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# Intelligent Aging Evaluation of Polymeric Insulators by Inclined Plane Test

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**Abstract—**Though polymers have tremendous advantages, but due to various disadvantages there usage has been limited. The main limitation is the surface ageing property of polymeric insulators. Though research on polymeric materials has been carried out, ageing properties are not determined exactly. In the present work, inclined plane tracking and erosion tests were carried out on specimen insulator material with different pollution severity prepared artificially. The effect of spacing between the electrodes used was studied by varying the distance between the electrodes. Further tests were also conducted on a section of the full-scale insulator of 66kV. Tests were conducted on specimen insulator material for 100 hours and the test samples were observed for their hydrophobicity property. The details of the experimental setup, the procedure followed, the results, and the discussions are presented in this paper. From the study carried out it was found that a lower severity is vulnerable to ageing of polymeric insulators, which is a valuable result as the surface condition along with electrical stress plays an important role in the ageing of the insulating material.

***Keywords—*** *Polymer insulator, Pollution Severity, Ageing,IPTE test, Hydrophobicity*

## I. Introduction

Generally, insulators produced were of porcelain and glass, which is widely used in overhead lines for transmission and distribution. However, in the early sixties, polymeric materials entered the insulation system and replaced ceramic insulators due to their numerous advantages. The main advantages are weight reduction compared to ceramic, reduced breakage, improved resistance to vandalism, and improved contamination performance.

Though polymers have tremendous advantages, their use has been limited due to their disadvantages.

The main limitation is the ageing property of polymeric insulators. Many difficulties were observed regarding their ageing performance. The factors responsible for polymers' aging are tracking and erosion, chalking and crazing, bonding failures, arcing and flashover, corona splitting and water penetration into the surface boundary, and reduction of hydrophobic properties. Though much work has been carried out on polymeric materials, ageing properties have not been understood thoroughly[1]–[9].

Polymeric insulators have very good hydrophobicity. This is another major advantage of the insulating material for its popularity. However, this property gets affected due to the various service conditions. Much work is still undergoing to understand the factors affecting the hydrophobicity of the polymeric insulating material[1]–[6], [9]–[21].

In the present work, inclined plane tracking and erosion tests were carried out on specimen insulator material with different pollution severity prepared artificially. The effect of spacing between the electrodes used was studied by varying the distance between the electrodes. Further, tests were conducted on a section of the full-scale insulator of 66kV. The details of the experimental setup, the procedure followed, the results, and the discussions are explained in the following subsections

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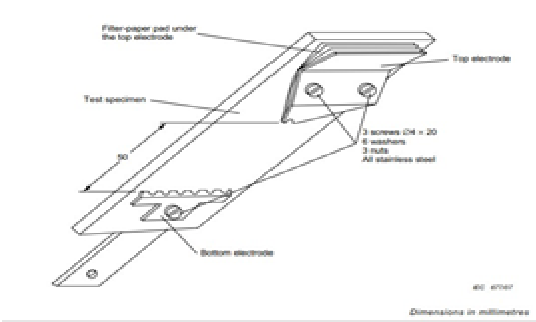


Fig. 1. Specimen mounting arrangement

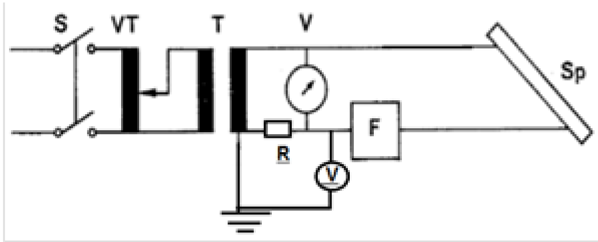


Fig. 2. Circuit schematic for inclined plane test.

Components:
S -Power supply switch, R - the series resistor
VT-variable voltage ratio transformer,V - voltmeter
T - High-voltage transformer, Sp -Specimen
F -Overcurrent device, fuse, or relay

## II. Tests On Polymeric Material Using Inclined Plane Test

Experiments were conducted on an inclined plane for assessing the parameters like pollution severity and electrical stress. Tests where conducted on three different polymeric samples. The measurements of the test sample, mounting procedure, preparation of contaminant solution, and test procedure were in general accordance. The details of the samples, pollution severity, experimental setup, test procedure, results, and discussion are given in the ensuing subsections.

### A. *Specimen Preparation and Mounting:*

Specimen samples were of dimensions 150mmX50mmX6mm considered. Before mounting, samples surface was cleaned with distilled water. Electrodes were fixed symmetrically about the center with a 50mm separation. To maintain a uniform contaminant flow onto the surface of the samples during the entire test duration, 8 layers of filter paper were clamped between the top high-voltage electrode. This acts as a reservoir of liquid contaminant and maintains the flow. The flow rate was maitained using a turntable knob. The desired level of flow was maintained during the entire testing duration. The arrangement for mounting the sample is shown in Fig. 1[22].

The contaminant solution was prepared in general accordance with IEC 60587[22]. Ammonium chloride (NH4CL) along with wetting agent diethyl ether at a concentration of 0.1% and 1% is used in the preparation of the contaminant solution. The contaminent resistivity was maintained at 3.95 Ωm ± 0.05 Ωm at 23 °C ± 1 °C.

### B. *Circuit and Experimental Setup:*

The schematic diagram of the test setup is shown in Fig. 2. Tests were carried out using a 50Hz, 230V/5kV AC testing transformer of continuous duty with a rated current of 0.5A.

The experimental test setup is as in Fig. 3. The specimen was mounted on an inclined plane. The arrangement was placed in a tray so that the contaminant after flowing on the specimen drops, down and gets collected in the tray. All the other devices shown in the schematic diagram can be observed in Fig. 3.

Three numbers of samples were considered for the test. Two severities viz., 0.1% and 1% with a conductivity of 2.53mS/cm & at 23 °C ± 1 °C, of the contaminant solutions were used for the tests. Two different severities were considered to find out, which one will give more deterioration. So that, the same severity will be considered for ageing test.

The flow of electrolytes was regulated at 6 drops per minute and allowed to flow during the entire testing period. The voltage applied was two hours with the flow of contaminant on the surface. A test voltage of 2kV was applied to the test specimen. Initially, both the electrode where separated by distance of 4.1cm. Further, the distance was reduced to 1.8cm. The details of the tests and results are presented in Section III.

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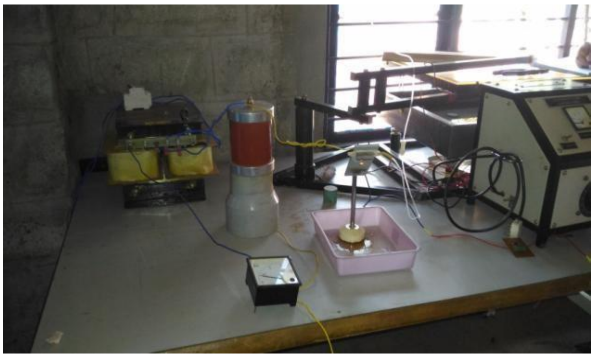

Fig. 3. Experimental test set-up for inclined plane test.

## III. Results Of Polymeric Material Using Inclined Plane Test

| **Table 1:** Test1 - Voltages and Currents For 1% Severity of NH4CL Solution with 4.1cmDistance Between Electrodes | | | |
|---|---|---|---|
| *Samples* | *Voltage (LSV)* | *Current (mA)* | *Remarks* |
| A | 140V | 6 | Not deteriorated |
| B | 120V | 7 | Not deteriorated |
| C | 120V | 5 | Not deteriorated |

Experiments were conducted on 3 samples of polymeric material. The two severities of NH4CL considered were 0.1% and 1%. Tests were conducted in two parts. Test- 1 with 1% severity and Test-2 with 0.1% severity. The voltages applied in each case of severities viz., 0.1% and 1%, along with the leakage current were tabulated with remarks on the condition of each sample, in Table-1 with 4.1 cm distance between electrodes and Table-2 with 1.8 cm distance between electrodes.

### A. *Test-1 On Sample-A, Sample-B, and Sample-C With 1% Severity of the Contaminant Solution.*

Tests were conducted on Samples A, B &C as per the procedure described in Section B, with a 4.1cm distance between the electrodes and 2kV applied. Figure 4a shows the photograph of Sample-A before conducting the test. Figure 4b shows Sample-A after the test.

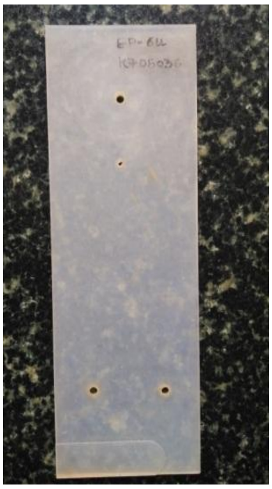

Fig. 4a. Specimen A before testing

Fig. 4b. Specimen A after testing

Figure 5a and Figure 5b show the photographs of Sample-B before and after conducting the test respectively.

Similarly, Figure 6a and Figure 6b show the photographs of Sample-C before and after conducting the test respectively.

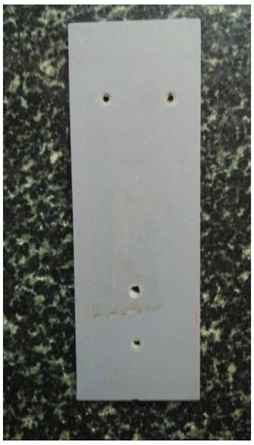

Fig. 5a. Specimen B before testing

Fig. 5b Specimen B after testing

Fig. 6a. Specimen C before testing

Fig. 6b. Specimen C after testing

### A. *Test-2 on Sample-A, Sample-B, and Sample-C with 0.1% Severity of the Contaminant Solution.*

Tests were conducted on Samples A, B &C as per the procedure described in Section II B. Fig. 7a and Fig. 7b show the photograph of Sample-A before and after conducting the test. Sample-A was observed to deteriorate. Fig. 8a and Fig. 8b show the photographs of Sample-B before and after conducting the test. Sample-B has slightly deteriorated. Fig. 9a and Fig. 9b show the photographs of Sample-C before and after conducting the test. It was observed that Sample-C has slightly deteriorated.

From the results in Table-1 and Table-2 and the photographs of the samples in Figure 4b, Figure 5b, and Figure 6b it can be observed that 1% severity and 4.1cm distance between the electrodes was not bringing significant deterioration. Therefore, the distance between the electrodes was reduced to 1.8cm and the tests were conducted with 0.1% severity of NH4CL in Test-2.

**Table 2:** Test1 - Voltages and Currents For 1% Severity of NH4CL Solution with 1.8cmDistance Between Electrodes

| *Sample* | *Voltage (LSV)* | *Current (mA)* | *Remarks* |
|---|---|---|---|
| A | 160V | 28 | Deteriorated |
| B | 120V | 8 | Not deteriorated |
| C | 120V | 5.2 | Lightly deteriorated |

Fig. 7a. Specimen A before testing

Fig. 7b. Specimen A after testing

Fig. 8a. Specimen B before testing

Fig. 8b. Specimen B after testing

fig 9a. sample before testing

fig 9b. sample after testing

From the results tabulated in Table 3, it can be observed that the severity of 0.1% was causing the deterioration of all three samples. Hence it is inferred that a pollution severity of 0.1% is more effective compared to 1 %, hence the 0.1% severity will be used for testing the section of 66kV polymeric insulator.

## IV. Test On Section Of Polymeric Insulator

From the above analysis of Inclined Plane Test on samples, a test for a full-scale insulator was conducted. It was observed from the results in Section III, that the severity of 0.1% is higher, therefore 0.1% severity was selected for the Full-scale Insulator. Test were carried out on one section of polymeric insulator, to analyse the effect of insulator geometry. One section of the polymeric insulator was considered for the experiment as in Fig. 10.

Test where conducted for about 2 hours. A small track has been formed at the parting line as shown in Fig. 11 for an applied voltage of 2.6kV. The deterioration of the section of the insulator was not much so, it can be inferred that more hours of the test may be required which has to be carried conducted for future work.

Fig. 10. Experimental set up on a section of 66kV polymeric insulator

## V. Aging Test Using Inclined Plane Test For 100hours

Tests were conducted on polymeric samples and a part of polymeric insulator for about 2 hours. Though slight erosion was there on good samples, not much deterioration was seen. To perform the ageing further, ageing tests using Inclined Plane Facilities were conducted for about 100 hours, Inclined Plane Tests where conducted out using a 50 Hz , 230 V / 15 kV AC testing transformer (continuous duty) with an output voltage stabilized to ±5 % , it can be varied up to about 10 kV with a rated maximum current of 1 A.

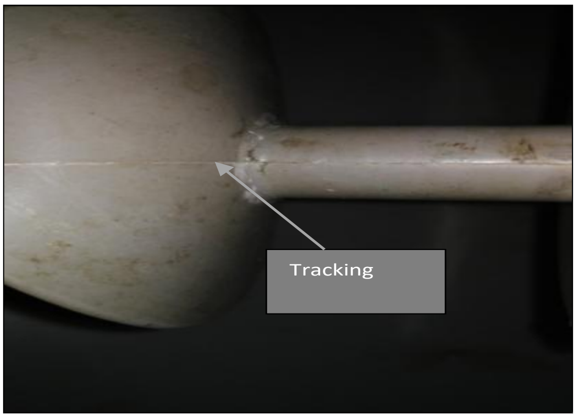


Fig. 11. Tracking on a section of 66kV polymeric insulator after Inclined Plane Test.

Three different samples A, B, and C were used for the test. Initially, the samples surface was cleaned with demineralized water before mounting them for the Inclined Plane Tests as per the sample mounting arrangement presented in Fig. 1. A test specimen of size 150mmX50mmX6mm was cut from the sample. Liquid contaminant for Inclined Plane test of Insulating Materials was prepared as per IEC-60587. A contaminant solution was prepared by using ammonium chloride and wetting agent diethyl ether at a concentration of 0.1 % and 1% respectively. The contaminant resistivity was maintained at 3.95Ωm ± 0.05Ωm[23]. The entire test duration is continuously monitored and the endpoint criterion of the test is decided as per Criterion A or Criterion B mentioned in standard IEC-60587.

The laboratory setup used for the inclined plane facility used for ageing test is shown in Fig. 3. The arrangement is done as per the circuit schematic presented in Fig. 2.

Evaluation of withstanding test followed by ageing test was verified by following criteria. The leakage currents should not exceed more than 60mA and also there should not be any over-current tripping and also there should not be any tracking and erosion on the surface. If tracking occurred more than 25mm with a radius greater than 0.25mm from the bottom electrode, the sample will be treated as failed. Further, it has to be observed that if only erosion occurred without tracking, the depth of the erosion should not exceed 3mm. If any of the conditions occur then the same will be treated as a failure.

## VI. Results Of Inclined Plane vFor 100hrs

Results of the Inclined Plane Test for 100 hours are presented in this section. Leakage current starts flowing through the contaminant on the surface of the samples, after the application of voltage from 0 to 4.5kV. This results in heating and hence drying of the contaminant close to the ground electrode. In this area, dry bands start developing resulting in arcing and leading to erosion in the vicinity of the ground electrode. Tracking and erosion activity and loss of hydrophobicity were observed after the test.

**Table 3:** Test2 - Voltages and Currents for 0.1% Severity of NH4CL Solution with 1.8cm DistanceBetween Electrodes

| *Sample* | *Voltage (LSV)* | *Current(mA)* | *Remarks* |
|---|---|---|---|
| A | 140V | 26 | Deteriorated |
| B | 130V | 6 | Slightly Deteriorated |
| C | 120V | 5 | Slightly Deteriorated |

### A. *Test Results on Sample-A:*

The tracking and erosion were not observed on Sample-A as seen in Fig. 12, and the specimen withstood the applied 4.5kV test voltage for about 100 hours.

In addition to the tracking and erosion, the hydrophobicity of the test Sample-A was also observed. Immediately after the test, water sprayed onto Sample-A resulted in the droplet formation as in Fig. 13. The sample has lost its hydrophobic nature as can be seen from the distorted water droplets on Sample-A in Fig. 13.

After about 48 hours the surface regained its hydrophobic nature as shown in Fig. 14. The reversal process is due to the natural diffusion process, which brings the LMW components from inside to the surface.

**Table 5:** Hydrophobicity classification according to STRI guidelines.

| Sample | Immediately after test | 48 hours after the test |
|---|---|---|
| Sample-A | HC-3 | HC-1 |
| Sample-B | HC-4 | HC-1 |
| Sample-C | HC-3 | HC-1 |

Fig. 12. Test Sample-A after the IPTE test

Fig. 13. Water droplets on Sample-A immediately after the IPTE test

Fig. 14. Water droplets on Sample-A, 48 hours after the IPTE test

The low molecular weight component present at the outer surface of the material is responsible for the hydrophobicity nature of the material. Hydrophobicity is directly proportional to the amount of LMW component present in the material. Sample-A has lost its hydrophobicity due to the loss of the LMW component on the surface. This may be due to the eradication of LMW either by unrestricted wetting along with the application of an electric field or by arcing due to dry band formation.

*B. Test Results on Sample-B:*

Though the specimen withstood a test voltage of 4.5kV, slight erosions were found on the surface after 100 hours of ageing test as in Fig. 15. The anti-tracking properties are governed by the type of Aluminium trihydrate(ATH) in High-temperature galvanizing coating(HTV) silicon rubber.

Immediately after the test and the sample losses its hydrophobic nature shown in Fig.16.The loss of hydrophobicity is similar to that of Sample-A.Within 48 hours Sample-B regained its hydrophobic properties as shown in Fig. 17.

*C. Test Results on Sample-C:*

There was no tracking and erosion observed on the silicone rubber sample C as shown in Fig. 18.

Immediately after the test and Sample -C losses its hydrophobic nature shown in Fig. 19. Within 48 hours Sample-C regained its hydrophobic properties as shown in Fig. 20.

**Table 4:** Surface observation of samples after 100 hours of ageing.

| Sl. No | Samples | Remarks |
|---|---|---|
| 1 | Sample-A | No erosions were found. |
| 2 | Sample-B | Slight erosions were found at the end of the ground electrode. |
| 3 | Sample-C | No erosions were found. |

Fig. 15. Test Sample-B after the IPTE test

Fig. 16. Water droplets on Sample-B immediately after the IPTE test

Fig. 17. Water droplets on Sample-B, 48 hours after the IPTE test

The surface condition of the samples after 100 hours of the IPTE test is tabulated in Table 4. It can be seen that all three samples withstood 100 hours test.

At the end of every test, the image of the samples was captured as in Fig. 15, Fig. 18, and Fig. 21, respectively of Samples A, B, and C. They were classified for hydrophobicity according to the STRI guide. The classification is listed in Table 5, for both cases immediately after the test and 48 hours after the test. It is also perceived that there is a loss in hydrophobicity of the samples with the progression of the test shown in Table 5.

Fig. 18. Test Sample-C after the IPTE test

Fig. 19. Water droplets on Sample-C immediately after the IPTE test

Fig. 20. Water droplets on Sample-C, 48 hours after the IPTE test

## VII. Conclusion

In the present work, experiments were first conducted on samples of polymeric material to ascertain the severity of the contaminant. The tests were on three samples. It was observed that the severity of 0.1% was suitable to carry out further tests as it was causing significant deterioration.

A test conducted on a section of a 66kV polymeric insulator showed light tracking with an applied voltage of 2.6kV for 2 hours. Since the tracking observed was very light, further testing with more hours may be carried out before concluding the effectiveness of the severity.

Further IPTE tests for 100 hours were conducted on all three samples at 0.1% severity. All the samples withstood the test.

The samples were also tested for their hydrophobicity condition after 100 hours of IPTE test. It was observed that the samples were losing their hydrophobicity immediately after the test. But they were regaining their hydrophobicity after 48 hours of conducting the test.

Further work may be carried out to understand the effect of the type of filler material to an in-depth level.

## VIII. Acknowledgments

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