, become a reality nowadays.

This paper is devoted mainly to the comparison of AC and DC breakdown voltages of a potential natural substitute (vegetable oil) for mineral oil that is JMEO (Jatropha curcas methyl ester oil) and mixtures of JMEO and mineral oil (MO); JMEO is derived from Jatropha curcas, a non-food crop [3]. Note that vegetable oils are known for their high biodegradability, non-toxicity, and their higher fire safety guarantee [4-7]. The knowledge of the behavior of oil mixtures is of a great interest especially during maintenance and the replacement of mineral oil. Indeed, the draining of a mineral oil-filled transformer is never complete. Some amount of mineral oil subsists in the spaces between windings and the bottom of tank. One estimates the residues of mineral oil at about 10 to 20% of the total volume of oil. Fofana *et al* [8] reported that during the replacement of the insulating liquid, up to about 10% of the old liquid remains in the pores of the transformer board, the windings, the core and at the walls of the transformer vessel. This explains why it is of interest to examine the mixture percentage on breakdown voltage. In this

Manuscript received 28 November 2017, in final form 13 June 2018, accepted 14 June 2018. Corresponding author: A. Beroual.

DOI: 10.1109/TDEI.2018.007219

work two JMEO/MO oil mixtures namely 50%JMEO/50%MO and 80%JMEO/20%MO are investigated. The experimental data are analyzed using statistical methods.

2 EXPERIMENTAL TECHNIQUE

A test cell of Baur Dieltest type of 400 ml volume was used in breakdown voltage testing according to the main lines of IEC 60156 standard [9]. The electrode arrangement consists of two brass spheres of 12.5 mm diameter, separated by a distance of 2.50 ± 0.05 mm. Accordance to IEC 60156 specifications, the test cell and electrodes were cleaned by using volatile solvent before testing. The sphere electrodes were polished by using abrasive cloth. Then, they were washed by hot tap water in temperature of 60-80°C. The electrodes were assembled in the test cell and followed drying process by using a hot air dryer.

The tested liquids were: (1) JMEO (Jatropha curcas methyl ester oil), produced through trans-esterification process of Jatropha curcas oil which comes from the pressing of the jatropha fruits; (2) Mineral oil (MO) (naphtenic type); and (3) two JMEO/MO oil mixtures namely 50%JMEO/50%MO and 80%JMEO/20%MO. The samples of oil/mixtures were poured into the test cell slowly and allowed to stand for 30 minutes and 15 minutes for JMEO and MO, respectively, for giving a chance to the gas trapped in the oil to escape. All oil samples were new and their water content measured by Karl Fisher titration (IEC 60814) after treatment and before each test. Treatment consists in passing the oil through a sintered glass filter (10-16 μm) under vacuum. This process (adsorption process) enabled to reduce the water content less than 10%.

In breakdown voltage testing, the AC high voltage at power frequency is supplied by a high voltage test transformer 200 kV - 50 Hz - 60 kVA Hipotronics having control desk where the control of the rate of rise of voltage and the digital voltmeter are installed. A Maxtron 60 MHz oscilloscope is used for measuring effective voltage, maximum voltage and frequency of the output voltage wave. The oscilloscope is connected to the output of the capacitive voltage divider having a ratio of 1:10000. We use the same protocol for determining the breakdown voltage as that adopted in previous work [4, 10]. For comparison, we considered the peak voltage values.

The direct high voltage source is supplied by a 200 kV/2 mA DC generator (Spellman). The applied voltage is raised by steps and maintained at each level for 60 seconds up to breakdown. Similarly as for AC tests, the same protocol is used to determine the breakdown voltage.

3 EXPERIMENTAL RESULTS

3.1 AC AND DC BREAKDOWN VOLTAGE

Figure 1 shows the AC breakdown voltage scattering of JMEO-BT (Jatropha curcas methyl ester oils before treatment), JMEO-AT (Jatropha curcas methyl ester oils after treatment) and MO (mineral oils) by 40 of measurement series. Note that the treatment reduces the water content of JMEO from 1159.9 to 64.9 ppm.

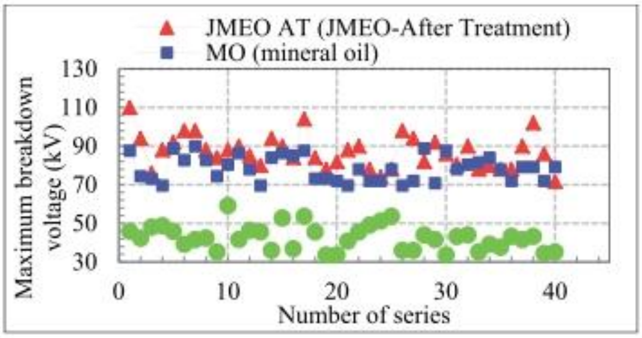

Figure 1. Distribution of breakdown voltage of JMEO-BT, JMEO-AT and MO under AC voltage; the circles in green correspond to JMEO BT (JMEO-before treatment).

The average breakdown voltage of JMEO-BT, JMEO-AT and MO are 42.6, 87.0 and 78.5 kV, respectively. We observed that the treatment process significantly increases the breakdown voltage of more than 100%. The esterification process does not reduce the water content nor improve the breakdown voltage as reported elsewhere [3]. It means that the decrease of water content really influences the enhancement of breakdown voltage. The AC average breakdown voltage (V_{av}) of JMEO-AT is higher than that of MO. We also observed occasionally that in some series of measurements, JMEO BDV can be lower than the breakdown voltage of MO. Similar observations have been mentioned in previous work [11, 12].

Figures 2 and 3 give a comparison of the breakdown voltages of the investigated samples under AC and DC voltages, respectively. Table 1 summarizes the mean values and standard deviations of AC and DC breakdown voltages of tested oils and mixtures. It is observed that: (1) AC mean BDV of MO is the lowest one; (2) AC mean BDV of JMEO is higher than that of MO and 50% JMEO - 50% MO mixtures, but it is similar to that of 80% JMEO + 20% MO mixture; and (3) DC mean BDV of JMEO and MO are similar; and DC BDV of 50% JMEO - 50% MO mixture is somewhat lower (of about 3%) than those of both oils. While DC BDV of 80% JMEO + 20% MO mixture is of 29% higher than that of MO. This improvement which seems surprising could be due to some synergy between both liquids (JMEO and MO) and the interaction between the molecules of both liquids. At such concentrations, the interaction between the molecular bonds of JMEO and MO would give birth to a new structure that improves the dielectric strength of mixture. Note that a significant improvement of the dielectric strength of mineral oil has been observed when adding 20% of synthetic ester [12, 13]. This improvement has been attributed to the chemical interactions that can exist between both liquids. Also, the fact that the mixture of (80%JMEO+20%MO) is characterized by better results than (50%JMEO+50%MO) is also due to the dielectric strength of JMEO which is higher than that of MO.