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Magdalena VAVERKOVÁ[1*], Dana ADAMCOVÁ[1], Jana KOTOVICOVÁ[1]
and František TOMAN[1]

EVALUATION OF BIODEGRADABILITY OF PLASTICS BAGS IN COMPOSTING CONDITIONS

OCENA BIODEGRADACJI PLASTIKOWYCH TOREB W WARUNKACH KOMPOSTOWANIA

Abstract: Biodegradation of plastics bags advertised as 100%-degradable or certified as compostable was tested in composting conditions. Samples were placed into frames and inserted into one clamp within the compost pile to investigate the biodegradation. The plastics bags were obtained from chain stores in the Czech Republic and Poland. The shopping bags were made of HDPE with the TDPA additive (sample 2), PP with an addition of pro-oxidants (d_2w) (samples 1, 3) and materials certified as compostable (starch, polycaprolactone) (samples 4, 5, 6, 7). Control sample (cellulose filtering paper, sample 8) was to check the potential of biological decomposition in the tested environment. At the end of the 12-week experimental period it was found that the polyethylene samples with the additive (samples 1, 2, 3) had not been decomposed, their colour had not changed and that no degradation neither physical changes had occurred (did not biodegrade). Samples certified as compostable (samples 4, 5, 6, 7) were decomposed. The results at the municipal compost facility demonstrate that the compostable plastics biodegrade and polyethylene samples with the additive did not biodegrade in compost.

Keywords: biodegradation, 100%-degradable bags, compostable bags, composting, real conditions

Introduction

Composting is a natural process by which organic material is decomposed into humus. Decomposition is principally done by microorganisms, but also earthworms, small insects, play an important role in composting at lower temperatures. The major groups of mesophilic and thermopile microorganisms involved in composting are bacteria, fungi, and actinomycetes. These organisms decompose the organic matter as their food source. The process requires carbon, nitrogen, water, oxygen, and heat. Organisms that decompose organic matter use carbon as a source of energy and nitrogen for building cell structures [1].

Biodegradation of plastics depends on both the environment in which they are placed and the chemical nature of the polymer. Biodegradation is an enzymatic reaction; hence it is very specific to the chemical structures and bonds of the polymer. There are different

[1] Department of Applied and Landscape Ecology, Faculty of Agronomy, Mendel University in Brno, Zemědělská 1, 613 00 Brno, Czech Republic, phone +420 545132484
[*] Corresponding author: magda.vaverkova@uake.cz

mechanisms of polymer biodegradation. One common mechanism is hydrolysis, in which random non-enzymatic chain scission of ester groups leads to reduction in molecular weight. The hydrolysis process is affected by the rate of diffusion of water through the polymer. As mentioned before, the biodegradation of plastics depends on both environmental factors (*ie*, temperature, moisture, oxygen, pH) and the chemical structure of the polymer. Biodegradable polymers usually contain ester, amide, or carbonate hydrolysable bonds in the polymer backbone. The presence of these hydrolysable functional groups increases the susceptibility to biodegradation. Other factors that affect biodegradability are crystallinity, molecular weight, and, in the case of copolymers, the copolymer composition [2].

Standards for compostability have been developed by the American Society for Testing and Materials (ASTM), the International Standards Organization (ISO) and the European Committee for Standardization (ECN) for evaluation of the compostability of biobased polymeric materials. ASTM standards, ISO standards and ECN standards allow evaluation of materials under laboratory conditions. As such and until now, no standard has focused on the compostability of complete packages under real conditions [1].

Biodegradation of biodegradable packages in composting conditions has been reported and correlated to visual changes and variation in physical properties of the materials [3]. Composting studies give clear representation of the biodegradability nature of the whole package configuration and the time required for the disintegration in different compost recipes and composting processes. This information can further provide a basis for deciding on compostable packaging materials and the planning of composting processes. Composting conditions are governed by the outer atmosphere, the type of compost, and the compost parameters such as temperature, moisture, and pH. Hence, they may differ from the controlled composting conditions as proposed by ASTM and ISO standards for materials and whole packages [3].

As mentioned before, the standards mainly focus on providing information about compostability of biodegradable polymeric materials in simulated composting conditions. Simulated and real composting conditions vary due to several factors such as temperature and relative humidity, and in general simulated conditions only poorly represent composting conditions [1].

Therefore, the aim of this paper is to provide information about biodegradability of plastics bags advertised as 100%-degradable or certified as compostable in composting conditions.

Experimental procedures

The research of biodegradability was carried out in real conditions in the Central Composting Plant in Brno. The company operates a regionally important (South Moravia) facility processing biological wastes. The composting plant is used for the conversion of biologically degradable waste (bio-waste) (see Fig. 1) from the city of Brno and its surroundings. The composting plant is producer of high-quality organic fertilizers and substrates and operates a controlled intensive composting system with aeration containing twelve separately ventilated troughs sized 6x36 m. The technological base of the composting plants is among other things represented by mobile biomass crushers and chippers, loaders, homogenizer, drum screen, tractors, etc.

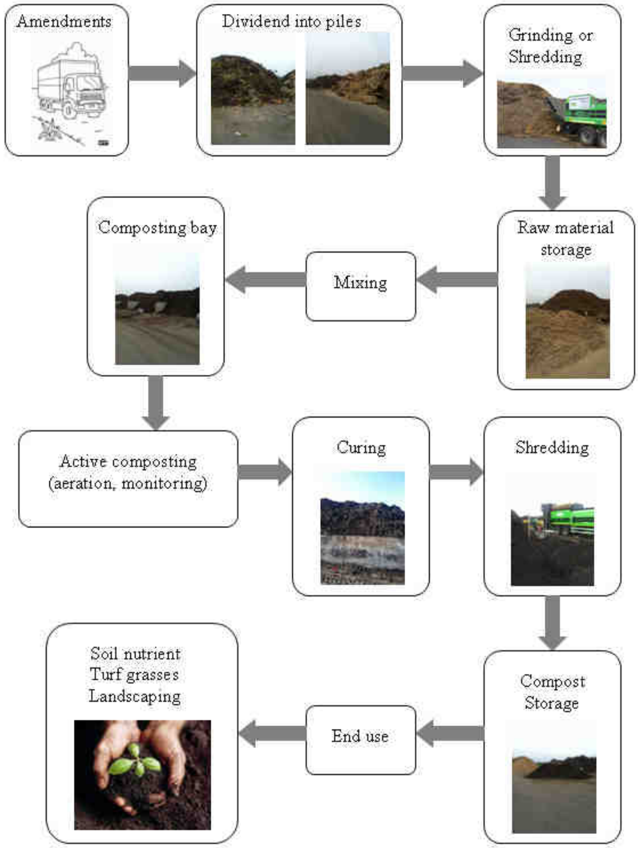

Fig. 1. Composting system process

Materials

In our research, we tested seven single-use plastic bags available in various networks of shops on the Czech and Polish markets, advertised as 100%-degradable or certified as compostable (samples 4, 5, 6, 7). The material composition of samples is presented in Table 1.

Table 1

Material composition of samples

Sample	Type	Description
1	N/A	BIO-D Plast
2	HDPE+TDPA	100% degradable
3	N/A	100% degradable
4	Starch	Compostable 7P0147
5	Starch and Plycaprolactone	OK Kompost AIB VINCOTTE
6	N/A	Compostable 7P0202
7	Natural material	Compostable 7P0073
8	Cellulose (blank)	-

The shopping bags were made of HDPE with the TDPA additive (sample 2) and some bags were made of polyethylene with an addition of pro-oxidants (d_2w) (samples 1, 3). The eighth, control sample was cellulose filtering paper (sample 8). This last sample was to check the potential of biological decomposition in the tested environment.

Biodegradation test: procedure

Samples (1, 2, 3, 4, 5, 6, 7, 8) were placed into frames. A 3D image of the wooden frame is presented in Figure 2.

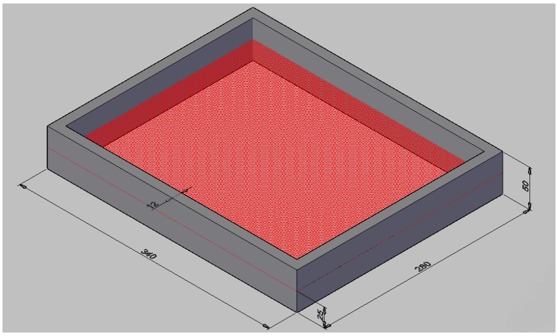

Fig. 2. Image of the wooden frame

The frames were designed and made by the authors themselves of wooden slats as follows: width = 280 mm, length = 340 mm and height = 50 mm. A 1x1 mm polyethylene mesh was fixed onto the frames. The frames were designed so that they would facilitate the placement and identification of the samples in the compost pile and at the same time the removal of the samples from the given environment. The experimental samples were inserted into the produced frames; in seven cases, the experimental samples were complete plastic bags (samples 1, 2, 3, 4, 5, 6, 7) and the eighth (control) sample was represented by cellulose filtering paper. The frames with the samples were properly marked and photographed to document future visual comparison.

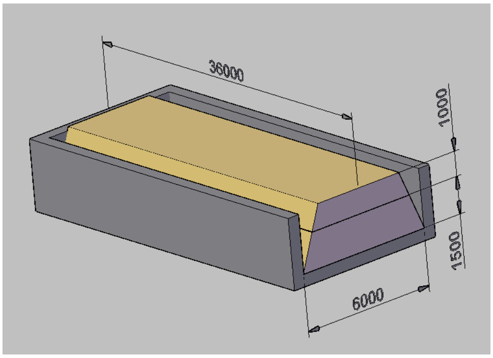

Fig. 3. Schematic representation of the composting clamp

The experiment started in May 2011. The samples were brought to Composting Plant in Brno. All eight samples were inserted into one clamp within the compost pile. A 3D image of the compost file and the clamp is presented in Figure 2. The samples were installed at a height of 1 m from the upper side of the compost file and at 1.5 m from the lower side of the pile (Figs. 3 and 4). Dimensions of the clamp into which the compost pile was placed were 6x36 m and its height was ca. 2.5 m. In these conditions, the experimental period was estimated to be 12 weeks.

Fig. 4. Placement of samples in the compost pile

The samples were checked visually at regular intervals of about 14 days. The schedule of testing dates and operations is presented in Table 2. The checks were also used to record possible changes of appearance.

Table 2

Experiment schedule of works

Time from start	Date	Operation
0	05.05.2011	Start-up of the test
15	20.05.2011	Sample checking
36	10.06.2011	Sample checking
49	23.06.2011	Sample checking
63	07.07.2011	Sample checking
89	02.08.2011	End of test

In order to be able to analyze possible effects of weather on the compost pile, composting process and decomposition of disposable plastic bags, we asked the branch of the Czech Hydrometeorological Institute (CHI) in Brno-Tuřany for the records of average daily temperatures and precipitation amounts in the concerned area for the given period. The data on daily precipitation amounts in millimeters and average daily air temperatures in degrees Celsius (T) in the monitored experimental period are presented in the diagrams (Figs. 5 and 6). Figure 5 characterizes daily precipitation amounts for the months of May, June and July 2011. The daily precipitation amount was measured once a day at 7.00 o'clock and was at all times recorded for the previous day. As shown in the graph, the highest daily precipitation amounts were recorded in July. The sum of daily precipitation amounts for that month was 92.4 mm. Sums of daily precipitation amounts for June and May were 61.5 and 44.2 mm, respectively.

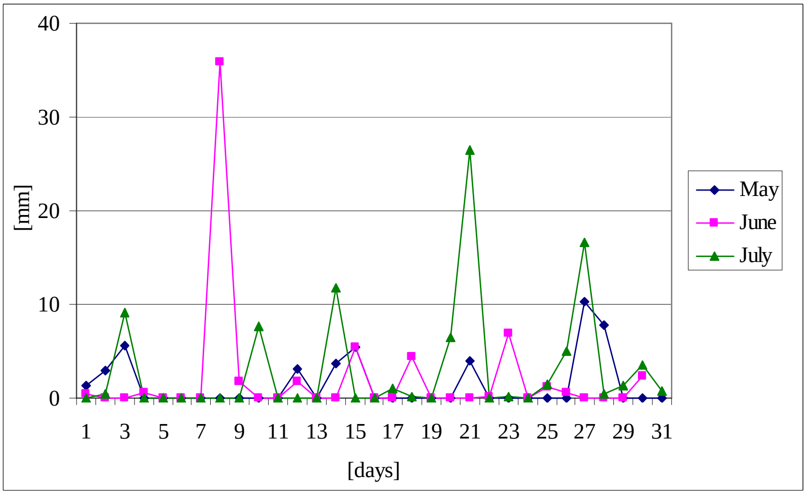

Fig. 5. Daily precipitation amounts for the experimental period

Figure 6 illustrates the development of average daily air temperatures at Central Composting Plant in Brno during the experimental period. As shown in the graph, the highest daily air temperatures were reached in the month of June when the average temperature amounted to 19.2°C. Average daily air temperatures in May and July amounted to 15.1 and 18.9°C, respectively.

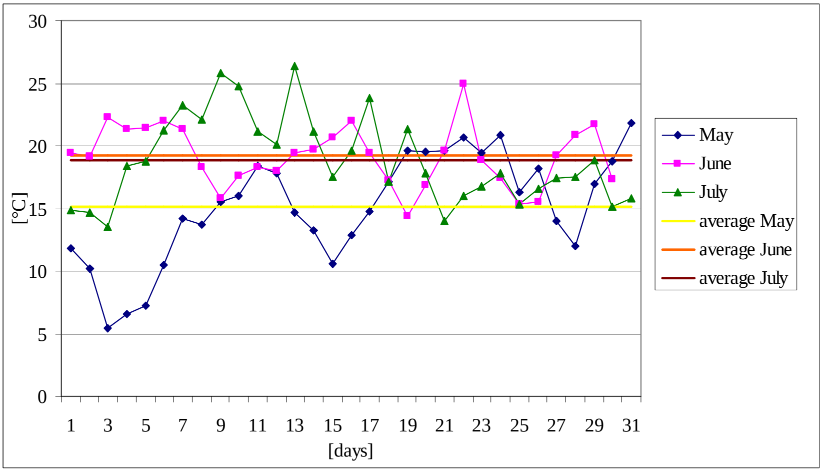

Fig. 6. Average daily air temperatures for the experimental period

The experiment ended at the beginning of August 2011, *ie* the experimental period lasted 13 weeks. After the end of the experiment, the samples were lifted from the compost pile and all eight samples were subsequently photographed and assessed.

Results

Upon the end of the experiment in composting plant the samples were taken to laboratories of the Department of Applied and Landscape Ecology at Mendel University in Brno where they were subjected to detailed evaluation. In all samples, a visual comparison was made of their initial and final states. In terms of this visual assessment, samples 4 and 5 exhibited the highest degree and rate of decomposition. The manufacturer of sample 4 informs that it was made of starch. Photographs of the initial condition of the sample, its condition in week 10, and the final condition of the sample upon the end of the experiment are presented in Figure 7.

Fig. 7. Sample No. 4

The manufacturer of sample 5 informs that it was made of starch and polycaprolactone. Photographs of the initial condition of the sample prior to being placed in the compost pile, its condition in week 10, and the condition of the sample upon the end of the experiment, *ie* in week 13, are presented in Figure 8.

Fig. 8. Sample No. 5

Upon the end of the experiment, samples 6 and 7 were decomposed to about 80% of their initial condition. The material composition of sample 6 was not available.

The manufacturer of sample 7 informs that it was made of natural material with no detailed specification. Photographs of the initial condition of the two samples, their condition in week 10 and after 13 weeks when the experiment was finished are presented in Figures 9 and 10.

Fig. 9. Sample No. 6

Fig. 10. Sample No. 7

Fig. 11. Sample No. 1

The remaining samples 1, 2 and 3 did not show any significant visual changes or signs of decomposition. Sample 3 however exhibited some changes in pigmentation. The material composition of sample 1 was not available. Photographs of the initial condition of the sample, its condition in week 10 and at the end of the experiment after 13 weeks are presented in Figure 11.

The manufacturer of sample 2 informs that it was made of HDPE + TDPA. Photographs characterizing the condition of the sample during the experiment at intervals mentioned above for other samples are presented in Figure 12.

Fig. 12. Sample No. 2

The material composition of the last assessed sample 3 was not available. Photographs characterizing the initial condition of the sample prior to being placed in the compost pile, its condition in week 10 and after having been lifted from the compost pile at the end of the experiment in week 13 are presented in Figure 13.

Fig. 13. Sample No. 3

A detailed analysis of the effect of weather conditions was not made. Nevertheless, it can be stated that total daily precipitation amounts for the experimental period were low. These low precipitation amounts might have been reflected in the rate and degree of decomposition of the experimental samples namely in sample 8 (cellulose filtering paper - Fig. 14) that served as a reference sample.

Fig. 14. Sample No. 8

Discussion

Composting seems to be the most promising for waste management options for degradable plastics because the composting process is designed to degrade wastes. There are, however, obstacles that make many communities reluctant to accept plastic bags for composting [4].

Large-scale composting operations are well established in many countries, and are an efficient way of producing useful material from what at present is largely garden and agricultural waste. Food wastes may also be used, and this would likely become much more common if inexpensive “one-way” containers were available. Such containers would need to have the low cost and the serviceability of conventional PE bags but, in addition, would need to be compostable. The ASTM definition of compostable is “capable of undergoing biological decomposition in a compost site as part of an available program, such that the material is not visually distinguishable and breaks down into carbon dioxide, water, inorganic compounds, and biomass, at a rate consistent with known compostable materials.” To be convenient for composting, degradable plastic bags should not only break down, but also hold moisture, not be lighter than composting feedstock and begin to degrade after several days [5, 6].

Various studies have shown that starch-based plastics do biodegrade under controlled composting conditions. This has been demonstrated for bags from cornstarch and PCL, and for Mater-Bi in particular [7-11]. These studies found no toxic residue from the degradation process.

The degradation of polyethylene (PE) modified with TDPA pro-oxidant additives been assessed by a variety of laboratory-scale and field-scale tests. Chiellini et al [12] studied the degradation of LDPE containing TDPA pro-oxidant additives from EPI Inc. They found that the LDPE-TDPA did undergo ultimate biodegradation (*ie* mineralization) in simulated soil burial but not readily in composting (mature compost) conditions. Oxidatively degraded LDPE-TDPA films were found to undergo biodegradation as mediated by soil microorganisms reaching a mineralization level of about 60% albeit over a relatively long time frame. They observed only limited biodegradation however of the LDPE-TDPA films in mature compost as opposed to soil burial. Chiellini et al points out that the completeness of biodegradation of LDPE-TDPA films and the cumulative time for oxidation are still answered questions at this stage [12].

Biodegradability of PEs modified by prodegradants additives has been assessed by a variety of laboratory-scale [13], and field-scale composting tests. An extensive commercial-scale composting trial of TDPA additives has been carried out in the municipal composting plant of Vienna Neustadt, Austria, directed by Dr B Raninger (Leoben University) [14, 15]. The results show that PE films modified by the EPI additives are oxidatively biodegradable under composting conditions, yielding high-quality compost. No toxic effects could be detected on either seed germination or organism survival [14, 15]. All tests showed absolutely no toxic or harmful by-products. The final conclusion of this testing was that products using PE and TDPA technology meet all requirements to be classified as degradable compostable plastics and the compost end product is fully acceptable as land fertilizer [14, 15].

The biodegradable and oxodegradable materials were tested as well in composting environments, including, traditional windrow, in-vessel manure, in-vessel food waste, and in-vessel municipal solid waste. All of the compost facilities were commercial operations and produce compost for the public [16].

After the composting period, the materials were recovered where possible. In all facilities, the PLA items and the Ecoflex bags had completely disintegrated. The results for the oxydegradable bags in each study were as follows:

- City of Chico Municipal Compost Facility: "The oxodegradable and UV-degradable plastics were completely intact and did not show any signs of disintegration".
- Vacaville Food-waste Compost Facility: "The oxo-degradable plastic bags, LDPE plastic bags and UV-degradable plastic bag did not appear to experience any degradation".
- Mariposa County MSW Compost Facility: "The oxo-degradable plastic bags, LDPE plastic bags and UV-degradable plastic bag did not appear to experience any degradation" [16].

Conclusions

The corroboration of decomposition in laboratory conditions according to current standards answers only the question whether the plastic wrapping material is biologically degradable. However, it does not answer the crucial question whether the wrappers are successfully degradable in the environment of industrial composting plant.

The experimental samples were placed in the compost pile operated by the Central Composting Plant in Brno and were checked and visually assessed during the experiment which lasted 13 weeks (standards for the laboratory test required 12 weeks). All existing norms related to this issue describe tests in laboratory conditions. Research in real conditions is not supported by norms neither exist methodologies describing procedures for the research of the decomposition of these materials in real conditions. Up to now, no laboratory tests were capable of copying the conditions of industrial composting plants. A similar experiment was carried out by Loeben University in Austria with EPI bags with the addition of TDPA [15].

The goal of our experiment was to test the decomposition of the above-described samples in real conditions of the industrial composting plant. After the expiration of the experimental period we found out that the polyethylene samples with the additive (samples 1, 2 and 3) had not been decomposed, their colour had not changed and that no degradation neither physical changes (thickness) had occurred. Therefore, the samples made of polyethylene with additives cannot be claimed to be compostable as they do not meet requirements of the existing standards and did not decompose within the time stipulated by the norms. They should have exhibited at least some changes or signs of the occurring decomposition (similarly as common organic waste), which were however not observed in the tested samples in our research. Temperatures reached over a long term in the compost pile ranged from 50-60°C. Although Chiellini et al [12] determined the time after which the LDPE-TDPA film looses its mechanical properties at a temperature of 55°C to be 11 days, the changes of mechanical properties were not recorded in the samples with the TDPA additive in our experiment. Samples 4, 5, 6 and 7 (certified as compostable) were decomposed. Sample 5 exhibited the highest decomposition rate (before the expiration of the set-up 13 weeks). Sample 8 was a control reference sample to confirm that the conditions of decomposition were suitable during the experiment, which was the case.

The experiment was carried out with the same samples in laboratory conditions, too. Results of this experiment were published in the environmental journal Ecological Chemistry and Engineering, 2012 [17]. Results of this experiment were similar as the results achieved in the real conditions. In laboratory conditions, it was possible to verify the quality of the resulting compost and hence the effect of decomposable polymers on the resulting product. In the conditions of industrial composting plant, it is difficult to find out whether the decomposition of samples affects the quality of the resulting compost. However, some studies claim to have had included measurements of eco-toxicity [14]. In contrast to the laboratory conditions, the real conditions are affected by a number of factors that cannot be influenced such as air temperature, pH of the environment, water content of the compost pile, precipitation etc. All these factors can significantly affect the rate and degree of decomposition.

The experiment was carried out in real conditions for the first time and its repetition is planned to be carried out again in the Central Composting Plant in Brno in order to verify the achieved experimental results.

Acknowledgments

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References

[1] Kale G, Auras R, Paul Singh S. Degradation of commercial biodegradable packages under real composting and ambient exposure conditions. J Polym Environ. 2006;14(3):317-334.

[2] Kale G, Kijchavengkul T, Auras R, Rubino M, Selke S, Paul Singh S. Compostability of bioplastic packaging materials: An Overview, Macromolecular Biosci. 2007;7(3):255-277.

[3] Kale G, Auras R, Paul Singha S, Narayanb R. Biodegradability of polylactide bottles in real and simulated composting conditions. Polymer Testing. 2007;26(8):1049-1061.

[4] Garthe JW, Kowal PD. Degradable Plastics, http://www.age.psu.edu/extension/factsheets/c/C15.pdf, Department of Agricultural and Biological Engineering, College of Agricultural Science, Penn State University, Pennsylvannia, 2002.
[5] Chapman G. Compostable bag differences. BioCycle 1999.
[6] Billingham NC, Wiles DM, Cermak BE, Gho JG, Hare CW, Tung JF. Controlled-lifetime environmentally degradable plastics based on conventional polymers. Addcon world 2000 (Basel, 25-26 October, 2000). International plastics additives and modifiers confernce No. 6, Basel.
[7] Kaiser JP. Testing the performance and the disintegration of biodegradable bags for the collection of organic wastes. Macromol Symp. 2001;165:115-22.
[8] Ohtaki A, Nakasaki K. Ultimate degradability of various kinds of biodegradable plastics under controlled composting conditions. Waste Manage Res. 2000;18(2):184-189.
[9] Booma M, Selke S, Giacin JR. Degradable plastics. J Elastomers Plastics. 1994;26(2):104-142.
[10] Chiellini E, Solaro R. Biodegradable polymeric materials. Adv Materials. 1996;8(4):305-313.
[11] Piccinini S, Rossi L, Innocenti FD, Tosin M, Bastioli C. Behaviour of biodegradable Mater-Bi Z101U plastic layers in a composting pilot plant. In: The Science of Composting. De Bertoli M, Sequi P, Lemmes B, Papi T, editors. London: Blackie Academic Publishers; 1996:1271-1273.
[12] Chiellini E, Corti A, Swift G. Biodegradation of thermally-oxidised, fragmented lowdensity polyethylene. Polym Degrad Stab. 2003;81:341-351
[13] Jakubowicz I, Yarahmadi N, Petersen H. Evaluation of the rate of abiotic degradation of biodegradable polyethylene in various environments. Polym Degrad Stab. 2006;91:1556-1562.
[14] Billingham NC, Bonora M, De Corte D. Environmental degradable plastics based on oxo-degradation of conventional polyolefins. Proceedings of the 7th World Conference on Biodegradable Polymers and Plastics. Pisa, June 4-8, 2002.
[15] Raninger B, Steiner G, Wales DM, Hare CWJ. Tests on composting of degradable polyethylene in respect to the duality of the end product compost. Microbiology of Composting, Springer, 2002.
[16] Rojas E, Greene J. Performance Evaluation of Environmentally Degradable Plastic Packaging and Disposable Food Service Ware - Final Report. 2007:1-70.
[17] Vaverková M, Toman F, Adamcová D, Kotvicová J. Study of the biodegrability of degradable/biodegradable plastic material in a controlled composting environment. Ecol Chem Eng S. 2012;19(3):347-358. DOI: 10.2478/v10216-011-0025-8.

OCENA BIODEGRADACJI PLASTIKOWYCH TOREB W WARUNKACH KOMPOSTOWANIA

Abstrakt: Badano biodegradację plastikowych toreb reklamowych ulegających w 100% rozkładowi oraz certyfikowanych jako kompostowalne w warunkach kompostowania. W celu oceny biodegradacji próbki zostały umieszczone w ramach, a następnie w materiale przeznaczonym do kompostowania. Plastikowe torby są dostępne w sieci sklepów w Czechach, jak również w Polsce. Badaniu poddano osiem próbek. Jedną z nich była jednorazowa torba wykonana z folii HDPE z dodatkiem TDPA (próbka 2). Kolejne torby były wykonane z polietylenu z dodatkiem oxo-biodegradacji d_2w (próbki 1, 3). Cztery próbki posiadały certyfikat kompostowalności (próbki 4, 5, 6, 7). Próbka ósma była próbką kontrolną (celulozowy papier filtracyjny, próbka 8), która miała na celu sprawdzenie potencjału biologicznego rozkładu badanego środowiska. Test został przeprowadzony w warunkach kompostowni przemysłowej. Pod koniec 13-tygodniowego okresu doświadczalnego stwierdzono, że próbki z polietylenu (próbki 1, 2, 3) nie uległy rozkładowi, ich barwa się nie zmieniła oraz że nie ma zmian fizycznych potwierdzających degradację. Próbki posiadające certyfikat kompostowalności (próbki 4, 5, 6, 7) uległy rozkładowi w różnym stopniu. Z przeprowadzonego doświadczenia wynika, że kompostowalne torby uległy rozkładowi, a torby wykonane z polietylenu z dodatkiem TDPA oraz d_2w nie ulegają rozkładowi w kompoście.

Słowa kluczowe: degradacja, biodegradacja, kompostowanie, kontrolowane warunki kompostowania