Effect of Aging on Dielectric Behavior of Outdoor Polymeric Insulators

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Abstract: This paper demonstrates the use of a dielectric spectroscopy technique for monitoring the effect of different ageing: ultra violet radiation (UV), thermal, water immersion, humidity and water boiling on silicone rubber, ethylene-propylene diene monomer (EPDM) and alloy of SIR-EPDM (50/50 wt %). The measurement of dielectric constants and dielectric losses in frequency domain help to quantify the chemical and physical changes in the bulk of polymer due to aging. Samples were subjected to UV light for 1000 h, immersed in water for 1200 h, treated in boiling water for 100 h, heated for 600 h at 100 °C and were exposed to 90-95% humidity for 1000 h. Low values of dissipation factor (tan δ) for EPDM reflect its non-polar and loss free nature. EPDM and alloy of SIR-EPDM show low dissipation factor after hydro-thermal aging. In the other hand, silicone rubber show lower tan δ after UV and thermal stress compare to EPDM and alloy of them. Results of this study show the effect of ageing parameters on a material and the comparability of materials with dielectric response measurements in the frequency region (10³ to 10⁻²) Hz.

INTRODUCTION

Composite polymers insulators are finding increasing application for outdoor use at both transmission and distribution levels. While these materials provide many advantages over the porcelain insulators that they replace, the question of life prediction continues to receive considerable concentration. A typical composite insulator consists of a glass fiber reinforced (GFR) resin bonded rod onto which metal end fitting are attached. To protect the core from environmental stresses, it is covered with a polymeric cover, called housing or weather shed. Today common housing materials are ethylene-propylene rubbers (EPDM and EPR), different types of silicone rubber (SIR) and so-called alloy rubbers, which are blends of EPDM and SIR. Polymeric materials can be degraded by environmental stress like heat, moisture, UV-radiation, contamination and this could lead to variety of dielectric and electrical properties [1-4]. The surfaces of polymers are relatively dynamic in comparison to porcelain and glass. Polymer molecules have much greater freedom for rearrangement in the bulk or at the surface. The relaxation time for a polymer surface to establish equilibrium with a new environment varies dramatically between different polymers and within a generic polymer system such as silicones [5].

In this article, dielectric measurements performed on un-aged and different aged polymers for use as high voltage insulators.

EXPERIMENTAL PROCEDURE

Specimen Preparation

All the material used for this work were commercial products and they were used as received without further treatments. Three samples used for the study, silicone rubber (A), EPDM (B), and blend (50/50 wt %) of silicone and EPDM (C).

The silicone rubber (SIR), type Elastosil R401/60, was obtained from Wacker–Chemie, Germany, the ethylene propylene diene rubber (EPDM), type Vistalon 7500, was prepared from Exxon Chemical, Belgium, Diene (ethylene norbornene) content 5.7 %; ethylene content 55.5 %; Moneny viscosity ML (1+8) at (125 °C) 82; Density 0.86. The Di Cumyl Peroxide (DCP) 98 %; produced by Hercules Inc., USA.

Table 1. Chemical composition of the specimen

<table>
<thead>
<tr>
<th>Sample</th>
<th>Material (gr)</th>
</tr>
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<tbody>
<tr>
<td>A</td>
<td>SIR 100 EPDM - DCP 2</td>
</tr>
<tr>
<td>B</td>
<td>- 100 EPDM 2</td>
</tr>
<tr>
<td>C</td>
<td>50 50 EPDM 2</td>
</tr>
</tbody>
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Several formulations containing silicone rubber and EPDM were prepared (Table 1). Silicone rubber was blended with EPDM at 130 °C in an internal mixer from Haake Co, model Sys9000, Germany, for 10 min at a rotor speed of 100 rpm for preparation alloy of SIR-EPDM. The compounding of the elastomers and the blend with DCP were carried out in an open roller mill at room temperature. Vulcanization was done in hydraulically operated press at 170 °C and 15 bar for 10
min. The thickness of the samples was 1mm for this study.

**Aging Processes**

- The used UV carbon arc lamp as a light source has a wave length between 300 and 400 nm which is more than 90% of the whole spectrum. The test condition was maintained as 50 ± 5% relative humidity and 30 ± 3 °C, and samples were subjected to UV light for 1000 h. It is well known that 200 hours of test period is equivalent to 1 year of actual outdoor exposure considering only the UV wave length (300-400 nm) that is mainly related to the deterioration of polymers [6].
- Thermal aging was performed at 100 °C for 600 h in a circulating oven.
- The samples were immersed in water boiling for 100 h.
- The samples were immersed also in distillated water for 1000 h.
- The samples were exposed to 90-95% humidity for 1000 h.

**Dielectric Spectroscopy Technique**

Dielectric relaxation spectroscopy has become an established tool in material analysis. Its principle consists in the measurement of the response of both permanent and induced dipoles to the application of an external electric field either in the time domain or more often in frequency domain. A special dielectric spectrometer manufactured by Programma Electric AB model IDA 200 was used in this study. By applying good EM shielding of the instrumentation and the test cells, a test voltage of only 140 V was used to perform the measurements.

**RESULT AND DISCUSSION**

**Un-aged Samples**

Dielectric spectroscopy is based on the interaction of electromagnetic radiation with the electric dipole moments of the material under test. The frequency range of the radiation is between $10^{-6}$ Hz and about $10^{10}$ Hz. Above $10^{10}$ Hz, in the infrared optical and ultraviolet region, the absorption and emission of radiation is due to changes in the induced dipole moments, which are dependent on the polarizability of the atoms or molecules. At lower frequencies the contribution of the induced dipole moments becomes small in comparison with that of the permanent dipole moments of the system. Results of frequency domain measurements of silicone rubber, EPDM and blend of silicone and EPDM at 27 °C are reported in Fig. 1. It can be seen that sample A (silicone) shows considerably high values of loss tangent ($\tan \delta$) in low frequency region compared to sample of B and C. The high value of $\tan \delta$ for samples justify the assumption that a certain relaxation mechanism is operative at low frequency. The charge carriers might be playing a role in the present case. The sample of B (EPDM) shows a low loss $\tan \delta$ of polarization. It is confirmed in view of non-polar nature of EPDM.

![Fig. 1. $\tan \delta$ of the new samples over the frequency](image)

**Water Aging**

Results of frequency domain measurements of samples after immersion water for 1000 h are shown in Fig. 2. It can be seen that the value of $\tan \delta$ increased for samples after immersion water aging. It means that samples have absorbed water during aging.

![Fig. 2. $\tan \delta$ of the immersed water samples over the frequency](image)

**Humidity Aging**

Fig. 3 shows the results of frequency domain
measurements for humidity aged samples. It can be seen that silicone rubber (A) shows the higher \( \tan \delta \) after humidity aging compared to EPDM (B) and blend of silicone-EPDM (C). Silicone rubber shows significantly higher losses at about 1 Hz. Aging behavior of EPDM (B) in water humidity is almost similar to that of aging by humidity.

\[\begin{array}{c}
\text{Fig. 3. } \tan \delta \text{ of the humidity aged samples over the frequency}
\end{array}\]

Similar to UV aging, thermal stress can produces polar groups in samples (B and C). It can be seen from Fig. 5 that silicone rubber (A) shows lower loss with heat aging. Sample C (blend of silicone-EPDM) shows some increase in the value of \( \tan \delta \) compared to A and B. The enhanced level of polarization and loss for this two phase systems can be attributed to the charge carriers and the additional polar groups incorporated during thermal aging.

\[\begin{array}{c}
\text{Fig. 4. } \tan \delta \text{ of the UV aged samples over the frequency}
\end{array}\]

\[\begin{array}{c}
\text{Fig. 5. } \tan \delta \text{ of the thermal aged samples over the frequency}
\end{array}\]

**UV Aging**

Fig. 4 shows the results of dielectric response of UV aged samples. It was well known that the polymers can be deteriorated by UV radiation and some polar groups such as carboxyl and hydroxyl were formed in polymer after UV stress. In this case, \( \tan \delta \) will increase. Silicone rubber (A) shows good stability against UV stress compared to EPDM (B) and blend of silicone-EPDM (C). Fig. 4 shows that the value \( \tan \delta \) is lower for silicone rubber in the range of measurement frequency. The higher value of \( \tan \delta \) for EPDM due to polarization of polar groups is the result of UV aging. In polar molecules, orientation polarization contributes to the total polarizability (electronic polarization and atomic polarization).

**Thermal Aging**

Organic macromolecules as well as low molecular weight organic molecules (consisting essentially of carbon, hydrogen, oxygen, and nitrogen) are stable only below a certain limiting temperature range usually from 100 °C to 200°C, in special cases a few hundred °C higher. The chemical changes occur during thermal treatment of polymers. The increase of \( \tan \delta \) at Fig. 5 for EPDM (B) and blend of silicone-EPDM (C) is due to chemical change after thermal aging.

**Boiling Water Aging**

Results of frequency domain measurements of samples after boiling water aging are shown in Fig. 6. It can be seen that the sample A (silicone) shows considerably high values of loss tangent (\( \tan \delta \)) in low frequency region compared to samples B and C. The high value of \( \tan \delta \) for sample A (silicone rubber) can be due to the silanol groups formed during water boiling aging. The low value of \( \tan \delta \) for sample C can be caused by the effects of removal of charged species from silicone and its protection from hydrolysis by incorporation of
DISCUSSION

Most of dangerous breakdowns are caused by aging effects of high voltage insulation used within these components, and there is still a need of suitable tools to diagnose such systems non-destructively and reliably in the field. Several methods have been published in the last decade for which reliable diagnostics are claimed. One of these methods is based on changes of the dielectric properties of the insulation. Dielectric properties are dependent on many factors such as frequency or time, on temperature and chemical composition of an individual dielectric, or on the structure of an insulation system composed of different dielectrics. The results of frequency domain measurements in this contribution show that the effects of aging of insulators can be analysed by this method. The silicone and EPDM or their blends can be used as low loss dielectric material. Silicone shows better dielectric behavior against UV and thermal stress. EPDM and blend of silicone and EPDM seem to be suitable in humid environmental and show good hydrothermal resistance.

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REFERENCES