Humidity Influence on Corona Discharge Characteristics on Polymer Insulators under Polluted Conditions

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Keywords: polymer insulator, silicone rubber, corona discharge

Silicone rubber has been widely adopted for housing material of polymer insulators because of superior weatherability, heat resistances and hydrophobicity among various organic materials. Especially, silicone rubber has an excellent hydrophobicity with recovery properties, resulting in higher pollution performance.

However it is inevitable that even silicone rubber polymer insulators start generating corona discharge with time under humid and polluted conditions. And such a corona discharging causes rubber damage because of acid generation.

Since it is assumed that the corona discharge characteristics depend on humidity and pollution conditions on polymer insulators, corona discharge testings were conducted in order to investigate deterioration performance of silicone rubber polymer insulators.

Tests were performed on artificially polluted short specimen insulators by changing humidity in a fog chamber under several pollution conditions. The leakage distance per applied voltage was 100 mm/kV. Table 1 shows the pollution conditions of short polymer insulators.

Figure 1 shows the summarized test results. Under a heavy pollution condition of ESDD: 0.3 mg/cm² (NaCl) and NSDD: 1.0 mg/cm² (tonoko), corona discharge started on rubber housing at 70% level of relative humidity.

It was found that when including MgCl₂, which was a deliquescent material in pollutant, the humidity level to start corona discharge was reduced to 60% or below.

As indicated in Figs. 1 and 2, it was confirmed that although corona rings were effective to mitigate corona discharge to some extent probably due to relaxation of electrical stress, any drastic improvement could not be seen in these polluted and humid conditions.

When testing on washed insulators, no corona discharge appeared.

Table 1. Pollution conditions of short polymer insulators

<table>
<thead>
<tr>
<th>No.</th>
<th>ESDD (mg/cm²)</th>
<th>NSDD* (mg/cm²)</th>
<th>Ratio of ESDD components</th>
<th>Corona rings (dia. ≥ 80%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>NaCl (%)</td>
<td>MgCl₂ (%)</td>
</tr>
<tr>
<td>1-1</td>
<td>0.3</td>
<td>1.0</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>1-2</td>
<td>0.3</td>
<td>0.1</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>1-3</td>
<td></td>
<td></td>
<td>95</td>
<td>5</td>
</tr>
<tr>
<td>1-4</td>
<td></td>
<td></td>
<td>95</td>
<td>5</td>
</tr>
<tr>
<td>2-1</td>
<td>0.3</td>
<td>0.1</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>3-1</td>
<td>0.03</td>
<td>0.1</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>3-2</td>
<td></td>
<td></td>
<td>95</td>
<td>5</td>
</tr>
<tr>
<td>3-3</td>
<td></td>
<td></td>
<td>95</td>
<td>5</td>
</tr>
<tr>
<td>4 (Washed sample)</td>
<td>0.002</td>
<td>0.006</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Note: *NSDD is non-soluble deposit density. Tonoko was used as non-soluble material.
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Silicone rubber for polymer insulator has an excellent hydrophobicity with recovery properties, resulting in higher pollution performance. However it is inevitable that even silicone rubber polymer insulators start generating corona discharge with time under humid and polluted conditions. And such a corona discharge causes rubber damage because of acid generation. Since it is assumed that the corona discharge characteristics depend on humidity and polluted conditions, corona discharge tests were conducted on silicone rubber polymer insulators by changing humidity and polluted conditions. As a result, it was verified that the corona discharge phenomena were affected by humidity and pollution even on silicone rubber polymer insulators, and that contribution of corona rings to suppressing the discharge was not large.

Keywords: polymer insulator, silicone rubber, corona discharge

1. Introduction

A polymer insulator with silicone rubber housing has higher withstand voltage even in polluted environments because of excellent hydrophobicity of the silicone rubber comparing to ceramic insulators. If the polymer insulator is polluted and becomes more wet due to lowering of the hydrophobicity, corona discharge occurs as is the case with ceramic insulators, because dry band zone, where a higher allotted voltage appears, is generated. Such a corona discharge generates nitric acid, resulting in deterioration of the rubber housing during usage for years(1).

The investigations concerning the humidity dependence of moisture absorption and flashover voltage characteristics on polluted surface of ceramic insulator which has no hydrophobicity were carried out in the past(2)(3). On the other hand, in the case of silicone rubber polymer insulator which has high hydrophobicity, it is considered that moisture absorption characteristics and discharge activity on polluted surface are different from ceramic insulator. So far, however, these characteristics on polluted surface of the silicone rubber polymer insulator have not been sufficiently investigated. This paper describes the investigation result of humidity influence on corona discharge using the polymer insulators and the surface resistance measurement on test pieces of silicone rubber under various polluted conditions, and the study on the method of preventing corona discharge.

2. Corona Discharge Tests on Polluted Polymer Insulators

2.1 Test Specimens and Conditions New short polymer insulators were prepared as shown in Fig. 1 and Table 1. Table 2 describes the polluted conditions on the test specimens. Tonoko was used as a non-soluble material. As soluble

![Without corona ring](image1)

![With corona rings](image2)

Fig. 1. Test specimen

Table 1. Dimensional characteristics of silicone rubber polymer insulator

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective length, mm</td>
<td>200 (188°)</td>
</tr>
<tr>
<td>Leakage distance, mm</td>
<td>704</td>
</tr>
<tr>
<td>Shed diameter, mm</td>
<td>φ 132/φ 102</td>
</tr>
<tr>
<td>Shed pitch, mm</td>
<td>30</td>
</tr>
<tr>
<td>Trunk diameter, mm</td>
<td>φ 26</td>
</tr>
<tr>
<td>Corona ring diameter, mm</td>
<td>φ 80</td>
</tr>
</tbody>
</table>

Note ∗1: This length is the insulator with corona rings.
materials, not only NaCl but also MgCl2, which is a deliquescent material, were selected considering some effect of marine pollution. The polluted solutions which are mixture of water, Tonoko and NaCl/MgCl2 was applied by brushing after removing the hydrophobicity of test specimens (4). Considering recovery of hydrophobicity of the test specimens, the polluted insulators were subjected to corona discharge test after 2 days from the time when the insulator was polluted. The applied voltage on each sample was 7 kV. At this voltage condition the leakage distance per voltage became 100 mm/kV-l-g. This voltage stress imitated the design condition for actual heavy polluted condition.

For the investigation of the corona discharge characteristics of the polymer insulator attached corona rings, two φ80 mm corona rings for the metal end fittings of the polymer insulator were prepared.

2.2 Test Procedures As shown in Fig. 2, the polluted and dried samples were installed vertically in a fog chamber. The test sequence is shown in Fig. 3. The test voltage was applied before steam fog generation. In controlling the humidity, steam fog was injected into the fog chamber so as to gradually increase the relative humidity from about 60% to 95% in 30 minutes to 1 hour. At this time, the corona discharge was observed using a normal digital camera and a daytime corona camera. The leakage current flowing on the polymer insulator was also measured.

Fig. 2. Test set-up

2.3 Result of Corona Discharge Test The results are summarized in Fig. 4. In case of 100% NaCl, corona discharges always started at a relative humidity of about 70 to 80% at 0.3 mg/cm² and 0.03 mg/cm² in ESDD. When MgCl2 was included in ESDD, the humidity at the time when corona discharge occurred became lower as amount of MgCl2 increased. When 5% ESDD was composed of MgCl2, the humidity when corona discharge started lowered to 60% or less.

Fig. 4. Relative humidity when corona discharge occurred on the polluted polymer insulator

Table 2. Polluted conditions of short polymer insulators

<table>
<thead>
<tr>
<th>No.</th>
<th>ESDD (mg/cm²)</th>
<th>NSDD¹ (mg/cm²)</th>
<th>Ratio of ESDD² components</th>
<th>Corona rings</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-1</td>
<td>0.3</td>
<td>1.0</td>
<td>100 6</td>
<td>none</td>
</tr>
<tr>
<td>1-2</td>
<td>0.3</td>
<td>0.9</td>
<td>97  3</td>
<td>Attached on both end</td>
</tr>
<tr>
<td>1-3</td>
<td>0.3</td>
<td>0.7</td>
<td>95  5</td>
<td>none</td>
</tr>
<tr>
<td>1-4</td>
<td>0.3</td>
<td>0.6</td>
<td>100 0</td>
<td>none</td>
</tr>
<tr>
<td>2-1</td>
<td>0.3</td>
<td>0.1</td>
<td>100 0</td>
<td>none</td>
</tr>
<tr>
<td>2-2</td>
<td>0.03</td>
<td>0.1</td>
<td>100 0</td>
<td>Attached on both end</td>
</tr>
<tr>
<td>3-3</td>
<td>0.01</td>
<td>0.006</td>
<td>95  5</td>
<td>Attached on both end</td>
</tr>
<tr>
<td>4</td>
<td>0.002</td>
<td>0.006</td>
<td>-</td>
<td>none</td>
</tr>
</tbody>
</table>

Note *1: NSDD is non soluble deposit density. Tonoko was used as non-soluble material.

*2: ESDD is equivalent salt deposit density.
when corona rings were attached to the metal end fittings. In addition, when polluted insulator was washed, no corona discharge was detected even under the condition that the relative humidity was 98%.

3. Surface Resistance Measurement on Test Pieces under Humid Conditions

3.1 Test Pieces for Measurement

According to the paper (2),(3), which describes the influence on flashover characteristics on polluted insulators by deliquescent materials under various humid condition, it is reported that moisture absorption of MgCl₂ and NaCl starts around 40% and 70% respectively. In order to verify it on silicone rubber surface, the resistance measurement was conducted with test pieces. The dimensions of the test pieces prepared are shown in Fig. 9.

3.2 Measuring Method of The Resistance

The resistance was measured by an insulation resistance meter (the applied voltage: DC1 kV) under various relative humidity and temperature conditions. Measurement was conducted after the test piece was left as it was for 2 days from the time when the test piece had been polluted. Table 3 shows the polluted condition of the test pieces.

3.3 Result of Surface Resistance Measurement

Each graphs in Fig. 10 show resistance - relative humidity characteristics of the test pieces.

The graphs of (a)–(d) in Fig. 10 show the humidity influence on the resistances of test pieces under condition of NSDD: 1.0 mg/cm² and ESDD: 0.3 mg/cm². As the ratio of MgCl₂ in ESDD increased, the resistances in 40%–70% humidity range decreased.

The graph of (e) in Fig. 10 show it of NSDD: 0.1 mg/cm² and ESDD: 0.01 mg/cm². At this condition, in spite of containing MgCl₂ in ESDD, the resistance in 40–70% humidity range on the graph did not decrease.

The graph of (a) in Fig. 10 show it of NSDD: 1.0 mg/cm² and ESDD: 0.3 mg/cm². And the graph of (f) in Fig. 10 show it of NSDD: 0.1 mg/cm² and ESDD: 0.3 mg/cm². Larger
Humidity Influence on Corona Discharge on Polymer Insulators

4. Discussions

4.1 Effect of Humidity and Pollution It was confirmed that the corona discharge phenomena on silicone rubber polymer insulators was affected by humidity and polluted conditions. That is, the discharge started at a relative humidity of about 70% in the ESDD range from 0.03 to 0.3 mg/cm$^2$ when the ESDD components of the pollutants were composed of only NaCl (100% NaCl).

When MgCl$_2$ was contained in the ESDD, the corona discharge started at a lower humidity. It is assumed that deliquescent materials such as MgCl$_2$ absorb moisture in air even at a lower humidity, and the pollutant layer gets more conductive. And, this phenomenon was supported by the results obtained on the test piece samples subjected to surface resistance measurement under polluted and humid conditions.

4.2 Effect of Corona Rings The corona discharge of the both metal end fittings around the polymer insulator was suppressed by application of corona ring. But the generation of corona discharges of the sheath around the intermediate portion of insulator body was confirmed.

This phenomenon is considered that the electrical field stress around the boundary of the metal end fittings and rubber is decreased by corona rings. And, as indicated in Fig. 4, it was confirmed that although corona rings were effective to mitigate corona discharge to some extent probably due to relaxation of electrical stress, any drastic improvement could not be seen in these polluted and humid conditions.

4.3 Corona Discharge Mechanism on the Polluted Polymer Insulator Usually, the discharge mechanism on the polluted ceramic insulator is considered as follows. That

Fig. 10. Relationship between surface resistance on test piece and relative humidity under various polluted conditions
is, Joule heat due to the leakage current flowing on humid and polluted ceramic surface forms a dry band on it. Afterwards, the intermittent discharge bridging the dry band occurs because of higher voltage stress across the dry band. Generally, Maximum leakage current level was reported about 50 mA due to dry band arcing under similar polluted conditions (6).

On the other hand, in case of silicone rubber polymer insulators, the leakage current measured was so small (less than 1.0 mA) and not intermittent compared to ceramic insulators. Judging from the leakage current level and corona discharge activity by visible observation of polymer insulator in these corona tests, it was confirmed that the each discharge status on the polluted polymer insulator and the polluted ceramic insulator was different.

Further investigations such as testing on actual size polymer insulator samples and long-term corona discharge testing are needed in order to reveal the more detailed mechanism of corona discharge phenomena under humid and polluted conditions and the relationship between the discharge activity and rubber deterioration concerned.

5. Conclusions

(1) It was confirmed from this investigation that the corona discharge phenomena on polymer insulators was affected by humidity and pollution. That is, the discharge started at a relative humidity of about 70% in the ESDD range from 0.03 to 0.3 mg/cm² when the ESDD components of the pollutants were composed of only NaCl (100% NaCl).

And, if MgCl₂, which is deliquescent material, is contained in the ESDD, the corona discharge started at a lower humidity. It was confirmed that this phenomena of the polymer insulator with excellent hydrophobicity was the same as the ceramic insulator.

(2) At this experiment corona rings could be effective to make the corona discharge delay to start to some extent. However, they could not eliminate the corona discharge under the conditions tested this time completely.

(3) At this experiment it was found out that the washing of polluted insulators was effective to minimize the corona discharge on polymer insulators.

(4) Judging from the leakage current level and corona discharge activity in these corona tests, it was confirmed that the each discharge status on the polluted polymer insulator and the polluted ceramic insulator was different.

(5) Further investigations such as testing on actual size insulator samples and long-term corona discharge testing are needed in order to reveal the more detailed mechanism of corona discharge phenomena under humid and polluted conditions and the relationship between the discharge activity and rubber deterioration concerned.

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References


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