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Influence of humidity on surface potential decay of gamma irradiated polypropylene and poly(ethylene terephthalate) electrets

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In the present paper gamma irradiated polypropylene (PP) and poly(ethylene terephthalate) (PET) electrets stored at different humidity levels were studied. Polymer films were irradiated in air by a ^{60}Co source with total doses of 5 kGy accumulated in a single step at a dose rate of 0.25 kGy/h. After irradiation, the samples were charged in a corona discharge system, which consists of a corona electrode, a grounded plate electrode, and a metal grid placed between them at two polarities - positive or negative. All investigated samples were stored in desiccators at different humidity levels (0%, 55% and 100%). After that, the surface potential was measured periodically out of the desiccators by the method of the vibrating electrode with compensation. Time storage dependences of electrets surface potential at different relative humidity levels for all samples were investigated. The results obtained were analyzed with the percolation model. The percolation model was used to consider the surface potential decay of electrets. The model allowed to analyze the surface potential decay of the gamma irradiated electrets, caused by the influence of the humidity at which they were stored. It was established that the higher values of the relative humidity led to a faster decay of the surface potential.

Keywords: polypropylene, poly(ethylene terephthalate), electrets, humidity, gamma irradiated

INTRODUCTION

Electrets are dielectric materials capable to retain electric charges over a long period of time and to create an external quasistatic electric field. They have been a field of investigations for many years [1, 2]. Over the years, considerable interest has been shown in the surface potential decay of corona charged polymeric materials. Besides the electrets materials and conditions of producing electrets the surface potential decay depends on a number of factors under which the electrets have been stored or used, for example temperature, humidity, pressure, gamma irradiation, etc. [3-6]. For the formation of electrets different polymeric materials as polypropylene and poly(ethylene terephthalate) are widely used, because of their important commercial significance, structure and appropriate mechanical and electrical properties [7-9].

The influence of gamma irradiation of 5 kGy and 25 kGy on the stability of electret characteristics of corona charged PP and PET films was investigated by following the surface potential decay with time and with sample's storage temperature [10]. Significant changes in the electrets behavior of the polymer films after gamma irradiation were established. The surface potential decay depended on factors such as the corona polarity, the type of material and the irradiation dose. At 25 kGy the gamma irradiation induced enhancement of the electrets efficiency of the PP films which achieved the highest value. The possible mechanisms of surface potential decay responsible for the observed irradiation dependent behavior are discussed.

The aim of this paper is to investigate the influence of relative humidity on the surface potential decay of non-irradiated and gamma irradiated PP and PET corona electrets.

EXPERIMENTAL

Sample preparation

Isotactic polypropylene films with thickness of 20 μm (Assenova Krepost LTD, Bulgaria) and poly(ethylene terephthalate) films with thickness of 40 μm (Hostaphan RNK, Mitsubishi Polyester Films GmbH, Germany) were used. The polymer films were cleaned in an ultrasonic bath with ethanol for four minutes then washed in distilled water and dried on filter paper under room conditions. Samples of 30 mm diameter were cut from the clean films and subjected to gamma irradiation treatment.

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Gamma irradiation of the samples

Right after the samples were prepared, they were gamma irradiated. The samples were placed in special holders inside a metal tube under the ^{60}Co gamma source. The irradiation was performed in air at room temperature by a ^{60}Co source with total dose of 5 kGy at dose rates of 0.25 kGy/h. It was checked by thermometric control that the sample temperatures during the irradiation did not appreciably increase above room temperature. This was expected because of the low dose rate of the irradiation.

Corona charging and surface potential measurements

The samples obtained were charged in a corona discharge. The experimental set up described in [11] consists of a corona electrode (needle), a grounded plate electrode and a grid placed between them. The samples of the non-irradiated (0 kGy) and gamma irradiated (5 kGy) PP and PET films were charged at a room temperature for 1 minute. Positive or negative 5 kV voltage was applied to the corona electrode. 1 kV voltage of the same polarity as that of the corona electrode was applied to the grid. The electrets surface potential of the charged samples was measured by the vibrating electrode method with compensation by which the estimated error was better than 5%.

Storage of the samples at different relative humidity

After charging, all investigated samples were stored in desiccators at different relative humidity (RH = 0%, RH = 55% and RH = 100%) for 200 days at room temperature. The relative humidity in the desiccators was measured with hygrometers. The surface potential was measured periodically out of the desiccators.

The values of the relative humidity were obtained by chemical solutions shown in Table 1.

Table 1. Relative humidity.

Number of the desiccator	RH, %	
1	dry air	0
2	water solution of $Mg(NO_3)_2$	55
3	water	100

Computer analysis

The percolation model was used to analyze the experimental results obtained. A model that allows to analyze electrets surface discharge and to reveal the significant influence of the humidity level at which they have been stored is the model proposed by Kuzmin and Tairov [12, 13] based on the simultaneous utilization of the percolation theory, and the Kolmogorov's concept for the 2D kinetics of nuclei formation.

A computer program based on the percolation model was developed. The program selects the most appropriate parameters for which possible ranges of values have been created. Five parameters determining the relaxation of the electrets charge were obtained:

$X_1 = \alpha(t)$ – the rate of nuclei formation per unit time and unit area;

$X_2 = q(\tau)$ – the part of the electrets surface remaining free from such nuclei at the time of completion of electrification;

$X_3 = V_{01}$ and $X_4 = V_{02}$ – the rate of growth of the adsorbed nuclei as $V(t) = V_{01} \exp(-t/\tau) + V_{02}$;

$X_5 = f/g$, where $f = V$ – the steady state values of the surface potential and $g = V_0$ – initial surface potential.

RESULTS AND DISCUSSION

Time storage influence on the electrets surface potential decay

The dependences of the normalized surface potential on time storage for positively and negatively charged non-irradiated and gamma irradiated PP and PET films were studied for 200 days. The surface potential was measured periodically once in a week for the first 80 days when the charge was rapidly decaying. After this period, steady state values of the surface potential were established for all investigated samples. Time dependences of the normalized surface potential for positively and negatively charged non-irradiated and gamma irradiated PP samples are presented in Figs. 1 and 2, respectively.

In Figs. 3 and 4 the time dependences of the normalized surface potential for positively and negatively charged non-irradiated and gamma irradiated PET samples are presented.

Each point in the figures is a mean value of 5 samples. The calculated standard deviation was better than 5% of the mean value with confidence level 95%.

The experimental results presented in Figures 1–4 show that:

✓ The values of the normalized surface potential are initially decaying exponentially for the first 80 days after which they are slowly decreasing and are practically stabilized at 200 days. In the initial period of time the surface potential decreases rapidly due to the release of poorly captured charges from the shallow energy states. After that the steady

state value is reached caused by the tightly captured charges in the deep energy traps. This was observed for all investigated samples. Similarly, exponential decay of the electrets charge was observed in [14].

✓ The steady state values of the normalized surface potential for the samples charged in a negative corona are lower than those for the samples charged in a positive corona independently of material type, gamma irradiation and relative humidity.

Probably this is due to the fact that in case of a positive corona the dominant ions are $H^+(H_2O)_n$ and the ones for a negative corona - CO^{3-}. Those ions are bound in traps of various depths and they are released from them depending on the surrounding conditions.

✓ The steady state values of the normalized surface potential depend on the relative humidity. It was established that the steady state values of the normalized surface potential are lowest for the RH = 100%, independently of material type, gamma irradiation and corona polarity.

We assume that on the electrets surface an adsorption of water molecules happens, additionally stimulated by the electrets own electric field. The higher humidity of the medium in which the electrets are stored leads to the higher rate of adsorption.

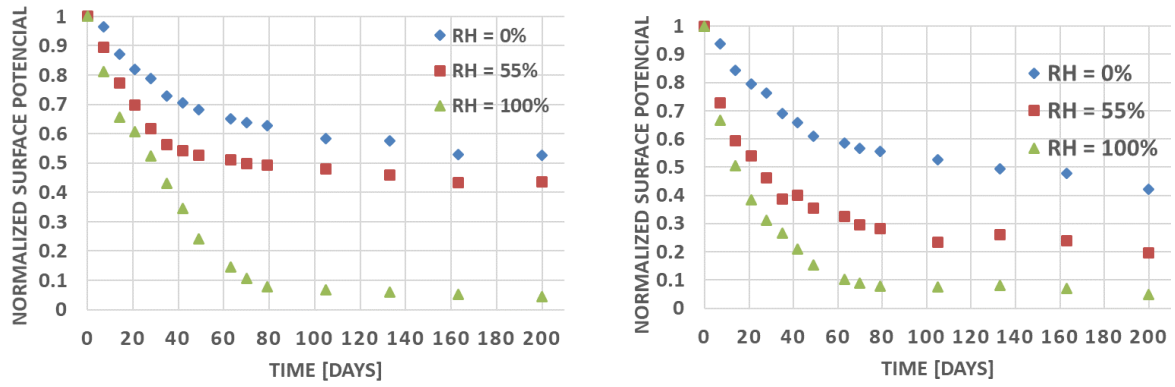

Fig. 1. Time dependences of the normalized surface potential for PP non-irradiated samples at both types corona charging: a) positive and b) negative.

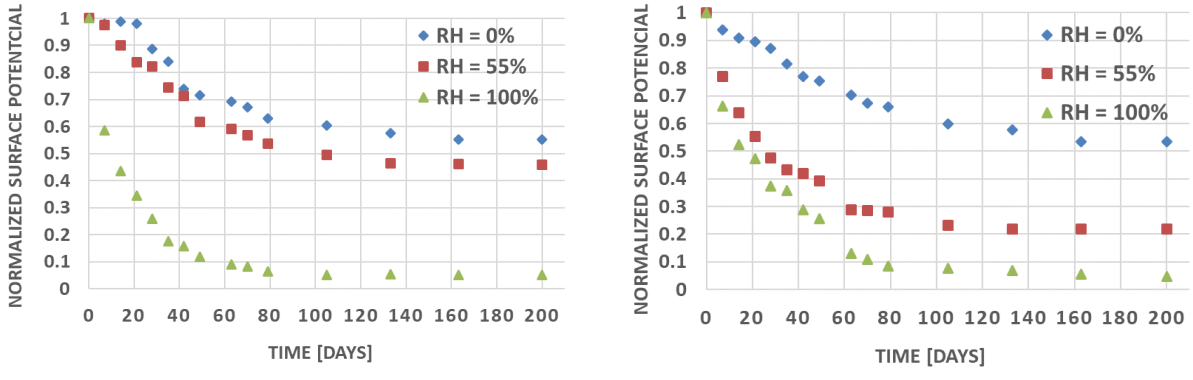

Fig. 2. Time dependences of the normalized surface potential for PP gamma irradiated samples at both types corona charging: a) positive and b) negative.

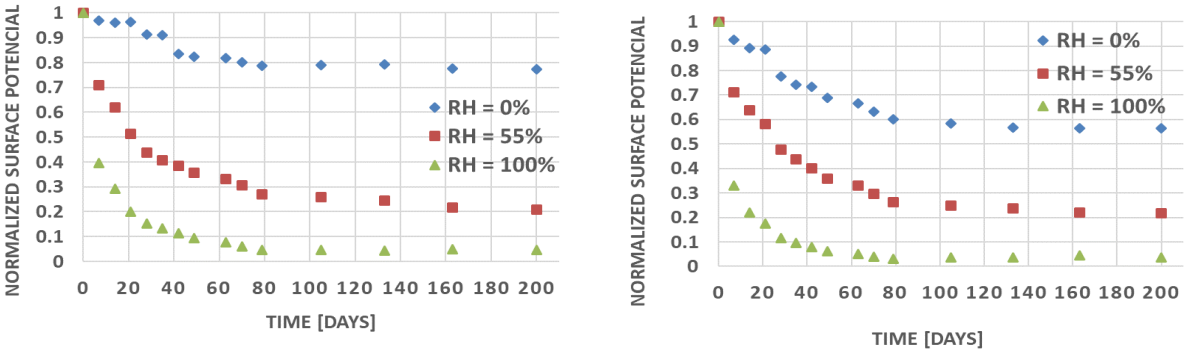

Fig. 3. Time dependences of the normalized surface potential for PET non-irradiated samples at both types corona charging: a) positive and b) negative.

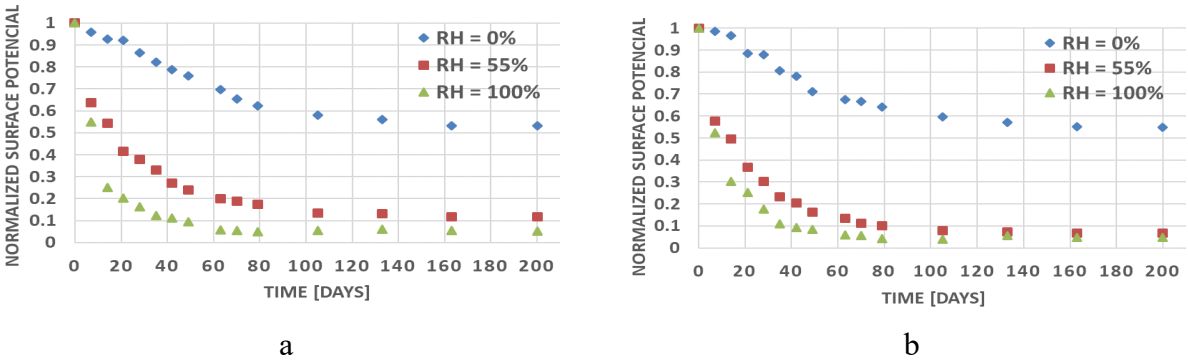

Fig. 4. Time dependences of the normalized surface potential for PET gamma irradiated samples at both types corona charging: a) positive and b) negative.

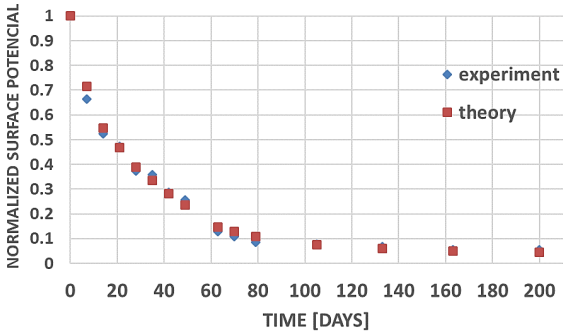

Fig. 5. Time dependences of the normalized surface potential for PP gamma irradiated samples, charged in a positive corona and stored at RH = 100%.

Comparison of the theoretical and experimental time dependences of the normalized surface potential

The experimental results obtained were analyzed by a computer program based on the percolation model. Experimental and theoretical curves for gamma irradiated PP and PET samples charged in a positive corona and stored at relative humidity 100% are presented in Figs. 5 and 6. Analogous curves were obtained for all investigated samples. The results presented in Figs. 5 and 6 show very good coincidence of the experimental and theoretical data. Therefore, the percolation model describes very well the influence of relative humidity for all investigated electrets.

The values of the five parameters determining the relaxation of the electrets charge obtained after the computer processing of the experimental results for PET samples are presented in Table 2.

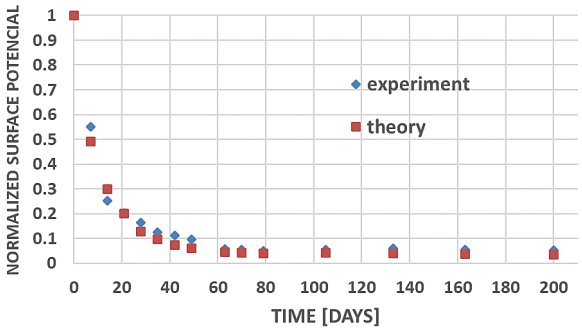

Fig. 6. Time dependences of the normalized surface potential for PET gamma irradiated samples, charged in a positive corona and stored at RH = 100%.

Table 2. Parameters determining the relaxation of electrets charge for non-irradiated and gamma irradiated PET samples, stored at RH = 0% and RH = 100%.

Samples	$\alpha.10^{9}$, $m^{-2}s^{-1}$	q	$V_{01}.10^{-13}$, ms^{-1}	$V_{02}.10^{-15}$, ms^{-1}	f/g
Positive corona, non-irradiated, RH = 0%	0.033	0.570	0.079	0.065	0.650
Negative corona, non-irradiated, RH = 0%	0.194	0.570	0.005	0.003	0.550
Positive corona, gamma irradiated, RH = 0%	0.071	0.570	0.003	0.068	0.500
Negative corona, gamma irradiated, RH = 0%	0,089	0.570	0.003	0.042	0.460
Positive corona, non-irradiated, RH = 100%	0.173	0.570	0.055	0.032	0.029
Negative corona, non-irradiated, RH = 100%	0.332	0.570	0.052	0.022	0.027
Positive corona, gamma irradiated, RH = 100%	0.373	0.570	0.072	0.001	0.035
Negative corona, gamma irradiated, RH = 100%	0/.384	0.570	0.063	0.003	0,031

Analogous data were obtained for all investigated samples. The results presented in Table 2 show that:

✓ The values of parameter X_2 are equal for all investigated samples, i.e. the part of the electrets surface remaining free of the adsorbed phase until charging is complete is the same. We suppose that the adsorption on the electrets surface and the formation of clusters is significantly stimulated during electrification. However, it is obvious that the charging conditions of the electrets (positive and negative corona) do not affect the amount of adsorbed phase.

✓ The rate of growth of the adsorbed nuclei depends on the parameters X_3 and X_4. X_3 has a determining role at the initial moment after charging, and X_4 determines the electrets behavior after a sufficiently long time.

✓ The parameter X_5 depends on the relative humidity. It was established that X_5 is lowest for the RH = 100%, independently of material type, gamma irradiation and corona polarity. Therefore, the higher humidity in which the electrets were stored leads to the greater rate of adsorption.

CONCLUSION

The influence of different relative humidity levels on surface potential decay of PP and PET non-irradiated and gamma irradiated films were studied. It was established that the higher values of the relative humidity led to a faster decay of the surface potential. The percolation model allowed to analyze electrets surface discharge, and to reveal the significant influence of the humidity level at which they have been stored. This is extremely important, and should be taken into account in the study of the stability of electret sensors and devices that are used at room temperature and function under real conditions involving various humidity levels.

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