The Journal of CPRI,
Vol. 4, No. 2, September 2008 pp. 149–154

Effect of Biocontamination on Polymer Insulators

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1.0 INTRODUCTION

Problems due to biocontamination of insulators have been reported in tropical areas of the USA, Sri Lanka, Tanzania, Germany, Sweden, Japan, Mexico, Paraguay and New Zealand. No systematic study has been done to investigate the long term performance of polymeric insulators with biocontamination. When fungi and other microorganisms colonise the surface of an insulator, they impede the drying of the insulator surface and there is a possibility of increased insulator degradation by enzymes secreted by fungal contaminants. Bio-contamination causes concern among utility engineers because it is not understood fully. In the present work, algae was allowed to form on silicone rubber insulators. These insulators were then tested under salt fog conditions for a period of 10000 hours and the results are presented.

2.0 EXPERIMENTAL SETUP AND TEST PROCEDURE

In order to simulate biocontamination/algae formation on insulators, the two commercially available SR insulators SR1 and SR2 were used. The creepage length of both the insulators was maintained at the same value of 588 mm. Both the insulators were put in a septic tank for a period of 13 months. The septic tank was kept open and insulators were fully immersed in water. The average conductivity of water in the tank was 0.528 m mho/cm. Insulators were inspected every month. For the first three months, there was no formation of algae/fungus on the insulators. Gradually there was a formation of fungus on the insulators. At the end of 13 months, there was a thick layer of dark-green algae on both the insulators.

Photograph1 shows the virgin insulator (SRV) which was not subjected to biocontamination. Photographs 2 and 3 show the insulators with biocontamination formed after 13 months. It can be observed that the formation of algae on the insulators was not uniform. Algae formation was observed on that part of the insulator which was exposed to the sun regularly.

2.1 Ageing test (Salt fog test)

The SR1 and SR2 insulators with algae formation were removed from the tank and put in an ageing chamber along with the virgin insulator SRV which was not subjected to algae formation process. The SRV and SR1 insulators are identical in all respects except for the algae formation on SR1. The experimental set up is shown in Fig. 1 and Photograph 4. A voltage of 17 kV was applied continuously using a 33 kV, 66 kVA high voltage transformer. Insulators were exposed to salt fog with the salinity of 10 kg/m^3.

Voltages across the resistances were measured randomly and the leakage current through the insulators was calculated. The test was carried out initially for a period of 5000 hours. After every 1000 hours, a very small portion was cut out from all the three insulators for EDXRF and XRD analysis.

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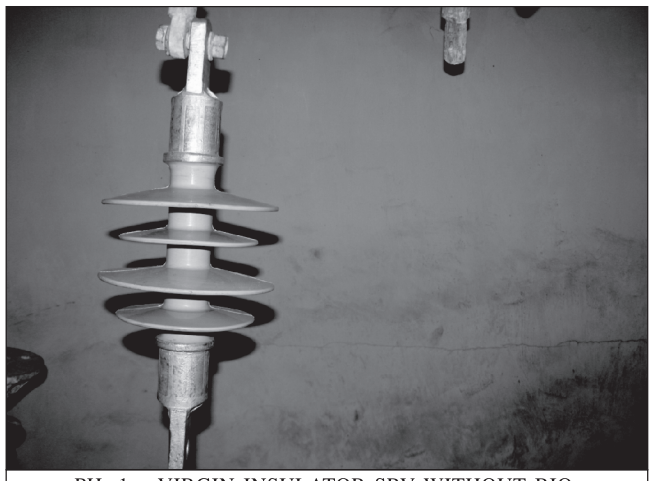
The test was further continued for a period of 5000 hours (totalling to 10000 hours) and only the leakage current was recorded during this period. At the end of 10000 hours, samples were cut out from all the insulators for EDXRF analysis.

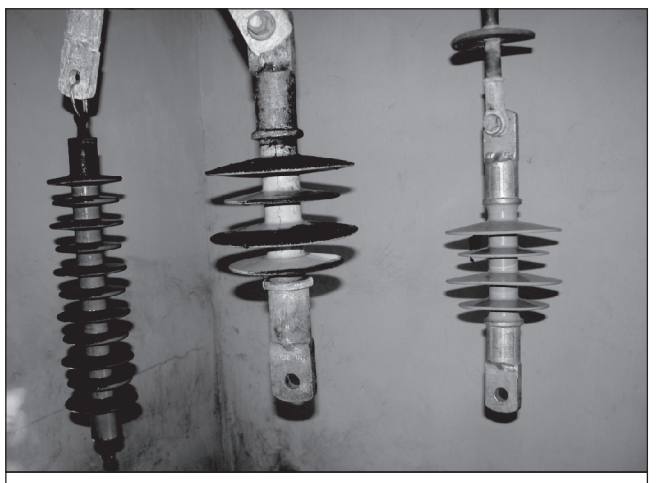
At regular intervals during the test, check for hydrophobicity was done by spraying water on to the insulator surface from a distance of 25 ± 10 cm.



PH. 1 VIRGIN INSULATOR SRV WITHOUT BIO-CONTAMINATION

PH. 2 INSULATOR SR1 WITH BIOCONTAMINATION

PH. 3 INSULATOR SR2 WITH BIOCONTAMINATION



PH. 4 TEST SETUP

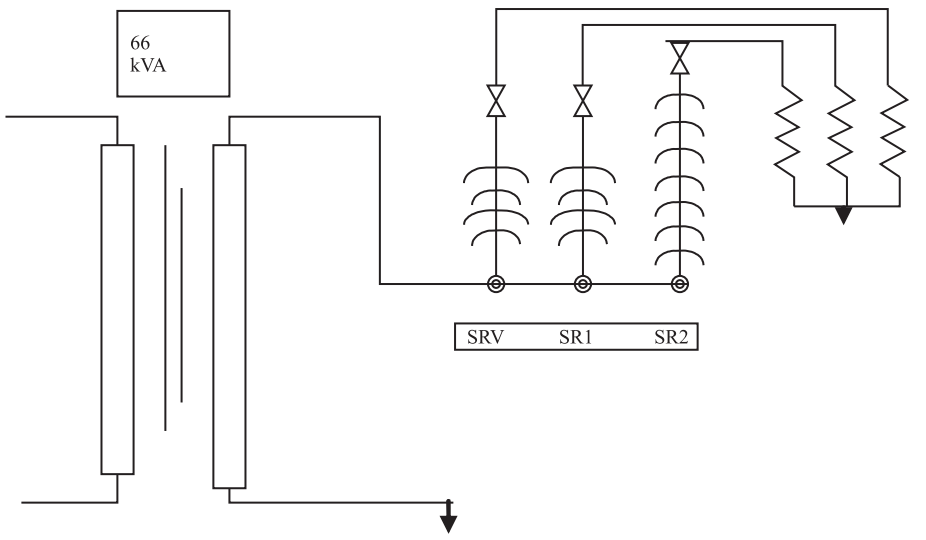


FIG. 1 TEST SETUP IN AN AGEING CHAMBER

2.2. Energy Dispersive X-ray Fluorescence Spectroscopy (EDXRF) analysis

EDXRF analysis was carried out on samples by using the equipment Mini Pal2 of PANalytical make. This analysis is used to estimate the silicone content in the insulator samples from the test. The basic principle of X-ray fluorescence is that an electron can be ejected from its atomic orbital by the absorption of a light wave (photon) of sufficient energy. The energy of the photon must be greater than the energy with which the electron is bound to the nucleus of the atom. When the inner orbital electron is ejected from an atom, an electron from a higher energy orbital will be transferred to the lower energy level orbital. During this transition, a photon may be emitted from the atom. This fluorescent light is called the characteristic X-ray of the element. The energy of the emitted photon will be equal to the difference in energies between the two orbitals occupied by the electron making the transition. As the energy difference between the two specific orbital shells, in a given element, is always the same, the photon emitted when an electron moves between these two levels, will always have the same energy. Therefore, by determining the energy of the X-ray light (photon) emitted by a particular element, it is possible to determine the identity of that element. For a particular energy of fluorescent light emitted by an element, the number of photons per unit time (generally referred to as peak intensity or count rate) is related to the amount of that analyte in the sample. The counting rates for all detectable elements within a sample are usually calculated by counting, for a set amount of time, the number of photons that are detected for the various analytes' characteristic X-ray energy lines. It is important to note that these fluorescent lines are actually observed as peaks with a semi-Gaussian distribution because of the imperfect resolution of modern detector technology. Therefore, by determining the energy of the X-ray peaks in a sample's spectrum, and by calculating the count rate of the various elemental peaks, it is possible to qualitatively establish the elemental composition of the samples and to quantitatively measure the concentration of these elements.

2.3 X-ray Diffraction (XRD) analysis

This analysis was used to study the changes in the physical structure of the polymer with ageing. The clustering of the filler particles on the surface with ageing was also studied using this technique. The samples were cut from the insulators under study after every 1000 hours. The instrument used was X'Pert PRO of PHILIPS. A copper anode sealed X-ray tube operated at 30 kV /30 mA provided the X-ray source and a scintillation counter was used for the detection.

The diffraction data on each polymer sample was obtained from 5 to 100º 2-theta, with a sampling interval of 0.02° and a scan rate of 2° per minute. Data reduction was carried out using the software provided by the manufacturer. This includes removal of k-alpha component of the copper radiation prior to peak identification. The diffraction pattern obtained is a plot of the intensity versus theta angle. The estimated sample depth of 10000 to 60000 Angstroms increased with a depth of 2-theta angle. The degree of crystallinity can be determined if the crystalline and amorphous scattering in the diffraction pattern can be separated from each other. The degree of crystallinity is equal to the ratio of the integrated crystalline scattering to the total scattering, both crystalline and amorphous, and is given by

$$x_c = s^2 I_e (s)ds / s^2 I(s)ds,$$

Where s is the magnitude of the reciprocal-lattice vector and is given by

$$s = (2 \sin\theta)/ \lambda$$

θ is one-half the angle of deviation of the diffracted rays from the incident X-rays

λ is the X-ray wavelength

I(s) is the intensity of coherent X-ray scatter from a specimen (both crystalline and amorphous)

I_c is the intensity of coherent X-ray scatter from the crystalline region.

The degree of crystallinity calculated from the above equation tends to be smaller than the true crystalline fraction, because part of the X-ray intensity that is scattered by the crystalline regions is lost from the peaks and appears as diffuse scatter in the background as a result of atomic thermal vibrations and lattice imperfections.

3.0 RESULTS AND DISCUSSION

3.1 Leakage current measurements

The variation of leakage currents of SRV, SR1 and SR2 are shown in Figs. 2, 3 and 4 respectively.

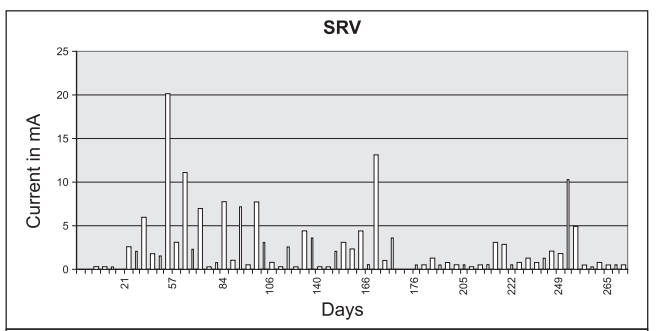


FIG. 2 LEAKAGE CURRENTS OF SRV

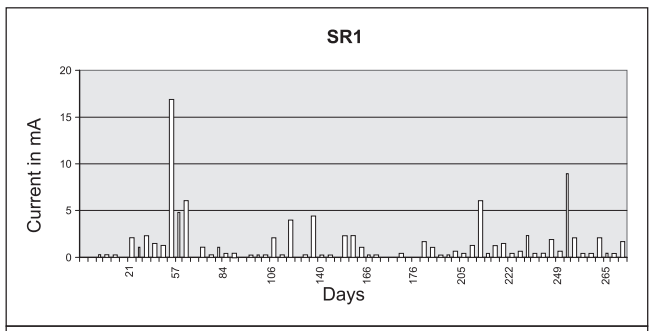


FIG. 3 LEAKAGE CURRENTS OF SR1

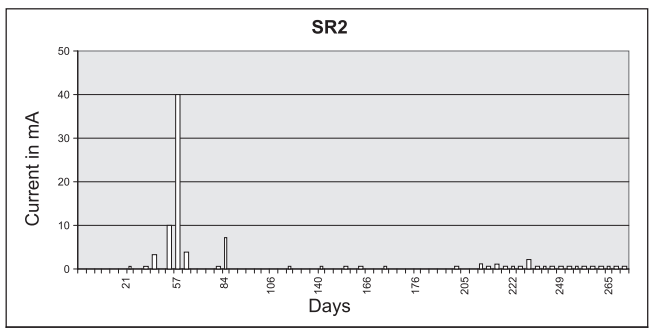


FIG. 4 LEAKAGE CURRENTS OF SR2

Pattern of variation of leakage current is almost the same for SRV and SR1 insulators. It can be observed that the maximum leakage current recorded is 20 mA in SRV, 16.9 mA in SR1 and 40 mA in SR2. There was no flashover during the entire ageing process. At the end of 10000 hours, the leakage currents in all the insulators were less than 1 mA.

3.2. Variation of hydrophobicity

It was observed that the hydrophobicity was partially lost during the test. Hydrophobicity was of the class HC 4, on that part of insulators where the biocontamination was present and on the other parts, it was HC 3/ HC 2. After the test was concluded (i.e. after 10000 hours) and after a recovery period of 24 hours, it was found that the hydrophobic value was HC 1 in spite of the scale formation on insulators. The scale formation of the insulator is shown in photographs 5, 6 and 7. This property of hydrophobic recovery makes the insulator to perform better under polluted conditions.

PH. 5 SCALE FORMATION ON SRV INSULATOR

PH. 6 SCALE FORMATION ON SR1 INSULATOR

PH. 7 SCALE FORMATION ON SR2 INSULATOR

3.3 EDXRF analysis

EDXRF analyses were carried out on small samples cut out of the insulators. Four silicone rubber materials with known ATH content of 10%, 20%, 30% and 40% was taken as a reference for creating calibration curve. Based on the calibration curve, the resultant % of silicone in various samples taken out is as indicated in Table 1.

TABLE 1

VARIATION OF SILICONE CONTENT WITH AGEING

Insulator	Silicone content after					
	1000 hours	2000 hours	3000 hours	4000 hours	5000 hours	10000 hours
SRV	10.20%	15.68%	21.40%	22.77%	28.05%	28.79%
SR1	8.12%	17.04%	16.55%	8.33%	10.02%	29.98%
SR2	20.76%	30.01%	34.70%	27.87%	29.12%	48.11%

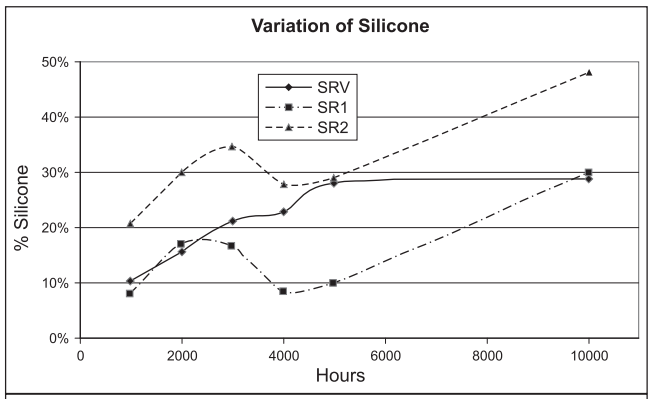


FIG. 5 VARIATION OF SILICONE WITH AGEING

It can be seen that there is an increase in silicone content in all the insulators at the end of the test. This increase in silicone content is due to the migration of low molecular weight chains from bulk to the surface. Due to this, the insulator displays good hydrophobic property and its performance is superior in contaminated conditions.

3.4 X-ray dispersion analysis

The results of the analysis are presented in spectra shown in Figs. 6, 7 and 8.

It can be seen that there is no appreciable variation in the state of the material. Thus the materials of all the three insulators are still amorphous even after being exposed to 5000 hours of salt fog and have not degraded.

The results show that the behaviour of insulators with or without biocontamination is virtually the same under salt fog conditions. Thus it can be concluded that biocontamination does not have a significant effect on the performance of polymer insulators.

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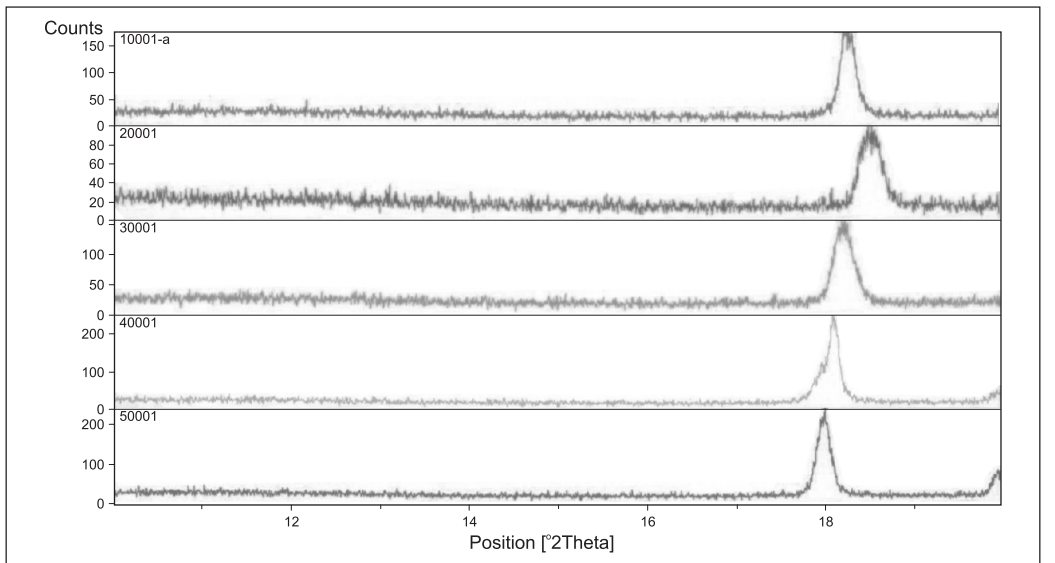

FIG. 6 XRD OF SRV INSULATOR

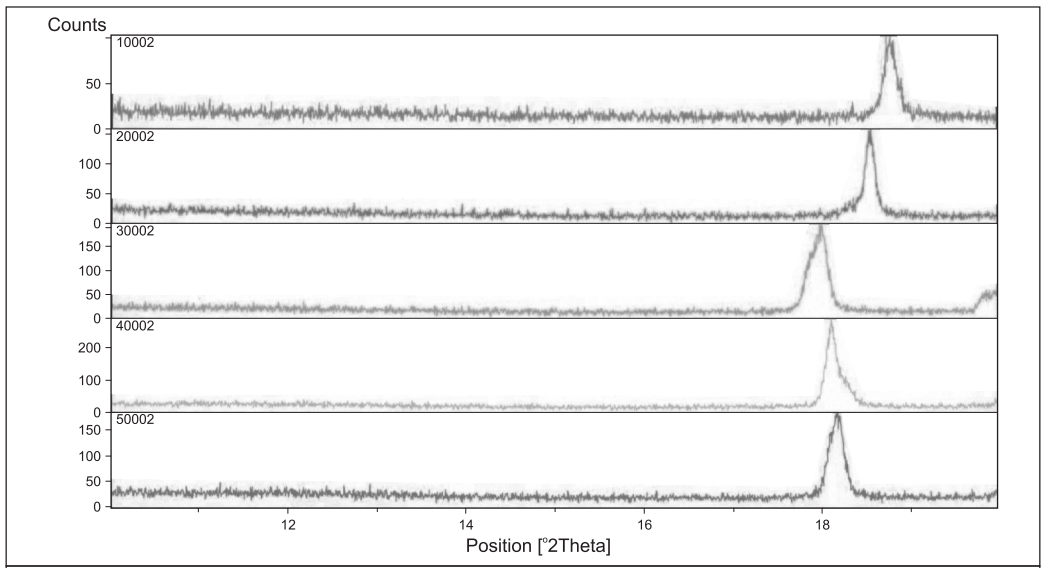

FIG. 7 XRD OF SR1 INSULATOR

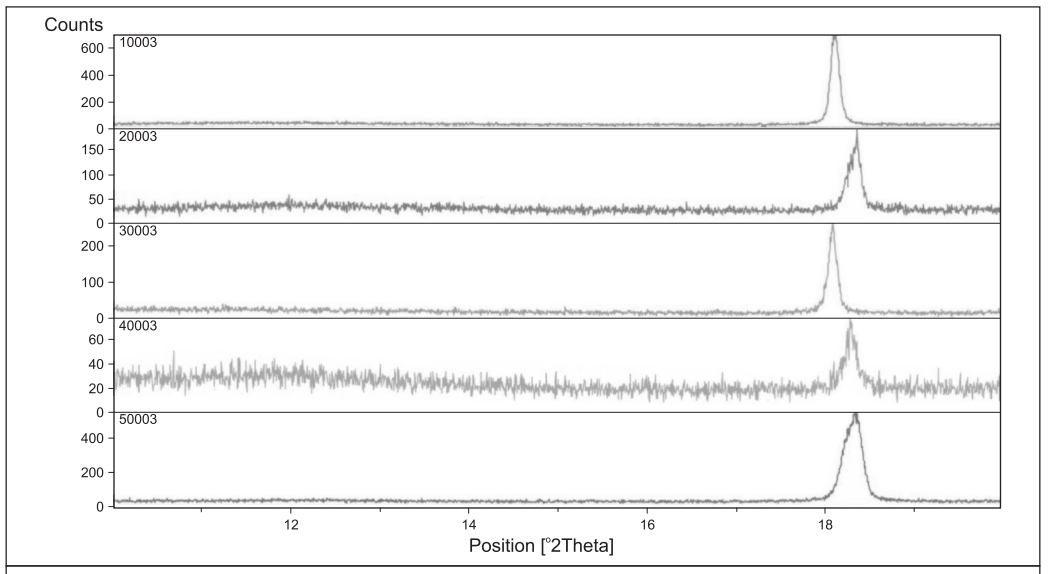

FIG. 8 XRD OF SR 2 INSULATOR

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