Investigation of Partial Discharges in Synthetic Ester-Pressboard under AC Stress

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***Abstract*— Pre-compressed pressboard was commonly used in power transformers along with mineral oil. Pressboard in combination with mineral oil is suitable composite insulation for oil filled transformers over several decades. Synthetic ester is a suitable alternative for mineral oil due to its biodegradable and fire resistant property. It is also compatible for transformer insulations as per recent research studies. Intent of this paper is to find out the suitability of synthetic ester as transformer insulation, with respect to partial discharge studies. Understanding partial discharge characteristics of synthetic ester with an influence of moisture, conducting particles and bubbles, the experimental study was carried out. Measurements of PDIV, PDEV, maximum apparent charges, and PRPD patterns were recorded in order to analyse the effect of various impurities over partial discharge activity. Oil moisture has more impact over board moisture.**

Keywords—Partial discharges (PD; synthetic ester; phase resolved partial discharge pattern (PRPD); apparent charge (pC).

I. INTRODUCTION

Oil-pressboard was commonly used in power transformer for electrical insulation and mechanical support purposes. Physical, chemical, electrical properties of transformer oil are subjected to change with environmental conditions, and these properties depends on the crude oil and on the refine process. Dielectric strength of mineral with pressboard is 200-250kV/cm and permittivity 4.4 [1]. Moisture and particle in the oil leads to local electric stress which initiates the discharges at interface of the insulation.

Naphthenic and paraffinic based liquids have been commonly used as liquid insulation and coolant in power transformers with pressboard material. In recent decades, there has been scientific research into the partial discharge and flashover at oil/pressboard interface of composite insulation system The focuses of the previous studies was formation of carbonization marks along the pressboard surface due to surface discharge phenomena and also change in PD behaviour of oil-pressboard samples with the effect of thermal or electrical ageing. However, research in the change of phase resolved PD pattern and apparent charge in pressboard samples impregnated with transformer oils especially in synthetic ester has not been widely reported. Experimental investigations of the change in PD behavior in oil-pressboard insulation with some impurities were performed. The purpose of this study is to find the suitability of synthetic ester as an alternative of mineral oil.

The pressboard with different oils and its breakdown properties have been discussed in next session. Followed by detailed experimental methods of oil pressboards. Last session describes the experimental results with some possible scientific explanations.

II. PRESSBOARD WITH TRANSFORMER OIL AND ITS BREAKDOWN MECHANISMS

A pressboard is actually nothing other than a thick insulation paper of high quality. Insulating papers are made from unbleached sulphate cellulose. Pine, poplar and straw are three cellulose types [2]. Mechanical strength of the cellulose is based on fibre length, out of the three types of cellulose; soft pine has highest mechanical strength. Alpha cellulose required for manufacturing is a high-polymer carbohydrate chain consisting of glucose units with degree of polymerization around 2000 Chemical formula of alpha cellulose is shown in Fig. 1.

Mineral oil is an excellent insulator and cooling media and is still dominant among all types of liquid dielectrics used in power transformers. However, environmental safety concerns have increased interest in ester based liquids. Effect of various stresses like AC stress, impulse voltage and formation of white marks due to partial discharge and surface flashover studies on mineral and ester based liquids has been investigated [3-6]. The dielectric behaviour at AC stress as a function of the water

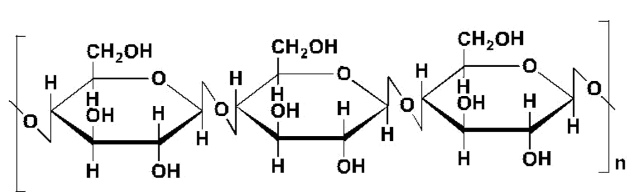

Fig.1. Chemical form of cellulose [2]

content of the samples, particularly at the oil/cellulose interface revealed pronounced effects [7]. In surface discharge studies high speed camera rate of 250 µs/frame and dead time between sequential frames is 0.5 µs have been used to observe the carbonization process and shadow graph images for streamer channel visualization of discharge marking. Streamer attachments observed by the shadowgraphs would suggest that charge carriers were stored on the surface of the solid dielectric barrier [8]. Effects of harmonic AC voltage on surface discharge formation in oil-pressboard insulation system investigated using ATR-FTIR and PRPD by R.Sarathi et al. [9]. Cavity formation timing of three differently aged oils with application of AC stress was investigated and it was observed an increase in PD voltage with average duration of burst varying from 0.7µs to 3µs [10]. Effect of high voltage impulses in PD activity was discussed in detail with the support of experimental work. R.C. Kiiza et al. found that decrease of the PD parameters like, PRPD pattern, PDIV voltage can be considered as a sign of severe degradation of oil-impregnated paper [11].

III. EXPERIMENTATION

Effect of moisture in pressboard, and oil on the PD behaviour of the synthetic ester-pressboard insulation system was studied by using suitable experiments.

A. *Sample Preparation*

Five different combination samples were used in this study 1) Pressboard moisture, 2) oil moisture 3) floating particle in oil, 4) particles in surface of the oil 5) bubbles in the oil. Pre-processing of all samples and high voltage experiments were complies with the IEC 61294 [12], IEC 60270 [13] standards respectively. Drying, filtering and impregnation are three main processes of sample preparation. Objective of drying of the pressboard is to remove the water content in pressboard surface. During the drying process, moisture is transformed from liquid to vapour. Pressboard size was kept 9 cm x 10 cm taking into consideration the size of the test cell. The thickness of the board was chosen to be 1.5 mm (see in Fig. 2). It must be pointed out that higher board thicknesses would have required large drying time.

Fig. 2. Pressboards kept in hot air oven for drying

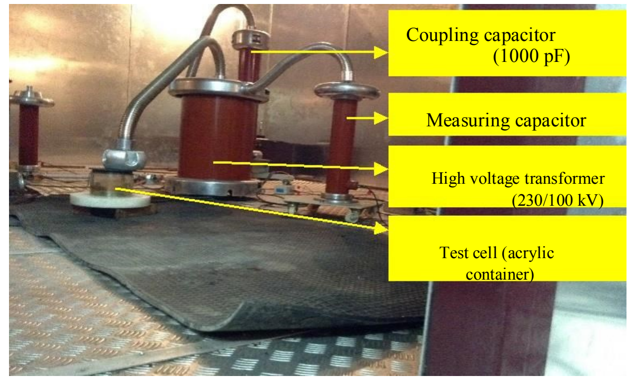

Fig. 3. Partial discharge experimental setup

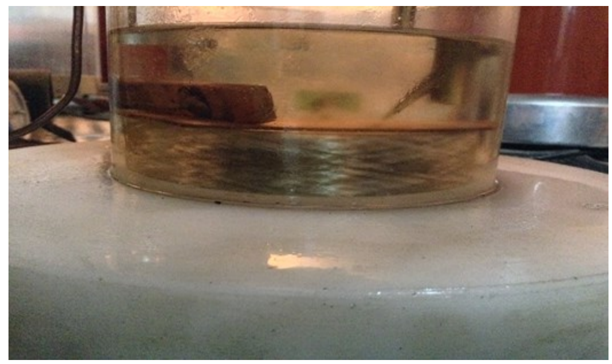

Fig 4. Test cell

All pressboards were kept in air circulated hot oven at 105°C, for 24hrs. Then, the dried boards were placed in vacuum desiccators at vacuum of less than 5 mbar. Oil was filtered using filter paper of pore size 42. The next step was the impregnation of the pressboard in oil. This was carried out under vacuum while ensuring a uniform flow rate. The HV experimental set up as shown in Fig.3.

The test cell is made of acrylic and needle is brass with a tip radius of 23 m (see in Fig. 4). We used a 5 mm thick planar ground electrode. The gap distance between the electrodes was kept 45 mm for all experiments. We cleaned the test cell and electrodes with acetone and rinsed twice with oil for each experiment.

Initially voltage applied is 0 kV then increased by step 1kV/sec up to PDIV. Humidity level and oil characteristics were measured before each experiment.

III. RESULTS AND DISCUSSION

We considered four different samples in this study: (1) moisture in the board, (2) moisture in oil, (3) copper particles at the center of the board with floating particles in the oil, and (4) bubbles in the oil. To compare the partial discharge behavior with the influence of oil and board moisture, we performed the measurements in following order at the following voltages: a) partial discharge inception voltage PDIV (30 kV), b) above 4 kV PDIV (34 kV) and c) above 8 kV PDIV (38 kV).

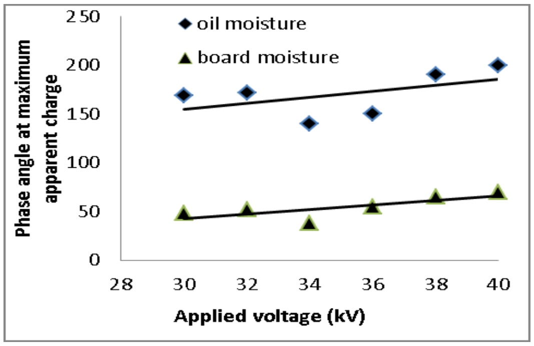

Fig. 5. Phase angle change with applied voltage (positive half cycle)

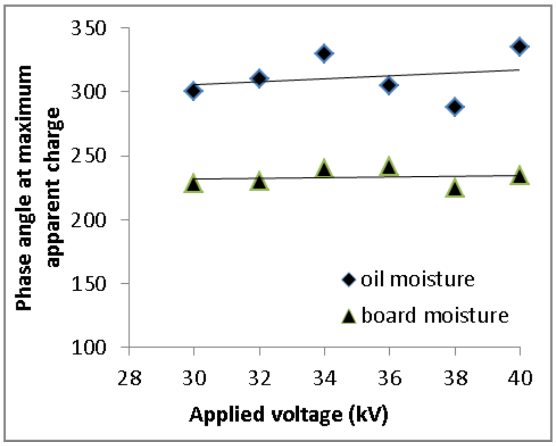

Fig. 6. Phase angle change with applied voltage (negative half cycle).

A. Behavior of PRPD Patterns with Respect to Oil Moisture and Pressboard Moisture

Fig. 5 and 6 indicates the maximum angle of PD repetitive pulses in positive, negative half cycle over applied voltage respectively. Phase angle difference is 30 % more in oil moisture over board moisture and also more fluctuations in positive half cycle is seen in Fig. 5. But in negative half cycle no much difference in phase angle. Possible reason for these changes was chemical reactions caused by oxidation process due to water content in oil.

Fig. 7 shows the rate of change of discharge against moisture synthetic oil. At different voltage levels the degradation process of pressboard with influence of moisture is investigated via PRPD patterns. Press paper holds 5-10% of moisture from ambient, but in case of pressboard it is based on its thickness and density.

This study used board with thickness of 1.5 mm. Fig. 8 shows the tendency of apparent charge against applied voltage. The overall discharge magnitude with effect of moisture on board does not change with applied voltage (as per Figs. 7 and 8); however, the discharge voltage increases with increasing oil sample moisture, indicating that oil has a greater influence on breakdown.

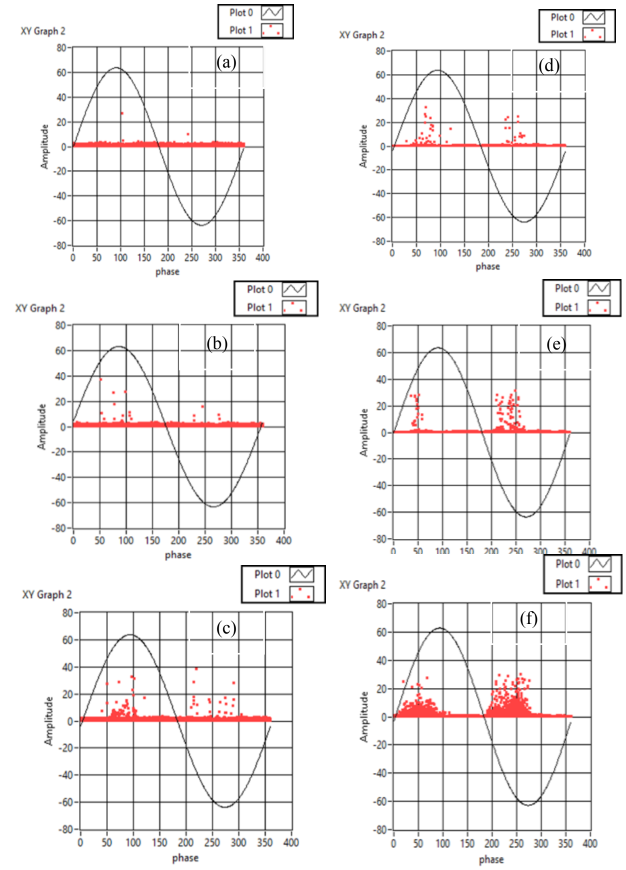

Fig. 7. PD patterns of board moisture at difference voltages (a) 30 kV; (b) 34 kV; (c) 38kV. PD patterns of oil moisture at difference voltages (d) 30 kV; (e) 34 kV; (f) 38kV.

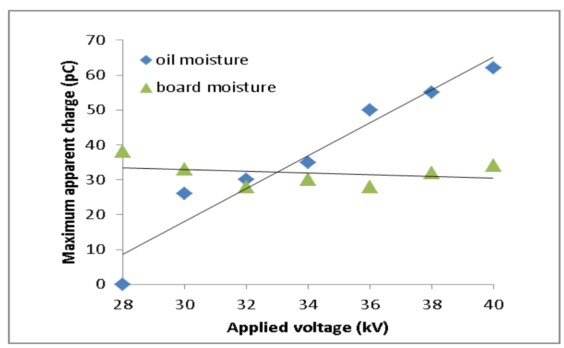

Fig. 8. Apparent charge with applied voltage

In the same case of partial discharge inception voltage level (30 kV) the apparent charge 33 pC in board moisture sample is higher than oil moisture 26 pC (in Fig. 8) due to contact between moisture board and tip of high voltage electrode. Then further increase of voltage the apparent charges were suddenly raising in oil moisture sample.

B. Copper articles on in oil

Copper particles at the center of the electrode as shown in Fig. 9. These kinds of particles may exist in transformer insulation due metallic tank wall dust, small metal particles inside the oil, particles from recirculation system, and badly

Fig. 9 Picture of copper particles at the center of the electrodes.

earthed objects [14]. Electrophoresis causes these particles to drift along oil and form a small conducting region. Fig. 10 (a) and 10 (b) show the PRPD patterns with copper particles on the surface of Pressboard at 17.5 kV and 22.5 kV, respectively

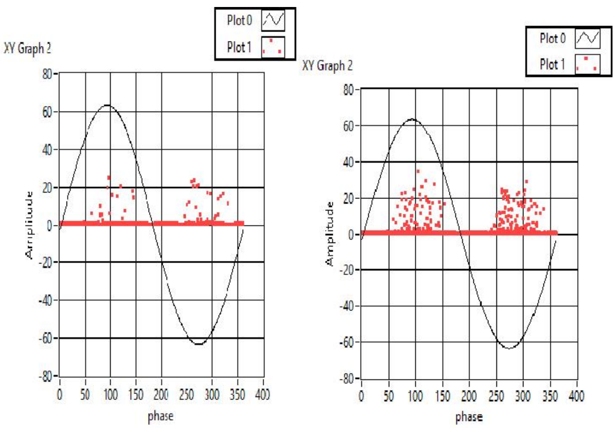

Fig.10. PD pattern of oil-pressboard samples with Cu particles a) 17.5 kV b) 22.5kV

Fig. 11 Oil-pressboard samples with copper particles.

Fig. 11 shows that Cu particles floating in synthetic ester. The PDIV voltage of particle in pressboard surface sample is 18.5 kV. It was higher than floating sample 13.5 kV. It implies that the local electrical field initiated by floating Cu sample is not enough to trigger the discharge pulses. In the same case discharge pulses on Cu particles were spread over the pressboard surface is quite high as shown in Fig. 12.

D. Gas Bubbles in the Oil

Artificial bubbles have been created with the help pump. The PD magnitude span over 30°- 120° in the positive half cycle and 230°-280° in the negative half cycle.

Bubbles of smaller size do not create local field stress or PD source but bigger size bubbles are turbulence in nature causes severe effect [14]. For experiments, we created artificial bubbles of smaller size that moved toward each other and coalesced into a single big bubble that will act as local stress with an applied AC voltage. Fig. 13 shows artificial bubbles created in synthetic oil. Most of the PD pulses appear in in vertical area of both cycles (50°- 70 °of positive and 220°-260° in negative half cycle shown in Fig. 14).

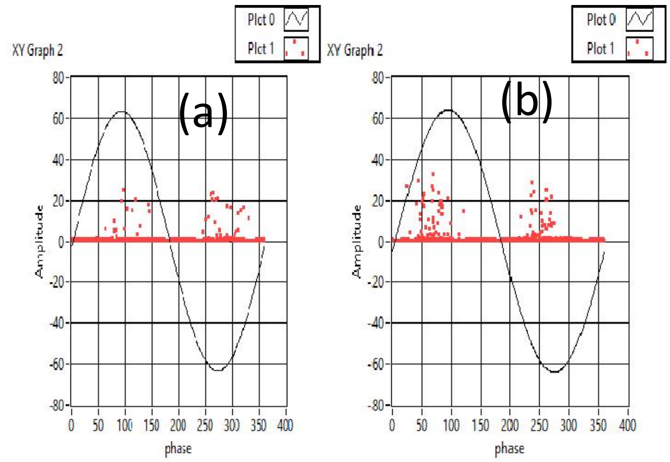

Fig. 12. PD pattern of oil-pressboard samples with floating particles for (a) 17.5 kV (b) 22.5kV.

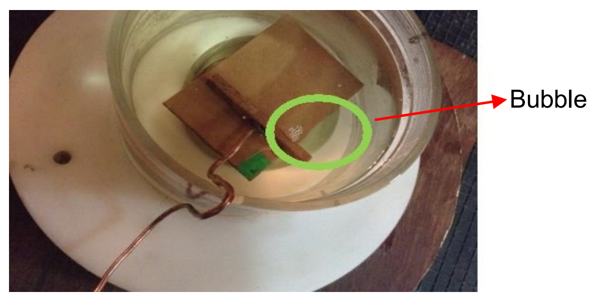

Fig. 13 Oil-pressboard samples with bubbles.

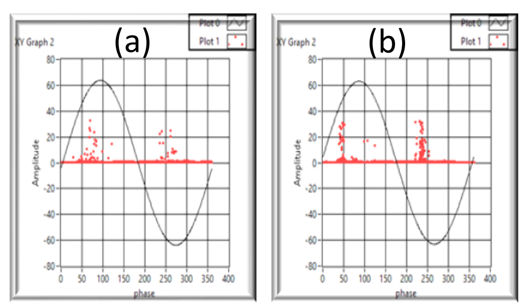

Fig. 14. PD pattern of synthetic ester -pressboard sample with bubbles for (a) 17.5 kV b) 22.5 kV.

IV. CONCLUSION

This study reported experiments that characterized the surface partial discharge phenomena at synthetic-ester and pressboard interfaces with various impurities. The impurities considered in this study include moisture in oil, moisture in pressboard, floating and attached copper particles, and gas bubbles. We have further investigated the suitability of synthetic ester as transformer insulation with respect to partial discharge. We observed less change in PD patterns and PD inception voltage because of moisture in Pressboard compared to moisture in oil samples. However, samples of moisture in oil exhibited a linear change in the magnitude of PD. Copper particles kept in between electrodes attached to the Pressboard surface have highest discharge magnitude compared to the floating particles in oil. PD behavior of gas bubbles in oil samples had similar effects to moisture in oil samples. These results of different impurities may elucidate PD behavior of synthetic ester-pressboard composite system.

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