Acta Universitatis Carolinae
Environmentalica 1–2 (2010): 61–82

Bio-degradable municipal waste management: source-separation awareness campaign, composition analysis, verification of d_2w plastics' decomposability

KAROLINA MAREŠOVÁ[1], ANTONÍN SLEJŠKA[2], LIBUŠE BENEŠOVÁ[1]

[1] Institute for Environmental Studies, Faculty of Science, Charles University in Prague, Benátská 2, CZ-128 01 Prague 2, Czech Republic; m.karol@centrum.cz

[2] Department of Ecotoxicology, Crop Research Institute, Černovická 4987, CZ-430 01 Chomutov, Czech Republic

Abstract: The article presents the results of research devoted to bio-degradable municipal waste (bio-waste) separation and its subsequent composting. The report also summarizes a decomposability test of ox-biodegradable d_2w plastics made by Symphony Environmental Ltd during composting process as well. The empirical part focused on research done in order to monitor and evaluate the impact of public awareness campaign re volume and quality of separately collected bio-waste. An analysis of bio-degradable and mixed municipal solid waste (MSW) composition was made – while selected waste parameters such as mass, volume, volume weight, specific weight (per inhabitant per week), and composition, were measured – in three different locales. The d_2w plastics were also evaluated in regard to changes of their mechanical properties exhibited over the time (tensile strength, elastic modulus, and relative elongation at breaking) both in and off compost environment, since their possible utilization in the source separation, collection, and management of bio-degradable municipal waste, had been considered. The MSW composition analysis confirmed that the mass portion of municipal bio-waste in mixed waste fluctuates between 30% and 50% wt. Where public awareness campaign was carried out, the pro rata volume of separated bio-waste in kilograms per inhabitant per week reached twice the size of that in the reference locale where the campaign was omitted. In spite of this, the recovery of separately collected bio-waste was generally low. The d_2w plastics decomposability test also showed that due to their overly slow decay in the compost environment, the d_2w plastics do not comply with some of the regulations as established by ČSN EN 13432.

Keywords: Bio-waste, source separation schemes, composition of MSW, biodegradable plastics

INTRODUCTION

While waste management is already governed by a substantial body of EU regulation, there is still room for improvement as far as the management of some major waste streams is concerned. Sustainable management of organic waste is gaining importance across Europe and all over the world. The member states of the European Union have a number of targets for the streaming of organic waste away from landfills to meet. In particular the 1999/31/EC Council Directive on waste landfilling in the EU focuses on organic waste with targets to reduce the amount of landfilled organic waste to 75% of the 1995 levels by

2010, 50% by 2013, and 35% by 2020, respectively. Although coming out on the bottom of the waste hierarchy as the least desirable option, landfilling is still the most frequently used Municipal Solid Waste (MSW) disposal method in the EU. Landfills have to be constructed and operated in line with the EU Landfill Directive (impermeable barriers, methane capturing equipment) in order to avoid environmental damages resulting from the methane, leachate, and effluent generation.

In general bio-degradable waste represents a significant portion of municipal waste; in the EU bio-waste usually amounts to between 30% and 40% wt. (although the value fluctuates within a wide range of 18% to 60% wt.) of solid municipal waste (Sirotková 2006; Green Paper 2008). The total annual formation of **bio-waste**[1] in the EU is estimated at 76.5–102 Mt of food and garden waste contained in mixed municipal solid waste, and up to 37 Mt generated by the food and beverage industry. Bio-waste is a putrescible and generally wet waste. Two major streams of bio-waste can be distinguished: green waste from parks, gardens etc., and kitchen waste (Green Paper 2008). The present volume of collected municipal bio-waste (including green waste) amounts to approximately 50 kg per inhabitant per year (Barth et al 2008).

In addition to prevention of origin, waste management options for bio-waste include its collection (separately or together with mixed waste), anaerobic digestion and composting, incineration, and landfilling. The environmental and economic benefits of individual treatment methods depend significantly on local conditions such as population density, infrastructure, and climate, as well as on associated products' (energy and composts) markets.

Today, a wide range of national policies – from little action taken by some Member States to ambitious policies adopted by others – is applied to bio-waste management, which can lead to increased environmental impacts and can hamper or delay full utilization of advanced bio-waste management techniques (Green Paper 2008). The Czech Waste act No.185/2001 Col. clearly stipulates that utilization of waste be assigned a higher priority than its disposal, and that material recovery be favored to energy recovery. This stipulation is also embodied in Waste Management Plan of the Czech Republic, which defines composting as an unequivocally preferred method with utilization of final product, particularly in agriculture, reclamation, and verdure maintenance.

Source separation schemes can help diverting biodegradable waste from landfills, provide quality input to bio-waste recycling and improve the efficiency of energy recovery. The implementation of separate collection schemes, however, is not without its challenges, which include: the need to re-design waste collection systems and change of citizens' habits (while properly designed separate collection systems are not necessarily more expensive, their proper design and management require more effort than mixed waste collection systems); the difficulties encountered during identification of areas suitable for separate collection of bio-waste (it is difficult to guarantee the necessary purity of the input in densely populated areas, while in scarcely populated areas the separate collection may prove too expensive, making home composting a better solution); the problems of matching the waste

[1] According to Green Paper on the management of bio-waste in the European Union (2008), **bio-waste** is defined as biodegradable garden and park waste, food and kitchen waste generated by households, restaurants, caterers, and retail premises, and comparable waste produced by food processing plants. It does not include forestry or agricultural residues, manure, sewage sludge, or other biodegradable waste such as natural textiles, paper or processed wood.

arising with the use of recycled material, as due to transport costs and low prices the use of compost is often confined to locations in the vicinity of the treatment plant (which may pose problems in densely populated areas); hygiene and odor issues, especially in warm and hot climates; and more (Green Paper 2008). The implementation of any bio-waste separation and collection scheme inevitably requires the cooperation of local inhabitants, their willingness to separate bio-waste, and a great amount of discipline employed therein. Provided the correct management method is used, the biodegradable waste yields an explicit benefit in the form of its complete recycling and reuse, for example as a fertilizer. This benefit cannot be gained unless a proper separation of bio-waste from other forms of waste is guaranteed at the earliest stage, i.e. at the source. For this very reason it is recommended to recover solely bio-waste obtained via separate collection (Kotoulová and Váňa 2001; Favoino and Habart 2003). Moreover, an analytic study undertaken by Institute for waste, sewage and infrastructure operating suggests that the collection of bio-waste in separate containers is cost-effective (Oelgemöller et al 2004).

Bio-waste (especially green waste) source separation schemes operate in many countries all over the world. In particular, the composting of kitchen and green waste has been adopted by many municipalities (Otten 2001; Hargreaves et al 2008). Circuit systems of bio-waste management are being developed successfully in the United Kingdom, USA and Canada. In the United Kingdom, the Landfill Directive alone has created the demand for composting facilities and anaerobic digestion as well; also a "Composting Association" was established in order to promote the sustainable management of biodegradable resources. It's main goal being the permanent support of the development of a new infrastructure needed for residual waste management and the survival of sustainable agriculture. The same circumstances have evolved in Scotland too (Yepsen 2008). BioCycle World (2005) describes a pilot project that started January 2004 in Bexley, London, and involved 289 local households which went on separating kitchen and garden waste for the rest of the year. For this purpose the households used special aerobic containers – ten liter bins lined with paper sacks – that were placed into outdoor containers (emptied every two weeks) for bulk separation when full. This system proved to be all-round satisfactory. Things have been running a most favorable course in the USA as well. A 2007 research conducted by BioCycle World identified a total of 42 communities or districts employing a particular collection scheme and organic waste management. Seventeen such areas were found in the state of California, one in Michigan, 7 in Minnesota and 17 in Washington (Yepsen and Goldstein 2007). A study of the western United States was published by Farrell (2005): in 1996, a campaign for separate collection of bio-waste from households, supermarkets, restaurants, cafés, hotels, bakeries, and similar enterprises, was started in the San Francisco area and by 1998 the whole city was already involved in it. Today, more than 150,000 households and approximately 2,500 entrepreneurs partake in this source separation scheme and the producer of compost has already found subscribers (Yepsen and Goldstein 2007). In Canada, the separation schemes and bio-waste management situation is similar. The "Composting Council of Canada" has been in operation for almost 20 years and contributing significantly to the diversion of bio-waste from landfills. According to the study there were 225 composting facilities in Canada in 2006 and about 4 million tons of bio-waste was diverted from landfills to individual plants in 2007 (note: 4 million tons of bio-waste represent 12% of all landfilled waste in Canada per year) (Antler 2008).

In the Czech Republic, the Landfill Directive, analogous to the situation in the United Kingdom, has created the demand for implementation of complex disposal systems for bio-waste, as well as the demand for composting facilities and anaerobic digestion. Nowadays there exist many disposal systems for biodegradable municipal waste in municipalities (at least in some of their parts) such as Vysoké Mýto, Prague, Olomouc, Plzeň, Bílina, Černošice, Kladno, Zlín, Náměšť nad Oslavou etc. (Zera 2008a). These systems exist mainly in the form of pilot projects and they are constantly broadening. According to special survey of the Zera Agency there were 160 composting facilities in total in the Czech Republic in the year 2008 and the amount of processed bio-waste was 828,971 tons (Zera 2008a). According to the map of facilities for anaerobic digestion in the Czech Republic we now have 9 facilities for anaerobic digestion of only municipal bio-waste and another 66 facilities utilizing all bio-waste (from agriculture especially) (CZ Biom 2009).

Implementation of separate collection of bio-waste has to go hand in hand with a viable method of bio-waste storage at the very source, i. e. at home. A special bin – either plain or fitted with a suitable paper or plastic liner – serves the purpose well. When asking whether it is "better to collect bio-waste in easily degradable decomposable bags, or use plastic bags instead and sieve these out during the final stage of composting process", one eventually reaches the following conclusion: if the composting facility processes negligible amounts of source-separated bio-waste, then several plastic bags present no problem for the sieves. However, the sieves processing significant volumes of source-separated bio-waste in plastic bags are in danger of clogging up. It is generally accepted that the conventional plastics are the main source of pollution within the frame of recycling schemes focused on bio-waste (Yepsen and Goldstein 2007). Moreover, decomposable bags are printed with information pertaining to the whole source separation scheme and therefore help raising public awareness at the same time (Slejška 2005). As for the purity of source-separated bio-waste, the decomposable bags used in the project VaV720/1/03 "Bio-waste" brought especially good results (Hodek and Vašutová 2005).

The only disadvantage of decomposable plastics compared to standard plastic materials such as polyethylene, polypropylene, polystyrene or polyethyleneterephtalate is logically their higher price. Nevertheless, demand for decomposable plastics raises every year by 30% (Laeversuch 2002). The fact that more and more companies and manufacturers (e.g. in Scotland and the United Kingdom) are looking at using compostable packaging confirmed Yepsen (2008). The Composting Association in the United Kingdom works with biodegradable plastics as well, serving as the UK certifying institution of European Bioplastics. The European Bioplastics functions much like the Biodegradable Products Institute in the United States and helps assure that products are biodegradable (Yepsen 2008). Broadening of compostable plastics and packaging is being supported also through the fact that in some municipalities (e.g. California – San Francisco) a ban on plastic grocery store bags is in place (Yepsen and Goldstein 2007). The most current information is for instance that the d_2w plastics are used by the national airline of the United Arab Emirates – the Etihad Airways. This company is using d_2w plastics as a packaging material for all of their on-board products.

Our research focused on spreading the awareness about separate collection of bio-waste amongst households via educational campaign and on monitoring the approach of such "educated households" to bio-waste separation – as compared to that of an ordinary community which was allowed the same opportunity to separate bio-waste – for the length of a single year. The project was carried out in a medium-sized Czech town (population ca 26,000), where bio-waste separation is being implemented since 1995. Regular analysis of source-separate waste as well as mixed municipal waste was conducted in selected parts of the town. Due to the increasing use of decomposable plastics and their possible utilization in source separation schemes we also decided to test decomposability of d_2w plastics (in comparison with the conventional polyethylene and starch-based plastics) during the composting process which is the most frequently used method of bio-degradable waste treatment.

METHODS

Separate collection of bio-waste; composition analysis of mixed MSW and bio-waste

The project was realized in a medium-sized Czech town Uherské Hradiště (population 26,000); the methodology was prepared under the leadership of an experienced specialist R.C. Hultermans and in cooperation with the local environmental department, OTR Inc. waste transport company in Uherské Hradiště, and the Institute for eco-policy in Prague.

The analysis of both biodegradable and MSW composition as well as the extent of their separation was carried out in three different locales within Uherské Hradiště (UH). Two of these were situated close to the Štěpnice housing estate. This type of locality was chosen on purpose since housing estates are – due to a "high degree of anonymity" – considered most difficult as far as the implementation of source separation schemes and the collection of separated municipal waste are concerned. The two housing estates were designated as PA (pilot area) consisting of 216 households and 448 residents, and RA (reference area) covering 399 households and 964 residents, respectively. The third locale was found in a build-up area of 150 family houses in Mařatice and was designated as PH (private houses). The distinction between pilot and reference area had to be made for the purposes of the **educational campaign**[2] which was launched in order to raise awareness about bio-waste separation. The campaign was introduced exclusively to the pilot area at the beginning of the project (May 2005) prior to the first analysis and waste monitoring. During the campaign every household received 100 free decomposable bags (made of starch-based plastic) supplied by the HBABio company, along with leaflets containing information about the project, a motivational letter from local authorities, the provider's credentials, and further information about the proper method of bio-waste composting. The equipment was delivered personally where possible. When no residents were present at the time of delivery, the equipment was delivered care of the neighbours or left at the front door. The first inquiry was also carried out in the pilot area at the same time; its results are not included herein.

The compositional analyses of mixed MSW and bio-waste were done every two months (seven times in total) at the plant run by OTR Inc. waste transport company. In the case of

[2] The primary aim of the campaign was to determine the significance of inhabitants' awareness about bio-waste separation and to test whether the volume of separated bio-waste will increase significantly as expected or not. The whole population of Uherské Hradiště was given information about the project regularly in a local press. The first studies were published via local television channel by the students involved in the project, who created a short coverage for the evening news, and by the means of a newspaper article which summarized the results of our inquiries from the beginning onwards.

PA and RA the following procedure was used for the purposes of both biodegradable waste and MSW analysis: a 1,100 L mixed-waste container and two 240 L compostainers were always singled out in each area. In the PH area, only mixed municipal waste was analyzed, since the inhabitants did not have access to separate-waste compostainers for bio-waste. Five 120 L mixed-waste containers were designated each time. Mixed municipal waste was analyzed in regard to the amount of kitchen waste and garden waste, paper (as a decomposable material), and the residual parts including plastics and glass. Analyses were done manually; each group was weighed as soon as the waste was separated, and volume as well as volume mass was measured. Analysis of bio-waste was conducted particularly in regard to the ratio of polluting agents present in separated waste; analysis of mixed municipal waste focused instead on the ratio of differently exploitable bio-waste.

In the PA and RA near the housing estates, all collected waste was weighed separately for each area as well. Separated bio-waste from compostainers was weighed every month, while all mixed MSW was weighed once a two month. The weighing was done in order to define specific mass of bio-waste, and mixed MSW, respectively, i.e. to specify the amount of a particular waste produced per inhabitant per time period (that is, in kilograms per inhabitant per week) in the area.

Degradability test of d_2w plastics

The manufacturer of d_2w plastics claims that these belong to the group of synthetic biodegradable plastics (i.e. polyethylene-based). Additive d_2w is an analogy better known as EPI TDPA, produced by EPI Environmental Products. TDPA stands for Totally Degradable Plastic Additives. The speed of degradation of d_2w film depends on the presence of d_2w additives. A film capable of total degradation in 2 months' to 6 years' time can be supplied on demand. The d_2w plastics degrade via chemical oxidation which can be initiated by heat, UV radiation, or mechanical stress. Like other types of polyethylene film, the d_2w plastics are hydrophobic and therefore biodegradation-resistant until their structure is eroded by oxidation, which makes them hydrophilic and bio-degradable. The methodology used for the degradability test of d_2w plastics was based on the conclusions of previously completed tests (for more information please visit the manufacturing company Symphony Environmental's website) and applied in compliance with the Czech norms ČSN EN 13432: Requirements on packaging media usable for composting and bio-degradation and ČSN EN ISO 527-3: Plastics – Determination of tensile properties: Test conditions for films and sheets. The test samples – 85 × 40 cm garbage liners made of 0.02 mm film in 2004 – were provided by Ecoplastic Company.

Three composts were established for the duration of 6 months (May to October 2005). Two of these – Compost C and Compost CA – became part of the experimental composting facility run by Research Institute of Agriculture Engineering in Prague, while the third was established as Compost LG at the Vyšehrad private composting facility. The volume of each compost amounted to mere 3 m^3. Compost C and CA's base consisted of straw mixture (30% vol.), pig manure (30% vol.), 14 days old grass (30% vol.) and grain (10% vol.). Compost CA was treated with Amalgerol in order to speed up its maturation process. Only the initial batch of Compost LG (leaves and grass), which consisted of leaves (50% vol.) and green grass (50% vol.), differed from the first two.

Three samples of degradable plastics and reference samples were then introduced into each compost. Three standard polyethylene garbage bags (PE samples) and three decomposable bags made by HBABio Ltd. (starch-based plastics) were used as reference samples. Each sample comprised of a bag filled with mixture of overturned compost and labeled with a descriptive tag. The compost could not be turned over during the maturation process due to the samples deposited in it. A homogenizing turning was carried out only at the beginning of the experiment before the samples were deposited. During the whole maturation process temperature was taken, humidity was controlled, and oxygen content was measured. Samples of d_2w plastics and reference PE samples from all composts were tested for their mechanical tensile characteristics after 5 weeks and subsequently after 12 weeks from the composting process initiation.

The experiment was carried out in an off-compost environment, i.e. samples were exposed to sunshine, weather conditions, and downfall. Ten samples (whole bags again) were hung on a rope with their bottom ends left loose.

There were ten d_2w bags, three standard PE bags and three decomposable starch bags supplied by HBABio. Outdoor samples were tested twice for their mechanical characteristics after 8 weeks and subsequently after 12 weeks, respectively, as well.

Samples taken from the composts were at first slightly rinsed with tap water. All samples including the outdoor ones were then prepared for the testing of mechanical tensile characteristics at the Prague Academy of Science's Institute of Macromolecular Chemistry. The reference samples – i.e. those prior to deposition into compost or unexposed to outdoor conditions – were of course tested as well; only the samples of decomposable bags made by HBABio, Ltd. were not tested due to their rapid degradability. At the time of the first test undertaken after 5 weeks it was already impossible to prepare test samples of HBABio liners due to the advanced degree of degradation. The tests were conducted by the Department of polymeric nets and mechanical characteristics with the help of INSTRON 6025 Static Testing Machine. In accordance with ČSN EN ISO 527-3, the plastics' strength was tested on Type 2 samples (film strips) that were 150 mm long and 20 mm wide. These were cut out from the film gradually so that their edges stayed smooth and without visible notches. The thickness of each sample was measured with micrometer and averaged 0.02 mm. Afterwards the samples were tested at the loading speed of 20 mm min^{-1}, while the machine's jaw span was set to 100 mm. In regard to the arrangement of polyethylene fibers in all samples it was necessary to carry out tensile tests both in orthogonal and parallel direction to the grain. Nevertheless, the charts reprinted in the "results" section show only values measured parallel to the layout of polyethylene fibers. Between 7 and 12 testing bodies from each of the samples were tested in both directions where possible. The testing machine calculated the following characteristics: tensile strength σ [MPa], proportional extension at breaking ε [%] and elastic modulus E [MPa].

RESULTS

Composition analyses of mixed MSW and bio-waste; specific volume and mass of all waste

In PA and RA areas the analyses of bio-waste and mixed MSW were carried out seven times in total; in PH area only mixed MSW was analyzed (five times altogether).

Table 1 shows basic statistic parameters for mass ratio (in %) of individual components of bio-waste and volume mass in PA and RA areas. These are mean values yielded by all seven analyses in the course of a year. In both areas the separated bio-waste was polluted with other materials to a very low degree. In PA this component amounted to mere 0.4% wt. while in RA it reached only 1.9% wt. Such results imply that the households were separating in a proper and orderly fashion. Plastic liners, and rarely cardboard packaging too, appeared as the most frequent pollutant. The ratio of polluting components was smaller in the pilot area, which might have been caused by the distribution of decomposable bags during the educational campaign that took place in the early stage of the project. Analyses showed that households in the pilot area used decomposable starch bags instead of plastic bags.

Tab. 1: Basic statistical parameters for mass ratio of individual components in separated bio-waste and for volume mass as recorded in PA and RA.

Pilot area – mass ratio in % of total				
Waste type	*Mean*	*Minimum*	*Maximum*	*SD*
kitchen waste	94.7	80.3	100.0	8.6
garden waste	4.9	0.0	19.3	8.4
impurities	0.4	0.0	0.9	0.3
volume mass (kg m^{-3})	280.7	198.0	384.0	58.9
Reference area – mass ratio in % of total				
Waste type	*Mean*	*Minimum*	*Maximum*	*SD*
kitchen waste	81.1	19.9	99.9	30.6
garden waste	17.0	0.0	79.4	31.2
impurities	1.9	0.2	9.0	3.2
volume mass (kg m^{-3})	257.9	174.0	351.5	67.5

SD – standard deviation.

Table 2 shows basic statistical parameters for mass ratio (in %) of individual components in MSW as well as volume mass in both PA and RA. Again, these are mean values yielded by all analyses in the course of a year. During the year no significant deviations in the volume of bio-waste present in MSW were recorded; this was mainly attributed to the fact that the localities consisted of housing estates producing only a small amount of garden waste, which in the course of the year turned out to be the most frequent variable component of bio-waste. The table shows that mass ratio of residual municipal waste was 50% of that in the pilot area and 46% of that in the reference area. The ratio of biological component amounted to 40% wt. in PA and 43% wt. in RA; the lower ratio recorded in the pilot area might be again a consequence of the educational campaign undertaken at the beginning of the project. Mass ratio of paper as decomposable material, which accounted for about 10% wt. in the monitored areas, was recorded as well.

Table 3 shows the results of mixed MSW analyses conducted in the PH area. Kitchen and garden waste were in consideration of the overall estate character and the expected higher ratio of said types of waste evaluated separately. Basic statistical parameters for mass ratio

Tab. 2: Basic statistical parameters for mass ratio of individual components in MSW and for volume mass as recorded in PA and RA.

Pilot area – mass ratio in % of total				
Waste type	*Mean*	*Minimum*	*Maximum*	*SD*
residual waste	50.2	43.3	56.1	4.8
kitchen and garden waste	40.2	33.3	46.9	5.0
paper	9.6	7.1	11.6	1.5
volume mass of all waste (kg m^{-3})	86.6	61.0	114.0	16.8
volume mass of bio-waste (kg m^{-3})	349	280	446	51.6
Reference area – mass ratio in % of total				
Waste type	*Mean*	*Minimum*	*Maximum*	*SD*
residual waste	45.9	38.5	59.2	7.7
kitchen and garden waste	43.3	32.8	50.2	6.5
paper	10.6	8.0	14.2	2.2
volume mass of all waste (kg m^{-3})	78.7	42.0	98.0	18.1
volume mass of bio-waste (kg m^{-3})	360	253	480	76.6

SD – standard deviation.

(in %) of individual components in mixed MSW are summarized. These are mean values of the five analyses that involved all containers designated for collection of MSW. The aforementioned data imply that the PH area had a substantially lower mass ratio of residual waste than the housing estate areas. Bio-waste featured quite prominently – kitchen waste together with garden waste amounted to the total of 60% wt. With as much as 39.3% wt., garden waste was the single most abundant type of waste and the one most often represented in the mixed municipal waste; its predominance also explains the relatively low mean value of bio-waste's volume mass: 216 kg m^{-3}. Total volume mass, i.e. the volume of all mixed municipal waste, amounted to 122 kg m^{-3}.

Tab. 3: Basic statistical parameters for mass ratio of individual component in MSW and for mass volume as recorded in PH.

Private house area – mass ratio in % of total				
Waste type	*Mean*	*Minimum*	*Maximum*	*SD*
residual waste	32.2	22.3	50.2	12.0
kitchen waste	20.5	13.1	27.3	6.1
garden waste	39.3	25.7	53.2	10.4
paper	7.3	2.2	19.8	7.2
volume mass of all waste (kg m^{-3})	122.1	67.7	168.2	36.5
volume mass of bio-waste (kg m^{-3})	216.4	167.8	253.4	43.3

SD – standard deviation.

Specific mass was measured only in the housing estate PA and RA. In both areas the separated bio-waste from compostainers was weighed every month (excluding February and April 2006 when transport could not be organized), while MSW was weighed once every two months. MSW in these areas is regularly collected by a transporting company twice a week; biodegradable municipal waste is collected weekly in summer and fortnightly in winter. These factors were taken into consideration during data processing.

Table 4 shows mean values of mass and specific mass of bio-waste weighed monthly in the PA and RA. The amounts of bio-waste were recalculated for weekly collections' intervals in both areas.

The pilot area inhabitants had eight 240 L bio-waste containers and a single 120 L container at their disposal. The average mass of bio-waste recalculated per one container was

Tab. 4: Basic statistical parameters for mass and specific mass of separated bio-waste in PA and RA.

Values from May 2005 to May 2006	**Pilot area** (448 inhabitants)		**Reference area** (964 inhabitants)	
	mass (kg)	specific mass (kg per inhabitant per week)	mass (kg)	specific mass (kg per inhabitant per week)
Mean	103	**0.23**	105	**0.11**
Minimum	63	0.14	79	0.08
Maximum	150	0.34	166	0.17
SD	30	0.07	30	0.03

SD – standard deviation.

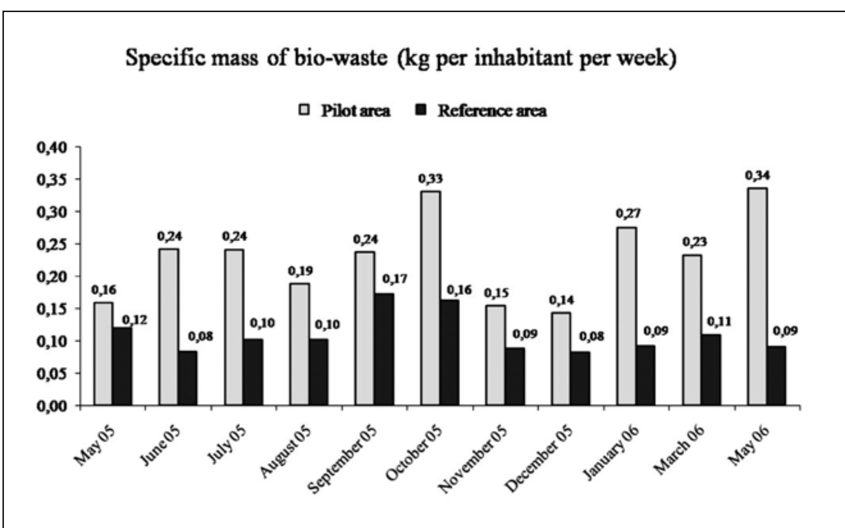

Fig. 1: Specific mass of separated bio-waste in the pilot and reference areas during the monitored period.

11.6 kg in the PA and 10.5 kg in the RA. When adjusted in regard to population – since the RA has nearly twice as many residents as the PA – the average specific mass produced by RA per inhabitant per week is half of that produced by PA. It amounts to 0.23 kg per inhabitant per week in the PA, which can be recalculated as a yearly bio-waste production of 11.96 kg per inhabitant per year in the PA and 5.72 kg per inhabitant per year in the RA. Fig. 1 offers comparison of specific masses of separated bio-waste in the PA and RA in the individual months.

Table 5 shows mean values of mass and specific mass for the MSW weighed in the PA and RA in the individual months, while including other basic statistical parameters as well. The mixed municipal waste was collected twice a week as shown in mass values, while specific mass is recalculated for weekly intervals.

Tab. 5: Basic statistical parameters for mass and specific mass of mixed MSW in PA and RA.

Values from May 2005 to May 2006	**Pilot area** (448 inhabitants)		**Reference area** (964 inhabitants)	
	mass (kg)	specific mass (kg per inhabitant per week)	mass (kg)	specific mass (kg per inhabitant per week)
Mean	640	**2.86**	1,635	**3.39**
Minimum	457	2.04	1,377	2.86
Maximum	808	3.61	2,153	4.47
SD	136	0.61	271	0.56

SD – standard deviation.

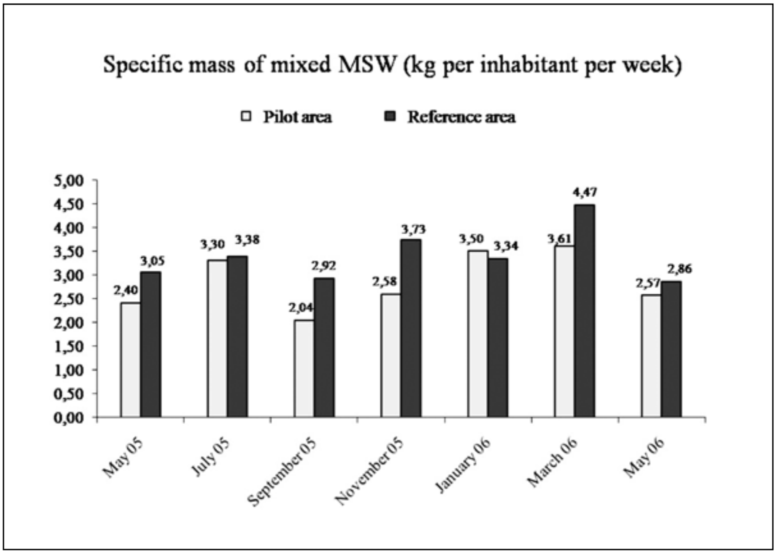

Fig. 2: Specific mass of mixed MSW in the pilot and reference areas during the monitored period.

The pilot area inhabitants had 9 mixed-waste containers – as compared to 18 containers in the reference area – at their disposal. Each of these held 1,100 L. The average mass of mixed waste recalculated per container amounted to 71 kg in the pilot area and 91 kg in the reference area. In the reference area the specific mass per inhabitant per week was higher – 3.39 kg – than in the pilot area, where it reached only 2.86 kg per inhabitant per week. Fig. 2 shows comparison of specific masses in the pilot area and the reference area in the individual months.

Degradability of d_2w plastics

Composting process went on for 12 weeks. Its course was monitored in regard to the temperature, which was regularly taken. Figs 3 and 4 show the course of maturation in batches of all three composts.

There was sufficient humidity during the whole process and there was no need for watering. The composts were deliberately left un-overturned since it was necessary to keep the samples deposited in the batches intact. During the process, the temperatures did not exceed 55 °C at any batch. The most persistent bout of temperature above 45 °C was recorded in Compost C, where it lasted for six days, as opposed to both Composts CA (five days) and LG (one day only); the indisputable cause of this was the diminutive volume of the composts' initial batches, which was mere 3 m^3. Even so, Composts C and CA complied with sanitary requirements of the ČSN standard 46 5735 which stipulates that a temperature above 45 °C should be maintained for at least 5 days. At the final sampling conducted after 12 weeks a simplified chemical analysis was carried out for all types of composts. The test complied with the requirements of the ČSN standard 46 5735.

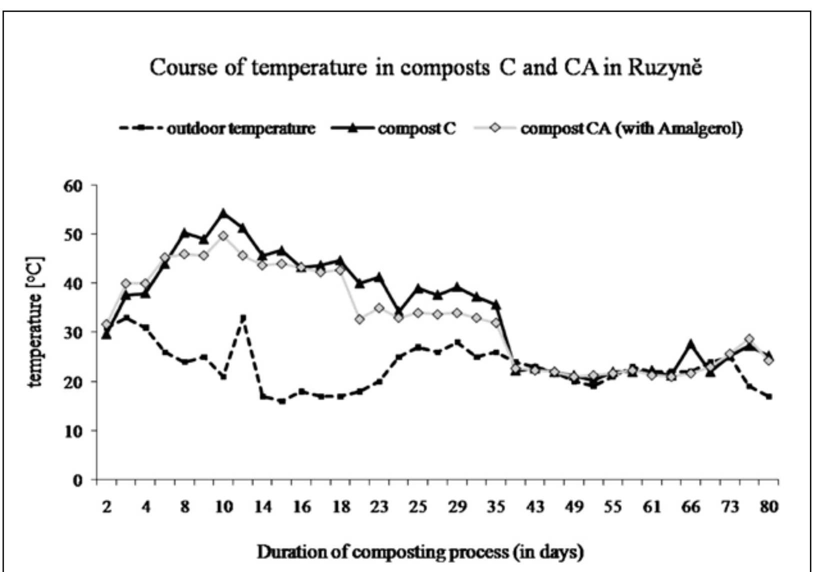

Fig. 3: The course of temperature in composts C and CA with deposited samples (Ruzyně).

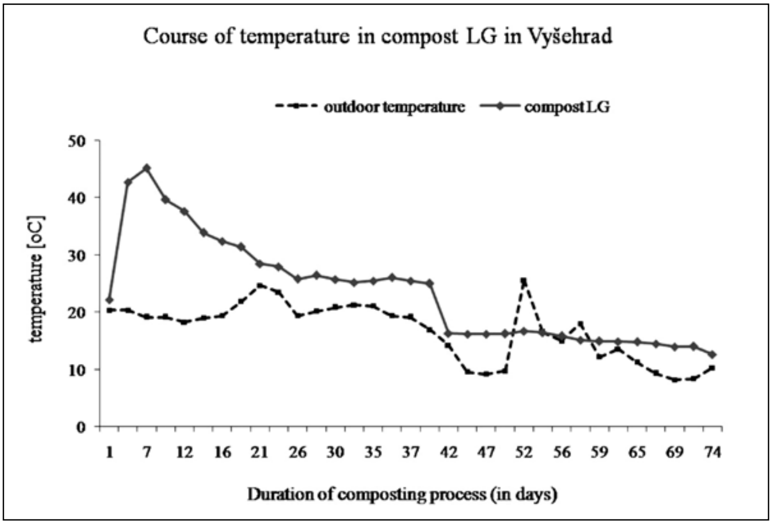

Fig. 4: The course of temperature in compost LG with deposited samples (Vyšehrad).

The mechanical properties of plastics were tested on two types of samples – polyethylene film (PE) and d_2w film (D_2W). In both types of samples their environment, or compost they were taken from, was also taken into account. There were outdoor samples (OUT) apart from samples taken from the individual composts (C, CA, LG). Measurements taken along the grain of polyethylene fibers with the static testing machine were then processed into charts with the Origin software. Figs 5 to 10 show the graphical representations of measured characteristics including statistical dispersion and variability.

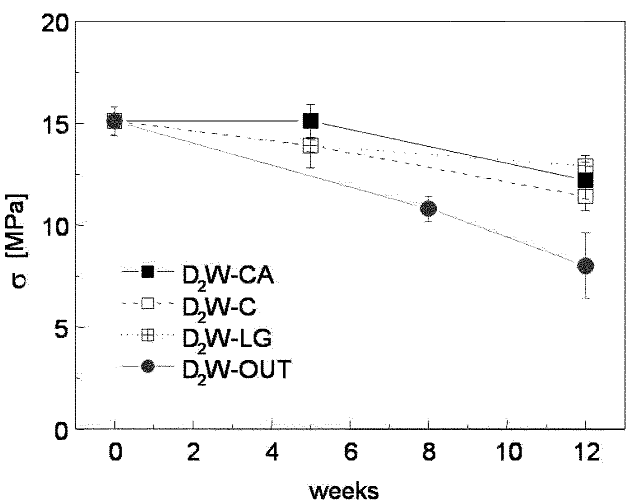

Fig. 5: Tensile strength σ [MPa] of the individual types of D_2W samples.

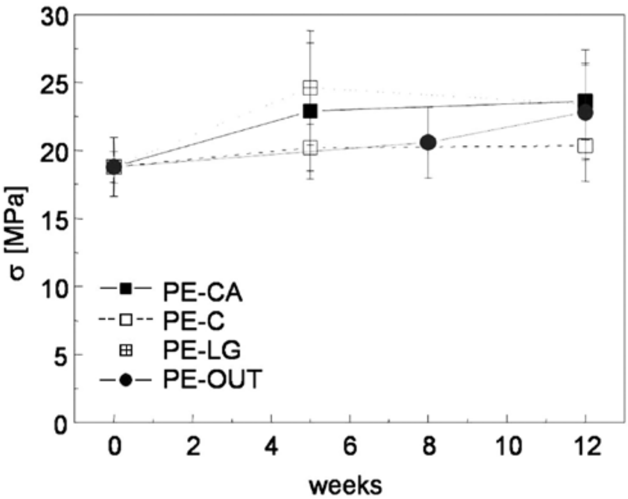

Fig. 6: Tensile strength σ [MPa] of the individual types of PE samples.

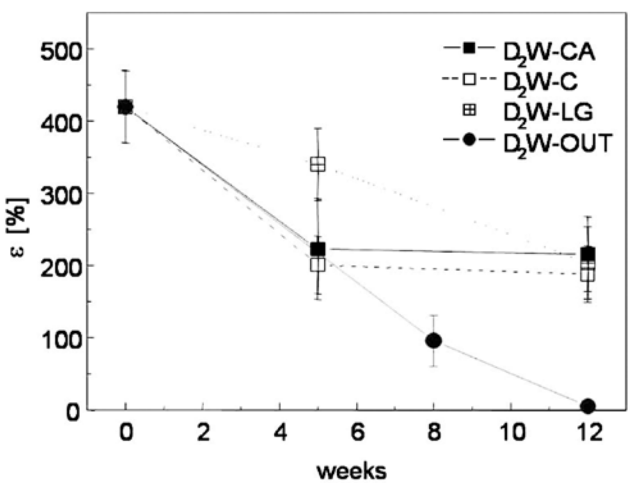

Fig. 7: Relative elongation at breaking ε [%] of the individual types of D_2W samples.

Tensile strength of all D_2W samples decreased particularly at outdoor samples, where the original value of 15.1 MPa dropped as low as 8 MPa. Of the D_2W compost samples, the lowest value (11.4 MPa) was recorded in those taken from the untreated compost C. The samples taken from compost LG featured the smallest drop in tensile strength – to 12.9 MPa only –, which in the PE samples increased slightly. The samples taken from the treated compost CA

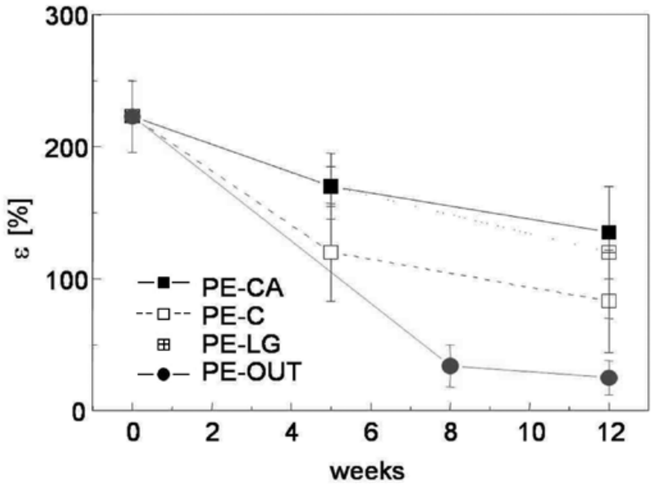

Fig. 8: Relative elongation at breaking ε [%] of the individual types of PE samples.

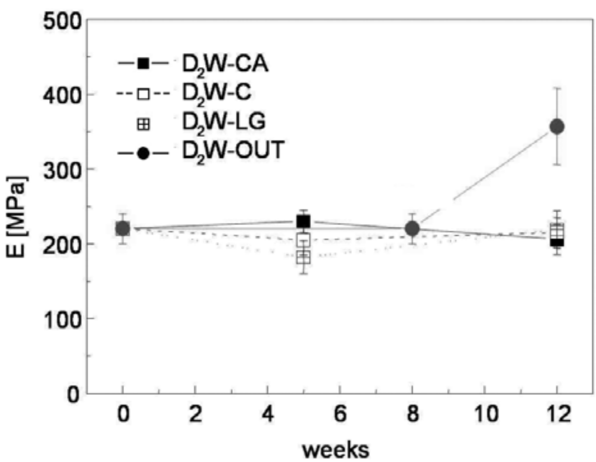

Fig. 9: Elastic modulus E [MPa] of the individual types of D_2W samples.

featured the greatest increase – from 18.8 MPa to 23.6 MPa – as opposed to the samples from the untreated compost C, in which the tensile strength dropped to 20.3 MPa.

The most significant drop in the relative elongation at breaking was recorded in both outdoor samples, namely from 420% to 5.2% in the D_2W samples and from 220% to 25% in the PE samples. The D_2W compost samples featured no significant decrease of this property. The lowest value (188%) was recorded in the sample taken from the untreated compost C. The PE compost samples degraded possibly slightly more than D_2W compost samples. The most significant decrease in this property (from 220% to 85%) was observed

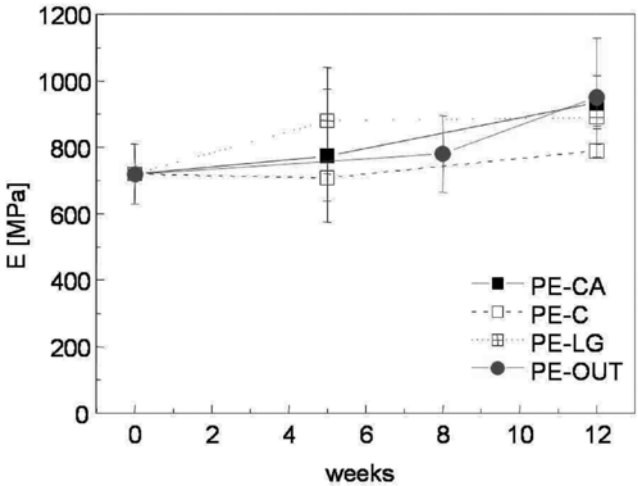

Fig. 10: Elastic modulus E [MPa] of the individual types of PE samples.

in samples taken from the untreated compost C, while the smallest decrease (to 135% only) was recorded in the samples from compost CA.

The greatest increase in elastic modulus (from 220 MPa to 357 MPa), which describes the material's stiffness, was recorded in the D_2W outdoor samples. The increasing stiffness is obviously the result of polyethylene chains' crystallization; in general, shorter chains crystallize much easier than longer chains. This along with the other properties would imply a quick degradation of outdoor samples. Again, the outdoor types of PE samples exhibited an increase of elastic modulus from 720 MPa to 950 MPa.

The results of d_2w plastics decomposability test suggest that the outdoor samples underwent the quickest degradation (as it was difficult to collect sufficient test material after 12 weeks). There were no important dissimilarities in the degradability of various d_2w compost samples despite varying composition and/or treatment of the individual composts (apart from the value of ε in the d_2w sample taken from compost LG after 5 weeks; see Fig. 7). The undertaken experiment clearly shows that d_2w plastics do not comply with the requirements of ČSN standard EN 13432; this is particularly true in regard to the time requirement, which stipulates that after 12 weeks of aerobic composting no more than 10% of the original tested solids should pass through sieves as fragments larger than 2 mm. This requirement was not met. We have reasons to believe that neither would it be met at a constant temperature, and even if the composts were overturned (in order to speed up the disintegration of the film).

DISCUSSION

Composition analysis of mixed MSW and bio-waste; specific mass of bio-waste

In both areas PA and RA the separated bio-waste was polluted with other materials to a very low degree. In PA this component amounted to mere 0.4% wt. while in RA it reached only 1.9% wt. Such results imply that the households were separating in a proper and orderly fashion. Plastic liners appeared as the most frequent pollutant; this fact in general confirmed also Chudárek et al (2009) within their research pilot project. The lower ratio of polluting components in our PA might have been caused by the distribution of decomposable bags during the educational campaign; analyses showed that households in the PA used decomposable starch bags instead of plastic bags. A short comparison of polluting components in separated bio-waste was done, but it is important to keep in mind that it is not possible to do some final and general conclusions. All projects and surveys differed in at least a single condition – for example the type of estate, the number of population or separation possibilities. The city of Plauen (population 49,000) in Saxony (Germany) presented the ratio of polluting components no more than 1.1% wt. (Bačík 2005a). The other area near Bluemel (population 70,000) in Bavaria (Germany) mentioned this ratio between 3–5% wt. (Bačík 2005b). In the city of Prague (locale Dolní Chabry – family houses only; population 3,000), there was determined the ratio of 2% wt. on average (Vedralová 2006). Similarly the area Na Výsluní (family houses only; population 85) in Bílina (North Bohemia) presented the ratio of 3–4% wt., while the area of housing estates Pražské Předměstí (population 1,000) in the same city noted this ratio much higher – between 8–9% wt. (Hora et al 2005). Up-to-date results concerning the polluting components in separated bio-waste presents Chudárek et al (2009) – 1.9% wt. ratio was recorded in the city of Tišnov near Blansko (family houses and housing estates in the same rate; population 700).

The composition analyses of mixed municipal waste confirmed the fact that bio-waste in the EU usually amounts to between 30% and 40% wt. of solid municipal waste, sometimes also markedly higher. The exception was the private homes' area, where the amount of bio-waste in mixed MSW reached record-breaking rates: almost 60% wt. (39% wt. of garden waste plus 21% wt. of kitchen waste). It could be a consequence of starting positive effect of bio-waste separation opportunity. Generally, it is very difficult to make some comparison of MSW composition, because as mentioned above all projects differ in at least a single condition – for example the methods of analyses, the type of estate, the number of population etc. Especially the analyzing method is the key factor. Within our research pilot project the composition analyses of mixed MSW (using the same method of analyzing) in three locales near Hradec Králové city were also made. The amount of bio-waste in mixed MSW reached following rates: Velichovky municipality (family houses and housing estates in the same rate; population 360) – 40% wt.; Hermanice municipality (family houses; population 326) – 36% wt. and Dubenec municipality (family houses; population 668) – 26% wt. Except for one municipality (Dubenec) generally reported amounts were confirmed again.

The specific mass of separated municipal bio-waste was up to 12 kg per inhabitant per year in the pilot area, and almost 6 kg per inhabitant per year in the reference area, which is in both cases very low value. The most effective factor influencing the yield of bio-waste per year is undoubtedly the system of bio-waste collection and then also the type of estate. Generally the specific masses of separated bio-waste vary on a large scale and they are highest mostly in rural areas. For instance Chudárek et al (2009) stated that the specific mass of separated bio-waste in Tišnov municipality (family houses and housing estates in the same rate; population 700) reached rate of 120.5 kg per inhabitant per year (2008/2009), which really is a record-breaking rate. Similar results presented Kragl (2009) – the specific mass of separated bio-waste in 2008 was 121 kg per inhabitant per year for garden waste only and 39 kg per inhabitant per year for kitchen waste (Austria, region near the town of Freistadt – population 65,000). Both above mentioned results are almost incredible, but in the case of Tišnov municipality there was a very good campaign executed and the inhabitants had 147 bins for bio-waste at their disposal. The Freistadt region in Austria is a typical rural region, where bio-waste separation is being realized for almost twenty years. However there are many areas, where the separation rate was much lower analogous to our pilot and reference areas in Uherské Hradiště, such as town Bílina – the area of Pražské Předměstí (housing estates; population 1,000) – the specific mass of separated bio-waste in 2005 reached a rate of only 17 kg per inhabitant per year (Hora et al 2005). Similarly, in the town of Náměšť nad Oslavou near Brno (mixed build-up area; population 5,300) the specific mass of separated bio-waste was only 6 kg per inhabitant per year in 2006 (Zera 2008b). These areas with low separation rates would require regular educational campaigns in order to spread awareness about source separation and otherwise motivate citizens to participate in separate collection of bio-waste.

Degradability of d_2w plastics

The following section is devoted to the comparison of the tests results with empiric data yielded by similar research projects. All projects varied in at least a single test condition – for example the initial compost batches, the course of temperature during maturation process, the size of test samples, the speed with which load was applied to the film etc. For this reason it is necessary to take the following survey of the individual tests as a general summary only.

Kay and Leatherdale (1998) have tested a film made by Symphony Environmental although failing to specify whether or not it was a d_2w plastic film. They tested the mechanical properties of a degradable (DE), and a reference non degradable, film which was deposited in compost for 12 weeks. Their compost differed in composition from those we used, while the course of temperature was very similar to ours. Temperatures above 45 °C persisted for several days only and reached the maximum of 47.2 °C. The degradable film's characteristics were similar as well; the test samples' width differed by 5 mm and the static testing machine's jaw span was a half of that we have set for our tests, i.e. 50 mm. Surprisingly enough, the tensile strength of DE compost samples tested after 12 weeks increased from 28.5 MPa to 33.1 MPa, while our test recorded a decrease in tensile strength of d_2w samples from 15.1 MPa to 12.2 MPa (taking into consideration the average values in three different compost types). The relative elongation at break decreased in both experiments. Kay and Leatherdale (1998) recorded a decrease from 329% to 318% in the DE samples, while in our d_2w samples the value dropped from 420% to 203% (taking into consideration the average values in three different compost types). The only unambiguous conclusion that can possibly be reached is that the degradable film does not decompose very quickly – in other words, it degrades too slowly – if the composting process takes place at the abovementioned low temperatures. However, Kay and Leatherdale (1998) also tested the decomposability of the same degradable film for 4 weeks at the temperature of 60 °C. Surprisingly, after the said period the film disintegrated completely and it was impossible for the researchers to collect sufficient test sample. Verstichel (2003) has subjected the d_2w plastics as well as reference non degradable samples to a photo-thermo-degradable test, in which both types of samples were exposed to an alternating 12-hour light-and-darkness cycle for the duration of 4 weeks. The minimal intensity of light was 3,000 luxes; a stable temperature around 20 °C was also maintained. Subsequently the samples were exposed for 5 days to a temperature of 70 °C. The non degradable reference samples did not exhibit almost any change in their mechanical properties neither after 4 weeks of light exposure, nor after the subsequent heat load. The d_2w plastics showed a significant decrease in the tested mechanical properties after the heat treatment. In the early phase of the experiment, the tensile strength of d_2w samples was 20.9 MPa. After four weeks of light exposition its value was still quite high (17.9 MPa), only to drop to 6.5 MPa after the last phase of the experiment had been completed. The exposure to the heat load decreased the samples' relative elongation at break from the original 290% to a mere 1%. In his research, Angold (2005) notes that the deposition of d_2w film in compost for 30 days at the temperature of 45 °C causes a disruption of the material structure and colonization by microorganisms, which can be further examined via electron microscope scans. In regard to the speed and extent of microbial colonization Angold (2005) concludes that a prolonged exposure to such environment would bring about the complete disintegration of the d_2w film. The reference samples of a non degradable material exhibited only a slight microbial colonization and no disintegration of their internal structure.

The abovementioned test results imply that temperature plays a very important role in the disintegration of d_2w film. Our experiment did not include temperatures above 55 °C during the composting process, and temperatures above 45 °C were sustained in the maturing batches for only a short time. Aeration turnings of composts were not employed due to the samples deposited therein. In central composting facilities, where aeration turnings are performed regularly, temperatures tend to reach 60 °C and temperature above 55 °C usually persists for at least 21 days. It remains unclear, however, how the samples would have reacted if a higher temperature had been reached during the composting process and an aeration turnover had been carried out.

Many tests on plastics containing the EPI TDPA additive were undertaken in the past. Such plastics have similar characteristics to the d_2w plastics (Slejška 2004). When Bonhommea et al (2003) tested the disintegration of 470–640 nm thick PE film with added TDPA, it reached its highest speed at temperatures around 60 °C. A further increase of temperature did not significantly alter the speed of disintegration. Chiellinia et al (2003) calculated the length of time needed for LDPE-TDPA film to lose its mechanical characteristics as 11 days at the temperature of 55 °C. ExcelPlas (2003) quotes the research conducted by Prof. B. Raninger (Leoben University), who tested plastics containing the EPI TDPA additive at the municipal composting facility near Vienna, Austria. PE bags with added TDPA did not influence the composting process and were partially decomposed during composting. The resulting compost containing plastic particles had a perfect quality and met all standard eco-toxic tests, including the seed germination test, plant growing test, and organism (Daphnia, earthworms) survival test, in compliance with the DIN standard V 54900-3 as well as the British ON S 2200 and ON S 2300 national standards. Foster (2003) claims that when composted for 4 to 16 weeks, the disintegration of materials containing the EPI TDPA additive does not meet – principally due to the slowness of the process – the requirements prescribed by the EN standard 13432.

CONCLUSIONS

The composition analyses of separate bio-waste showed that the pollution with other materials reached a very low degree. In the pilot area the presence of undesirable pollutants was very scarce (0.4% wt. only), probably thanks to the awareness campaign. In the reference area the degree of pollution was slightly higher: 1.9% wt. Such households that decided to separate waste did so in a very thorough fashion. The ratio of garden waste was exceeded profoundly by that of kitchen waste, which – in regard to the estate type – was logical and foreseeable. The composition analyses of mixed municipal waste confirmed that mass ratio of municipal bio-waste in mixed waste sometimes exceeds 40% wt. In the pilot area the ratio of biological components in MSW averaged about 40% wt., while in the reference area it amounted to 43% wt. In the private homes' area the amount of bio-waste in MSW reached record-breaking rates: almost 60% wt. (39% wt. of garden waste plus 21% wt. of kitchen waste). For the duration of the project only a slight recovery of bio-waste was achieved in Uherské Hradiště despite the awareness campaign conducted during its early phase in the pilot area. The specific mass of separated biodegradable municipal waste was up to 12 kg per inhabitant per year in the pilot area, and almost 6 kg per inhabitant per year in the reference area. The areas with low separation rate would require regular educational campaigns in order to spread awareness about source separation and otherwise motivate citizens to engage in separate collection of bio-waste.

The results of d_2w decomposability test indicate that outdoor samples featured the quickest degradation. After 12 weeks it was indeed quite difficult to collect sufficient material for preparation of test samples. Despite variant composition, and treatment, of the individual composts, the degradability of d_2w compost samples did not vary greatly except for a single characteristic; see Fig. 7 (Compost LG in 5 weeks time). No significant statistic difference was recorded. The experiment proved (despite the abovementioned imperfections) the d_2w plastics to be incompliant with the requirements of the ČSN standard EN 13432, particularly with the requirements concerning degradation time. The fact that d_2w plastics are not very suitable for composting due to their incompliance with some of these requirements is advertised on the manufacturer's (Symphony Environmental) website – which mentions the slow disintegration during composting as a drawback of d_2w degradable plastics. The implementation of source separation schemes and extraction of bio-waste from MSW with its subsequent composting should therefore focus on other types of degradable plastics (e.g. starch-based plastics etc.) instead of d_2w degradable plastics.

ACKNOWLEDGEMENTS

The results presented by this paper were obtained via research pilot project PPA03/CZ/7/8: "Management of bio-waste present in municipal solid waste and its composting in the Czech Republic". The project was supported by the Czech Ministry of Environment, sponsored by the Dutch government, and designed by the Dutch company Tebodin.

REFERENCES

Angold R (2005) The growth of microorganisms on degradable film under selected disposal conditions with specific reference to a d_2w product from Symphony Environmental (Microstructure Investigation Report). Pyxis CSB Ltd., 9 pp.

Antler S (2008) The pulse of the composting industry in Canada. BioCycle 49(2): 21–22.

Bačík O (2005a) How to deal with bio-waste? Experiences from Germany (Part I). Waste 10: 11–12. [In Czech.]

Bačík O (2005b) How to deal with bio-waste? Experiences from Germany (Part II). Waste 11: 22–23. [In Czech.]

Barth J, Amlinger F, Favoino E, Siebert S, Kehres B, Gottschall R, Bieker M, Löbing A, Bidlingmaier W (2008) Compost production and use in the EU. ORBIT e. V. & European Compost Network ECN Final Report, Tender No. J02/35/2006, 182 pp.

BioCycle (2005) Borough near London, UK collects full range of organics – "from hedge trimmings to porridge". BioCycle 46(3): 10.

Bonhommea S, Cuerb A, Delortb A-M, Lemairea J, Sancelmeb M, Scottc G (2003) Environmental biodegradation of polyethylene. Polym Degrad Stabil 81: 441–452.

Chiellinia E, Cortia A, Swift G (2003) Biodegradation of thermally-oxidized, fragmented low-density polyethylenes. Polym Degrad Stabil 81: 341–351.

Chudárek T, Friedmann B, Horsák Z, Hejč M, Pilliar F, Hřebíček J (2009) Systems of municipal bio-waste collection; evaluation of results obtained within the pilot project aimed at municipal bio-waste collection in the city of Tišnov. In: International conference proceedings "Biodegradable Waste V.: Sustainable development in the context of bio-waste disposal; quality of inputs and outputs". ZERA Agency, Náměšť nad Oslavou, Czech Republic, pp 81–87. [In Czech.]

CZ Biom (2009) Map of facilities for anaerobic digestion in the Czech Republic. Biom.cz: http://biom.cz/cz/produkty-a-sluzby/bioplynove-stanice. Accessed 30 March 2009. [In Czech.]

ExcelPlas (2003) Australia Centre for Design at RMIT, Nolan-ITU: The impacts of degradable plastic bags in Australia - Final Report to Department of the Environment and Heritage. http://www.cfd.rmit.edu.au/content/download/232/1787/file/degradables.pdf. Accessed September 2003.

Farrell, M (2005) Vineyards make switch to "four course" compost. BioCycle 46(2): 33–36.

Favoino E, Habart J (2003) Oddělený sběr kompostovatelných odpadů, kompostování a biologická úprava zbytkového odpadu, zkušenosti a současné trendy v Evropě. Biom.cz: http://biom.cz/cz/odborne-clanky/oddeleny-sber-kompostovatelnych-odpadu-kompostovani-a-biologicka-uprava-zbytkoveho-odpadu-zkusenosti-a-soucasne-trendy-v. Accessed 8 October 2003. [In Czech.]

Foster C (2003) Degradable Plastic Bags, A European Perspective. Report to ExcelPlas. Macclesfield, Cheshire.

Green Paper on the management of bio-waste in the European Union (2008). Final version, Brussels 2008, 19 pp.

Hargreaves JC, Adl MS, Warman PR (2008) A review of the use of composted municipal solid waste in agriculture. Agr Ecosyst Environ 123: 1–14.

Hodek T, Vašutová H (2005) Economical utilization of biodegradable plastics within bio-waste separation and its disposal. In: International conference proceedings "Bio-degradable waste, its processing and utilization in agricultural and municipal practices". ZERA Agency, Náměšť nad Oslavou, Czech Republic, pp 123–126. [In Czech.]

Hora L, Soukalová I, Iljučoková A (2005) Separation of municipal bio-waste in Bílina city (Pilot projects in the areas of housing estates and family houses). Waste Management Forum 1: 16. [In Czech.]

Kay M, Leatherdale D (1998) Establishing of degradation characteristics of a film sample (for Symphony Environmental Ltd.). Pira International, 36 pp.

Kotoulová Z, Váňa J (2001) Manual for disposal with municipal waste. Ministry of the Environment of the Czech Republic and Czech Institute for Ecology, Prague. [In Czech.]

Kragl G (2009) Region Freistadt – twenty years of successful achievement of prevention and recycling of bio-waste. In: International conference proceedings "Biodegradable Waste V.: Sustainable development in the context of bio-waste disposal; quality of inputs and outputs". ZERA Agency, Náměšť nad Oslavou, Czech Republic, pp 67–74. [In German.]

Leaversuch R (2002) Biodegradable polyesters: packaging goes "green". Plastic Technology 9: [online] http://www.ptonline.com/articles/200209fa3.html. Accessed 2002.

Oelgemöller D, Becker G, Dornbusch HJ (2006) Kostenbetrachtung für die separate Bioabfallsammlung und -behandlung im Vergleich zur gemeinsamen Entsorgung mit dem Restabfall, INFA (Institut für Abfall, Abwasser

und Infrastruktur-Management GmbH) – Endbericht für den Verband der nordrhein-westfälischen Humus- und Erdenwirtschaft e.V. [online] http://www.lbk-bayern.de/uploads/media/VHE-Bericht_Kurzfassung_01.pdf. Accessed 2006. [In German.]
Otten L (2001) Wet-dry composting of organic municipal solid waste: current status in Canada. Can J Civil Eng 28: 124–130.
Sirotková D (2006) Legislation on bio-degradable waste. Biom.cz: http://biom.cz/cz/odborne-clanky/legislativa-biologicky-rozlozitelnych-odpadu. Accessed 28 April 2006. [In Czech.]
Slejška A (2005) Can composting plants loose their commissions due to increasing development of small-scale and community composting. Biom.cz: http://biom.cz/czbiom.shtml-kapalna-biopaliva/odborne-clanky/prijdou-kompostarny-rozvojem-domovniho-a-komunitniho-kompostovani-o-praci. Accessed 29 March 2005. [In Czech.]
Slejška A (2004) Oxo-biodegradable plastic material d_2w. Biom.cz: http://biom.cz/cz/odborne-clanky/oxo-rozlozitelny-plast-d2w. Accessed 12 July 2004. [In Czech.]
Vedralová A (2006) Development of bio-waste collection in Prague. Waste Management Forum 6: 13. [In Czech.]
Verstichel S (2003) Photo – Thermo degradation test on Symphony degradable film (d_2w) and non degradable film (control sample), Final Report, 6 pp.
Yepsen R (2008) Composting infrastructure trends in the UK. BioCycle 49(2): 49–50.
Yepsen R, Goldstein N (2007) Source separated residential composting in the U.S. BioCycle 48(12): 27–33.
Zera (2008a) Bio-waste and possible solutions in the Czech Republic. In: International conference proceedings “Biodegradable waste: How to fulfil statutory duties regarding municipal bio-waste”. ZERA Agency, Náměšť nad Oslavou, Czech Republic, pp 118. [In Czech.]
Zera (2008b) Pilot Project: Regional solving of bio-waste collection. ZERA Agency, Náměšť nad Oslavou, Czech Republic, pp 60. [In Czech.]