

STUDY ON THE (BIO)DEGRADATION PROCESS OF BIOPLASTIC MATERIALS UNDER INDUSTRIAL COMPOSTING CONDITIONS

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Abstract

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The objective of this study was to determine the biodegradability of bioplastic materials – sponge cloths – available on the European market. They are labeled as 100% biodegradable but not certified as compostable. The test was carried out in real composting environment. The project duration was 12 weeks. The emphasis was put on discovering whether the sponge cloths are biodegradable or not. Based on the results, it can be concluded that sponge cloths have decomposed completely (sample C and sample D). Samples A have decomposed but exhibited slower degradation rate. Samples B exhibited the higher degradation rate. The main conclusion from this study is that biodegradation of bioplastics materials strongly depends on both, the environment where they are placed and the chemical nature of the material.

Keywords: waste treatment, composting plant, biodegradation, sponge cloth

INTRODUCTION

With the advances in technology and the increase in the global population, plastic materials have found wide applications in every aspect of life and industries. However, most conventional plastics such as polyethylene, polypropylene, polystyrene, poly(vinyl chloride) and poly(ethylene terephthalate), are non-biodegradable, and their increasing accumulation in the environment has been a threat to the planet. To overcome all these problems, some steps have been undertaken. The first strategy involved production of plastics with high degree of degradability (Tokiwa *et al.*, 2009).

There are significant economical and industrial interests in seeking environmentally friendly alternatives to traditional petroleum-based plastic products (Lee *et al.*, 2016; Tokiwa *et al.*, 2009). In this regard, efforts to develop and utilize biodegradable

plastics that can be naturally degraded by microorganisms have received global attention.

The word 'bio-plastic' is used confusingly. In our understanding, however, bio-plastics consist of either biodegradable plastics (i.e., plastics produced from fossil materials) or bio-based plastics (i.e., plastics synthesized from biomass or renewable resources) (Tokiwa *et al.*, 2009).

Biodegradable plastics are seen by many researchers as a promising solution to above described problem because they are "environmentally-friendly". They can be derived from renewable feedstocks, thereby reducing greenhouse gas emissions. For instance, polyhydroxyalkanoates (PHA) and lactic acid (raw materials for PLA) can be produced by fermentative biotechnological processes using agricultural products and microorganisms (Tokiwa *et al.*, 2009). Biodegradable plastics offer a lot of advantages,

such as increased soil fertility, low accumulation of bulky plastic materials in the environment (which invariably will minimize injuries to wild animals), and reduction in the cost of waste management. Furthermore, biodegradable plastics can be recycled to useful metabolites (monomers and oligomers) by microorganisms and enzymes. A second strategy involves degradation of some petroleum-derived plastics by biological processes. A typical example can be seen in the case of some aliphatic polyesters, such as PCL and biodegradable plastics that can be degraded by enzymes and microorganisms (Tokiwa *et al.*, 2009). Studies have also shown that polycarbonates (particularly the aliphatic types) possess some degree of biodegradability (Tokiwa, 2002; Tokiwa *et al.*, 2009).

Two classes of biodegradable plastics, aliphatic polymers and aliphatic-aromatic co-polymers, have become popular in the industry. Aliphatic polymers can be biodegraded with relative ease, however, hold little market value due to their fragile nature and low durability (Lee *et al.*, 2016; Vert, 2005). In turn, development of aliphatic-aromatic co-polymers that combine the excellent mechanical properties of conventional aromatic polymers and biodegradability of aliphatic polymers has received a boost (Lee *et al.*, 2016; Shah *et al.*, 2014). However, proper disposal of biodegradable plastics (i.e., complete neutralization and little contamination with other waste and human food) remains challenging, especially in the existing framework of waste management (Lee *et al.*, 2016; Shah *et al.*, 2014).

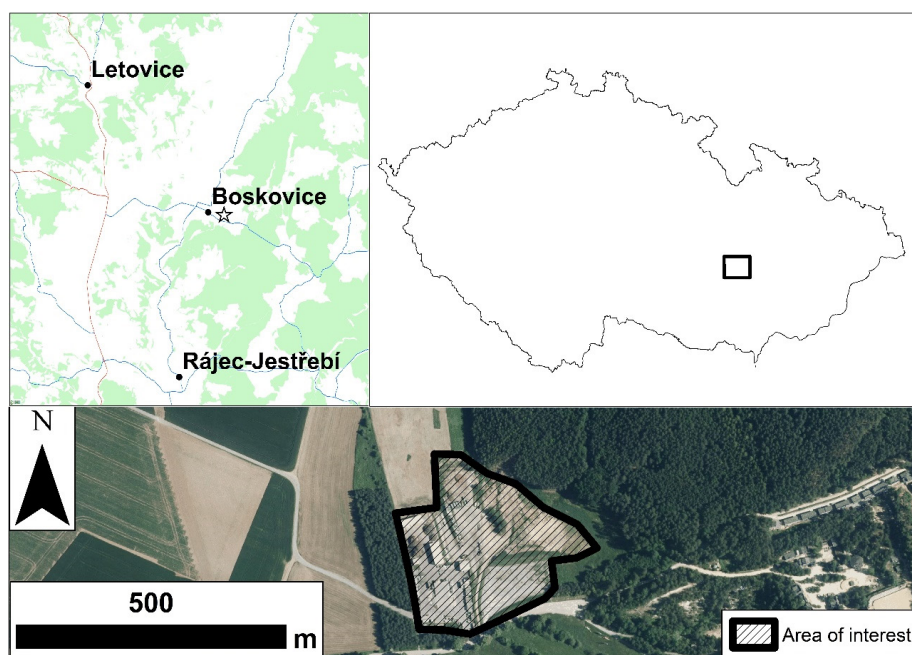
Composting plays an important and growing role in sustainable organic waste management and recycling. However, plastics are one of the main contaminants in composts. Biodegradable plastics are meant to address this problem. Composting of these materials also reduces their environmental impact in fact that they will largely be converted to CO₂ and not to CH₄ as if they were in a landfill (Gómez *et al.*, 2013). Above all, composting represents one of the technologies of processing of biodegradable municipal waste (Vítězová *et al.*, 2012).

The objective of this study was to determine the biodegradability of bioplastic materials – sponge cloths – available on the European market, labeled as 100% biodegradable but not certified as compostable. The test was carried out in a real composting environment. The project period was 12 weeks. The emphasis was put on discovering whether the sponge cloths are biodegradable or not.

MATERIALS AND METHODS

Experimental procedures

The degradability potential under aerobic composting conditions of biodegradable sponge materials was considered. The research was conducted in the static composting pile under industrial composting conditions in the Composting Plant in Boskovice-Doubravy operated by SUEZ Využití zdrojů a.s. (Czech Republic). The company operates a regionally important (South Moravia) facility processing



1: General site location (modified according Vavrková *et al.*, 2014).

I: *Samples of biodegradable sponge cloths.*

Sample	Country of origin	Description	Composition
Sample A	Made in EU	100% biodegradable	Renewable resources, organic cotton mesh
Sample B	Germany	100% biodegradable	Cellulose, Cotton mesh, Water, Salts, Pigments
Sample C	Germany	100% biodegradable	70% Cellulose, 30% Cotton
Sample D	Sweden	100% natural, bio-degradable, compost OK	75% Cellulose, 25% Cotton
Sample E (blank)			Cellulose

biological wastes. The composting plant is used for the conversion of biologically degradable waste (bio-waste) from the city of Boskovice and its surroundings (Fig. 1). The composting plant is producer of high-quality organic fertilizers and substrates, and operates a controlled intensive composting system with aeration handling about 995×10^3 kg of bio-waste per year.

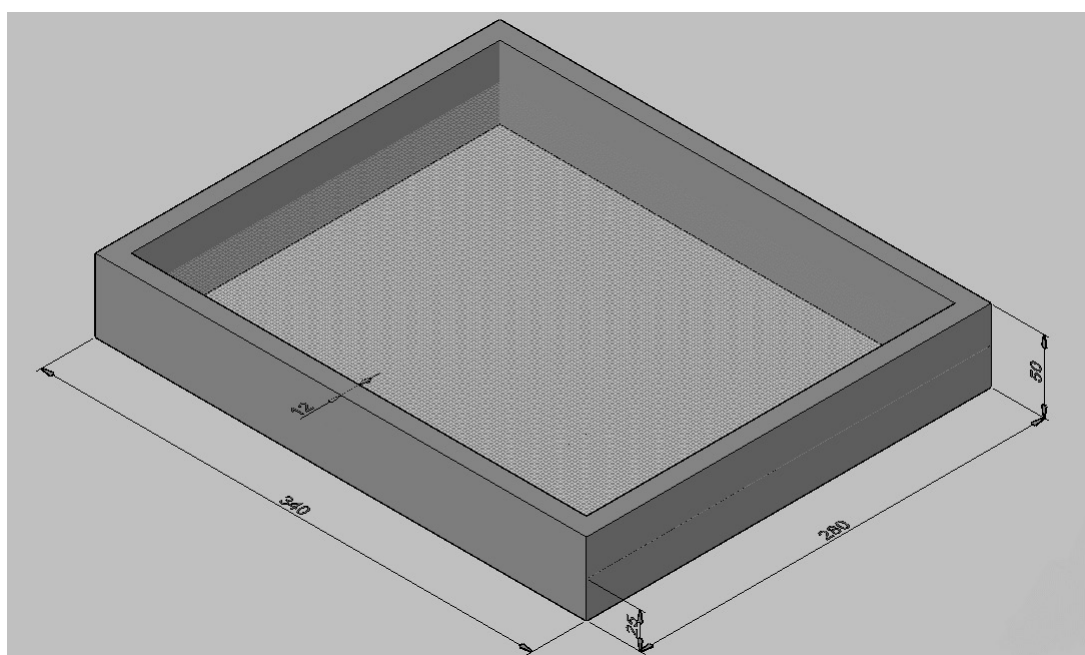
Bioplastic materials – sponge cloths

The investigated materials were labeled as 100% biodegradable sponge cloths obtained from chain stores on the European market. Four kinds of biodegradable sponge cloths (commercially available) (Tab. I) and cellulose filter paper as a positive control (reference mixture) were used in this study. Sample A was presented by a sponge made from renewable resources and using an internal organic cotton mesh. Another (stated by the manufacturer) was a sponge super absorbent,

easy to rinse, washable at 95 °C, durable with an internal cotton mesh, made from natural fibers – samples B. Sample C – described as biodegradable and compostable. Sample D was a sponge described as natural, bio-degradable and compost OK. Sample E – positive control – was cellulose filter paper. Cellulose is ubiquitous in nature, readily degraded in the environment, and used as the positive reference material within compostability studies (ISO 14855-1; ASTM D 5338-98). Two replicates were prepared for each sample.

Biodegradation test: procedure

Samples (A, B, C, D, and E) were placed into frames. A 3D image of the wooden frame is presented in Fig. 2. The frames size was as follows: width = 280 mm, length = 340 mm and height = 50 mm. A 1 × 1mm polyethylene mesh was fixed onto the frames. The frames were

2: *Image of the wooden frame (Vavřková et al., 2014).*

II: Monthly precipitation amounts in millimeters (data source: CHI).

Description	April	May	June	July
Precipitation [mm]	17	41	32	34
Long-term precipitation standard 1961-1990 [mm]	38	65	75	64
Deviation from normal	21	24	43	30

III: Tab. III. Monthly air temperatures in degrees Celsius (data source: CHI).

Description	April	May	June	July
Air temperature [°C]	9.2	13.7	18	21.9
Long-term temperature standard 1961-1990 [°C]	8.6	13.5	16.6	18.1
Deviation from normal	0.6	0.2	1.4	3.8

designed in order to facilitate the placement and identification of the samples in the compost pile and to the removal of the samples from the given environment.

The experimental samples were inserted into the produced frames; in four cases, the experimental samples were complete sponge cloths (sample A,B,C,D) and the control (sample E) was represented by cellulose filtering paper. The frames with the samples were properly marked and photographed to document future visual comparison.

The experiments were conducted between April and July 2015. The samples were brought to Composting Plant in Boskovice-Doubravy. All five samples were inserted into one clamp within the compost pile. The samples were installed at a height of 1 m from the upper side of the compost pile and at 1.5 m from the lower side of the pile. In these conditions, the experimental period was estimated to be 12 weeks. The samples were checked visually at regular intervals of about 14 days. The average weight loss of the samples was determined and recorded. Also, the temperature of the compost was measured and recorded daily. During the biodegradation of the samples in the composting pile, the average outside temperature was 15.7 °C and average rainfall 31 mm.

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) for the records of average daily temperatures and precipitation amounts in the concerned area for the given period. The data on monthly precipitation amounts in millimeters and average monthly air temperatures in degrees Celsius in the monitored experimental period are presented in the tables (Tab. II and III). Table III characterizes monthly precipitation amounts for the months of April, May, June and July 2015.

The experiment ended at the beginning of August 2015, i.e. the experimental period lasted 12 weeks. After the end of the experiment,

the samples were removed from the compost pile to assess their biodegradation and all five samples were subsequently photographed. After removal from the compost, samples were washed with distilled water twice to remove compost residue and dirt, and dried in vacuum oven until observing a constant weight. The degree of biodegradation of samples was assessed by measuring their weight loss and surface morphology. The recovered fragments were weighed for calculating the corresponding disintegration degree (D) (Eq.1):

$$D = \frac{M_i - M_r}{M_i} 100 \quad (1)$$

where: M_i corresponds to the initial dry mass of sponge pieces, M_r represents the dry mass of the recovered sponge pieces after composting and sieving.

RESULTS

A pilot-scale composting test was performed to evaluate degradation of examined samples during the natural composting process. During the composting experiment, the temperature increased to +40 °C in 10–11 days and the maximum temperature of +65–66 °C was reached in 23–24 days. According to the EN 14045, the test is considered valid if the temperature is below +75 °C during composting, the temperature is above +60 °C for at least 1 week, and the temperature is above +40 °C for at least 4 consecutive weeks. All these criteria were fulfilled during the pilot-scale composting.

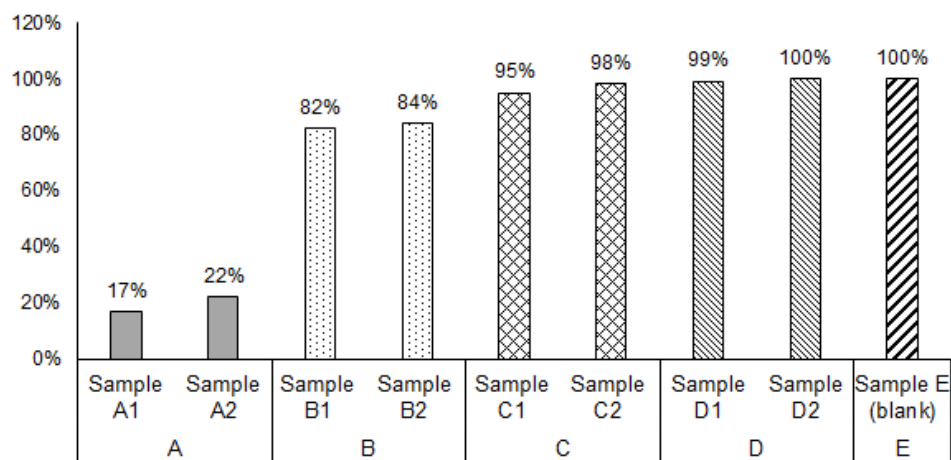
Upon the end of the experiment in composting plant, the samples were taken to laboratories of the Department of Applied and Landscape Ecology at Mendel University in Brno where they were subjected to detailed evaluation.

Disintegration calculation

Tab. IV presents the exact amounts of sponge pieces before (M_i) and after (M_r) composting from each reactor, as well as their corresponding

IV: Amounts of sponge pieces before (M_i) and after composting (M_r).

Sample	Type	M_i [g]	M_r [g]
A	Sample A1	18	15
	Sample A2	18	14
B	Sample B1	18	3.2
	Sample B2	18	2.9
C	Sample C1	12	0.6
	Sample C2	12	0.2
D	Sample D1	22	0.2
	Sample D2	22	0
E	Sample E (blank)	20	0



3: Disintegration degree of Samples A-E.

disintegration degree (D), and calculated according to Eq. (1). In all samples, a visual comparison was made at their initial and final state. In terms of this visual assessment, samples D and C exhibited the highest degree and rate of decomposition (nearly 100%). Upon the end of the experiment, samples B were decomposed to about 80% of their initial condition. The sample A did not show visual changes or signs of decomposition but the sample decomposed to about 20%. The values of disintegration degree for Samples A – E are listed in Fig. 3.

At the same time, the analysis of the effect of weather conditions was made. 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 A because the lowest level of sponge cloths decomposition was found there. On the other hand, the measured results indicate easy degradability of materials which were used for the production of samples C and D.

DISCUSSION

There are significant economical and industrial interests in seeking environmentally friendly alternatives to traditional petroleum-based plastic products (Tokiwa *et al.*, 2009). In this regard, efforts to develop and utilize biodegradable plastics, which can be naturally degraded by microorganisms, have received global attention (Lee *et al.*, 2016). Proper disposal of biodegradable plastics remains challenging, especially in the existing framework of waste management (Shah *et al.*, 2014).

Biodegradable plastics, based on cellulose and cotton, primarily the plastic decomposed in soil or water have been studied since second half of the 90's. There were studies of the important properties of biodegradable plastics (e.g. cellulose and cotton) including biodegradation, mechanical strength, impact resistance, transparency, colorability, fabricating versatility, moldability, and di-electric strength (Kopinke *et al.*, 1996, Calmon *et al.*, 2000, Sato *et al.* 2001, Fischer *et al.*, 2008 and Jinghua *et al.*, 2009, Mostafa *et al.*, 2016). In recent years, the development of biodegradable materials from renewable natural resources has received increasing attention, particularly in EU countries (Davis and Song, 2006) and the use of renewable resources has been revitalized (Tabone

et al., 2010, Cateto *et al.*, 2008 and Kiatsimkul *et al.*, 2008). If properly managed, this will reduce their environmental impact upon disposal (Davis and Song, 2006) and, also, it will be technically and economically practicable (Tanaka *et al.*, 2008).

The screening-level biodegradation tests can provide information about the inherent biodegradability of plastics but the rate of degradation and the ultimate fate of polymers in environmental conditions must be determined using real conditions. In this study, the samples were examined in the real composting conditions. Comparative studies on the biodegradation process of samples under industrial composting conditions (in the composting pile) and under laboratory conditions were performed. Results of this experiment were published in the Journal of Ecological Engineering (Vavřková and Adamcová, 2015). The research was carried out to determine whether the samples are biodegradable or not. In the laboratory conditions, some of the bioplastic materials – sponge cloths – were biodegraded to an appreciable extent and some did not improve the biodegradability of those recalcitrant materials. Above all, further field and laboratory experiments on the above topic were implemented in recent years (Vavřková *et al.*, 2012; Vavřková *et al.*, 2014).

The experimental results showed that the samples were decomposed in following extent: sample A - about 20%, sample B - 80%, sample C and sample D nearly 100% of their

initial weight. These results indicate that compost can affect the fate of biodegradable plastics in ways that would not be anticipated from results obtained in laboratory conditions (Vavřková and Adamcová, 2015). The course of the composting process depends on a number of factors where the most important are the ratio of the macro elements, such as C and N, water content, pH, and heavy metal content (Diaz *et al.*, 2007), as well as the profile and number of microorganisms living in the compost environment (Vítězová *et al.*, 2012, 2013). Moisture content is another critical factor during composting. Water serves as a solvent and a distributing factor for low molar mass compounds, but an excess of water can cause a lack of aeration leading to anaerobic conditions (Liang *et al.*, 2003, Sikorska *et al.*, 2015). On the other hand, the biodegradability of plastics does not depend only on properties of composting process. The very important parameter represents composition of individual plastic materials (Tokiwa *et al.*, 2009) and their shape (Yang *et al.*, 2005). The presented results indicate sponge clothes made of cotton and cellulose (sample C and D) can be decomposed by conventional composting process (EN 14045). Above all, the field experiment showed that the addition of other substances (salts, pigments) can inhibit decomposition of sponge clothes during composting process. These findings are in accordance with Tokiwa *et al.* (2009), Leja and Lewandowicz (2010), Gómez and Michel (2013).

CONCLUSION

Biobased plastics are still at an early stage of commercialization, only starch-based bioplastics and PLA are available considerably for packaging and other industrial applications. The biodegradability of plastics is a complex process and is influenced by the nature of each plastic. The present study monitored biodegradability of sponge cloths composed mainly of cellulose and cotton. The experimental samples were placed in the compost pile operated by the Central Composting Plant in Boskovice-Doubravy and were checked and visually assessed during the experiment which lasted 12 weeks. The validity of the tests was confirmed in positive controls (cellulose paper) 100% biodegradable. The biodegradation of the sponge cloths, labeled as 100% biodegradable but not certified as compostable (sample B), proceeded very well. From this test, it can be concluded the sponge cloths (sample C and sample D) showed a high level of biodegradation during the 12-week composting real-scale test. However, sample A, sponges made from renewable resources and using an internal organic cotton mesh, showed slower degradation rate. Thus, it can be concluded that the biodegradation of bioplastics materials strongly depends on both, the environment they are placed and the chemical nature of the material.

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