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# Studying properties of corona electret based on compositions of polylactic acid and bentonite

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***Abstract.*** The study focuses on the composites of polylactic acid and bentonite as well as corona electrets based on them. The paper explores rheological, electrical, physical and mechanical properties of the composites as well as the effect of corona charging on their properties. Differential scanning calorimetry was used to assess transition temperatures in the compositions. Surface potential, electric field strength and effective surface charge density were measured. Optimal performance was shown by the compositions of polylactic acid with 4% bentonite.

***Keywords:*** polylactic acid, bentonite, corona electret, fine filler, polymer.

## Introduction

The global polymer market grows every day. Polymers are used almost in every sphere of our life to produce a wide range of goods for different industries (packaging, electronics, automotive, medicine, agriculture, etc.). However, synthetic polymers have some significant disadvantages—they are made from a non-renewable source (oil) and disposed polymer products are accumulated in landfills causing harmful environmental effects. Environmental concern and industrial policies in many countries that promote natural resource conservation stimulate research, development, production and application of biodegradable polymers. An attractive biopolymer that is now used in the packaging industry is polylactic acid (PLA). It belongs to the group of biodegradable polymers. Its monomer is lactic acid which is produced from renewable plant sources. Polylactic acid undergoes decomposition under both aerobic and anaerobic conditions, while the degradation rate depends on temperature. Properties and processing temperatures of PLA are relatively close to those of bulky polymers (Auras et al. 2010).

One of the fast developing applications of polymers is production of polymer electrets that are used in air filtration, electronic devices, packaging, etc. (Galikhanov et al. 2014; Kestelman et al. 2000; Sessler 1998). In this context production of electret material based on polylactic acid is promising (Galikhanov et al. 2016; Gencheva et al. 2010; Zhang et al. 2020). However, unipolar corona discharge as the fastest and simplest method to obtain an electret is not suitable for polar polylactic acid. In order to change electrical and physical properties of the polymer, attempts were made to introduce fine fillers into the polymer matrix (Gilmutdinova et al. 2017; Guzhova et al. 2016; Ismayilova, Kuliev 2020; Kilic et al. 2013; Kurbanov et al. 2018; Liu et al. 2019).

The objective of the paper was to study electret properties of polylactic acid composites.

## Materials and methods

The subject of research was D-polylactic acid (ρ = 1.24 g/cm$^3$, $T_g$ = 60 °C, $T_m$ = 165 °C) and fine bentonite (d = 0.89 μm, ρ = 0,78 g/cm$^3$). The polymer and the filler were mixed with Brabender Mixer W 50 EHT. Mixing was performed at temperature of 180 °C for 300 s at blades rotation of 150 rpm. Samples were compression moulded as 0.5 mm films using Gotech GT-7014-H10C according to GOST 12019-66 (Russian standard). Moulding parameters were as follows: temperature—180 °C, pressure—15 MPa, preheating time—5 min, holding-pressure time—5 min, cooling time—5 min.

Charging of the films was done using corona discharge system. It consists of 196 sharp needles uniformly distributed at a square of 49 cm$^3$. The space between the sample and the charging electrode was 20 mm, polarisation voltage was 30 kV, and polarisation time was 30 s. Before charging, the samples were preheated in a heating chamber at 90 °C for 10 min. The samples were stored in paper envelopes under ambient conditions.

Surface potential $V_s$, electric field strength $E$ and effective surface charge density $\sigma_{eff}$ were measured with an IPEP-1 field meter. The measurement error of the electret properties did not exceed 3%. The results given were average values of 5 trials. A differential scanning calorimeter (Q-200TA) was used to assess the effect of the fine filler addition on its transition temperatures. The heating rate was 10 °C/min. The melt flow index was measured according to GOST 11645-73 using an IIRT instrument. The specific volume resistivity $\rho_v$ was measured and calculated according to GOST 6433.2-71. Infrared spectra of the composite materials were obtained with an ATR-FTIR spectrometer InfraLUM FT-08 within the range of 600–4000 cm$^{-1}$. Stress-strain behaviour of the samples was measured according to GOST 11262-80 using a universal testing machine (Test P 108).

## Results and discussion

Polylactic acid is a universal commercial biodegradable thermoplastic material made from lactic acid. It is produced from renewable plant sources such as corn, grains or beetroot.

PLA has insufficient electret properties—low initial surface potential value and fast charge relaxation (Galikhanov et al. 2016; Gencheva et al. 2010; Zhang et al. 2020). Polar groups of the polymer promote trapping of the injected charge carriers by small shallow traps which results in a fast charge decay of the corona electrets. Meanwhile, corona charging has such advantages as high speed, simple apparatus, and uniform charge distribution over the surface.

In order to increase the electret properties of polylactic acid, fine filler was added. Bentonite was used as the filler. It is a hydroalumosilicate, natural swelling clay mineral able to absorb large quantities of water, non-toxic and chemical resistant.

The study of the electret properties of polylactic acid–bentonite compositions revealed the following pattern. An increase in the bentonite content initially improves and then slightly reduces the electret properties of the polymer (Fig. 1); this finding is compliant with the earlier studies (Gilmutdinova et al. 2017; Guzhova et al. 2016; Kilic et al. 2013; Kurbanov et al. 2018).

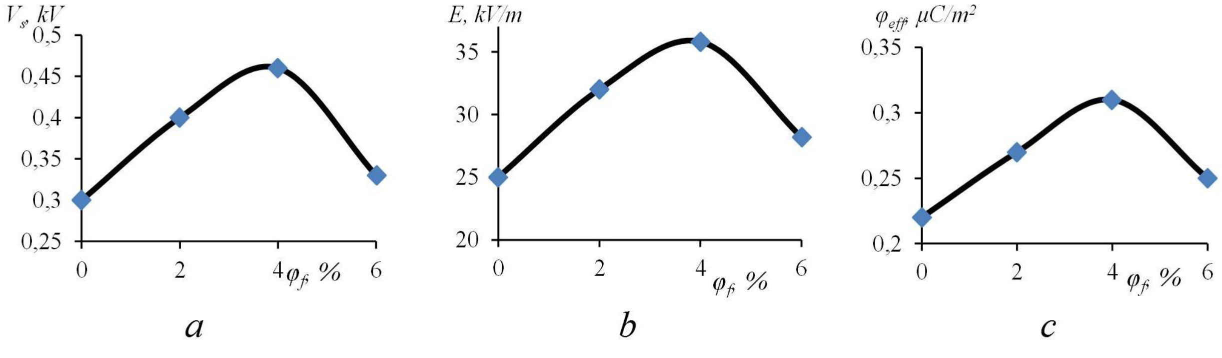

Fig. 1. Surface potential *(a)* electric field strength *(b)* and effective surface charge density *(c)* vs. bentonite content on the 60th day after charging of polylactic acid corona electrets

Fine filler is known to affect the energy depth of the traps of polymers (Galikhanov et al. 2005; Gojayev et al. 2015; Temnov et al. 2013). Besides, filler introduction results in the appearance of new trapping levels (i.e., new categories of traps) of the injected charge carriers. This is the main reason for the electret properties enhancement of the bentonite-filled polylactic acid.

The introduction of fine filler particles into the polymer matrix causes new structural defects that act as charge carrier traps. Filler addition changes size, shape and size distribution of polymer supramolecular structures as well as packing density with filler particles serving as crystal-nucleating agents and a source of crystal imperfection. Besides, adsorption of polylactic acid macromolecules on a solid surface reduces their flexibility that decelerates relaxation processes including the electret state relaxation.

Macromolecule mobility of a polymer can be estimated by both its characteristic temperatures—glass transition or flow temperatures—and rheological properties—melt flow index (MFI).

Fig. 2 illustrates that the position of peaks associated with glass transition (~67–69 °C) and the melting point (~159–162 °C) of polylactic acid filled with 2–6% bentonite changed little, if at all.

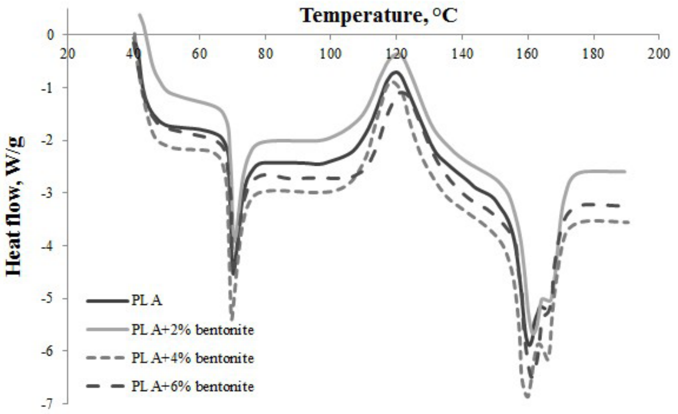

Fig. 2. DSC curves of polylactic acid and its compositions with 2, 4 and 6% bentonite

Many fillers tend to significantly decrease the melt flow index of polymers. The performed study (Table 1) showed that melt flow index decreased, i.e., the viscosity of the melt grew with the increase of the bentonite content.

Table 1. Melt flow index and specific volume resistivity of polylactic acid-bentonite compositions

| Sample | *MFI*, g / 10 min | *ρv*, $10^{12}$ *Ω · m* |
|---|---|---|
| 100% PLA | 11.2 | 21 |
| 98% PLA + 2% bentonite | 10.8 | 26 |
| 96% PLA + 4% bentonite | 9.4 | 29 |
| 94% PLA + 6% bentonite | 8.9 | 40 |

The observed MFI reduction of the polymer can be explained by the fact that solid particles of the filler were not deformed together with the surrounding fluid layers that prevented the fluid flow and increased its viscosity. The flow resistance was increased by macromolecules adsorbed on the filler as well. Besides, collisions of the particles in the flow and energy expenditures on their mutual friction were possible, therefore causing viscosity growth. It is obvious that the higher the bentonite content, the stronger the effect of these factors, and the melt flow index of polylactic acid decreases. Thus, the foregoing assumption that the rate of relaxation processes reduces when polylactic acid is filled with bentonite was proved and it affects the electret properties of compositions.

Another reason for the bentonite effect on the electret properties of polylactic acid can be a change in the electrical resistivity of compositions (Table 1). It is evident that the electrical resistance of PLA compositions slightly grew along with the filler content increase. In other words, the electret properties increase of the filled polylactic acid may occur due to an electrical resistivity change, but to a limited extent (4%), and then other reasons prevail.

Physical and chemical transformations during manufacturing (e.g., mechanical destruction) can significantly affect polymer properties. These transformations are stepped up by the filler. IR spectra of the system under study allow us to estimate chemical structure changes of the bentonite-filled polylactic acid. IR spectroscopy of the samples showed no appreciable difference in the peaks that correspond to oxygen-containing groups of PLA and PLA with bentonite (Fig. 3).

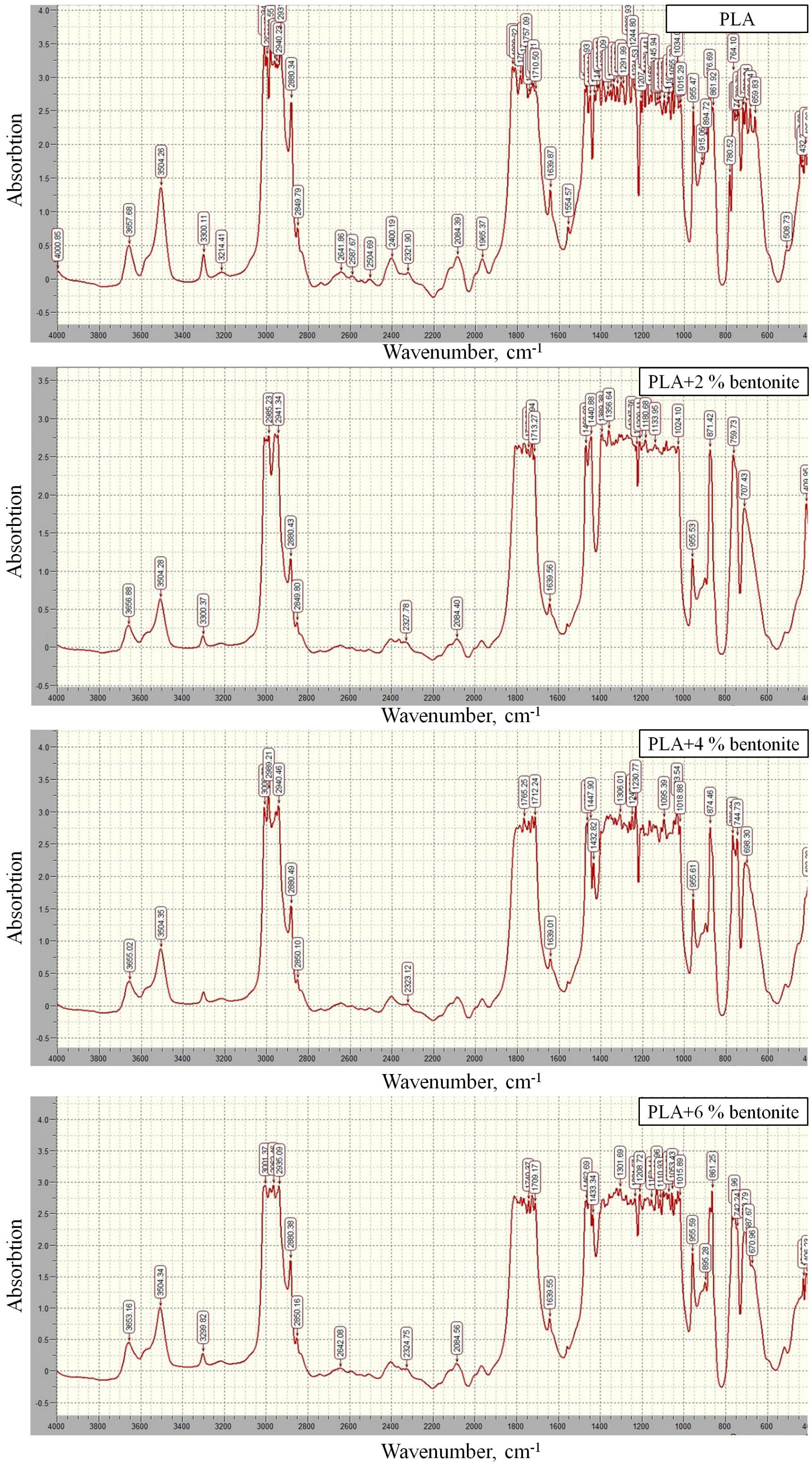

Fig. 3. IR spectra of polylactic acid and its compositions with 2, 4 and 6% bentonite

It implies that the macromolecule oxidation process during the material manufacturing was negligible. Consequently, this reason for the change in the electret properties of polylactic acid when filled with bentonite is not decisive.

With long-term operation of polymer products, the level of their deformation and strength properties comes to the fore. Table 2 shows that with the introduction of bentonite a decrease in the deformation and strength properties of polylactic acid occurs.

Table 2. Stress-strain behaviour of polylactic acid-bentonite compositions

| Sample | $\sigma_{UTS}$, MPa | ε,% |
|---|---|---|
| 100% PLA | 50.4 | 8.5 |
| 98% PLA + 2% bentonite | 40.2 | 5.3 |
| 96% PLA + 4% bentonite | 39.7 | 4.3 |
| 94% PLA + 6% bentonite | 29.6 | 3.7 |

This is due to the fact that bentonite particles are rather big and scarcely deformed with a polymer matrix owing to a great difference in elastic moduli. It results in the formation of overstress and cracks at a polymer-filler interface boundary during the deformation that loosens the composite material.

## Conclusion

The obtained results allow us to conclude that the best electret properties were shown by the composition of PLA and 4% bentonite. The increase in the electret properties of the filled polylactic acid was due to the appearance of a new type of injected charge carrier traps at the polymer-filler interface boundary. Changes in the chemical structure, rheological and electrical properties of the filled polymer were of minor importance. The application of polylactic acid and 4% bentonite composition as an electret material that will degrade under environmental conditions after being used can be suggested.

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