

Hygroscopic properties of natural pollutants on silicone rubber surfaces

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Abstract: The aim of this research is to determine whether hydrophilic and hygroscopic particulate pollutants on glass and silicone insulator surfaces maintain their electrical and water absorption properties, once low molecular weight siloxanes have migrated through the pollution layer. Surface conductivity measurements were performed on glass and silicone rubber plates (HTV and RTV) under conditions of extremely high humidity. Test dusts from the Sahara and Negev Deserts, from Glogow insulator pollution test station (Poland), fly-ash and also standard kaolin were applied in a laboratory to virgin glass and rubber plates. It was found that the value of the surface conductivity measured on the HTV silicone rubber is similar to that on virgin glass. This is true even after time is allowed for possible hydrophobicity transfer to the applied hygroscopic pollution dust. Surface conductivity on RTV silicone rubber with dusts, applied two weeks earlier, was 30% to 60% lower than on a freshly polluted sample. Surface conductivity measured at 100% humidity, increases, where the final surface conductivity depends on the dust type, yet is considerably lower than the surface conductivity measured on a sample wetted by a sufficient amount of water.

1 INTRODUCTION

The wetting processes on polluted ceramic insulators have been investigated previously [1], [2]. Much research has been focussed to study the resistance of polymer dielectrics to tracking and erosion performance under various environmental conditions. The specific properties of siloxanes have been reported previously i.e. the loss, recovery / transfer of hydrophobicity [3] and also the dynamics of water droplets on a hydrophobic surface of typical electrical insulator materials used outdoors in high voltage applications [4]. Historically, already for 40 years, the absorption of water vapour by a pollution layer on a glass insulator surface has been examined [2]. The theoretical explanation of the identified process is simple since a glass surface is inert and does not influence the absorption process. Siloxanes are dynamic materials since they allow hydrophobicity transfer, giving rise to hydrophobization of any pollutants on the surface. As a result, the hydrophilic pollution layer can theoretically become hydrophobic. The question arises: Do the

hydrophilic/hygroscopic pollutants preserve their properties when placed on silicone rubber surfaces? Do the initially hygroscopic, hydrophilic pollutants lose their ability to absorb water vapour when they become gradually hydrophobic on silicone rubber? In this paper we try again to answer this question following our previous investigations [5].

2 HYGROSCOPIC PROPERTIES OF POLLUTANTS

Fog or high humidity conditions in nature can last in certain geographical regions for many hours / days. The moisture absorption by pollution layers on HV insulators, plays an important role in such circumstances. The degradation of polymeric insulators could be caused by small but stable discharges with the current in the range of 1 to 5 mA [6]. The onset of partial discharges on polluted insulators is possible at a very low surface conductivity value. Due to a non-uniform voltage distribution, the discharges arise often in the vicinity of the metal hardware [6]. The concentrated discharges burning for a long periods could be catastrophic. There are two different ways of moisture absorption by pollutants from a high humidity atmosphere, absorption by the insoluble deposit and absorption by the soluble part of contaminants.

2.1 Hygroscopic properties of salts

In a closed volume, the vapour pressure over a salt solution (P_S) is always lower than the vapour pressure over pure water (P_W). The process is described by Raoult's law [2]:

$$P_S = X_W \cdot P_W \quad (1)$$

where: X_W is the mole fraction of water in the salt solution.

A salt solution can either evaporate or absorb water from air depending on the sign of the difference ($P_S - P_a$). where: P_a is the water vapour pressure in an open air over a salt solution.

A saturated salt solution cannot absorb moisture if the vapour pressure over it is lower than P_{SS} (the vapour pressure over its saturated solution). Therefore, a dry salt does not absorb water so long as the vapour pressure in the surrounding air is smaller than P_{SS} . On

the other hand, in air of 100% humidity all saturated solutions absorb water.

2.2 Moisture absorption by insoluble deposits

The insoluble components of the contamination also do not absorb much moisture. However, some industrial types of dust have a very porous structure for example fly ash. The artificial pollutant kaolin absorbs traces of moisture even at 50% relative humidity. Therefore, a small current can be measured on NaCl / kaolin contaminated insulators even under low humidity [7].

3 EXPERIMENTAL PROCEDURE

The rectangular HTV or RTV silicone rubber and glass plates with the length of 10 cm, width of 5 cm and the thickness of 0,4 cm were selected for experiments. The special stainless steel electrodes with the dimensions of $5 \times 2,5$ cm were placed on either side of the polluted plates (Figure 1). Many small holes in the electrode surface could allow moisture ingress into the contamination layer situated beneath the electrodes. This could decrease the contact resistance between the pollution layer and the stainless steel electrode.

The samples were mounted in a glass cylinder with a diameter of 30 cm and the height of 50 cm (Figure 2). The cylinder was placed inside the water. The humidity was increased up to 97% within an hour inside the cylinder. The humidity was measured by means of the Testo 625 probe manufactured by TESTO LIMITED, (3% accuracy.) The DC voltage of 300 V was applied from the calibrator ZWN 2,5 Polon for a few seconds and the current was measured by means of the digital multimeter Brymet BM837R.



Figure 1: The silicone plate contaminated by desert dust and the perforated electrodes.

A sample of dust from the Negev desert (Israel), a dust sample from the Sahara desert (Algeria), a dust from Glogow copper smelter (Poland), fly –ash from a power plant using black coal and the standard kaolin were used as contaminants. About 300 mg of dust were mixed with 1 ml of distilled water and uniformly distributed across the whole surface of the plate. Then the surface conductivity was measured by means of a rod probe [8]. This value of surface conductivity is designated “**water saturated surface conductivity**” K_{sw} . The Kaolin concentration was 100 mg per millilitre for the applied contamination. In this case 1 ml of tap water with the conductivity of $480 \mu S/cm$ was mixed with the kaolin on the surface of the plate.



Figure 2: The sample inside the glass hygrostat

The pollution layer was dried out and after 1 hour put into the glass hygrostat. The voltage was switched-on every 30 minutes for a few seconds, the current was measured and the surface conductivity was calculated. The measurement of current was carried out for about 7 hours. Then the sample was left in the glass hygrostat (with the voltage switched off) for a further 17 hours. The measurement was then repeated. The value of the surface conductivity was termed; “**moisture saturated surface conductivity**” K_{SM} . The plate was removed from the hygrometer and the measurement cycles were repeated again after 10 and 20 days.

CONDUCTIVITY OF DUST-WATER MIXTURES

The dusts contain different chemical compounds and have different amount of salts with different solubility in water [9]. Therefore, the conductivities increase as a function of dust concentration in distilled water (Figure 3).

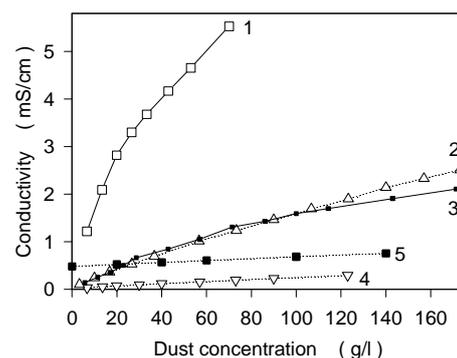


Figure 3: Conductivity of water-dust mixtures. 1 – Glogow, Poland, 2 – Sahara, Algeria, 3 – Dust precipitator, coal power plant, 4 – Negev, Israel, 5 – kaolin in tap water

The conductivity of the kaolin / distilled water solution is very low. At the kaolin content of 40 g/l a conductivity of $70 \mu S$ was measured. Therefore, the kaolin was mixed with tap water with the conductivity of $480 \mu S$.

4 RESULTS ON GLASS PLATE

All the dry pollution layers on the glass plates were hydrophilic and hygroscopic. The pollutant absorbs the water droplet building a moist stain (Figure 4). In contrast, the pollutants on the HTV or RTV silicone rubber become hydrophobic after about 24 hours after contamination was applied. The droplets are then not absorbed (Figure 5). This is a well known characteristic of silicone rubber.

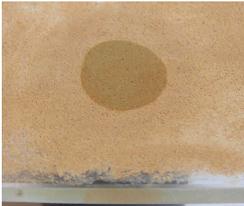


Figure 4: The moist stain left by an absorbed droplet on glass plate coated with Sahara dust

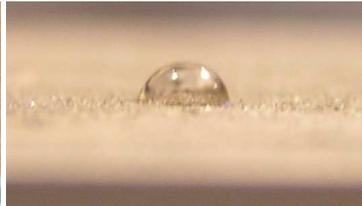


Figure 5: The droplet on HTV silicone surface polluted by Negev dust 5 days before.

When the glass plate is placed into the hygromat, the surface conductivity of the pollution layer increases over time as shown in Figure 6. When the plate is removed from the hygromat, dried and then returned to the hygrometer, the conductivity changes are similar, but not identical (Figure 6) and vary by approximately 10%.

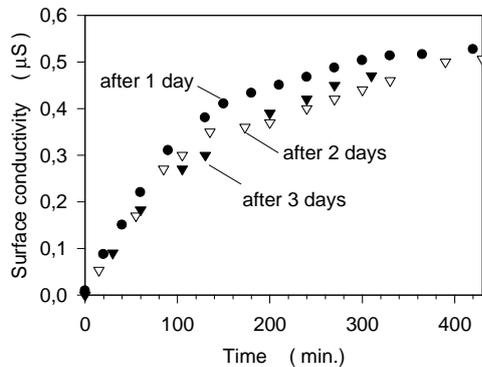


Figure 6: Surface conductivity of dust from Sahara desert on glass plate

5 RESULTS ON HTV SILICONE PLATES

HTV silicone plates were contaminated with dust from Negev (Figure 7) desert and also with dust from Glogow copper smelting plant (Figure 8). The surface conductivity measured 24 days after contamination by Negev dust is approximately 10% higher than the surface conductivity measured 1 hour after contamination. This result could be explained as a scatter in the measurements was also observed on the glass plate samples. The surface conductivity of the

pollution layer formed by dust from Glogow show an even greater scatter, more evident during the initial two hours of measurement (Figure 8). A rapid increase in the surface conductivity on the plate with the fresh contaminant falls within the experimental. The plate was placed inside the hygromat which had not been dried to the initial relative humidity of 50%. Therefore, at the outset of measurement, the air humidity was higher than the humidity during subsequent cycles.

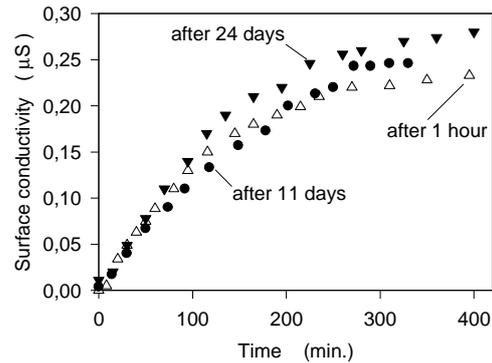


Figure 7: Surface conductivity of dust layer from Negev desert on HTV silicone rubber

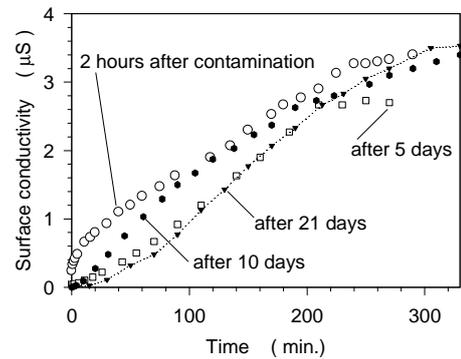


Figure 8: Surface conductivity of Glogow dust layer on HTV silicone rubber

Both figures suggest that the surface conductivity of the pollution layer was not influenced by the HTV silicone rubber under high humidity conditions even 24 days after contamination. It should be stressed that the pollution layer was hydrophobic. The droplets put on the pollution layer were not absorbed but stable (Figure 5). Additionally, the dust was removed from the HTV silicone rubber, 24 days after contamination. The dust floats, unlike in fresh samples of dust with disperse homogeneously (Figure 9a). The segregated dust can be homogeneously dispersed into the water after shaking and mixing (Figure 9b). This behaviour of hydrophobic dust was reported earlier and is due to the solubility of low molecular weight siloxanes which are coating the pollution particles [10].

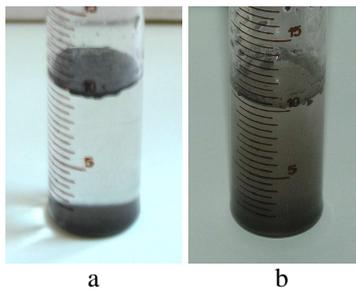


Fig. 9. Demonstration of hydrophobicity transfer. Dust from Glogow scraped from the HTV silicone rubber floats on water (a), can be dispersed after shaking and mixing (b)

6 RESULTS ON RTV SILICONE PLATES

The RTV silicone rubber base does however influence the value of surface conductivity of a polluted sample. In other words, the surface conductivity is dependent on the time period since the application of the pollutants. (Figure 10, Figure 11). The measurements presented in Figures 10 and 11 show that the surface conductivity decreases during 20 days after contamination by as much as 30% to 60% of the value measured on a fresh sample.

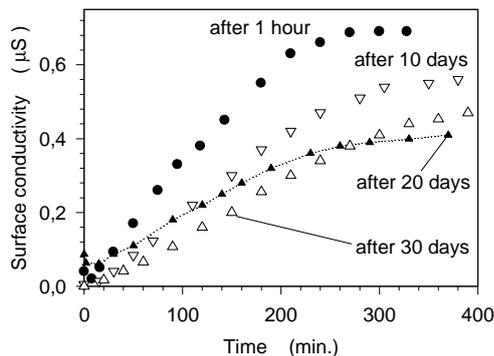


Figure 10. Surface conductivity of dust from the Sahara on a RTV silicone plate

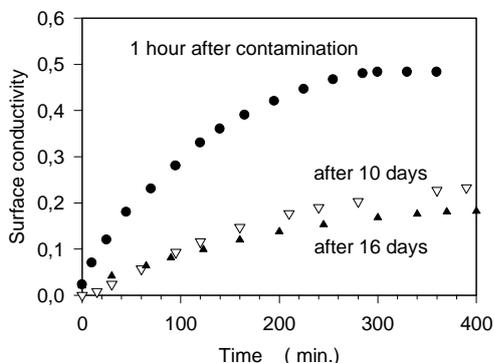


Figure 11: Surface conductivity of kaolin on RTV silicone plate

Similar results were recorded for the fly ash contaminant (Figure 12). In this case however, the surface conductivity decreased rapidly even after only four days. This dust is affected not only by the

diffusion of the low molecule weight (LMW) siloxane chains from the bulk of the RTV rubber but also by the chemical reactions occurring in the presence of water. The conductivity of this dust-water mixture decreases with time. The process will be explained on the following examples.

A solution of 0,3 g of fresh fly ash in 10 ml distilled water has a conductivity of 405 µS/cm. The same quantity of ash, removed from the RTV surface after 4 days mixed also with 10 ml of distilled water gives a conductivity of only 270 µS/cm.

The ash / water mixture with a concentration of 170 g/l in a beaker has a conductivity of 2,11 mS/cm. The water was allowed to evaporate and the dust was then re-dissolved in 10 ml water. A significantly lower conductivity of only 0,70 mS/cm was measured.

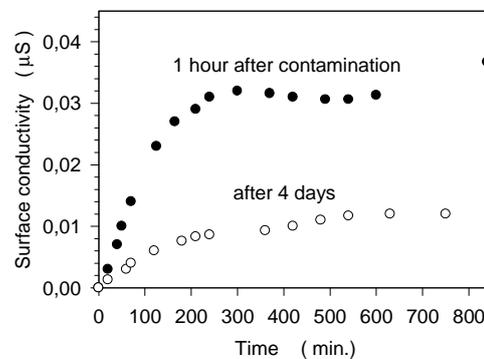


Figure 12: Surface conductivity of fly-ash on RTV silicone plate

7 MOISTURE SATURATED SURFACE CONDUCTIVITY

Moisture saturated surface conductivity measured 24 hours after conditioning of contaminated plates in air humidity of 100% is considerably smaller than the water saturated surface conductivity measured after mixing of dust with 1 ml of distilled water. The moisture saturated conductivity on silicone rubber plates listed in table 1 was measured on fresh contaminated samples (25 hours after contamination). The ratio of moisture saturated surface conductivity to water saturated surface conductivity depends on the dust properties and was found to vary from 0,4% for the ash contamination to 5,8% for dust from Glogow test station.

Table 1: The values and ratio of moisture saturated surface conductivity and water saturated surface conductivity

Dust origin	Fly ash	Negev desert	Sahara desert	kaolin	Glogow station
κ_{SM}	0,08 µS	0,2 µS	1,4 µS	0,63 µS	24,5 µS
κ_{SW}	22 µS	17 µS	55 µS	20 µS	420 µS
κ_{SM}/κ_{SW}	0,4 %	1,2 %	2,5 %	3,2 %	5,8 %

κ_{SM} – moisture saturated surface conductivity, κ_{SW} – water saturated surface conductivity

Under a continuous operating voltage the moisture saturated surface conductivity is lower than the value measured without the application of a continuous voltage stress. Therefore, the flashover voltage in high humidity air is possible only in very extreme cases. However, in such conditions the discharges can persist not only on disc insulators around the pin [2] but also on very lightly polluted composite insulators close to the terminals [11].

The achieved results give a new light on the performance of silicone insulators in a high humidity environments. These insulators are being installed more frequently in the tropics [12]. In these regions a relative humidity greater than 90% persists for months [13], and often a relative humidity close to 100% is experienced the whole day [14].

CONCLUSIONS

A hydrophobic pollution layer on HTV silicone rubber absorbs the moisture in humid air in a manner similar to a hydrophilic pollution layer on a glass surface.

However the hydrophobic pollution layer on a RTV silicone rubber causes a considerable decrease (30%-60%) in the surface conductivity compared with that measured on a glass surface.

The test dusts used in these experiments have different hygroscopic properties. The moisture absorption ability of dust can be described by the ratio of moisture saturated surface conductivity to the water saturated surface conductivity.

7 ACKNOWLEDGMENT

The authors thank Dr. Wolfgang Koehler, University of Stuttgart, for the loan of the glass hygrometer for an extended period of time. Radu Munteanu, Israel Electric and Sif Eddine Abdi, University of Medea, Algeria are

appreciated for delivery of dust samples from their countries.

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