Biodegradation of Plastics in Compost Prepared at Different Composting Conditions

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Summary: Maximum temperature during the thermophilic phase and moisture content were controlled in the course of composting to examine the effects of these composting conditions on the quality of the compost used for the evaluation of the biodegradability of plastics. The moisture content during composting was controlled at 65%, while keeping the maximum temperature below 46°C, 58°C and 70°C, respectively. In turn, the maximum temperature was controlled to be below 58°C, while maintaining the moisture content at 45%, 55% and 65% respectively. The number of microbial cells was examined in the five compost samples thus prepared. Biodegradation of cellulose, polycaprolactone and poly(butylene succinate-*co*-butylene adipate) was conducted in the five compost samples, and the consistency and reproducibility of the test results were explored.

Keywords: biodegradability test; biodegradation; compost; microorganisms

Introduction

Synthetic plastics have been a great boon to mankind. Due to their durability, light weight and processability, plastics have replaced ceramic and metallic materials in many applications.[1] However, almost one third of plastics are used for short-term applications such as single-use receptacles and packaging.[2,3] Many of these plastics remain un-degraded after discard and recycling them is often very difficult and uneconomical. In many cases, they are contaminated by foreign matter which makes their cleaning cost-intensive. Reprocessing of the recycled plastics inevitably suffers from serious decay in physical properties.[4] Biodegradable plastics can eventually settle these problems. A lot of effort has been devoted to developing economically competitive biodegradable plastics and significant progress has been accomplished.[5]

The measurement of CO_2 from the plastics in mature compost is preferred to other evaluation methods available for determining the biodegradability of plastics because

 DOI: 10.1002/masy.200550631

composting is the most environmentally friendly, and thus recommended, method for treating organic solid wastes.[6] However, the biodegradability test in compost often lacks in reproducibility [4], because many kinds of microorganisms participate in compost biodegradation, and the microbial activity depends not only on the conditions for the biodegradability test, such as temperature and moisture content, but also on the quality of the compost. Moreover, all the bioassimilable organic compounds are not available to the microorganisms due to the sequestration of the organic compounds within pores, which are inaccessible to microorganisms or due to complex formation with humic materials.[7] The quality of the compost, including the microbial activity and the composition of the bioassimilable organic compounds, depends on the conditions for preparation of the compost. The temperature of the compost is not self-sustainable and decreases when the moisture content is too low, requiring frequent overturning of the compost. Sometimes the temperature goes up uncontrollably and the compost dries up. Hence, great care must be taken to produce a compost with consistent quality.

In this study, animal fodder was composted to produce compost mediums for the biodegradability tests of plastics. Moisture content and maximum temperature in the course of the composting were set up differently with the intent of producing compost samples of different quality. Biodegradation behavior of cellulose (CEL), polycaprolactone (PCL) and poly(butylene succinate-*co*-butylene adipate) (PBSA) in the compost samples was examined to check whether biodegradability test results are consistently obtainable.

Experimental

Composting process. Animal fodder (Samyang Oil & Feed Corporation, Incheon, Korea) was used as the substrate. The composition of fiber, fat and protein in the animal fodder was similar to food garbage. The composting process lasted 50~60 days. Different compost samples were prepared by setting the moisture content of the compost at 45%, 55%, and 65% respectively, while keeping the temperature during the thermophilic phase at 58°C. In turn, the temperature during the thermophilic phase was controlled to be below 46°C, 58°C, and 70°C, respectively, while maintaining the moisture content at 65%.

Physicochemical analysis of the compost. Temperature, pH, moisture content, total carbon and C/N ratio were measured in the course of the composting. Samples from the compost were harvested at the lag phase, at an early stage, middle stage, and final stage of

the thermophilic phase, at an early stage of the cooling phase, and at an early stage and final stage of the maturation phase. PH was measured with a pH-meter (Beckman, pHΦ34) by dipping the pH probe in a water suspension composed of compost and distilled water at a 1 : 2(w/v) ratio.[8] The fresh compost sample was oven-dried at 105℃ for 24 h to determine the moisture content. The C/N ratio was measured by using an elemental analyzer(LECO, CHNS-932).

Microbiological assays. Bacteria and actinomycetes, both mesophilic and thermophilic, were enumerated by the plate counting methods. Incubation time was 1 day for bacteria, and 7 days for actinomycetes. The isolation media were as follows: plate count agar (Difco, 0479-17), and Actinomycete Isolation Agar containing glycerol (Difco, 0957-17) for actinomycetes. Incubation temperature was 37℃ for mesophilic bacteria, and 27℃ for actinomycetes. For the thermophilic bacteria and actinomycetes the incubation temperature was 55℃. Compost (10 g) was dispersed into 90 mL of sterile distilled water, which was then submitted to a mechanical shaking for 2 h (PC-620, Corning). The suspension was used for the microbial count. All the compost samples were assayed by dilution with at least three replicates of each compost suspension.[9]

Biodegradation of plastics in the compost. Cellulose (Sigma, sigmacell type 101) was used as a positive control. PCL was purchased from Union Carbide (USA) and PBSA was donated from Ire Chemical (Korea). All the plastic samples were powdered at a cryogenic condition for the biodegradation test. The number average molecular weight (Mn) and weight average molecular weight (Mw) of PCL were 63,000 and 117,000 respectively. For PBSA, the Mn and Mw were 60,000 and 130,000, respectively.

Biodegradation of the plastics was conducted in the laboratory-scale compost according to ASTM D5209-92 [10] and ASTM D5338-92.[11] The air flow rate was controlled at 40 mL/min. A mixture of mature compost (200g, wet weight) and the plastics (5%, on a dry basis) was introduced and incubated at 58℃. The moisture content of the compost was maintained at 65%. CO_2 produced from the compost was absorbed by a 0.4N potassium hydroxide and 2N barium chloride mixture solution, and was quantified by titrating the solution with 0.2N HCl.

Results and Discussion

Physico-chemical characteristics of the compost. Composting of animal fodder was carried out at different conditions, and five different compost samples (Compost A, B, C,

Table 1. Conditions for preparation of the composts.

Sample code	Moisture content(%)	Maximum temperature(°C)
Compost A	65	46
Compost B	65	58
Compost C	65	70
Compost D	45	58
Compost E	55	58

Table 2. Physicochemical analysis of the mature compost made from the animal fodder composting.

Property	Mature compost					
	Maximum temperature of the thermophilic phase			Moisture content during the composting process		
	46°C	58°C	70°C	45%	55%	65%
Moisture content (%)	65.5	64.5	64.5	45.6	55.6	64.5
pH	8.9	8.4	7.8	8.1	8.1	8.4
Total carbon (%)	40.8	42.5	41.2	39.9	41.7	42.5
Total nitrogen (%)	3.8	3.3	3.5	2.8	3.3	3.3
C/N	10.7	12.9	11.8	14.3	12.5	12.9
Volatile solid (%)	55.7	54.5	57.2	57.1	57.7	54.5
CO_2 produced by inoculum over the first 10 days of the test (mg CO_2 / g of volatile solids)	124.8	145.3	96.1	90.5	133.2	145.3

D and E) were prepared. The conditions for the composting are as shown in Table 1. Physico-chemical characteristics of the compost samples are summarized in Table 2.

The pH, total carbon and C/N ratio did not show any clear-cut trend of dependence on the preparation conditions for the compost samples. The pH of the compost decreased at the early stage of the composting but increased thereafter as the composting proceeded further. At the final stage of the composting, the pH went down again. According to Ohtaki et al.[12], organic acids are accumulated initially to lower pH, and then ammonification of protein follows to raise the pH of the compost. The decrease of pH at the final stage of composting is attributed to the transformation of ammonia into nitrate by nitrification bacteria.[13,14]

The total volatile solid was in the range of 54.5-57.7% and again did not show any clear dependence on the preparation conditions for the compost samples.

Microbial cell number. Fig. 1, 2 and 3 show the viable cell number of bacteria and actinomycetes in Compost A, B and C, respectively. During the preparation of Compost A, both the bacteria and the actinomycete increased in number as the composting entered into the thermophilic stage. It is worth noting that the mesophilic microorganisms were more numerous than the thermophilic ones all through the composting. This is attributed to the fact that many of the mesophilic microorganisms survived the maximum temperature reached during the preparation of Compost A, i.e., 46°C.

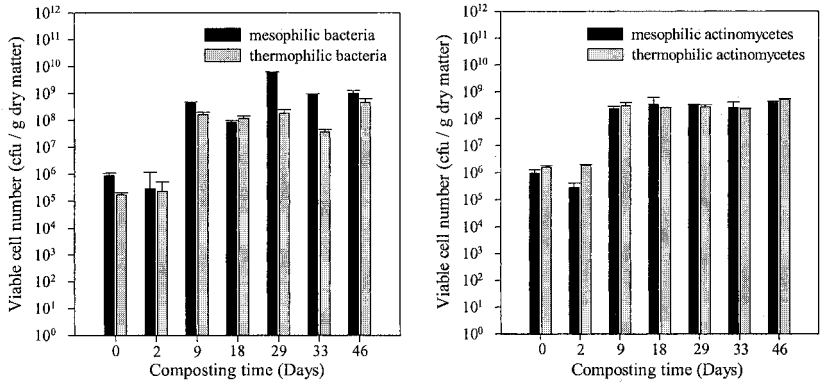

Fig. 1. Indigenous microbial concentration in Compost A during the composting process with a maximum temperature below 46 °C and a moisture content maintained at 65%.

The ratio of the viable cell number of thermophilic microorganisms to that of mesophilic ones became higher as the maximum temperature increased from 46°C to 58 and 70°C as demonstrated in Fig. 2 and 3 (Compost B and C respectively). The viable cell number of both the bacteria and the actinomycetes in Compost C was 10~100 times smaller than that in Compost A and B, indicating that the growth of the microorganisms was inhibited greatly during the thermophilic stage at 70°C. According to Katan[15] and Liang et al.[16], the activity of the microbial community in soil decreases at a temperature higher than 60°C. *Rhizobia* sp., *Mycorrhizae* sp. and microbial antagonists begin to die out when the temperature goes over 70°C in order to simplify the microbial community.

The viable cell number of the microorganisms in Compost D and E, which were prepared by keeping the maximum temperature below 58°C with a moisture content of 45% and 55% respectively, are exhibited in Fig. 4 and 5. The number of the thermophilic bacteria

decreased in the order of Compost B〉 Compost E〉 Compost D, which was the decreasing order of the moisture content, as can be perceived by comparing the results in Fig. 2 with those in Fig. 4 and 5. However, mesophilic bacteria and both mesophilic and thermophilic actinomycetes did not show any rising or falling trend in the cell number even though the moisture content decreased. Thus it can be said that the thermophilic bacteria were the most sensitive to the variation of the moisture content during the composting among the microorganisms in the compost.

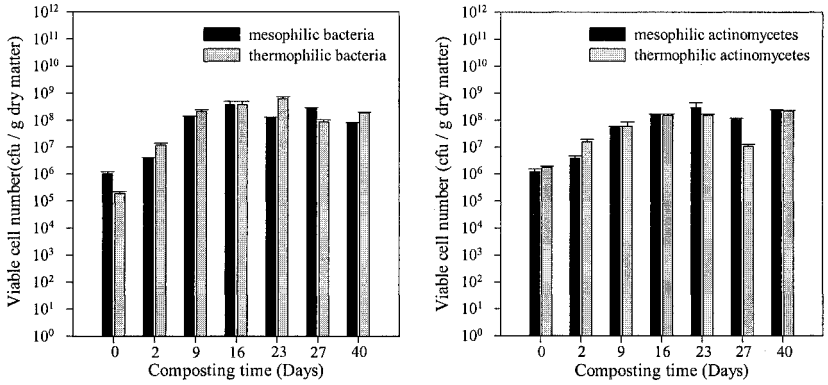

Fig. 2. Indigenous microbial concentration in Compost B during the composting process with a maximum temperature below 58 °C and a moisture content maintained at 65%.

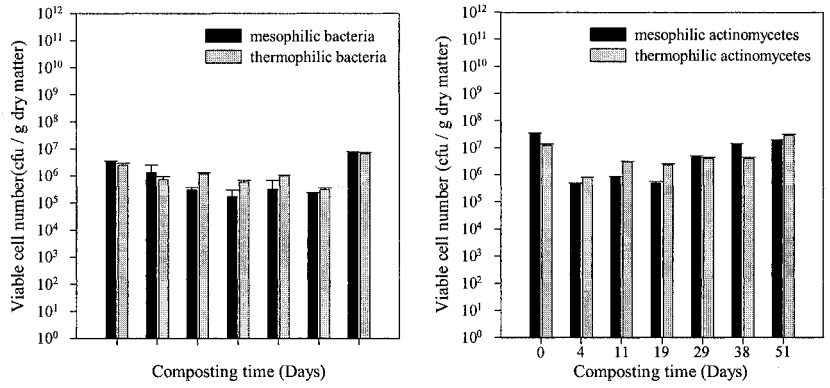

Fig. 3. Indigenous microbial concentration in Compost A during the composting process with a maximum temperature below 70 °C and a moisture content maintained at 65%.

Biodegradability test of plastics in the compost. The biodegradability of CEL, PCL and PBSA was tested in the five compost samples. All the biodegradation tests in the compost

were carried out in the same conditions (temperature: 58°C, moisture content of the compost: 65%).

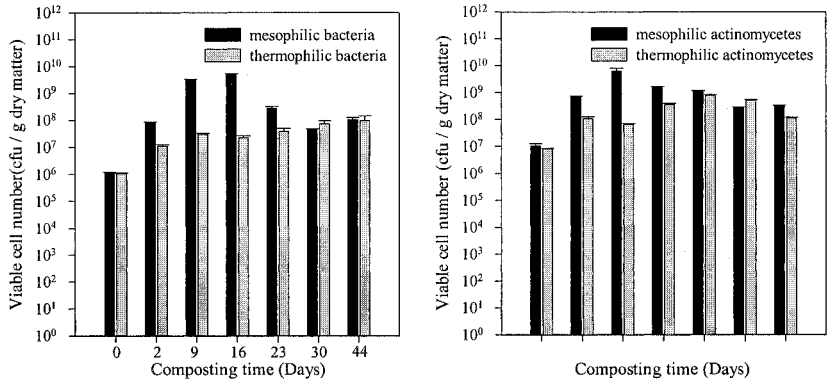

Fig. 4. Indigenous microbial concentration in Compost D during the composting process with a maximum temperature below 58 °C and a moisture content maintained at 45%.

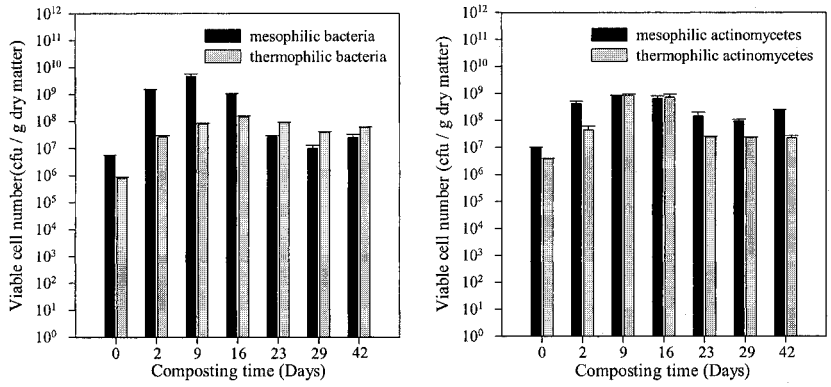

Fig. 5. Indigenous microbial concentration in Compost E during the composting process with a maximum temperature below 58 °C and a moisture content maintained at 55%.

Fig. 6 reveals that biodegradation of CEL in Compost A took place faster than in Compost B and C. About 94% of the CEL in Compost A was converted into CO_2 after 45 days of biodegradation, while in Compost B and C, the biodegradability of CEL was ca. 80% after the same period of biodegradation. The difference in the capability of CEL degradation of the three composts is attributed to the fact that the viable cells of bacteria and actinomycetes, both mesophilic and thermophilic, were more numerous in Compost A than in Compost B and C.

The same tendency of biodegradability was true for PCL and PBSA as demonstrated in Fig. 7 and 8 respectively, in that the biodegradability of PCL in Compost A, B and C was 100%, 87% and 87%, respectively, and for PBSA, the corresponding biodegradability was 94%, 78% and 77%, respectively, after 45 days of the biodegradation.

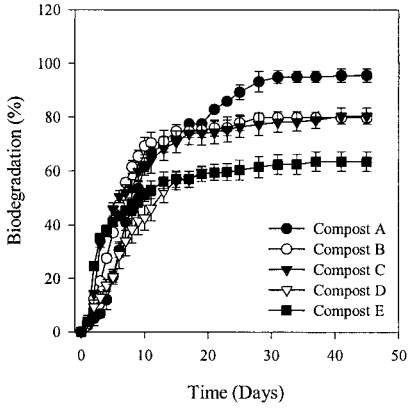

Fig. 6. Biodegradation of cellulose in the compost prepared at different maximum temperatures and moisture contents.

According to ISO 14855 [17] and KS M 3100-1 [18], the evaluation results of biodegradability in compost can be considered to be valid when the following criteria are met.

① More than 70% of CEL, used as a standard biodegradable material, should be degraded within 45 days of the biodegradation.

② The experimental error of the 3 replicated measurements for the CEL biodegradability should be less than 20%.

③ The accumulated amount of CO_2 evolved from the neat compost in the first 10 days of the biodegradation should be within 50~150 mg/g of volatile solid.

Compost A, B, C and E satisfied criterion ①, while the extent of degradation of CEL in Compost D was less than 70%. All the compost samples sufficed for criterion ②, indicating that the biodegradation tests were satisfactorily reproducible. The accumulated amounts of CO_2 evolved from the five compost samples in the absence of plastics over the first 10 days of the biodegradation was in the range of 90~146 mg/g of volatile solid

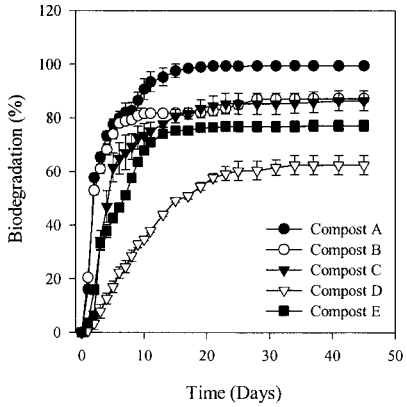

Fig. 7. Biodegradation of PCL in the compost prepared at different maximum temperatures and moisture contents.

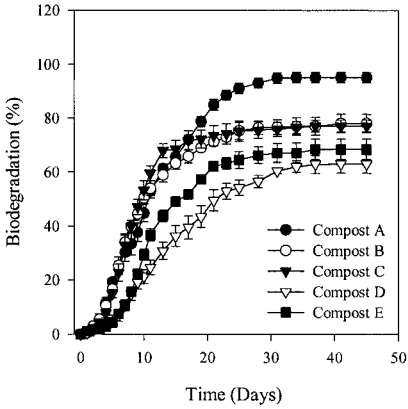

Fig. 8. Biodegradation of PBSA in the compost prepared at different maximum temperatures and moisture contents.

fulfilling criterion ③, as demonstrated in Table 1.

Composts B, D and E, which were prepared by keeping the maximum temperature during the thermophilic stage below 58°C but under different moisture content, met all the three criteria for the validity of the biodegradation results. However, the biodegradation results of not only CEL but also PCL and PBSA in Compost B, D and E were not consistent and depended strongly on the moisture content during the preparation of the compost samples. The capability of the compost samples for the degradation of CEL, PCL and PBSA was higher when the moisture content during the preparation of the compost samples was 65%. The standards such as ISO 14855 [15] and KS M 3100-1 [16] have suggested guide-lines

only for test methods and procedures of the biodegradability of plastics. Therefore, a new standard for preparation of the compost should be provided to obtain more reliable and reproducible test results of biodegradability of plastics.

Conclusion

Animal fodder was composted with different settings of maximum temperature and moisture content to prepare five different compost samples for testing the biodegradability of plastics. Biodegradability tests for CEL, PCL and PBSA were performed in the five compost samples controlling the moisture content and the temperature at 65% and 58°C respectively. All the three plastics were biodegraded faster in the compost prepared with a maximum temperature of 45°C than in the composts prepared at 58°C or 70°C, due to a larger number of microbial cells in the former compost sample. The biodegradation proceeded faster in the compost prepared with a moisture content of 65% than in the compost prepared with a moisture content of 45% and 55%. Nevertheless, four of the five compost samples fulfilled the criteria suggested by the existing standards for biodegradability tests of plastics. Therefore a new standard for the preparation of compost should be provided to obtain more reliable and reproducible results on plastics biodegradability tests, besides the existing standards for the test methods and procedures for the biodegradability of plastics.

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