Tracking and Erosion Resistance of Silicon Rubber Samples Subjected to Environmental Conditions

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Abstract— **Assessment of the material degradation properties in the laboratory similar to the field conditions is still a challenge. In the present work an attempt is made to study the effect of environment circumstances on the tracking and erosion resistance. The evaluation of tracking and erosion resistance of Silicone Rubber insulator samples is carried out for the normal and different acidic solution simulating acid rain. The conditions of pollution/ contamination severity level are also taken into consideration by keeping the conductivity of solution approximately 2.5 mS/m. A new experimental arrangement is set up based on the IEC 60587 and ASTM D-2303 standards. The constant voltage method is employed to find the relative performance of silicone rubber samples of different chemical composition. Comparative analysis is done for the acid rain solution and the standard solution of NH_4Cl. Harmonic analysis is carried out using the obtained leakage currents and physico-chemical analysis involving SEM EDAX is carried out on treated samples to verify the surface morphology.**

I. Introduction

Silicone rubber insulators are widely used in the high voltage insulation system including outdoor and indoor applications. In case of overhead line silicone rubber insulators has shown numerous advantages over conventional ceramic or glass insulators, like light weight, high mechanical strength, slim design, long post structure, better hydrophobic properties and better performance under polluted or contaminant conditions etc. [1]. With such desirable advantages there are some disadvantages also associated with the polymeric insulators one of them is the material being organic in nature, it gets degraded by itself over a period of time. So to deal with such problems related to aging and long term performance it is required to improve the material properties to make it resistive to self-degradation or aging.

The base polymeric compound in the Silicon rubber is polydimethylsiloxane (PDMS) having a main chain as Si-O-Si and two methyl group attached to each Silicon (Si). The methyl group is responsible for the better hydrophobic properties and it may lose its hydrophobicity temporarily when subjected to surface degradation and having an inherent property to regain it hydrophobicity with a short duration by movement of low molecular weight compounds form the bulk to the surface. One of the interesting property is that it transfers it hydrophobic characteristic to the pollution layer over its surface thereby avoid the problems of dry band arcing [2-5]. Different methods were used to find out tracking and erosion resistance and improvement of material properties by adding different fillers for e.g. Aluminum Trihydrate (ATH) is used as a filler that improves its thermal properties [6-9]. The tracking and erosion resistance is one of the important parameter to evaluate the insulating material as per CIGRE report WG D1.14 [10]. The well-established test for the evaluation of tracking and erosion resistance for insulating polymeric shed material is used for the study.

In this paper the effect of environmental stress has been studied on the tracking and erosion performance of Silicon rubber samples. This study is based on the std. ASTM D2303 [11] and IEC 60587 [12]. The effect of environment is taken into consideration by introducing the effect of acid rain and comparative study is done with standard test. The results observed are found to be interesting and this study provides a scope of improvement in material properties to make it batter for long term applications.

II. Experimental Arrangement

A. Experimental Set up

The experimental setup is designed and fabricated as per IEC 60587[12], ac source of 50 kV / 50 mA is used and the applied voltage is 4.5 kV rms between the electrode. The block diagram of experimental arrangement is shown in Fig. (1). A series resistor bank comprising of resistors of 1 kΩ, 11 kΩ, 22 kΩ and 33 kΩ, the suitable resistor is adopted accordingly for the selected voltage range. The electrodes are made of stainless steel of 0.5 mm thickness electrode and for each sample fresh electrodes are used in the study. A peristaltic pump is used for controlling accurate flow of contaminant. The discharges during the experiments are monitored using the RIGOL digital storage oscilloscope (100 MHz and 1 GS/s). The online Fast Fourier Transformation (FFT) is performed to obtain the frequency component of the discharge current. The test duration is kept fixed for about 3 hours.

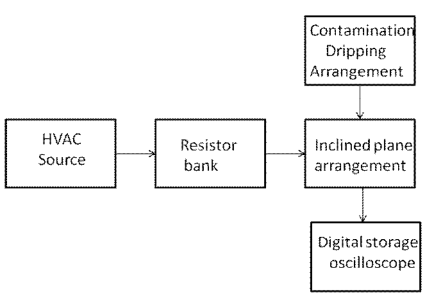


Fig. 1. Block diagram of experimental set up

B. Test samples

The Silicon rubber material are obtained directly from the commercial manufacturers for present study. Four different types of High Temperature vulcanized (HTV) silicon rubber samples are used. The samples are sized as per the std. 120 mm x 50 mm x 6 mm. All samples are cleaned using the mild cleaning agent Iso-propane alcohol before the experimentation.

C. Contaminant preparation

To simulate the effect of different environmental conditions the contaminant is prepared based on the data physically observed acid rain composition [13]. The comparative study is done with the contaminant as per [12] which suggests only NH_4Cl salt. The acid rain composition used in the present experiment is presented in Table 1. The pH value is adjusted to 3.3 approximately by adding nitric acid to the contaminant solution.

TABLE 1: SALTS USED FOR ACIDIC RAIN COMPOSITION

Ingredi-ents/Salts	Quantity (mg/l)
NH_4Cl	235
NaCl	170
KCl	5.9
$MgSO_4$	35.2
$CaSO_4$	29.4

III. EXPERIMENTATION, RESULTS AND DISCUSSION

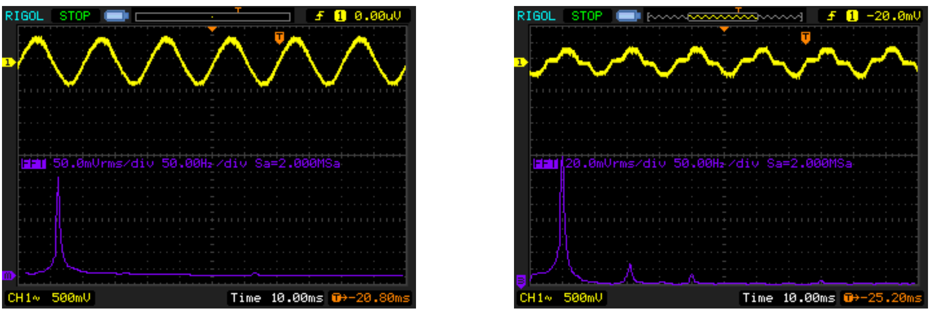
In the present experimental study, the authors attempted to investigate the effect of environmental stress in silicon rubber insulating samples by considering the highly acidic contaminant simulating aid rain case. The method utilizes the dry band acing phenomenon [14] which leads to the failure due to continuous exposure of sample surface due to the scintillation or partial arcs. When contaminant flows on the surface and with the application of voltage, leakage current starts flowing through the contaminant causes heating and leads to the evaporation initiating the formation of dry bands, across these dry bands the discharges happen due to huge potential difference across it. The continuous discharges lead to the formation of carbonaceous tracks on the surface and material gets eroded.

A. Leakage current measurements

The leakage current is measured at regular interval of time during the experimental period. Initially, the continuous channel of contaminant is formed on the surface of silicon rubber sample that bridges the gap between the electrodes, the leakage current observed to be 50 Hz frequency component due to flow of only resistive component in the circuit as shown in Fig. 2(a), but after some time the heating caused by the leakage current leads to the surface scintillation and dry band arcing and during this time the leakage current consists of higher order odd harmonics component as shown in Fig. 2(b), this heating may be localized and lead to severe burning and material erosion as shown in Fig.3(a-e).

B. Thermal imaging

The temperature profile of the sample surface is also captured using the infrared thermal imager (Testo-875II model). The thermal image and temperature profile is shown in Fig. 4(a-c), gives the thermal image of the sample under investigation along with the real image showing hot spot formation near ground electrode junction. This dry band arcing phenomenon is also given in [15] and temperature distribution over the surface and it is observed that the temperature is found to be more at lower ground electrode and this is because the scintillation due to dry band arcing (DBA) are more concentrated at the ground electrode further leading to huge material erosion form this region.



(a) *(b)*

Fig. 2. (a) Sinusoidal current component during bridging the gap between electrode (b) Leakage current during DBA

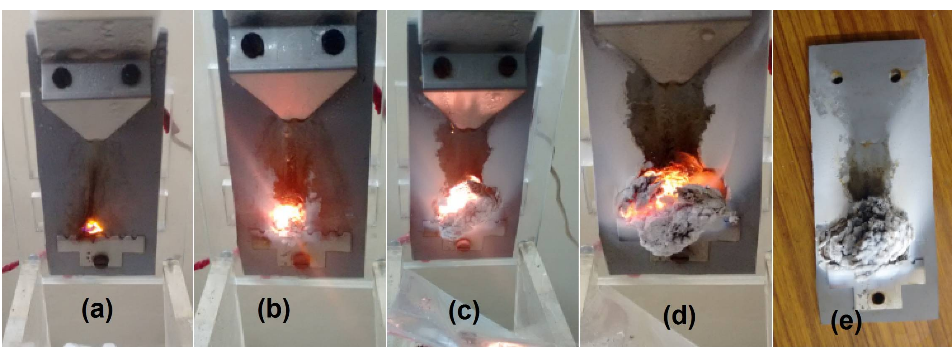
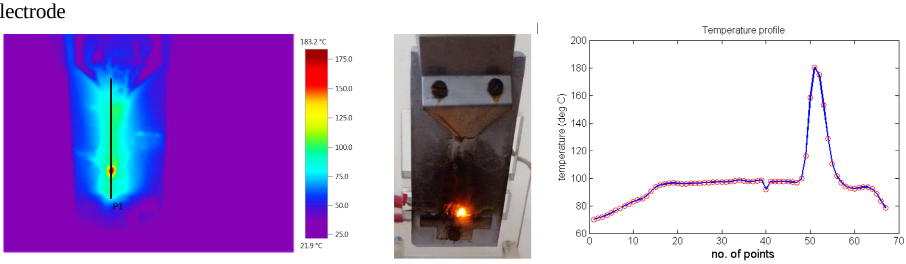


Fig. 3 Sample behavior during experimentation (a-d) and (e) is after experiment material erosion at ground electrode

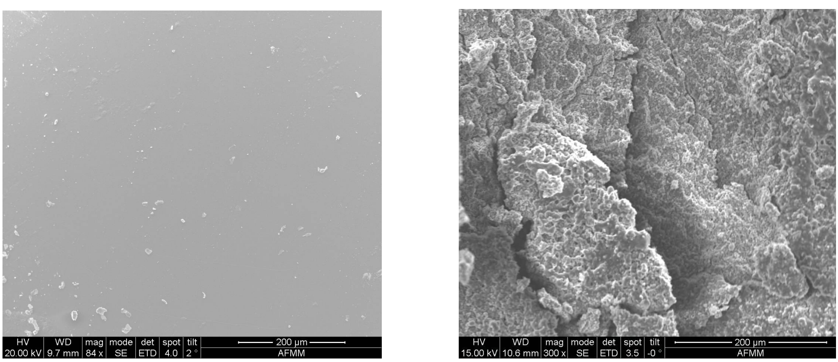


(a) *(b)* *(c)*

Fig. 4. (a) Thermal image of the sample under treatment (b) real image (c) temperature profile along the vertical line shown in (a)

C. SEM and EDAX Analysis

The scanning electron microscope (SEM) and energy dispersive X-Ray analysis (EDAX) is also carried out on the fresh and treated samples. Fig. 5 shows the SEM image of fresh and treated samples and Fig. 6 represents the EDAX plot showing the x-ray count from different elements on the surface on vertical axis and present element on horizontal axis. It can be observed that the treated sample compared to fresh sample, the peak of aluminium is higher. The reason can be attributed to release of the aluminum from the Aluminimum Trihydroxide (ATH) due to the severe localized heating. Thus the traces of aluminum element get into the surface and hence EDAX has detected more count for the aluminium peak.

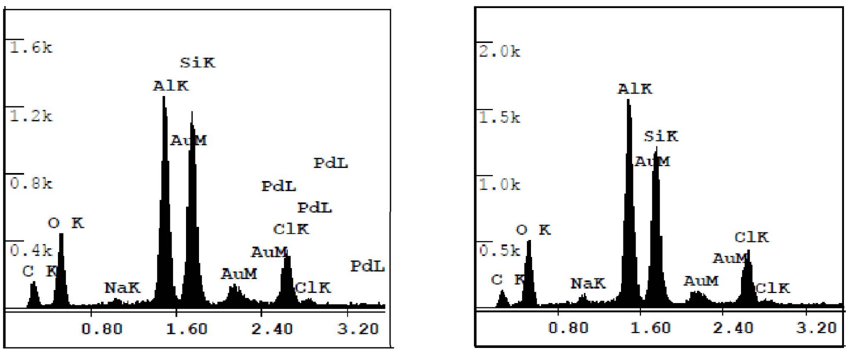


(a) *(b)*

Fig. 5. SEM images with 200 um (a) fresh and (b) treated sample of silicon rubber

D. FTIR Analysis

The Fourier Transform infrared spectroscopy (FTIR) also carried out on the samples to analyze the chemical changes happening on the surface during the treatment with different contaminants. The FTIR is performed using the Perkin Elmer make FTIR/ MIR spectrometer fronteir model with attunuated total reflection (ATR) furnished with the diamond crystal. In this study the samples were taken from several parts of treated material and worst affected visually observed regions. Total sixteen scans were carried out to get FTIR spectrum for one test samples to assure accurate spectrum. The chemical bonds of interest in the samples are C-H symmetric stretching in CH_3 at 2960 cm^{-1}, CH_3 asymmetric stretching at 1260 cm^{-1}, Si-O-Si at 1008 cm^{-1} and Si-C symmetric stretching at 788 cm^{-1}. The FTIR of fresh sample is compared with the treated sample as shown in Fig. 7. It is observed that the main chain Si-O-Si peak corresponding to wave number 1008 cm^{-1} is found to be shifting upwards, which means that the sample is lacking in these bonding and confirms the bond breakage. This also confirms the adverse effects of acidic environmental conditions on the sample material in service life.



(a) *(b)*

Fig. 6. EDAX analysis plots where x-axis is dispersive energy and y-axis is the X-ray counts where (a) is before treatment (b) after treatment

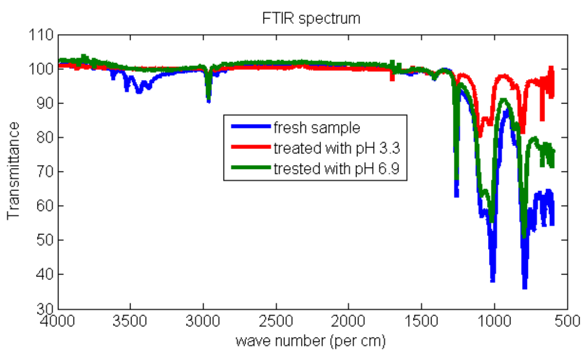


Fig. 7. FTIR spectrum comparing the fresh and treated samples with fresh and treated sample with pH 3.3 and pH 6.9

IV. Conclusions

The present investigation is conducted on the silicon rubber insulator samples to see the effects of different environmental conditions. The effect of differential environmental condition is simulated using acidic rain effect and the results for treatment of samples with acidic and normal contaminant are compared. It is observed that the application of acidic rain contaminant adversely affects the samples, also the damages caused under acidic environment is found to be more severe as compared to normal contaminant, this is confirmed by FTIR analysis and further the degree of acidity in contaminants resulted in more damages on the surface and further results in the reduction of the time to track.

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