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Impact of Ultraviolet Radiation on an Artificially Polluted Silicone Rubber during Inclined Plane Tracking Test

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This paper presents experimental results obtained on tracking and erosion resistance of Silicone rubber (SIR) with and without pollutants. The IEC-60587 Inclined Plane Tracking and Erosion Test method combined with UV radiations of different intensities was employed to assess two different formulations with same base polymeric material (SIR). The hydrophobicity recovery property of silicone rubber formulations before and after inclined plane tracking test was studied besides the effect of corona. Some of the physical, thermal and electrical properties were compared before and after inclined plane tracking test. It is inferred from the analysis carried out on the experimental results that the intensity of UV radiation plays a major role in deteriorating the surface characteristics of the material. It is also found that the introduction of UV in the test method has helped in distinctly evaluating polymeric materials. The effect of two different pollutants was not the same on formulations considered for the study, which implies that the additives play a dominant role in the overall performance of the material than the base polymer. The study also revealed that a formulation with a better performance under a certain pollutant need not have to behave the same way under a different pollutant. Presently, CIGRE Working Group (WG D1.14) is active in standardization of material aspects besides developing suitable methodology for the testing of polymeric materials for outdoor insulation application; the inferences appear to be an useful input to both CIGRE working group and International Electro technical Committee (IEC TC 15 PT 2).

Keywords: *Inclined plane tracking IEC 60587, UV radiation, Silicone rubber, Pollutant.*

1.0 INTRODUCTION

Polymeric materials are used as weather sheds for outdoor insulation for more than three decades. The choice of material for weather sheds is equally important for insulator design besides its processing. The material should not only be capable of withstanding the effect of environmental stresses, surface arcing and leakage currents but also should remain stable against these effects during the course of aging in order to provide a long and useful design life of the insulator. Aging is primarily due to the influence of environmental stresses, the effect of moisture and applied voltage which results in tracking and erosion of weather sheds. The evaluation of these materials in laboratory, to correlate with the types of failures that would occur in the field is of great concern to all those who are involved in making a polymer raw material into a product.

Outdoor insulation, in general, experiences environmental stresses like wind, fog, snow, rain

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besides exposure to UV radiation. Insulators made from polymeric materials are normally qualified for outdoor use by accelerated life tests that typically include salt fog, high AC voltages but with insignificant levels of UV [1]. The effect of UV with other stress factors present in the accelerated life test remains unknown for polymeric materials.

The standard IEC 60672 specifies the properties required for ceramic materials used for electrical insulating purposes. However, an adequate standard is yet to come out for polymeric material. Some of the utilities have laid stringent specifications for material and a few manufacturers have their own criteria or test routines for selection. This situation has led to different opinions on the significance of material parameters and their limits. CIGRE WG D1.14 is focused on developing and bringing completeness and adequacy in standard with minimum test requirement besides the material properties earlier identified [2,3]. This group is also into developing suitable methodology for the testing. Some efforts are also on going in Central Power Research Institute in this direction.

Among the housing materials used today for polymeric insulators, rubber based dominate, especially poly-di-methyl-siloxane (Silicone rubber, SIR). Hence, in the present investigation, the performance of commercially available two different formulations of silicone rubber is evaluated with modification to the conventional method prescribed in IEC 60587 standard [4]. The intent of present investigation is an attempt to bring out the impact of UV radiation during inclined plane tracking test.

The paper summarizes the results of the inclined plane tracking and erosion tests (IPTET) carried out on the materials without and with UV radiation of different intensities. Also, the performance of two different formulations with contamination coated on it subjected to IPTET+UV is discussed. The hydrophobicity recovery property of silicone rubber formulations before and after inclined plane tracking test and corona test are presented. Some of the physical (weight of the specimen), thermal (temperature at various locations on the specimen during IPTET) and electrical properties, viz. arc resistance, surface and volume resistance, permittivity and tan ∂ measured before and after inclined plane tracking test are also discussed. The inferences from this investigation are likely to form an input to CIGRE WG D1.14 and IEC TC 15 PT2.

2.0 EXPERIMENTAL INVESTIGATION

2.1 Inclined Plane Tracking Test with UV Radiation

A schematic diagram of test setup is shown in Figure 1. A flat specimen of dimension 120×50×6 mm is mounted at an angle of 45°. A conductive contaminant [ammonium chloride (NH_4Cl) 0.1% by mass and 0.02% by mass a non-ionic wetting agent in distilled water] is allowed to drip on filter paper at the rate of 0.6 ml/min and is allowed to flow along the surface of the sample towards the ground electrode, where dry band arcing mostly takes place. A constant voltage of 4.5 kV is applied between 50 mm inter electrode spacing throughout the test duration of 6 hours and the observation is recorded periodically. A photograph of the test arrangement with UV radiation imposed on the specimen is shown in Figure 2.

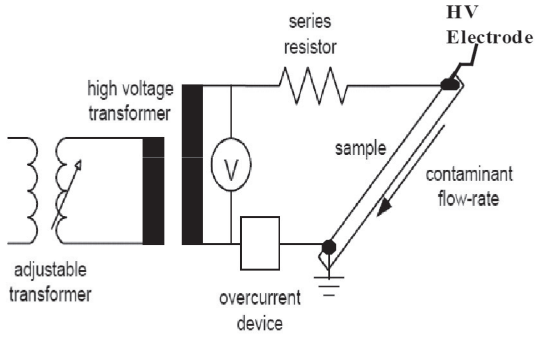

FIG. 1 SCHEMATIC DIAGRAM OF IPTET SETUP

In the present experimental study, UV lamp of OSRAM make, 300 W is used as the UV source.

The lamp is designed to emit only UV ‘A’ radiations greater than 300 nm wavelength as contained in the sunlight. A Radiometer, Lutron make-340, is used to arrive at placement of UV source from the center of the mounted test specimen, corresponding to three irradiances, viz. 23 W/m^2, 49.3 W/m^2 and 72.1 W/m^2, which resulted in distances 0.315 m, 0.21 m and 0.14 m respectively. Two types of pollutants were sprayed on the silicone rubber samples by spray method. The contaminants used are Fly ash and coal dust. These contaminants are generally seen near the thermal power stations and brick kiln industries, respectively. The coating solution is prepared in one liter of distilled water with 40 g of pollutant to achieve conductivity of 40 mS/cm. The effect of two different pollutants was investigated for the two material formulations during IPTET+UV.

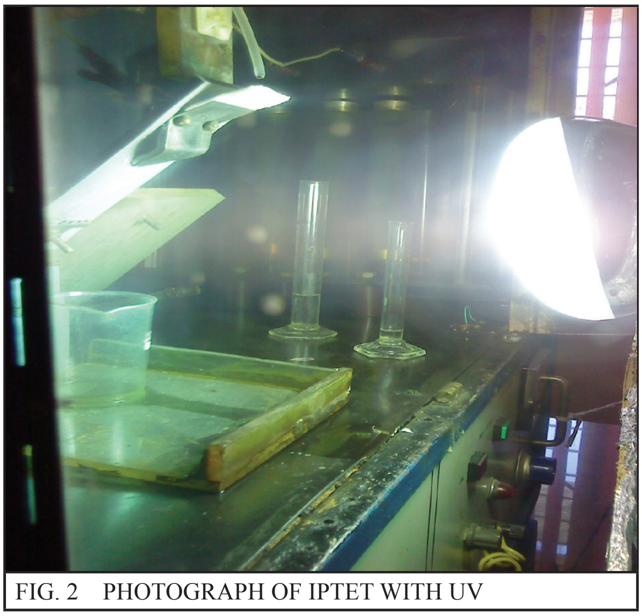

FIG. 2 PHOTOGRAPH OF IPTET WITH UV

The test method as briefed above is employed to differentiate between two materials on the basis of their resistance to the simultaneous action of both voltage and UV radiation stresses along the wet surface of the solid. The study derived qualitatively the effects resulting from the action of electrical discharge upon the material surface. The effects are similar to those that may occur in service under the influence of dirt, dust (fly-ash, coal) combined with moisture condensed from the atmosphere.

3.0 RESULTS AND DISCUSSION

This section presents typical results of two different material formulations “A” (Figure 3) and “B” (Figure 4). The specimens designated A1 to A6 and B1 to B6 are subjected to IPTET (a) according to the per standard IEC 60587; (A1, B1), (b) additionally with three different UV exposure intensities (A2, B2); (A3, B3); (A4, B4), and (c) with combined stresses of UV and pollutants (A5, B5), (A6, B6) to assess its resistance to tracking and erosion. Some of the properties, such as surface resistance (SR), volume resistance (VR), arc resistance (AR), dissipation factor (DF) and dielectric constant (DC), are presented, before and after the IPT test in Table 1 and Table 2, respectively, and discussed about the observation on hydrophobicity, loss of weight before and after IPTET and variation in temperature during IPTET.

FIG. 3 PHOTOGRAPH OF IPTET SAMPLE OF FORMULATION A
A1: ONLY IPTET
A2: IPTET+UV 72.1 W/m^2;
A3: IPTET+UV 49.3 W/m^2
A4:IPTET+UV 23 W/m^2;
A5: IPTET+UV72.1 W/m^2+FLYASH
A6: IPTET+UV72.1 W/m^2+COAL

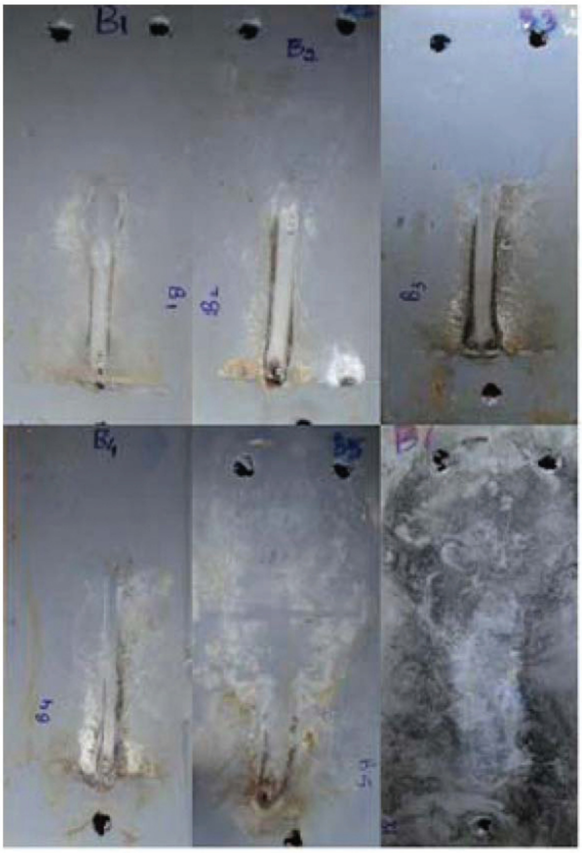

FIG. 4 PHOTOGRAPH OF IPTET SAMPLE OF FORMULATION B
B1: ONLY IPTET
B2: IPTET+UV 72.1 W/m^2
B3: IPTET+UV 49.3 W/m^2
B4: IPTET+UV23 W/m^2
B5: IPTET+UV72.1 W/m^2+FLYASH
B6: IPTET+UV72.1 W/m^2+COAL

It is apparent from ‘A1’ and ‘B1’ that, the deterioration is in the form of filamentary track of microscopic level with slight carbonization along the edges of the track. Slight discoloration was seen and no erosion was observed. The deterioration in ‘A2’ and ‘B2’, subjected to IPTET in the presence of UV exposure of 72.1 W/m^2, is observed to be in the form of erosion with slight pitting near the lower electrode area (ground) and no change in color was observed in ‘A2’.

Chalking, A rough and whitish powdery appearance, is seen on either side of the filamentary tracks in the specimen ‘B2’, besides surfacing of yellowish powder. This could pertain to another filler. The factors which are responsible for chalking are UV radiation and electrical discharge activity. When a small quantity of rubber is removed from the surface because of these factors, the filler material is exposed. One negative effect of chalking, however, is it allows more accumulation of water contamination on the surface. Similar deterioration is observed in ‘A3’ and ‘B3’, ‘A4’ and ‘B4’ subjected to IPTET under the exposure of UV irradiance of 49.3 W/m^2 and 23 W/m^2, respectively. The degradation in the form of erosion is observed to be slightly severe in samples A2:B2, A3:B3, A4:B4 (subjected to

TABLE 1

ELECTRICAL PROPERTIES BEFORE IPTET

Sample ID	Arc resistance (Sec)	Surface resistance, @ 500 V DC	Volume resistance, @ 500 V DC	Permittivity and tan ∂ @ 50 Hz. 500 V, room temperature
	Before	**Before (TΩ)**	**Before (TΩ)**	**Before**
A1, B1	241, 243	1.074, 70.4	204.7, 145.5	4.71, 0.0035 4.61, 0.0241
A2, B2	243, 245	134.3, 97.2	191.3, 136.6	4.77, 0.0030 4.62, 0.0223
A3, B3	245, 242	455.2, 83.6	273.5, 99.6	4.65, 0.0036 4.62, 0.0256
A4, B4	245, 246	775.6, 50.4	367.3, 245.8	4.72, 0.0039 4.63, 0.0247

TABLE 2

ELECTRICAL PROPERTIES AFTER IPTET

Sample ID	**Arc resistance (Sec)**	**Surface resistance, @ 500 V DC**	**Volume resistance, @ 500 V DC**	**Permittivity and tan ∂ @ 50 Hz. 500 V, room temperature**
	After	**After(GΩ)**	**After (TΩ)**	**After**
A1, B1	241, 241	132.5, 1.795	126.8, 100.7	4.87, 0.0273 4.76,0.0290
A2, B2	240, 243	30.5, 0.874	159.2, 99.8	4.96, 0.0292 4.75,0.0271
A3, B3	243, 241	0.11, 105.03	241.3, 35.7	4.85, 0.0292 4.78,0.0265
A4, B4	244, 244	1.234, 1.565	327.9, 159.8	4.85, 0.0276 4.76,0.0289

stresses as in IEC-60587 with UV exposure at different intensities) in comparison to sample A1:B1 (without UV exposure), wherein no erosion was noticed. Comparison of samples A2, A3, A4 and B2, B3, B4 respectively, showed that sample A is less deteriorated to sample B. It is evident from the test results that the introduction of additional UV stress seems to be more realistic and effective in assessing the formulation distinctly.

The samples A5:B5 and A6:B6 subjected to IPTET with UV exposure at the highest irradiance and flyash coal pollutants exhibited varied behavior. The deterioration appeared to be in the form of a filamentary track formation with slight carbonization along the tracked path. Discolouration was seen only in A5 and observed surfacing of filler materials with slight pitting in ‘B5’. Between flyashcoated samples. A5 and B5 erosion is found to be slightly more in B5, in comparison to A5. The surfacing out of filler materials is more in B5 as compared to A5. Hence, it could be inferred that in the presence of fly ash, resistance of sample A is better than sample B.

Similarly, in samples A6 and B6 coated with coal dust, subjected to IPTET combined with 72 W/m^2 irradiance, surfacing of filler materials, slight pitting near the ground electrode, filamentary tracking and erosion, discoloration are observed in sample A6, while all these are not noticed in sample B6. Hence, it is inferred that in the presence of coal dust, formulation B offered better resistance than formulation A. The effect of UV at lower irradiance is predominant in both the formulations in comparison to other irradiances. The repeatability of the inference needs to be checked and ascertained by performing more no. of tests. Chalking in both the formulations could be due to insufficient quantity of UV stabilizers added in the formulation. Thus, in order to differentiate the different formulation’s resistance to tracking and erosion distinctly, it is necessary to have UV, superimposed during IPTET.

It is inferred from the analysis carried out on the experimental results that, the intensity of UV radiation plays a major role in deteriorating the surface characteristics of the material. The effect of two different pollutants was not the same on formulations considered for the study, which implies that the additives play a dominant role in the overall performance of the material than the base polymer, which was the same in both the formulations. A satisfactory performance of a formulation for a particular type of pollutant need not have to behave the same way for other type of pollutant.

With regards to electrical properties (Tables 1 and Table 2), there is significant reduction in surface resistance, i.e. from TΩ to GΩ in samples A and B. However, there is no significant change in volume resistance. It remained in Tera ohm range for specimens before and after IPTET. This is obvious, as the degradation has taken place only on the surface of the specimen and not in volume to give raise to change in volume resistance. A drastic reduction in surface resistance confirms the formation of filamentary tracks. In both the formulations, after IPTET, the dissipation factor had increased, which could be due to ingression of moisture through the filamentary tracks during IPTET. However, there is an insignificant change in permittivity and arc resistance values in both the formulations.

Hydrophobicity classification (HC1 to HC6) is assigned before and after subjecting samples to 100 hours of corona test, according to the STRI guide [5]. Each HC class corresponds to a characteristic wetting pattern and all samples recovered within 48 hours. Immediately after IPTET, surface of all the samples became hydrophilic (HC6) and after 48 hours the samples had regained its initial hydrophobic property (HC1) in both A and B material formulations. Comparison of loss mass (184 mg–491 mg in formulation A and 566 mg–891 mg, in formulation B) to that reported [6] indicated that the higher loss of mass could be due to the poor thermal conductivity of the specimens. So, there is scope for further improving thermal conductivity in both formulations A and B. The temperature was recorded using digital IR thermometer and is observed to increase as IPTET progressed. The maximum temperature during IPTET is 123°C in formulation A and 103°C in formulation B. In IEC-60587, inclusion of UV radiation during tracking test appears necessary and inferences from this study appear to be an useful input, also to CIGRE WG 1.14 and IEC TC 15 PT 2.

4.0 CONCLUSION

Based on the results of inclined plane tracking and erosion tests carried on silicone rubber of two different formulations under UV radiation as additional stress and in the presence of different pollutants, the following conclusions are drawn.

The resistance to tracking and erosion offered by different artificially polluted polymeric materials became distinct and pronounced with UV radiation.

Silicone rubber is functionally specific with respect to its formulation and service conditions. A satisfactory performance of a silicone rubber formulation in the presence of a particular type of pollutant might behave differently in the presence of other pollutant.

The formation of filamentary tracks is substantiated with drastic reduction in the surface resistance from T Ω to G Ω range in both the formulations.

The temperature and loss of mass measurements indicate the requirement to improve thermal conductivity in both the formulations.

Between IPTET+UV test and hydrophobicity test after corona aging, the former is more effective in depicting the surface deteriorations and hence could form an integral part of the IPTET in qualifying a material. Before considering standardization of the proposed procedure IPTET+UV by CIGRE WG D1.14 and IEC TC 15 PT 2, it must be evaluated in various laboratories for checking repeatable and reproducible results in a merry go round procedure.

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