DETERIORATION OF POLYMERIC INSULATORS USING EXCLUSIVE AGENTS

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ABSTRACT

Nowadays, glass and porcelain insulators are being systematically changed by polymeric insulators, because of its advantages, as easy installation, reduced weight, low cost in the construction and transportation, and resistance to the vandalism. However polymeric insulators have disadvantages, as the difficulty about visual damage detection. Power outages due to polymeric insulators failures cause billions of dollars of product damage each year and, in most cases, a simple inspection of the ground is not enough to visualize the defects in operation insulators before the outage. As these equipments longevity is reduced according to eventual internal defects and hostile ambient conditions, it is necessary to develop and improve monitoring techniques.

In field, the polymer suffers a multi-stress aging, due to the many deterioration agents that are present. The result is a combination of effects that, in long term, turn the insulators inappropriate to use in electric system. These effects, however, mask each other, and it is hard to tell which agent is causing which effect, and how to detect it. This knowledge is very useful when the energy company has polymeric insulators in facilities under different climate conditions, as happens in Brazilian Northeast.

This paper brings some results of deterioration tests made in laboratory, with new (perfect) insulators taken from the warehouse. Initially perfect insulators have passed by a visual inspection and tested with some diagnostic techniques as thermograph, corona detection, and partial discharges inspection, Fourier-Transformed Infra-red Spectroscopy (FTIR), Thermal Analyses Techniques as Differential Scanning Calorimetry (DSC), Thermal Gravimetric Analyses (TGA), Scanning Electronic Microscopy (MEV) and Mechanical tests. Then, these insulators were exposed to different aging agents or aging agents groups, exclusively, in order to evaluate the effects of each agent or group of agents, in an isolated way. The aging methods used were dry high voltage application, salty fog and high voltage application, Weather-ometer, Thermal Aging and Water in high temperature.

INTRODUCTION

The objective of work is to present the experimental development and partial results of polymeric products from electric energy distribution lines, 15 kV insulators, surge arresters and spacers. One of the purposes of the study is the achievement of performance requirements to support standardization, for the purchase of new polymeric products with thermo and photo stabilization system, for durability in field. For this, accelerated aging tests on new insulators are being held for further evaluation of changes in physical, chemical and electrical properties. It also evaluated the state of polymeric insulators on the field, with non-invasive techniques such as thermography (Infrared radiation) ultrasound or radio-interference and quantification of corona discharges (Ultraviolet radiation), and partial discharges and digital radiography (X-ray).

Polymers might suffer thermo and photo degradation. The polymeric materials degradation process has several stages, taking factors like ultraviolet radiation and high temperature as initiators. The study of polymeric materials used in insulators and distribution surge arresters provides knowledge of the performance of products from various suppliers, through data acquired from field and laboratory tests. Aspects as thermo and photo stabilization systems are also important, since they are related to the durability of the equipments in field.

The choice of products from several suppliers with different insulation materials allows the realization of the experimental work: through accelerated aging tests in the laboratory, followed by physical-chemical, electrical and mechanical tests, it is possible to evaluate variations in the physical characteristics and performance properties. Through these experimental results, desirable characteristics of the products are identified, which might be used as a support for technical specifications by the concessionaire. The results could also serve as support to the laboratory during inspection, acceptance and approval of purchase. Energy companies can use this knowledge in future decisions related to replacements, development and implementation of technical internal specifications of optimized products and systems.

New samples of anchorage, pin type insulators and surge arresters provided by the power utility companies are under study. They were submitted to accelerated aging tests over a six-month period (weather-meter, temperature, water) to increase degradation speed, while electric, mechanical, chemical and physicochemical tests were carried out to determine properties variations and support functional performance requirements. Considering the polymeric degradation and stabilization, quality and functionality features more adequate to the required final properties are useful to optimize the performance of the products in the field and system integrity as well. The product functionality is also evaluated through electrical properties [1,2].

The electrical tests are also separated in two kinds: accelerated aging tests and monitoring aging tests. The first
tests are compound of: Aging test by Electrical Stress and also Aging test by Salty Fog more Electrical Stress. The Diagnosis Tests in development are: Partial Discharge; Leakage Current; Disruptive Discharge; Residual Voltage; Supportable Voltage in 60Hz; Disruptive Discharge under salty fog. Since the tests are still in development, only the leakage current methods and results will be shown in the next sections.

MATERIALS AND METHODS

The products being tested are new and removed from the warehouse including: Polymeric insulators, 15 kV class (suspension); Polymeric surge arresters, 15 kV class (pin type); Polymeric spacer, 15 kV class; Top plastic loop for pin type insulators. Natural aged samples will also be tested, after long time stress in field.

Leakage Current

The leakage current test provides important information about the state of operation of the insulator or surge arresters.

In the case of insulators, a high leakage current might indicate presence of pollution, loss of insulating capacity of polymeric material. An insulator in good condition usually presents leakage current in the order of some microamperes, when exposed to its rated voltage of operation. In ZnO surge arresters, the typical leakage current is around some miliamperes. The harmonic components analysis of the leakage current of ZnO surge arresters can also provide useful information. This kind of analysis can indicate the degree of deterioration of the varistors elements, fundamental semiconductor constituents of surge arresters.

The test for measuring leakage current can be described as an experimental arrangement in which the sample is exposed to high voltage (110% of normal operation voltage), while the current of the circuit is measured. Fig. 1 shows a schematic diagram of the assembly for leakage current measurement, and the equipments during the tests.

Physical-chemical tests to study degradation of polymers

Aging Tests in Weather-ometer, in High Temperature (120°C), and in Water (40°C) are in development. Those aging tests in chambers are used to accelerate the degradation of polymeric products, through an initiator of the process as temperature, ultraviolet radiation, among others. They are carried out on samples in duplicates, depending on the availability of each chamber for the samples under study, and, after six months of each aging test, the samples will have their properties assessed (physical-chemical, electrical and mechanical) and the results compared to those of samples without ageing, called \( t = 0 \). The results could also be compared with samples taken from long time in natural aging in the field, taken from Celpe’s system.

Various techniques are going to be used to study or monitor degradation of polymeric products, such as: DMTA, DSC, TGA; SEM/MA, FTIR with Optical Microscopy (MO) and Attenuated Total Reflectance (ATR); Electrical Testing in High Voltage with measurements of Leakage Currents. Those techniques are going to be applied before and after the aging tests.

Aging test in Weather-ometer, with xenon arc lamp of 6500 W, with filters of borosilicate; irradiation of 0.35 W/m2 at 340 nm , the panel black temperature during the drying of 63°C; cycles of 120 minutes, and 102 minutes of light, followed by 18 minutes of light and spray of water, repeated, periodically, without relative humidity control.

Aging test in Oven at 120°C, for 6 months in an oven with circulating air, and subsequent measurements of properties.

Differential Scanning Calorimetry (DSC)

The thermal analytical technique of Differential Scanning Calorimetry (DSC) (dynamic and isothermal way) is widely used for monitoring of polymeric degradation, through the following properties: melting crystalline temperatures (Tm), enthalpies ( H, which are related to the degree of crystallinity, in turn related to the mechanical properties of the final product), glass transition temperature (Tg, related to the amorphous phase), and temperatures of initiation of decomposition (Tid) or oxidation temperature(Tox or OOT). In the isothermal form, can also be getting the oxidation induction time (OIT). For example, OIT larger than 60 minutes are indicative of well stabilized material.

FTIR/MO

Fourier Transform Infrared Spectroscopy with Attenuated Total Reflectance (FTIR/ATR/MO, with optical microscopy) is a technique widely used in polymers. The absorption characteristics in certain regions of the spectrum can be
attributed to specific functional groups, with consequent identification of the type of the polymer, like a fingerprint of the material. Through this technique, products of degradation of polymers can be observed, like hydroxyls, carbonyls, silanes groups, showing if the polymer is thermo and photo stable or not, or if it resists with good performance on the field or not.

**Thermogravimetric Analysis (TGA)**

Through Thermogravimetric Analyses (TGA), it is possible to assess the thermal stability of polymers by variation in loss of weight when heating or through the initiation decomposition temperature.

**Dynamic mechanical thermo analysis (DMTA)**

Through dynamic mechanical thermo analysis (DMTA), it is possible to determine the point of Vicat softening and modules of loss ($\varepsilon''$) and storage ($\varepsilon'$), rheologic properties of polymers, very important to observe degradation and stabilization situations.

**Scanning electron microscopy (SEM/ MA)**

Photomicrography, obtained by scanning electron microscopy with micro-analyzes (SEM/MA) can show the morphological structures of polymer products under study, which are related to the mechanical properties of final products. The appearance of fissures and cracks, signs of degradation, can also be monitored.

**Mechanical test in traction to 80 and 100% RMS**

The tension test in insulators is held up to 80% of the RMS, then up to 100% of the RMS, on both new insulators and after the accelerated aging ones; bar of traction moving control is through load: 1000 N/s by 4,000 N; then moving slower. All insulators tested should not make visual changes up to 100% of the RMS.

**Computed Radiography tests and images processing**

Examples of the applicability of this study, very useful in non-destructive evaluation of products, can be seen in (Figures 09 to 12), which shows examples of bubbles at the centre and bubbles in the Side Region of Insulator pin type.

**PRELIMINARY RESULTS AND DISCUSSIONS**

**FTIR/MO**

In the next example, in Fig. 2, it is possible to see the spectrograms of FTIR coupled with optical microscopy, obtained for the samples under study.

![Fig.2. Spectrogram by FTIR/MO to polymeric samples of PVC and PEAD.](image1)

Figure 3 shows examples of thermograms obtained to products (insulators pin type). The atmospheres used can be oxygen or nitrogen.

![Fig. 3. Dynamic DSC curves to insulators pin type and spacers in nitrogen.](image2)

**Electrical tests**

The leakage current in the suspension insulators, as expected, was around some few microamperes, as shown on Table I. The typical waveform for these equipments can be seen in Figure 4. In all the figures presenting distorted current signals, except when contrarily said, the distortions are due to external noise, parasite capacitance and inductances.

![Fig. 4. Applied voltage (blue) and typical current waveform (orange) acquired during leakage current test with suspension insulators.](image3)

**TABLE I. LEAKAGE CURRENTS RESULTS (ALL PEAK VALUES IN µA)**

<table>
<thead>
<tr>
<th></th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>S6</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Susp. Insulator</td>
<td>12,93</td>
<td>13,47</td>
<td>10,24</td>
<td>10,24</td>
<td>11,31</td>
<td>11,04</td>
<td>11,54</td>
</tr>
<tr>
<td>Spacer</td>
<td>62,83</td>
<td>68,18</td>
<td>65,51</td>
<td>66,84</td>
<td>51,18</td>
<td>52,53</td>
<td>61,18</td>
</tr>
<tr>
<td>Surge Arrester</td>
<td>1016,0</td>
<td>1016,0</td>
<td>1443,8</td>
<td>962,5</td>
<td>2005,3</td>
<td>1104,3</td>
<td>1258,0</td>
</tr>
<tr>
<td>Plastic loop</td>
<td>8,56</td>
<td>6,55</td>
<td>7,89</td>
<td>8,56</td>
<td>5,21</td>
<td>4,14</td>
<td>6,82</td>
</tr>
</tbody>
</table>

For the polymeric spacers, the leakage currents were also inside the expected range, as seen on Table I. The typical waveform for these equipments can be seen in Figure 5.

![Fig. 5. Applied voltage (blue) and typical current waveform (orange) acquired during leakage current test with polymeric spacers.](image4)

The leakage current in the polymeric ZnO surge arresters was as expected in five of the six tested samples (Table I). The typical waveform for these equipments can be seen in Figure 6. In this case, the distortions are due the non-linear characteristics of the ZnO varistors.

![Fig. 6. Applied voltage (blue) and typical current waveform (orange) acquired during leakage current test with ZnO surge arresters.](image5)
Despite there were two different models of top plastic loop for pin type insulators, the leakage current for both of them were between the expected limits (Table I), and very similar. Due to this similarity, only one of the typical waveforms from the 12 samples is presented in Figure 7.

![Figure 7](image)

**Fig. 7.** Applied voltage (blue) and typical current waveform (orange) acquired during leakage current test with top plastic loop for pin type insulators.

**X- Ray application and images processing**

When an electrical insulator is in operation at the high voltage transmission line systems, those devices are subjected to a strong electrical stress and damage from the environmental conditions [3]. It is well known that the presence of voids and inclusions introduced in the manufacturing processes, or generation and propagation of cracks inside the electrical insulators, when those devices are in operation under high voltage stress, a partial discharge begins as localized dielectric breakdown. Furthermore, partial discharge can also occur along the boundary between different insulating materials. Once begun, partial discharge causes progressive deterioration of insulating materials, ultimately leading to electrical breakdown and, eventually, explosion with energy transportation stopping [3].

At the present work, in order to evaluate the structure integrity of composite insulators (Figure 9), these were inspected by the computed radiography [4,5] system consisted by compact X-ray source of 270 kVp, model XRS-3 from Golden Engineering coupled with a similar imaging plate reader, however, model Cyclone from Perkin-Elmer. Two types of imaging plate were employed: super resolution imaging plate (blue type) and super sensitive imaging plates. Digital imaging process was conducted employing IPT – imaging process toolbox and LOG filters of Matlab software.

Figures 9(a) and 9(b) show obtained X-ray radiographies by the computed radiography.

![Figure 9(a)](image)

**Fig. 9(a).** Two X-ray radiographic images from top (left) and side (right) views. A bubble is detected (white circle) of typical pin-type polymeric insulator for 15 kV.

![Figure 9(b)](image)

**Fig. 9(b).** Two negative X-ray radiographic images from top (left) and side (right) views. A bubble is detected (red circle).

In order to enhance those cracks that are visible on as-obtained digital radiography, Figure 10 (a) and (b) show two digital radiographies processed by enhance details and LOG – Laplacian and Gaussian filters. The bubble appears clearer than that in as-obtained X-ray radiographic images.

![Figure 10(a)](image)

**Fig. 10 (a).** X-ray radiographic images processed by enhance details filter.

![Figure 10(b)](image)

**Fig. 10 (b).** X-ray radiographic images processed by LOG filter, which show clearly bubble inside the insulator.

Furthermore, nowadays, using special processing, dimension analysis can also be conducted by X-ray processing, as shown in Figure 11.

![Figure 11](image)

**Fig. 11.** X-ray radiographic image processed in order to estimate the bubble size based on line histogram.

**CONCLUSION**

All techniques in study are useful to get variations in properties and to selection of main performance requirements to polymeric products. The contribution of scientific and technological resources on polymeric materials to the Electric Sector will be made by setting such performance requirements for polymeric products, innovative in the sector, to improving product life in field and providing increased reliability for the distribution line and higher system integrity. The contribution is in occurrence to ABNT and CIGRE studies workgroups to implementation in Norms.

**REFERENCES**


