Influence of the aging parameters in the Power Systems polymer insulators
dielectric properties

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Abstract: In this study, the aging of the silicon rubber polymer insulator, class 15kV, which is used in the
distribution and transmission of the power system was investigated. When compared to the glass and ceramics
insulator, the silicon rubber polymer insulator shows much better results due to its excellent dielectric
properties, light weight and low cost. The micro structural characterization of the samples’ surfaces was done
through the use of the following techniques: Optical Microscopy, Impedance Spectroscopy and Dielectric
Breakdown. The analysis was carried out in many samples classified in: New Sample, Naturally Aged Sample
and Artificially Aged Sample (exclusively under UV irradiation).

Key-Words: silicon rubber, insulator, impedance spectroscopy, dielectric breakdown

1 Introduction
The polymer insulators, due to their low cost, low
dielectric constant and acceptable mechanical
properties among other practical reasons for
industrial usage, are increasingly being used in the
distribution and transmission of energy. Experimental studies have been undertaken with the
objective of characterizing and offering behavior
models of the polymer insulators to mechanical and
environmental overcharging [1]. In a tropical
country, such as Brazil, these insulators are exposed
to different kinds of environmental conditions
including high humidity, rain, urban polluting gases,
contact with trees, vandalism and solar radiation.
In particular, the ultra violet level in the
Northeastern Region is one of the highest in the
whole country (CPTEC/INPE) [2]. These adverse
conditions usually accelerate the aging process
provoked by the oxygen absorption, carbonyl,
hydroxyl and vinyl group formation, as well as the
evolution of cetones, carbon monoxide and dioxide
that can lead to a premature failure of the insulating
material [3].

The present study united the UFS Physics
Department, through the Materials Preparation and
Characterization Laboratory (LPCM) and the
Electro technical Laboratory of the Federal Centre
of Technological Education – SE aiming to
investigate the aging under UV irradiation of the
silicon polymer insulator, used in the Power
Systems Distribution and Transmission. The
comparative study between the natural and artificial
aging of any given material is extremely important
and really do justify the investment in equipments
that accelerate the results of degradation by
weathering analysis that have valid results.

2 Experimental details
All the samples used in this study were extracted
from the CEFET-SE Electro technical Laboratory
insulators and prepared for the aging in the Material
Preparation and Characterization Laboratory
(LPCM). The procedure and the techniques used for
the preparation of the samples, as well as the
techniques used for the characterization and study of
some of its electrical properties are described in this
chapter.

2.1 Sample preparation
Initially, the samples were cut from the polymer
insulator in the shape of a 2 x 2 cm square (fig. 2.1)
by using a stylet and were sealed with wax, as
shown in fig. 2.2. Next, supported by the UFS
Morphology Department, a rotating Microtome –
(Rotary Microtome 820) – American Optical, Model:820 Series 66292. Scientific Instrument Division. Buffalo, NY 14215 – Made in USA – was used, as shown in fig. 2.3, and the samples were sealed, put in a support and cut (laminated) as thick as 400µm. Once obtained, all the samples were washed with distilled water in an ultra-sound washing equipment in order to be decontaminated (fig. 2.4). At this point, the samples were ready to be aged with UV irradiation in an aging chamber, produced in the CEFET-SE Laboratory.

Fig. 2.1 and 2.2 – Silicon rubber insulator, class 15 kV and sealed paraffin sample, respectively.

Fig. 2.3 and 2.4 – Microtome and Ultra-sound washing equipment, respectively.

2.2 Ultraviolet Irradiation Aging Chamber

The Chamber was built in aluminum and is 40cm wide, 80cm long, 60cm tall and essentially constituted of:

- A metallic vapor 400W × 220V OSRAM Power Star lamp, HQI – T 400W/D Brazil K488U.
- An ELCO N5-13/527BR, 110/220V-60Hz, 40W, 1300-1500rpm refrigerating ventilator.
- A mobile sample holder.

The xenon arc lamps with a boronsilicone glass filter are better than the metallic vapor, carbon arc or fluorescent (UVA and UVB) lamps to stimulate the total spectrum of the sunlight [4].

The chamber’s electrical circuit schematic diagram can be seen on fig. 2.5. The lamp bulb was taken (fig. 2.6) and then the lamp was installed in a porcelain socket, which is located in the superior part, 60cm from the base. The height of the chamber was projected so that the sample holder would have a certain flexibility in the vertical position (lamp distance), due to the fact that the temperature factor is very relevant, since the objective is to age the polymer insulator under exclusive incidence of UV irradiation.

Before turning the lamp on, there is a need to refrigerate the chamber so that the temperature (25°C - 27°C) is stable on the sample. Since the lamp filament cannot be exposed to temperature variation, a height regulation device is placed to control de ventilation over it. Besides the height regulation devices, the ventilator is put on rails in order to allow the back and forth movement and this makes it possible to keep control of the temperature in the chamber. The temperature measurement was done using a type K Termopar (chromel +, alumel -) and a Minipa multimeter, model ET-2081, aiming to monitor the thermal effects on the sample and lamp filament. The UV Aging Chamber can be observed closely on fig. 2.7 including a few of the details described.

Fig. 2.5 – Schematic diagram of the UV aging chamber electrical circuit

Fig. 2.6 – Light bulb and reactor used in the aging chamber.

Fig. 2.7 – Aging Chamber.
2.3 Impedance Spectroscopy

In many materials, specially those considered insulators, the impedance varies according to the frequency of the tension applied and the temperature, among other factors, due to the characteristics of the material structure. The measurement of the impedance, in a range of frequency values and temperature and the projection of these measurements in proper graphs is named impedance spectroscopy and can reveal details on the structure of the material [5]. Measurements of impedance spectroscopy were done using a Solartron, model 1260, impedancimeter, with the samples put in a sample holder adapted from an old quartz crystal stand (fig. 2.8). The assemblage of the measurement circuit can be observed in fig. 2.9. The software ZPlot version 2.6 was used to control the impedancimeter and collect the data.

Fig. 2.8 – Sample carrier used in the impedance spectroscopy.

Fig. 2.9 – Assemblage for the impedance spectroscopy.

The measurements were done over the application of senoidal tension with a 1 V\textsubscript{RMS} amplitude, from 100Hz to 10 MHz, without a continuous component, 10 cycles of interaction by measurement, 10 measurements by octave and 26ºC sample temperature.

2.4 Optical microscopy analysis

The optical microscopy is a plausible technique for the study of changes in the morphology caused by photo-degradation, because the ultraviolet irradiation has a localized action on the surface of the polymers [6]. The microscopy technique was used to study the samples’ surface properties, making it possible to correlate its morphology with the analysis of the Impedance Spectroscopy and Rupture Tension. All the photographs were obtained using a Carl Zeiss/Jena optical microscope with an image acquisition system constituted by a GKB chamber model CC9602 CCD in the LPCM of the UFS Physics Department (fig. 2.10). The images allowed the analysis of the aging process in the polymer insulator.

Fig. 2.10 – Optical Microscopy System.

2.5 Dielectric Breakdown

The samples were broke under tension with the objective to reach a correlation of the aging from a rupture tension point of view. In order to reach that, a continuous tension source that supplies up to 30kV in a 500V/s slope was projected in the CEFET-SE Electronics Laboratory. The experiments were undertaken based on the norms NBR 5389 Nov/1981 and NBR 6937 Nov/1981.

The samples’ dielectric breakdown, even the old, is a lot higher than the air’s. This makes it impossible to apply high electrical tensions on the samples without breaking the air’s dielectric breakdown that surrounds them. There are three more common solutions to this problem; to create a vacuum in the trial chamber, pressurize the chamber or put the sample in isolating oil. The pressurization or depressurization of the chamber is the applications of the Pasche’s Law, which correlates the rupture tension in a certain distance in the air to the product between this distance and the air pressure (fig.2.11).

Fig. 2.11 – Pasche’s Law for air rupture tension.
Since the usage of very delicate samples in the dielectric breakdown trials is common to this study, the solution adopted was to build pressurized chambers, able to support 6 Bar (4.500 mmHg), pressure in which the dielectric breakdown of the air is about 65 kV/mm. Practically speaking, the dielectric breakdown is lower, due to the air humidity. The sample holder and the electrodes were produced with a bronze rectangular base, a porcelain part and two bronze screws, according to the norms of high tension trials.

3 Results and Discussion

3.1 Impedance Spectroscopy

The information obtained with the analysis by impedance spectroscopy on the silicon polymer insulator was compared to the technical specifications set by the norms. Both old and aged samples were measured at ambient temperature. Comparing both (fig. 3.1), it is possible to observe that:

![Fig. 3.1 – Impedance spectroscopy of the new and artificially aged samples.](image)

The graph of the new sample does not complete the cycle, but there is a tendency. The lack of points for the construction of the curb is a result of the non variation of the temperature over the sample. Since the resistivity of the sample is very high, the difference of potential applied on the sample would have to be set higher, and that is not possible because the limitations of the equipment should be considered. Differently than the graph of the new sample, the graph of the aged sample shows a higher tendency to a shorter radius cycle and, therefore, presents a lower resistivity when compared to the new sample.

The measurements were repeated for each of the 6 samples and the results are shown on table 3.1 and in fig. 3.2 and fig. 3.3.

<table>
<thead>
<tr>
<th>Aging period</th>
<th>R (MΩ)</th>
<th>C (pF)</th>
<th>Resistivity (x10¹⁰ Ω.cm)</th>
<th>Dielectric Constant</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 h</td>
<td>534</td>
<td>17.2</td>
<td>2.67</td>
<td>3.88</td>
</tr>
<tr>
<td>2 h</td>
<td>505</td>
<td>22.4</td>
<td>2.53</td>
<td>5.06</td>
</tr>
<tr>
<td>4 h</td>
<td>456</td>
<td>25.6</td>
<td>2.28</td>
<td>5.78</td>
</tr>
<tr>
<td>6 h</td>
<td>396</td>
<td>30.8</td>
<td>1.98</td>
<td>6.96</td>
</tr>
<tr>
<td>8 h</td>
<td>276</td>
<td>33.2</td>
<td>1.38</td>
<td>7.50</td>
</tr>
<tr>
<td>10 h</td>
<td>186</td>
<td>39.6</td>
<td>0.93</td>
<td>8.94</td>
</tr>
</tbody>
</table>

The downfall of the electrical resistivity as the aging evolves can be observed on fig. 3.2 and occurs due to the sprouting of free radicals, proceeding from the rupture of polymer chains.

![Fig. 3.2 – Electrical resistivity according to the aging period.](image)

- Limit value of the electrical resistivity of the insulator.
- Electrical resistivity slope x Aging period.

It can be observed in fig. 3.3 that as the insulator gets old, its dielectric constant gets higher, but it still fits the technically specified range (3.2 – 9.8) in the period of ten hours.

![Fig. 3.3 – Graph showing the dielectric constant over aging period.](image)
3.2 Optical microscopy

After analyzing the naturally and artificially aged samples (fig. 3.4) it is evidenced that there are changes not only in the color, but also some degradation, surface tracking. A possible explanation for this fact can be the formation of initial degradation products due to the deterioration of the surface and absorption of UV radiation, causing a consequent rupture of the molecule chains, followed by a reticulation process [7, 8].

3.3 Dielectric Breakdown

The artificially aged samples were submitted to the trials at a temperature of 20ºC and 6 Bar pressure. The samples of the same period of aging time were submitted to 5 trials (table 3.2). The table shows that the dielectric breakdown values are within the technical specifications range (16 – 20 kV/mm).

<table>
<thead>
<tr>
<th>Trial</th>
<th>Trial 2</th>
<th>Trial 3</th>
<th>Trial 4</th>
<th>Trial 5</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>(kV/mm)</td>
<td>(kV/mm)</td>
<td>(kV/mm)</td>
<td>(kV/mm)</td>
<td>(kV/mm)</td>
<td>(kV/mm)</td>
</tr>
<tr>
<td>17,9</td>
<td>18,1</td>
<td>19,2</td>
<td>18,3</td>
<td>18,8</td>
<td>18,46</td>
</tr>
<tr>
<td>18,0</td>
<td>18,8</td>
<td>18,1</td>
<td>17,5</td>
<td>18,8</td>
<td>18,24</td>
</tr>
<tr>
<td>18,0</td>
<td>17,5</td>
<td>17,5</td>
<td>17,6</td>
<td>17,8</td>
<td>17,68</td>
</tr>
<tr>
<td>16,3</td>
<td>15,8</td>
<td>15,2</td>
<td>16,1</td>
<td>15,8</td>
<td>15,84</td>
</tr>
<tr>
<td>14,5</td>
<td>13,4</td>
<td>13,7</td>
<td>13,1</td>
<td>14,1</td>
<td>13,76</td>
</tr>
<tr>
<td>11,7</td>
<td>11,5</td>
<td>12,4</td>
<td>12,8</td>
<td>12,7</td>
<td>12,22</td>
</tr>
</tbody>
</table>

Fig. 3.6 – Dielectric Breakdown versus Aging period graph.

Limit value of the insulator’s dielectric breakdown

Dielectric breakdown slope x Aging period

It can be observed on fig. 3.6 that after an aging period of 6 hours, the insulator’s dielectric breakdown has already reached its limit value and that if a 15kV line, by chance, is in contact with this period were photographed and compared, to clarify any possible variations of radiation intensity in the samples, after all we cannot forget the aging of the light bulb itself. However, there were no changes between the analyzed samples for the same period of time.
insulator, there can be a superficial electrical discharge and cause problems on the power system.

The trials of electric breakdown, undertaken according to the norms cited before (fig. 3.6), prove that older samples have lower dielectric breakdown, since in this stage the samples are superficially degraded and vulnerable to less intense applied electric fields. The images of two samples after the dielectric rupture were obtained through optical microscopy (fig. 3.7).

When comparing both samples, it is clear that the new one, after being breached, presents only one hole where the difference of potential was applied, but in the aged sample, besides the hole, there is an extrusion on the insulator surface which was set by the formation of tracking when exposed to UV irradiation.

![Fig. 3.7 – New and old samples, both breached, respectively, in a magnifying scale of 160x.](image)

### 4 Conclusion

The construction of the UV aging chamber was actually the main object of this study, since it made possible to analyze a correlation between the degradation of the polymer insulators’ surfaces and the electrical properties (dielectric breakdown, resistivity, dielectric constant), even without knowing the accurate dose of irradiation that the samples were exposed to. In the elapsing of the aging, a decrease in both electric resistivity and dielectric breakdown could be observed. This evidences that the decrease is, somehow, associated to the formation of tracking on the surface. The dielectric constant gets higher as the aging takes place due to the fact that, when the polymer chains are broken, polar groups appear.

The polymer insulators are different than the ceramics ones due to their low chemical bonding energy, what makes them more susceptible to degradation. The aging of the polymer insulator exclusively under UV irradiation characterizes a strong morphology over its surface. Knowing that the insulators have their electric properties affected, it might be a strong aspect for researching and redimension the solar filter additives in its surface, since the breaking of the polymer chains, besides originating polar groups, diminishes the average size of these chains. The analysis of the impedance spectroscopy was only possible with the support of the microtome, because it started to show good results that were worthy of conclusive analysis over the electric properties of the polymer insulator, when dealing with very thin and parallel-faced samples.

The analysis by optical microscopy was enough to observe the formation of tracking through the aging process. If this insulator is used in an ambient where the atmosphere deposits micro particles in these spaces caused only by UV irradiation, the insulator will be susceptible to superficial charges, what will compromise the good performance of the transmission and distribution of the power system.

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### References:


