Low pressure and humidity influences on the electret surface potential decay

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Abstract. In the present paper the influence of both relative humidity and low pressure on the surface potential decay of charged 20 µm polypropylene films was investigated. Sample charging was performed in a three-electrode corona discharge system. After charging the initial surface potential was measured using the method of the vibrating electrode with compensation. Two groups of tests were performed. In the first group, after charging the electrets were placed into a vacuum chamber under various low pressures (from 0.1 mbar to 1000 mbar) for 30 minutes. After that the electrets were removed from the vacuum chamber. The surface potential was measured again and the normalized surface potential was calculated. The influence of low pressure was analyzed by the equation that describes processes of desorption from the electret surface. In the second group after charging the electrets were put in desiccators at 0% and 100% relative humidity for 220 days at room temperature. After that the surface potential was measured periodically out of the desiccators. The results obtained were analyzed with the percolation 2D model. It was established that the higher values of the relative humidity led to a faster decay of the surface potential. We assume the presence of surface discharge processes.

1. Introduction
Electrets have been a field of investigations for many years [1-3]. They have been used in different areas of science, techniques and medicine. A number of factors, which influence the charge storage and charge transport in electrets, have been investigated [4-6]. The surface charge decay has been explained by various polarization mechanisms or charge injection and charge transport through the electrets [7]. The influence of the surface on charge relaxation has been neglected. However, there are some experimental data, which show that the surface charge relaxation should not be neglected under certain conditions in particular at different relative humidity and low pressure [8, 9]. It has been shown that corona discharge modifies the surface [10] and the surface potential decay depends on the surface charge distribution [11].

The aim of this paper is to study (investigate) the influence of the surface processes on charge decay of polypropylene corona electrets stored at different relative humidity and low pressure.

2. Experimental
2.1. Samples
Nonmetalised samples of 20 µm thick polypropylene (PP) films manufactured by Assenova Krepost Ltd, Bulgaria were investigated. Initially the PP films were cleaned with alcohol in an ultrasonic bath
for 4 minutes, washed in distilled water, and dried under room conditions. The 30 mm diameter samples were cut from that cleaned film and were put onto the same diameter metal pads.

2.2. Corona charging and surface potential measurement
The charging of electrets in the corona discharge was carried out by means of a conventional three-electrode system consisting of grounded plate electrode, corona electrode and a grid placed between them. The distance between the corona electrode and the grid was 10 mm and the distance between the grid and the grounded plate electrode was 3 mm. The samples were charged for 1 minute under room conditions. The voltage of the corona electrode was -5 kV. The electrets surface potential was limited by the grid potential and was of the order of 500 V and 650 V.

Electrets surface potential was measured by the method of the vibrating electrode with compensation by which the estimated error was better than 5%. After charging, the initial surface potential $V_0$ was measured and the electrets were divided in two groups according to the kind of treatment – different low pressure and humidity.

2.3. Low pressure treatment
After samples charging the initial electret surface potential $V_0$ was measured and then the electrets were placed into a vacuum chamber under various low pressures for 30 minutes. The pressure values in the vacuum chamber were 0.1 mbar, 1 mbar, 10 mbar, 20 mbar, 66 mbar, 132 mbar, and 1013 mbar. After that the samples with their metal pads were removed from the vacuum chamber, their surface potentials $V$ were measured again and the normalized surface potentials $V/V_0$ were calculated.

2.4. Humidity treatment
To investigate the influence of relative humidity (RH) on the surface charge decay the samples were stored for 50 days in two desiccators at different RH denoted in the following manner: 1 (0% RH) and 2 (100% RH). Then the samples were charged to an initial surface potential $V_0$ and placed again in desiccators 1 and 2. The samples were marked as BA: 11, 12, 21, 22. The first figure (B) denotes the controlled RH desiccator in which the samples have been stored before charging, the second figure (A) denotes the same after charging. Periodically the surface potentials $V$ were measured again and the normalized surface potentials $V/V_0$ were calculated. The measurements were performed out of the desiccators.

3. Results and discussion
The conditions that propose the presence of surface discharge processes are the relative humidity and the low pressure and that is why we investigate the influence of these two factors on electrets surface potential decay.

3.1. Influence of low pressure on electrets surface potential decay
Dependences of normalized surface potential $V/V_0$ on normalized pressure $p/p_0$ for PP electrets charged in a negative corona to different initial surface potential are presented in figure 1.

The symbol $V_0$ indicates the initial value of the surface potential, measured just after the sample had been charged, and $p_0$ is the atmospheric pressure. Each point in the figure 1 denotes the average value for the normalized surface potential calculated from six samples. The maximum standard deviation from the average value at 95% confidence level was 5%.
The results, illustrated in figure 1 demonstrate the following peculiarities:

- Three parts are existed in each curve. At higher and lower pressures the surface potential is constant. For each curve a relatively narrow region of pressures exists where a sharp decay of surface potential occurs. Similar behaviour has also been observed in [12, 13].
- The values of the normalized surface potential at a pressure of 0.1mbar for the samples charged to a 500V initial surface potential are higher than those for the samples charged to a 650V initial surface potential.
- The higher the initial surface potential, the higher the pressure at which the sharp decay occurs. Hence, the potential sharp decay region is shifted to the lower pressures when the initial surface potential value decreases. The similar behaviour has also been observed for PET and PTFE [12, 14].

It is difficult to explain the dependence of the charge decay on pressure by means of injection and polarization models. As the pressure in the vacuum chamber decreases, desorption of ions from the electret surface is most likely to occur. As shown in [15], desorption is accompanied by surface diffusion and the following diffusion equation analyzed in [16] is proposed to describe the experimental results.

\[
\frac{V}{V_0} = a + \frac{b}{2} \left[ 1 + \text{erf} \left( \frac{x - c}{\sqrt{2d}} \right) \right]
\]  

(1)

where \( \frac{V}{V_0} \) is the normalized surface potential, \( x = \log \frac{p}{p_0} \) and \( a, b, c \) and \( d \) are parameters. The solid line in figure 1 is the theoretical prediction and the values of the parameters are: \( a=0.3604\pm0.0004; \ b=0.6398\pm0.0004; \ c=-2.4728\pm0.0025; \ d=0.2542\pm0.0013 \) for initial surface potential of 500V and \( a=0.3046\pm0.0032; \ b=0.6954\pm0.0041; \ c=-1.8939\pm0.0077; \ d=0.0859\pm0.0056 \) for initial surface potential of 650V.

The really good agreement between the theoretical curves and the experimental data (figure 1) shows that the surface potential decays due to desorption ions from the electret surface accompanied by surface diffusion.
3.2. Influence of relative humidity on electrets surface potential decay

The dependences of normalized surface potential on the time of storage for samples charged to different initial surface potentials were studied for 220 days. The curves are presented in figures 2, 3. All points are mean values from six samples and the calculated standard deviation was better than 5% with a confidence level of 90%. The surface potential time dependence curves for all samples have similar behavior.

Figure 2. Time storage dependences of electrets surface potential for samples, charged in a negative corona to a 500 V initial surface potential.

Figure 3. Time storage dependences of electrets surface potential for samples, charged in a negative corona to a 650 V initial surface potential.
The results presented in figures 2 and 3 show that:

- No matter whether the samples before charging are kept at a relative humidity 0% or 100% their behaviour is determined mainly from the storage conditions after charging, independently of the initial surface potential.
- In both cases of different initial surface potential (500 V and 650 V) sizable charge decay is observed if the electrets are kept after charging at the highest relative humidity 100%.
- For the samples that after charging have been stored at 0% relative humidity the established value for the normalized surface potential (after 165 days) is higher ($V/V_0 = 0.6$), compared to the one for the samples stored after charging at 100% relative humidity ($V/V_0 = 0.15$), independently of $V_0$.

If an electret is stored at a controlled RH, adsorbed water molecules from the environment and water-molecule clusters are formed on its surface, due to moisture adsorption. The aggregation of these clusters generates a two-dimensional (2D) percolation lattice that develops with time. If the concentration of absorbed water increases, a connection of the separate clusters takes place which may lead to an unbounded cluster (UC). The specific conductivity of water is much higher than the one of the polymer samples. Consequently, UC ensures fast neutralization of electret charge and a sharp decay of the surface potential. A model that accounts for these changes is the model proposed by Kuzmin and Tairov [17, 18] based on the simultaneous utilization of the percolation theory, and the Kolmogorov’s concept for the 2D kinetics of nuclei formation.

The surface potential time dependence curves for the samples 22 (charged to a 500 V initial surface potential) obtained from experimental studies, and the theoretical calculations, are presented in figure 4. Analogues curves were obtained for all the investigated samples. The theoretical calculations were made by computer software for nonlinear programming, using the Flexyplex software package, presented in [8].

The results obtained show a good conformity of theory with experiment. The really good agreement between the theoretical results and the experimental data (figure 4) shows that the percolation model allows to analyze electrets’ surface discharge, and reveal the significant influence of the humidity level at which they have been stored. We assume that moisture adsorption is stimulated by electrization, and further cluster growth depends on the storage medium after the charging of electrets. This is extremely important, and allows one to quantitatively describe the surface charge.
relaxation and predict the stability of polymer electret films that function under real conditions involving various relative humidity values.

Finally, surface potential decay for electrets kept at different values for the low pressure and humidity can well be described by theoretical models that assume the availability of surface processes. Equation (1) describes linear desorption of charges which is accompanied by surface diffusion. The percolation theory presupposes surface decay of electret charges. Consequently, the influence of both low pressure and humidity on the electret surface potential decay should not be explained as a result of the injection of the surface charge into the bulk and its subsequent transport through the sample.

4. Conclusion

Our experimental data show that the surface charge relaxation should be the main factor determining charge decay of electrets stored under low pressure and different humidity. The used theoretical models allowed to analyze electrets surface discharge, and to reveal the significant influence of the low pressure and humidity levels at which they have been stored. This is extremely important, and should be taken into account in the study of the stability of electrets sensors and devices that are used at room temperature and function under real conditions involving various low pressure and humidity levels.

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References

[1] Sessler G and Gerhard-Multhaupt R 1999 Electrets 3rd Ed. (Laplacian: Press Morgan Hill California)
[2] Nalwa H S 1995 Ferroelectric polymers (Marcel Dekker Inc. New York)
[3] Hilezer B and Malecki J 1986 Electrets (Elsevier Amsterdam)
[4] Herous L, Nemamcha M and SAAD S 2006 J. Engin. Appl. Sci. 1 (4) 329-334
[5] Gang-Jin C, Hui-ming X and Chun-feng Z 2004 J. Zhejiang University Sci. 5 (8) 923-927
[6] Kovacheva, Mekishev G and Nedev St 2005 JOAM, 7 (1) 237-240
[7] Moulinie P 1999 J. Electrostatics 45 265-273
[8] Kovacheva T A, Mekishev G A and Marinov A T 2004 J. Phys.: Condens. Matter 16 455-464
[9] Mekishev G, Kovacheva T, Guentcheva E and Nedev St 2003 J. Mater. Sci.: Mater. in Electronics 14 779-780
[10] Kovacheva, Avramova I, Mekishev G and Marinova T 2007 J. Electrostatics 65 667-671
[11] Karmazova P G and Mekishev G A 1992 Europhys. Lett. 19 (6) 481-484
[12] Mekishev G A, Kovacheva T A and Viraneva A P 2007 J. Non-Crystalline Solids 353 4453–4456
[13] Viraneva A P, Kovacheva T A, Gencheva E A and Mekishev G A 2010 J. Non-Crystalline Solids 356 560–563
[14] Viraneva A, Kovacheva T, Gencheva E and Mekishev G, 2008 JOAM 10 (2) 302 – 305
[15] Viraneva A P 2010 PhD thesis University of Plovdiv Bulgaria
[16] Viraneva A P, Kovacheva T A, Pisanova E S, Gencheva E A and Mekishev G A 2010 AIP Conference Proceedings BPU7 382-388
[17] Kuzmin Y and Taitov V 1984 J. Tech. Phys. 54 964-965
[18] Kuzmin Y 1999 Proc. 10th Int. Symp. on Electrets Eds A. Konsta, A. Vassilikou-Dova, K. Vartzeli-Nikaki 55