CONDUCTIVITY OF SOLID LAYERS POLLUTION ON SILICONE RUBBER IN HUMID AIR

K. L. Chrzan
Wroclaw University of Technology
Wybrzeze Wyspianskiego 27, 50-370 Wroclaw, Poland
krystian.chrzan@pwr.wroc.pl

Abstract: The surface conductivity changes of solid layers deposited on silicone rubber under high humidity as a function of conditioning time in room conditions were studied. The measurements were carried out on flat samples in a glass hygrostat. It was shown that the surface conductivity of kaolin layer deposited on RTV-2 silicone decreases 4 times after 30 days of conditioning. However, the layer prepared from a natural dust from Glogow pollution test station shows different properties. The increase of layer hydrophobicity is related with the hygroscopicity decrease.

1 INTRODUCTION

The solid layer pollution consists of dusts that are the main pollutant of outdoor insulators in industrial or desert areas. The dusts contain soluble and non-soluble components with different contents [1]. The main dust parameters are grain dimension, specific surface and strew density. Note that the Aerosil, rarely used as an artificial insulator pollutant [2, 3] is a few times lighter than a typical natural dusts, however, its specific surface 200 m^2/g is very large (table 1).

Table 1: Strew density of different dusts

Dust name or its source	Strew density (g/cm^3)
Sahara, Algieria	1,01
Głogow Copper smelting plant	0,64
Elektrostatic precipitator, power plant in Wroclaw	0,52
Kaolin	0,30
Aerosil silicone oxide	0,11

In humid air, the dusts adsorb water as a result of chemical adsorption, physical adsorption or by the so called capillary condensation. The sorption ability is proportional to dust specific surface and to its porosity. The soluble components of dust (salts) absorb moisture and increase the surface conductivity. This process (hygroscopic properties of dusts and salts) was studied earlier on contaminated glass samples [1]. The author began similar investigations on contaminated silicone rubber a few years ago. It seemed initially, that the hygroscopicity of dust deposited on high temperature vulcanised 'HTV' silicone rubber is the same as that on glass. In other words the HTV silicone rubber does not influence the moisture absorption by the pollution layer deposited on its surface [4]. The latest measurements with natural dusts and flat samples made of HTV or room temperature vulcanised 'RTV' silicone rubber have shown, that the RTV silicone rubber considerably decreases hygroscopic properties of dusts [5]. In this paper, we show that also HTV silicone rubber, although in a smaller grade, can decrease the dust hygroscopicity.

Conductivity of pollution layer on insulators in humid air is very important. It is responsible for a strange behaviour of silicone insulators. In very humid air the leakage current on naturally contaminated silicone insulators could be even a bit higher than that on porcelain insulators with the same profile [2].

2 RESEARCH OBJECTS AND EXPERIMENTAL PROCEDURE

The measurements were carried out on flat samples with dimensions of 10 × 5 × 0,4 cm made of glass or HTV silicone rubber or RTV-2 silicone rubber. The special stainless steel electrodes with dimensions of 5 × 2,5 cm were placed on opposite sites of dry solid layer deposited on the sample. Numerous small holes in electrodes enable the moisture ingress to the dust layer deposited under the electrodes (Figure 1). This design decreases the resistance between the electrode and the pollution layer.

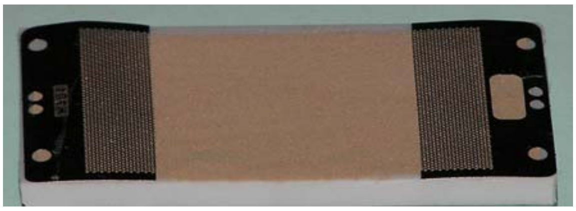

Figure 1: The flat sample contaminated by solid layer with specially perforated electrodes.

The contaminated samples were put into the glass hygrostat with 30 cm diameter and with 50 cm height. Then the hygrostat was placed in distilled water and the air humidity inside it increased after 1 hour to the value of 97%. All experiments were carried out in the room temperature of 20 °C. The surface conductivity was measured according to two procedures: by switching-on the DC voltage of 300 V for about 10 seconds or by using the conductivity-meter SML4 manufactured by the University of Applied Sciences in Zittau, Germany [7].

The dust from Algerian Sahara, dust from Glogow Copper Smelting Plant and kaolin were chosen for experiments. Three hundred mg of natural dust were uniformly distributed on the surface sample and mixed with 1 ml distilled water. Kaolin has smaller strew density and contains a very small amount of conducting components. Thus, 100 mg kaolin were mixed with 1 ml of conducting water. The conductivity of water was increased to 2,5 mS/cm by addition of NaCl. The surface conductivity of totally wet pollution layer was measured by means of rod probe [6] and the measured value were called as water saturated surface conductivity K_{SW}. The contaminated sample was carefully dried for about 1 – 2 hours and then was put into hygrostat. The surface conductivity was measured periodically for a longer period of time. The experiment was stopped when the measured values were getting constant. This value was called moisture saturated surface conductivity K_{SM}. The silicone rubber samples were later taken out of hygrostat and stored in room conditions for several days and at different paces of time. Next, the samples were put again into hygrostat and surface conductivity measurement were repeated at each pace of time.

3 SURFACE CONDUCTIVITY OF POLLUTION LAYER DEPOSITED ON GLASS

The surface conductivity of pollution layer deposited on glass increases gradually up to a steady value as a result of moisture absorption. The increase rate depends on the layer thickness, fraction and chemical composition of dust. The dust layer from Sahara get saturated after about 30 hours (Figure 2) but the dust layer from Glogow smelting plant – only after 500 hours (Figure 3).

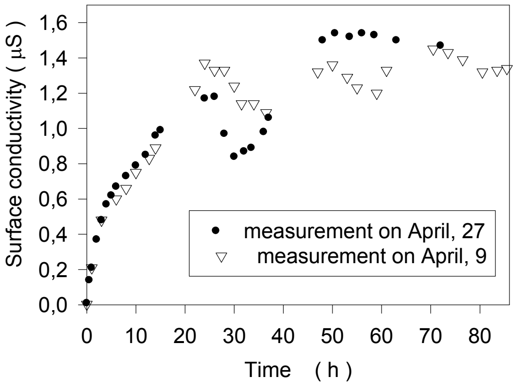

Figure 2: Surface conductivity of dust layer from Algerian Sahara deposited on glass.

In spite of the same dust masses, the moisture saturated surface conductivity K_{SM} of Sahara dust amounts merely 1,4 µS but that of Glogow dust goes up to 85 µS. The values of water saturated surface conductivities K_{SW} of both pollutants were also considerably different, K_{SW} of Sahara dust amounted around 90 µS and that of Glogow dust indicates up to 450 µS.

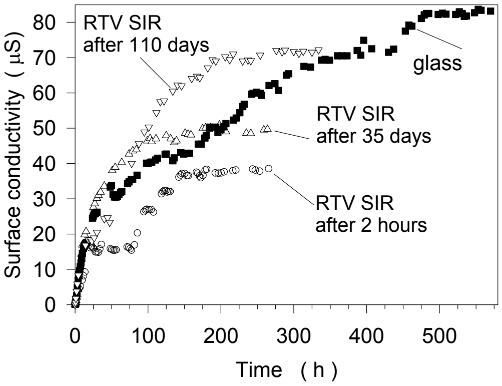

Figure 3: Surface conductivity of dust layer from Glogow Copper Smelting Plant deposited on glass or on RTV-2 silicone rubber.

4 CONDUCTIVITY OF POLLUTION LAYERS ON SILICONE RUBBER

The conductivity of pollution layer deposited on silicone rubber depends additionally on the conditioning time of dust on silicone surface. The moisture saturated surface conductivity K_{SM} decreases with conditioning time. Figure 4 shows the surface conductivity changes of kaolin layer deposited on HTV silicone rubber for conditioning times from 2 hours to 37 days. This means that the layer was deposited 2 hours or 37 days on silicone surface before the conductivity measurements were started.

Figure 5 shows analogous layer deposited on RTV-2 silicone layer for conditioning times from 2 hours to 33 days. It could be concluded that RTV-2 silicone rubber stronger limit the value of surface conductivity. The surface conductivity K_{SM} measured after 24 days or after 33 days conditioning time decreases 4 times compared to that, measured after two hours of conditioning. Similarly measured K_{SM} after 37 days of conditioning on HTV silicone rubber decreases nearly 2 times. In other words, silicone rubber limits the hygroscopicity of pollution layer.

The decrease of surface conductivity in humid air with increasing conditioning time could probably be explained by phenomenon described in numerous papers and called as hydrophobicity transfer [8]. However, the behaviour of dust layer from Glogow is different. With increasing conditioning time on RTV-2 silicone rubber, the moisture saturated surface conductivity K_{SM} increases (Figure 3). After

110 days of conditioning, the value of surface conductivity in a time range, was even higher than that measured on glass surface.

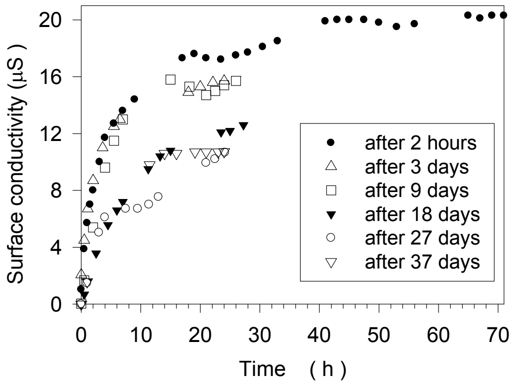

Figure 4: Surface conductivity of kaolin layer deposited on HTV silicone rubber for different conditioning times.

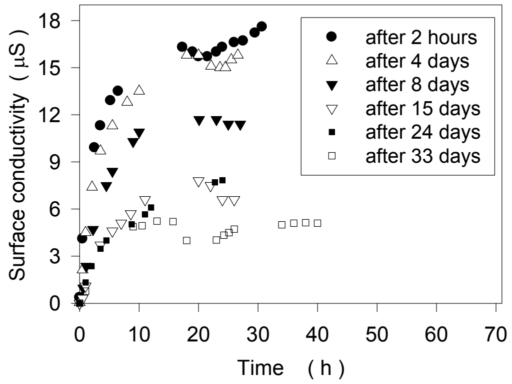

Figure 5: Surface conductivity of kaolin layer deposited on RTV-2 silicone rubber for different conditioning times.

After 5 months of conditioning of dust from Glogow on glass or on RTV-2 silicone rubber the layers were removed and mixed with 20 ml of distilled water. The conductivities of both mixtures were practically the same, 1,87 and 1,88 mS/cm. The calculated equivalent salt deposit density 'ESDD' is equal to 0,42 mg/cm^2. Note that ESDD of kaolin layer with NaCl-addition amounts only to 0,03 mg/cm^2. In spite of more than ten times smaller ESDD, the surface conductivity κ_{SM} of fresh kaolin layer measured in humid air (Figures 4 and 5) is only 4 times smaller than the surface conductivity κ_{SM} of Glogow dust deposited on glass (Figure 3). This shows that kaolin layer with NaCl addition is more hygroscopic than the layer consisting of Glogow dust.

5 THE LOSS AND RECOVERY OF HYDROPHOBICITY OF DUST LAYER

The pollution layer deposited on RTV-2 silicone rubber after long influence of very humid air losses its hydrophobic properties. Figure 6 shows the behaviour of water droplet put on Glogow dust layer 10 days after removing it from the hygrostat (air humidity of 100%) to the room with the air humidity of 50%. The sample was subjected earlier to two long-term conductivity measurements in very humid air. The results of these measurements are shown in figure 3. After the second conductivity measurement that lasted for 240 hours, the sample was placed in a room with 50% humidity and droplets behaviour were later observed.

The droplet placed down on Glogow dust layer deposited on glass is immediately (within one second) absorbed and form a wet stain with a diameter of 1 cm (Figure 6b). The Glogow dust layer on silicone rubber did not recover its hydrophobicity after 10 days conditioning in dry conditions. Initially the wetting angle of 20° was observed (Figure 6a) and it was slowly absorbed by dust layer (Figure 6c). The wet stain in this case was about 50% smaller than the droplet on glass (Figure 6d).

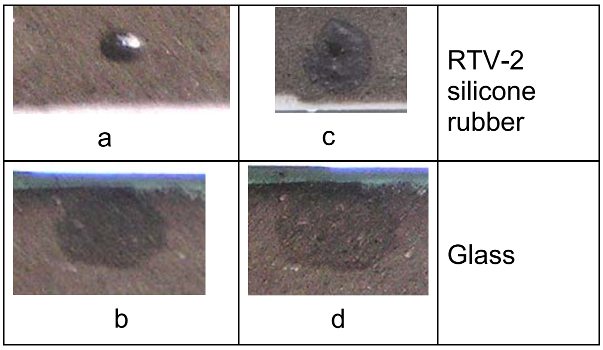

Figure 6: Water droplets after placing down on RTV-2 silicone rubber contaminated by dust from Glogow. The sample was earlier conditioned for a long time in the humidity of 100%. The picture was taken after successive 10-days conditioning in dry conditions of 50% RH. a, b – 10 seconds earlier droplets were put down on pollution layer, c, d – 4 minutes later

The kaolin layer on RTV silicone rubber is much more hydrophobic than the layer made from Glogow dust. Kaolin layer becomes hydrophobic 24 hours after removing the sample from the hydrostat. On the contrary, the layer from Glogow dust remains hydrophilic even 16 days after removing it from the hydrostat (Figure 7).

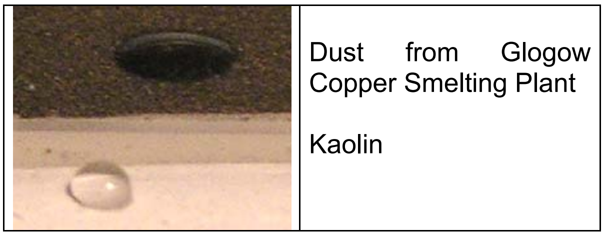

Figure 7: Water droplets after putting down on RTV-2 silicone rubber contaminated by Glogow dust or by kaolin. The pictures were taken 1 minute after the droplets were put down.

The Glogow dust layer recovers the hydrophobic properties very slowly. The wetting angle measured directly after putting down the droplet increases with conditioning time (beginning with sample removing from the hydrostat). So measured wetting angle has increased to 90° after 28 days of conditioning in dry air. However, when the droplet is placed down, the wetting angle decreases gradually because of water absorption by hygroscopic pollutants (Figure 8).

The droplet is pulled into the pollution layer and get gradually smaller. At the same time, a wet area around the droplet is formed. The wetting angle increases and the wet area decreases with conditioning time in dry room. This process is very slow. It was observed that after 66 days-conditioning in dry room, the pollution layer became hydrophobic (Figure 9c).

Figure 8: The droplet placed on the Glogow dust layer on RTV silicone rubber. Picture made 42 days after taking out the sample from the hydrostat, one minute after putting down the droplet. The wetting grade greater than 90° was measured directly after placement down the droplet.

a b c

Figure 9: The droplet on Glogow dust layer deposited on RTV silicone rubber, a) 130 days after contamination, including 10 days in hygrostat and 4 days after removing from hygrostat, the picture was made 1 minute after the droplet was put down, b) Nearly totally absorbed, the same droplet 4 minutes after putting down, c) The droplet put down 56 successive days after - the pollution layer recovered its hydrophobic properties.

Similar processes can be observed also on kaolin layer with addition of NaCl. However, in this case the transfer of hydrophobicity after sample contamination and the recovery of hydrophobicity after removing the sample from the hydrostat takes place much quicker than that on the Glogow dust layer. Figure 10 shows the water droplet placed down on kaolin layer with NaCl addition, deposited on RTV silicone layer 33 days before. The sample was taken out from the hydrostat after the last measurement of surface conductivity (shown in Figure 5). Around the droplet the darker, wet area is visible. Thirty three days after the conditioning in room conditions, this kaolin layer became totally hydrophobic (or fully not hygroscopic). Therefore, on such pollution layer, no wet area around the droplet is formed.

Figure 10: The droplet placed down on kaolin layer with NaCl addition, 33 days after the contamination of RTV silicone rubber.

6 CONCLUSION

In very humid air, the surface conductivity of kaolin layer with NaCl addition deposited on silicone rubber decreases with earlier conditioning time of polluted sample in dry room conditions.

The speed and range of this process is greater on RTV-2 silicone rubber than on HTV silicone rubber.

In a very humid air, the surface conductivity of natural, Glogow dust layer deposited on RTV-2 silicone rubber increases with earlier conditioning time of polluted sample in dry room conditions. However, the moisture is absorbed considerably slower by this layer than by the kaolin layer.

7 ACKNOWLEDGMENTS

The author thanks M. Sc. Sif Eddine Abdi, Medea University, Algeria for the delivery of Sahara dust.

8 REFERENCES

[1] K.L. Chrzan, “Hygroscopic properties of pollutants on HV insulators”. *IEEE Trans. on Electrical Insulation,* Vol. 24, No. 1, pp. 107-112, 1989

[2] B. Macchiaroli, F.J. Turner, “A new contamination test method”. *IEEE Trans. Power Apparatus and Systems*, Vol. 88, Sept., pp. 1400-1411, 1969

[3] F. Exl, J. Kindesberger, R. Baersch, F. Gerdinand, “Round robin test for the evaluation of the hydrophobicity transfer ability of polymeric insulating materials”. *ETG Fachtagung Grenzflaechen in elektrischen Isoliersystemen*, Hanau, pp. 73-78, 2005

[4] K.L. Chrzan, “Hygroscopic properties of pollutants on silicone rubber surface”. *Int. Symposium on HV Engineering ISH*, Ljubljana, paper T4-111, 2007

[5] K.L. Chrzan, C. Greyling, "Hygroscopic properties of natural pollutants on silicone rubber surfaces". *Int. Symposium on HV Engineering ISH*, Cap Town, paper E-32, 2009

[6] K.L. Chrzan, "Leakage current on naturally contaminated porcelain and silicone insulators". IEEE Trans. on Power Delivery, Vol. 25, No. 2, pp. 904-910, 2010

[7] K.L. Chrzan, C. Stec, M. Farzaneh, "Probes for spot measurement of surface conductivity on polluted insulators". *IET Sci. Meas. Technol*., 1, (5), pp. 295–300, 2007

[8] D.A. Swift, C. Spellman, A. Haddad, "Hydrophobicity Transfer from Silicone Rubber to Adhering Pollutants and its Effect on Insulator Performance"*. IEEE Transactions on Dielectrics and Electrical Insulation,* Vol. 13, No. 4, pp. 820-829, 2006