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Investigation On Electrical Properties And Partial Discharge Characteristics Of Liquid Insulating Oil For Transformer Applications

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Abstract: A liquid dielectric coolant should have good electrical, chemical, physical and thermal properties. In order to characterize the liquid insulation, the electrical properties like Breakdown voltage, Dissipation factor, Relative Permittivity, Resistivity and Partial Discharge activity are to be measured. In this paper investigation on electrical properties and Partial discharge Characteristics of mineral oil and eco-friendly Rice bran and Sesame oil are discussed. Experimental results shown that the Rice bran and Sesame oil have potential to be used as insulating oil in transformers.

***Index Terms* – Partial Discharge, Breakdown voltage, Dissipation factor, PD inception voltage.**

I. INTRODUCTION

The high voltage transformers used for voltage levels varying from 765 kV to 1200 kV need at utmost care during design. This calls for an efficient insulation design (both solid and liquid) for high voltage power transformers. The unexpected failure of high voltage transformer results in shutdown of power and affects completely the power system reliability. Millions of transformers are in service in transmission and distribution networks globally. The major cause for the failure of HV transformers is due to the insulation problems. Compared to the failure rate in other nations, which is between one and two percent, the distribution transformer failure rate in India is between 15 and 20 percent. Most transformer failures are caused by overloading and insulation-related problems, such as contamination in oil, failure of core insulation, and ageing of insulation. In case of transformers, liquid insulations used are petroleum based mineral oils, silicone oils, natural esters and synthetic esters. Solid insulation is used between the windings, windings and core, windings and ground and between the turns.

Partial discharge (PD) in a transformer deteriorates the insulating materials qualities and may eventually cause failures. The significance of PD measurement of high voltage equipment has been noted by several researches. Electrical discharge that only partially bridges the distance between two conducting elements, or across a small section of the insulation, is known as partial discharge.

II. Electrical Properties of Insulating oil

a) **Electrical Breakdown Voltage (BDV):** Breakdown voltage of a liquid dielectric is an important feature of its insulation strength. This is measured by applying a voltage to the liquid dielectric in a standard cell and increasing till breakdown (IS 6792:1992). As per IS: 335-1993 (reaffirmed 2005) clauses 5.1 and 9.1, the minimum breakdown voltage of the new unfiltered mineral based transformer oil is 30 kV (rms) and filtered oil is 60kV (rms).

b) **Dissipation factor:** Tan delta or loss angle is a measure of power loss occurring in the dielectric liquid when subjected to an AC field. Low value of dissipation factor indicates low power loss and hence less heated generated in the insulation. Measurement of dissipation factor helps to assess the condition i.e., deterioration of liquid insulation due to impurities present in it. As per IS: 335-1993, the value of dissipation factor of new processed mineral oil is 0.002 (maximum) at 90^0C.

c) **Relative Permittivity:** The relative permittivity of the mineral based transformer oil is in the range of 2.1 to 2.3. Natural ester based oils investigated have relative permittivities in the range of 2.6 to 3.7. Paper used in transformers has relative permittivity of 5.

d) **Resistivity:** Good mineral based transformer oil has resistivity of the order of $35x10^{12}$ Ω-cm as per IS: 335-1993. Higher values of resistivity are desirable.

III. Investigation on Electrical Properties

1) Measurement of Breakdown Voltage

The breakdown voltage test of insulating oil was carried out as per Indian Standards (IS: 6792/1992). The test set which operates on 230V, 50Hz supply. The output of test set is a variable high voltage (0-100kV). The circuit arrangement is as shown in figure-1. The test cell made of acrylic which is transparent and non-absorbent. The test cell capacity is 500ml. The electrodes are mounted on horizontal axis with a spacing of 2.5mm. The test cell is cleaned before a test according to the standards.

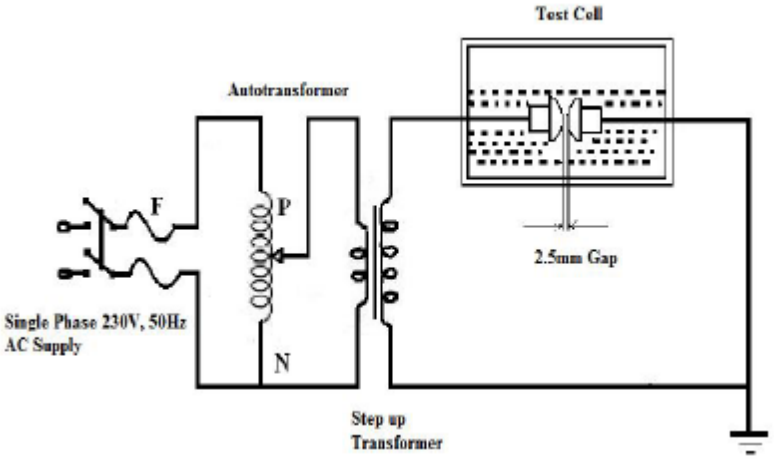

Figure 1: Circuit arrangement of Breakdown Voltage measurement

Experimental investigations were carried out on the samples – Rice bran oil, Sesame oil and Mineral oil. Breakdown Voltages (BDVs) were measured as a function of temperature (from temperature 30^0C to 90^0 C) for selected natural ester based oil samples and mineral oil. The average of five BDVs is plotted as a function of temperature as shown in figure 3. The BDVs of selected natural ester based oils were compared with Mineral oil. (Percentage variations given below are with respect to mineral oil values). At 30^0C BDVs of selected natural ester based oils were lower by about 40% to 60%. At 50^0C, BDVs of Rice bran and Sesame oil were lower by about 31% and 45% respectively. At 80^0C, BDVs of Rice bran and Sesame oil improved by about 30% and 66% respectively compared to their BDVs at 50^0C. It is interesting to note that at 90^0C, Rice bran has shown BDV of about 62kV and Sesame oil has shown BDV of about 59kV.

2) Measurement of Relative Permittivity and Dissipation factor

Relative permittivity and Dissipation factor at 50Hz are measured as Standards- IS: 6262, IEC-60247 and ASTM D-1169 using Eltel Industries make test set ADTR-2K shown in figure-2. The ADTR-2K is a device that automatically measures the electrical properties of samples of transformer oil, insulating liquids, and other insulating materials. It analyses the test sample's capacitance, dielectric constant, dielectric loss, Tan delta (dissipation factor), resistance, and resistivity. Figure 4 shows the plot of Dissipation factor (DF) as a function of temperature. At 30^0C, the DF of Mineral oil was 0.0025 and at 90^0C, it was 0.0754. At 30^0C, the DF of Rice bran was 0.01538 and at 90^0C, it was 0.0852. At 30^0C, the DF of Sesame oil was 0.1665 and at 90^0C, it was 1.052. The DF of selected natural ester based oil is higher than that of Mineral oil. The moisture content will be naturally high in the natural ester based oils without any moisture removal treatment

Figure 2: Capacitance –Tan delta bridge

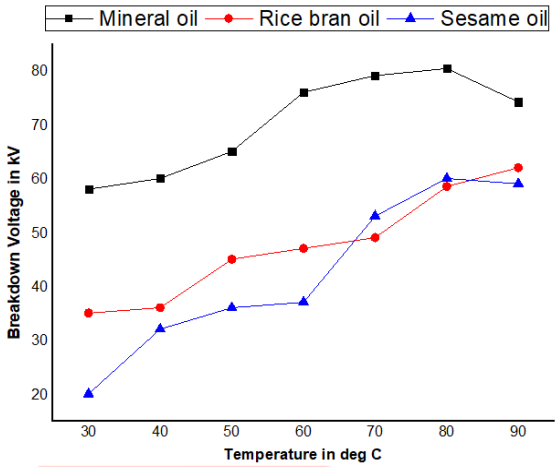

Figure 3 BDV as a function of Temperature

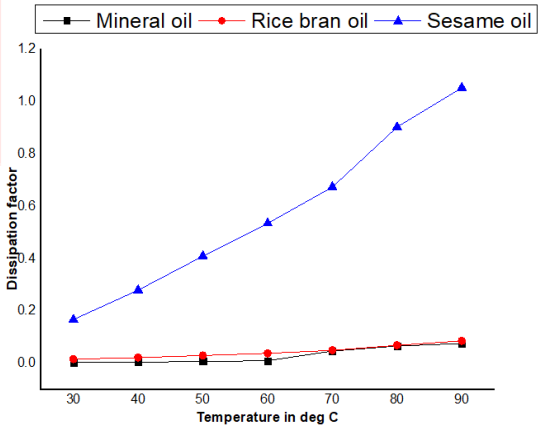

Figure 4 DF as a function of Temperature

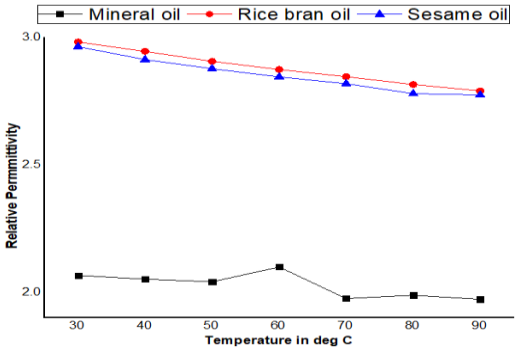

Figure 5 Relative Permittivity as a function of Temperature

Figure 5 shows the relative permittivity as a function of temperature. The permittivity of mineral based transformer oil was about 2.065 to 1.971. The paper used in transformers has permittivity of about 5. In the temperature range of 30^0C to 90^0C, the permittivity of Rice bran oil and Sesame oil was about 2.982 to 2.790 and 2.964 to 2.774 respectively. These permittivities are advantageous from the point of view of better dielectric matching between paper and oil [6]. From the above, it is seen that selected natural ester based oil samples have dielectric parameters which are encouraging to take up the further studies.

IV. PARTIAL DISCHARGE CHARACTERISTICS

The PD measurements are carried out as per IEC 60270 standards by using MPD-600 system. This system for analysing partial discharge events contains an acquisition and analysis toolbox for finding, capturing, and analysing partial discharge events. The variable High voltage source is obtained by using a 10kVA, 100kV transformer (PD free). A 1000pF capacitor is used as coupling device. The whole test setup is enclosed inside the Faraday's chamber (cage) in order to avoid the noise pickup by the PD system [7]. The PD measurement is carried out according to the Standard test procedures (IS-60270). Figure 6 shows the laboratory setup of the PD measurement system enclosed in Faraday's cage.

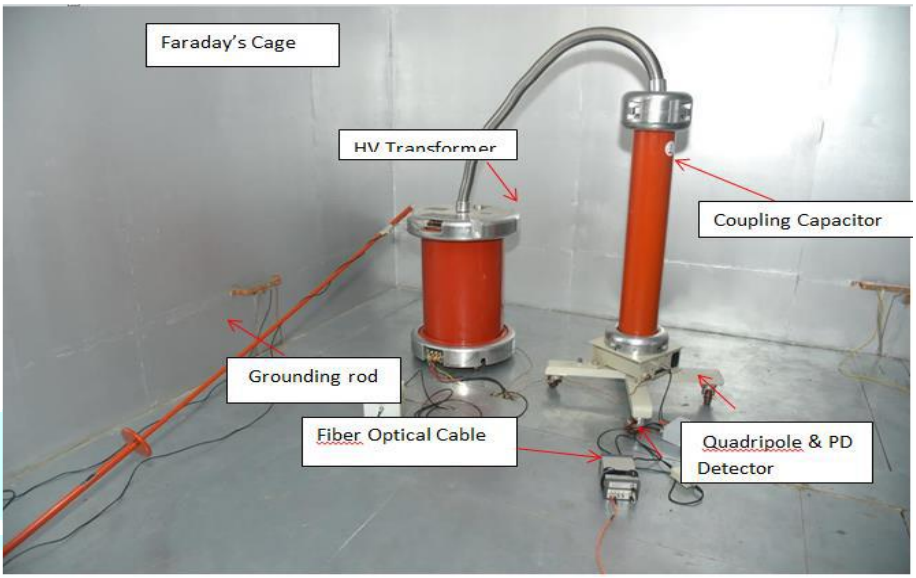

Figure 6: PD measurement system with PD free transformer and coupling capacitor

a) PRPD pattern of Mineral oil/Pressboard under Uniform field

The phase-charge (Φ-q) and phase-charge-number (Φ-q-n) plots of mineral oil with 1mm and 3mm pressboards under uniform field electric stress are captured when the applied voltage is varied [11]. The test voltage is varied until the observable PD pulses are detected by the detector. Figure 7 shows the Phase-charge and phase-charge-number plots of Mineral oil/1mm Pressboard during the inception of PD. when the test voltage is 0.878kV (PDIV), Qpeak=293pC, Qavg=12pC, n=12.2PD/sec values are captured by the detector. The PD charge distribution is more distributed in negative half cycle (140^0-360^0) of applied voltage which indicates the surface discharge on the pressboard layer.

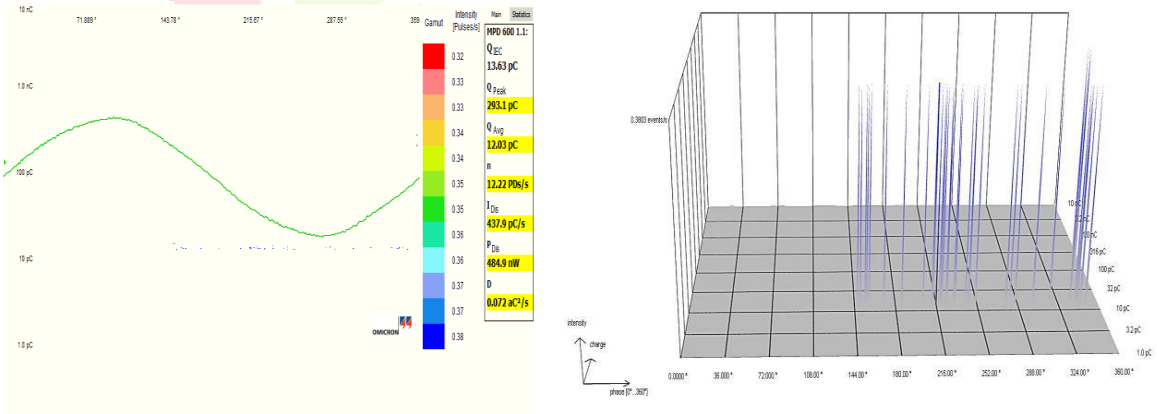

Figure 7: Phase-charge and phase-charge-number plots of Mineral oil/1mm Pressboard under uniform fields at PDIV

b) PRPD pattern of Rice bran oil/Pressboard under Uniform field

Figure 8 shows the Phase-charge and phase-charge-number plots of Rice bran oil/1mm pressboard during the inception of PD. when the test voltage is 1.13kV (PDIV), Qpeak=346pC and n=7.33PD/sec values are captured by the detector. The PD charge is located in positive half cycle (0^0-45^0) and very few charges in -ve half cycle of applied voltage which indicates the surface discharge on the pressboard layer.

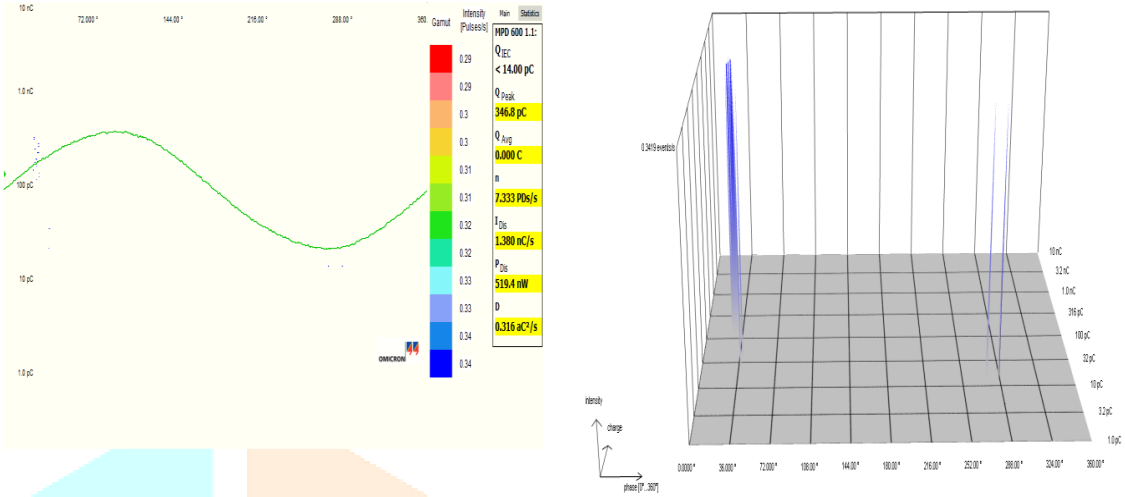

Figure 8 Phase-charge and phase-charge-number plots of Rice bran oil/1mm Pressboard under uniform fields at inception of PD

c) PRPD pattern of Sesame oil/Pressboard under Uniform field

Figure 9 shows the Phase-charge and phase-charge-number plots of Sesame oil/1mm pressboard during the inception of PD. when the test voltage is 1.02kV (PDIV), Qpeak=258pC and n=2.35PD/sec values are captured by the detector. In positive half cycle PD charges are very less and for negative half cycle (320^0-360^0) of applied voltage which indicates the corona discharge.

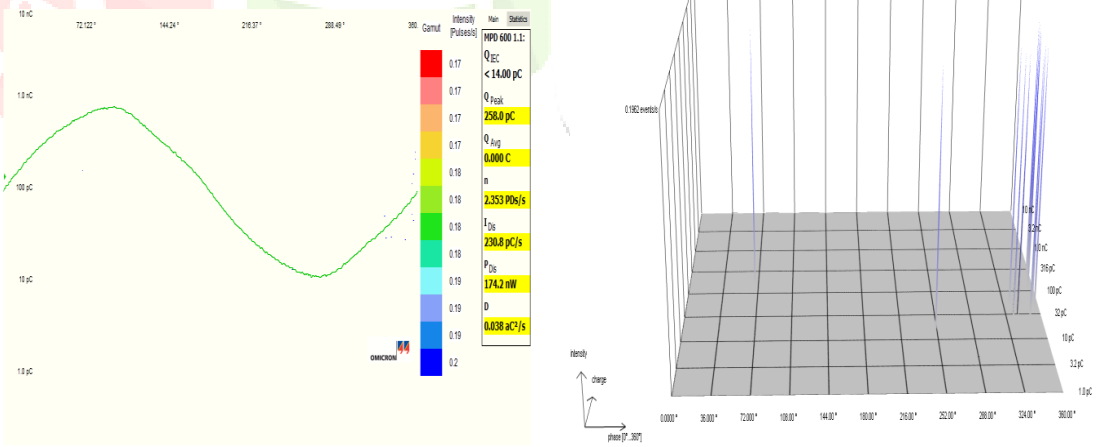

Figure 9 Phase-charge and phase-charge-number plots of Sesame oil/1mm Pressboard under uniform fields at inception of PD

V. CONCLUSION

Rice bran oil and Sesame oil possess encouraging dielectric parameters in particular BDV, Tan delta and permittivity better than mineral oil. The values of Partial Discharge inception voltage are different for different types oils used in the present work. From the PD results of treated vegetable oils it is evident that, the PD inception voltage of Rice bran oil and Sesame oil were almost same and are nearly 20-30% more than the mineral oil. This shows that the PD activity will begin at lower voltages in mineral oil compared to vegetable oil. Also, during the inception of PD, the magnitude of peak charge in mineral oil is 1.5 times more than that of the vegetable oils. From the results, it is

evident that the Rice bran oil and Sesame oil have required potential to be used as liquid dielectric coolant in transformers.

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