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CONTROL AND DIAGNOSTIC SYSTEMS

Impact of Electron-Beam Irradiation on Multilayer Polymer Materials: Immediate and Long-Term (1 Year) Effects

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Abstract—We investigate the impact of electron-beam irradiation (doses of 3–18 kGy) on polyamide/polyethylene (thickness of 80 μm), a multilayer polymer film material. Irradiation is performed on a compact unit for radiation sterilization with local bioprotection. We study the changes in the physicomechanical properties and barrier characteristics of the polymer material that may have a negative impact on the shelf life of packaged agricultural produce.

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INTRODUCTION

The irradiation of packaged food by ionizing radiation is used to prolong its shell-life and sterile condition inside the package. Packaging materials typically consist of multilayer films of different compositions. Packaging films with properties tailored to every type of agricultural produce, with account for the breathing processes, are created by stacking together several layers of different polymers. Along with destruction of pathogenic bacteria and viruses, treating food products with electron beams induces certain chemical changes. For instance, during sterilization with ionizing radiation, the polymers of the package undergo crosslinking and destruction [1–3]. This urged us to study the changes that occur to the structure of multilayer polymer materials soon after radiation treatment and during storage.

EXPERIMENTAL RESULTS AND DISCUSSION

Polyamide/polyethylene (PA/PE) composite film (PA/PE ratio 20 : 80; thickness 80 μm) obtained from the Dmitrovskiy Plant of Flexible Packaging was used as the packaging polymer material under study. The structural units of these polymer materials are shown in Fig. 1.

Irradiation treatment was carried out in the Moscow Radiotechnical Institute, Russian Academy of Sciences, on a compact irradiation sterilization unit with local bioprotection; the energy of accelerated electrons was 5 MeV, and the power of electron beam was 1.5 kW. The changes to the film, induced by radiation treatment, were analyzed on an FSM 1201 IR spectrometer (Russia), which has an operating range of 400–4000 cm^{-1} and a resolution of 1 cm^{-1}. IR absorption spectra of film samples were recorded before and after treatment. For the measurements, the film samples were placed in the measurement cell at exactly right angle to the light beam. Wetting angle measurements were performed using a TRACKER instrument. For these measurements, a 5 × 3 cm film sample was first degreased with alcohol and then mounted on the support of measurement cell. The cell was then fixed to a horizontal holder and illuminated.

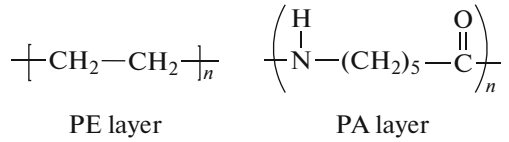

Fig. 1. Structural units of PA/PE composite polymer.

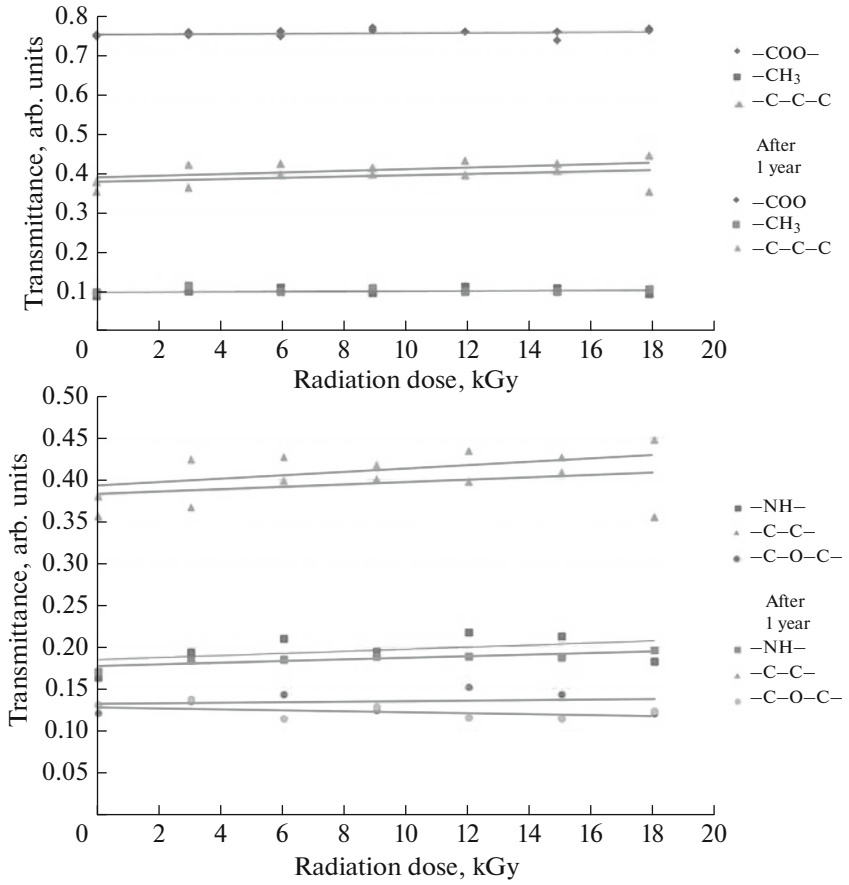

Fig. 2. Dependencies of peak intensities on the applied radiation dose for the functional groups in a PA/PE sample subjected to electron-beam irradiation.

A 1-mm^3 drop of a liquid was placed on the specimen surface by means of a microsyringe, and a still image of the sessile drop was then captured by the instrument's camera [4].

PA/PE film samples were irradiated repeatedly ten times with a dose of 3 to 18 kGy using standard dosimetry films to measure the radiation dose. The structure of the samples was analyzed by IR spectroscopy in the range of 400–5000 cm^{-1} prior to and soon after irradiation and then after a year of storage. The bands most characteristic of the functional groups in the polymer material under study can be found in work [5]. The dependencies of band intensities for the polymer functional groups on the applied radiation dose and after a year of storage are shown in Fig. 2.

As can be seen in Fig. 2, increasing the radiation dose does not affect the intensities of the bands associated with –COO– and $-CH_3$ groups, and the same observation holds for the samples stored for 1 year. Note that a fall in the number of –C–C– groups was observed at higher radiation doses, and an even greater decline was registered for the samples put on storage for 1 year. We can also see a slight decline in –C–C– (584 cm^{-1}) and –NH– (3085 cm^{-1}) groups with increasing dose (Fig. 2). The amount of –NH– groups in the samples subjected to higher radiation doses increased after a year of storage. Presumably, degradation processes that had occurred to the –NH– groups in the PA layer have reversed with time. After 1 year of storage, a slight increase in the amount of –C–O–C– groups (1257–1275 cm^{-1}) was noted for the samples that initially (immediately after irradiation) showed no correlation between their –C–O–C– content and applied radiation dose.

An increase in the number of oxygen-containing groups affected the wetting angle of specimens (Fig. 3). We can see that the wetting angle measured on the PA side does not vary with radiation dose, and it decreased by 5% (within the experimental error) after 1 year of storage, but the dependency on the radiation dose remained the same. In contrast, the wetting angle for the PE side fell considerably, from 80° to 70°, with increasing radiation dose. The wetting angle for the PE side decreased for the samples stored for 1 year.