Low pressure influence on the electrets stability of gamma irradiated PP and PET films

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Abstract. The influence of low pressure on the surface potential decay of gamma irradiated polymer films of polypropylene (PP) and poly(ethylene terephtalate) (PET) were studied. Polymer film samples were subjected to integral irradiation doses (Ey = 1.25 MeV, 60Co source) of 5 kGy and 25 kGy accumulated in air at a dose rate of 0.26 Mrad/h. After irradiation, the samples were charged in a corona discharge by means of a corona triode system for 1 minute under room conditions. Positive or negative 5 kV voltages were applied to the corona electrode. Four different voltages of the same polarity as that of the corona electrode were applied to the grid. The electret surface potential $V_0$ was measured by the method of the vibrating electrode with compensation. After charging the electrets were placed into a vacuum chamber as the pressure was reduced step by step in the range of 1000 mbar to 0.1 mbar. At each step the samples were stored for 1 minute and the surface potential $V$ was measured again. Then values of the normalized surface potential $V/V_0$ were calculated. Low pressure dependences of the normalized surface potential for positively and negatively charged PP and PET films were presented. It was established that the low pressure led to the surface potential decay of the electrets. The influence of low pressure was analyzed by the equation that describes processes of desorption from the electret surface accompanied with surface diffusion. The experimental results obtained show a significant change in the electret behaviour of the polymer films after gamma irradiation and storage at different low pressure. It was established that the surface potential decay depends on the corona polarity, gamma irradiation and the values of low pressure.

1. Introduction

Electret materials find broad application in various fields of science, engineering and technology because of their ability to create a permanent electric field long enough without additional power supply [1-3]. Over the years, the corona discharged has been one of the most commonly used methods of materials treatment as it is inexpensive and easy to realise from a technical point of view. In order to obtain stable electrets for numerous applications the influence of different factors (temperature, humidity, low pressure, gamma irradiation etc.) on charge decay has been studied [4, 5]. However, the gamma irradiation influence on the electret state of polymer electret films has been studied in relatively few articles, there are only a few publications about the influence of the charge decay. The gamma irradiation effect (up to 100 kGy) on the electret behavior of corona charged biobased polymer films of polylactic acid have been investigated in [6]. It was established that the degradation process is predominant. The values of the surface potential of the irradiated samples were higher than the non-
irradiated ones, independently of the corona polarity and irradiation dose. The influence of low dose gamma irradiation on the stability of electret characteristics of corona charged PP and PET films was investigated in [7]. It was established that the significant changes in the electret behaviour of the polymer films induced by gamma irradiation are of complex origin. The PP electrets charged in a negative corona and irradiated by dose of 25 kGy achieved the highest surface potential. The possible surface potential decay mechanisms responsible for the above may be due to degradation, scissioning and crosslinking of the polymer chains with the increasing dose of gamma irradiation and formation of different charges trapping surface states. The surface potential decay of gamma irradiated low density polyethylene (LDPE) films has been examined in [8]. Samples with different absorbed doses between 5 kGy and 500 kGy were obtained by exposing samples to $^{60}$Co for various times at room temperature. It was established that the surface potential decay is significantly affected by gamma irradiation with different doses. The effect of gamma irradiation on the surface conductivity of low density polyethylene (LDPE) was investigated in [9]. The samples had been previously irradiated at room temperature in air to 100 kGy and then to 1000 kGy with a dose rate of 10 kGy/h by using a $^{60}$Co gamma-source. The results obtained show that the surface conductivity increases with the growth of the total dose. The influence of gamma irradiation on the structural properties of non-irradiated and gamma irradiated with different doses (0–2000 kGy) PET polymer films was analyzed in [10]. A significant increase of crystallinity of the investigated samples was established. For the formation of electrets different polymeric materials as polypropylene (PP) and poly (ethylene terephthalate) (PET) are widely used, because of their important commercial significance, structure and appropriate mechanical and electrical properties [11, 12]. In the literature, however, there is no data available for the influence of gamma irradiation on the charge decay of PP and PET electret films stored at low pressure. The aim of the present paper is to investigate the influence of low pressure on the electrets stability of corona charged PP and PET gamma irradiated films.

2. Experimental

2.1. Formation of gamma irradiated polymer films

40 µm thick PET films, (Hostaphan RNK, Mitsubishi Polyester Films GmbH, Germany) and 20 µm thick PP films (Asenova krepost Ltd, Bulgaria) were used. Initially, the films were cleaned in an ultrasonic bath with alcohol for 4 minutes, followed by rinsing with distilled water, and then were dried under room conditions. The 30 mm diameter samples were cut from the cleaned films and subjected to gamma irradiation treatment. The irradiations were performed in air by a $^{60}$Co source with total doses of 5 kGy and 25 kGy accumulated in a single step at a dose rate 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.

2.2. Corona charging and measuring of the surface potential

The corona charging of the samples was carried out by the method of the corona discharge using a point-to-plane three-electrode corona discharge system [13] consisting of a grounded plate electrode, a corona electrode and a grid placed between them. The samples of the non-irradiated (0 kGy) and gamma irradiated (5 kGy and 25 kGy) PP and PET films were charged for 1 minute at room temperature. Positive or negative 5 kV voltage was applied to the corona electrode. Voltages of 500 V, 650 V, 800 V and 950 V of the same polarity as that of the corona electrode were applied to the grid. The electret surface potential was measured by the method of the vibrating electrode with compensation [1] and the estimated error was better than 5 %.

2.3. Low pressure measurement

After charging the samples, the initial electret surface potential $V_0$ was measured and then the electrets were placed into a vacuum chamber. The pressure in the vacuum chamber was reduced step
by step in the range from 1000 mbar to 0.1 mbar. At each step the samples were kept at a respective constant pressure for 1 minute. After that the electrets were removed from the vacuum chamber, the surface potential \( V \) was measured again and the normalized surface potential \( V/V_0 \) was calculated.

3. Results and discussion

The dependences of the normalized surface potential \( V/V_0 \) on the low pressure for positively and negatively charged non-irradiated and gamma irradiated PP and PET films have been investigated. Dependences of normalized surface potential on normalized pressure for positively and negatively charged to different initial surface potentials (650 V and 800 V) non-irradiated and gamma irradiated PP films are presented in figures 1 and 2.

![Figure 1](image1.png)

**Figure 1.** The normalized surface potential dependences on the normalized pressure for non-irradiated and gamma irradiated PP films positively and negatively charged to initial surface potential 650 V.

![Figure 2](image2.png)

**Figure 2.** The normalized surface potential dependences on the normalized pressure for non-irradiated and gamma irradiated PP films positively and negatively charged to initial surface potential 800 V.

Dependences of normalized surface potential on normalized pressure for positively and negatively charged to different values of the initial surface potentials (650 V and 800 V) non-irradiated and gamma irradiated PET films are presented in figures 3 and 4.
Figure 3. The normalized surface potential dependences on the normalized pressure for non-irradiated and gamma irradiated PET films positively and negatively charged to initial surface potential 650 V.

Figure 4. The normalized surface potential dependences on the normalized pressure for non-irradiated and gamma irradiated PET films positively and negatively charged to initial surface potential 800 V.

Analogues curves for positively and negatively charged to grid potentials 500 V and 950 V non-irradiated and gamma irradiated PP and PET films are obtained. In figures 1 – 4 the symbol $V_0$ marks the initial value of the surface potential measured just after electrets charging, and the symbol $p_0$ marks the atmospheric pressure. Each point in the figures is a mean value of 6 samples. The calculated standard deviation was 10% better than the mean value with confidence level 90%.

Table 1. The steady state values of the normalized surface potential at a pressure of 0.1 mbar for non-irradiated and gamma irradiated PP films.

| $V_0$, V    | PP positive corona | PP negative corona |
|-------------|--------------------|--------------------|
|             | $V/V_0$            | $V/V_0$            |
|             | 0 kGy               | 5 kGy               | 25 kGy | 0 kGy               | 5 kGy               | 25 kGy |
| 500 V       | 0.47                | 0.45                | 0.43   | 0.42                | 0.40                | 0.39   |
| 650 V       | 0.36                | 0.42                | 0.41   | 0.30                | 0.28                | 0.27   |
| 800 V       | 0.34                | 0.33                | 0.35   | 0.32                | 0.31                | 0.30   |
| 950 V       | 0.32                | 0.34                | 0.33   | 0.25                | 0.22                | 0.22   |
Table 2. The steady state values of the normalized surface potential at a pressure of 0.1 mbar for non-irradiated and gamma irradiated PET films.

| $V_0$, V | $V/V_0$ PET positive corona | $V/V_0$ PET negative corona |
|----------|----------------------------|-----------------------------|
|          | 0 kGy | 5 kGy | 25 kGy | 0 kGy | 5 kGy | 25 kGy |
| 500 V    | 0.53  | 0.52  | 0.46   | 0.48  | 0.46  | 0.38   |
| 650 V    | 0.53  | 0.49  | 0.39   | 0.40  | 0.39  | 0.26   |
| 800 V    | 0.48  | 0.44  | 0.36   | 0.35  | 0.36  | 0.25   |
| 950 V    | 0.39  | 0.37  | 0.33   | 0.33  | 0.35  | 0.23   |

The results presented in figures 1-4 and tables 1 and 2 show that:

- Independently of the gamma irradiated doses in each curve three parts are observed. At higher pressures the surface potential is constant and equals initial surface potential. At lower pressures the surface potential is also constant but has different values for the different cases. For each curve a relatively narrow region of pressures exists where a sharp decay of surface potential occurs. A similar behavior has also been observed in [14].

- The steady state values of the normalized surface potential at the 0.1 mbar pressure for the samples charged in a positive corona are higher than those for the samples charged in a negative corona independently of the gamma irradiated doses. It was established in [15] that during the corona discharge in the air, at atmospheric pressure, different types of ions are deposited on a sample. In the case of a positive corona the ions are mainly $H^+(H_2O)_n$ and the ones for a negative corona - $CO_3^-$. Those ions are bound in traps of various depths and are released from them depending on the surrounding conditions.

- The steady state values of the normalized surface potential at the 0.1 mbar pressure for PET samples are higher than those for PP samples independently of the corona polarity except for samples irradiated by dose of 25 kGy. We assume that this is due to the different structures of the polymers, which leads to the formation of different localized surface states that capture charges.

- The surface potential values of the PET samples irradiated by a dose of 25 kGy were smaller in comparison with the non-irradiated samples and the irradiated ones by a dose of 5 kGy, independently of the corona polarity.

- The surface potential values of the gamma irradiated PP samples stored at low pressure do not depend on the irradiation dose.

Therefore, the low dose of 5 kGy does not cause changes of the electret’s behavior at low pressure. The gamma irradiation by a greater dose of 25 kGy leads to creation of different localized surface states and the surface charge decrease [16]. The charge accumulation depends upon the density of localized surface states, which is varied by the radiation induced cross-linking and the degradation reactions of the molecule structure [17]. The results obtained (figures 1-4) were analyzed by the equation that describes the processes of desorption from the electrets surface accompanied with surface diffusion. This equation was used and described earlier in [18]:

$$\theta = a + \frac{1}{2} \left[ 1 + \text{erf} \left( \frac{x - c}{\sqrt{2}d} \right) \right],$$

where $\theta = V/V_0$ is the normalized surface potential, $x = \log p/p_0$ and $a$, $b$, $c$ and $d$ are parameters. Values of the parameters $a$, $b$, $c$ and $d$ for all investigated samples are obtained by fitting.

The data obtained in table 3 for PP and PET electrets positively and negatively charged to initial surface potential 500 V could have practical benefits in its usage under conditions of reduction pressures. If you know the initial surface potential value $V_0$ of different materials, data obtained for parameters could be used to determine the pressure range in which there will be a potential sharp decay.
Table 3. Values of the parameters $a$, $b$, $c$ and $d$ obtained by fitting data to the equation.

| Material type | Corona polarity | $a$     | $b$     | $c$     | $d$     |
|---------------|-----------------|---------|---------|---------|---------|
| PP 0 kGy      | +               | 0.43±0.01 | 0.54±0.01 | -2.50±0.01 | 0.24±0.01 |
|               | -               | 0.45±0.01 | 0.51±0.02 | -2.45±0.05 | 0.04±0.07 |
| PET 0 kGy     | +               | 0.55±0.01 | 0.39±0.01 | -2.33±0.09 | 0.03±0.01 |
|               | -               | 0.51±0.01 | 0.45±0.01 | -2.46±0.07 | 0.25±0.04 |
| PP 5 kGy      | +               | 0.48±0.01 | 0.45±0.01 | -2.41±0.07 | 0.28±0.05 |
|               | -               | 0.44±0.01 | 0.50±0.01 | -2.44±0.06 | 0.24±0.03 |
| PET 5 kGy     | +               | 0.54±0.01 | 0.39±0.01 | -2.46±0.09 | 0.28±0.05 |
|               | -               | 0.49±0.01 | 0.46±0.01 | -2.39±0.17 | 0.24±0.1  |
| PP 25 kGy     | +               | 0.46±0.01 | 0.49±0.01 | -2.53±0.07 | 0.23±0.03 |
|               | -               | 0.35±0.01 | 0.59±0.01 | -2.34±0.27 | 0.18±1.25 |
| PET 25 kGy    | +               | 0.43±0.01 | 0.51±0.01 | -2.16±0.01 | 0.07±0.01 |
|               | -               | 0.42±0.01 | 0.53±0.01 | -2.44±0.13 | 0.22±0.07 |

4. Conclusion

The influence of low pressure on electret behavior of PP and PET non-irradiated and gamma irradiated films were studied. The results obtained show that charge decay depends on initial surface potentials, corona polarity and gamma irradiated dose. Our experimental data show that the low pressure at which PP and PET electrets have been stored should be the important factor of determining their charge decay. 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 low pressure levels.

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