Degradability of Biodegradable Plastic Under Controlled Composting Conditions

Kiyohiko Nakasaki

Department of Materials Science and Chemical Engineering, Shizuoka University
3-5-1 Johoku, Hamamatsu 432 , Japan

Abstract: Biodegradability of poly(ß-propiolactone) (PPL), one of biodegradable plastics, was tested in a bench-scale composting reactor under controlled conditions, with uniform temperature, moisture content, and aerobiosis maintained. The composting raw mixture was prepared by mixing commercial dog food instead of real organic waste, saw dust as a bulking agent, commercial inoculum sold for acceleration of composting, and PPL in the ratio of 10:9:1:10 on dry weight basis. The degree and rate of PPL degradation were determined by comparing the difference in the CO_2 evolution for composting with and without addition of PPL. The influence of temperature on the degradability of PPL was investigated at 40, 50, and 60 °C and the optimum temperature was found to be around 40-50 °C where ca. 40 wt.-% of PPL was decomposed in 8 days. The effect of inoculum on the degradability of PPL during 50 °C composting was then examined, a considerable difference (100 %) being observed in the biodegradability using two different inocula.

INTRODUCTION

Since the amount of municipal refuse has recently been increased, its treatment becomes a serious problem in Japan. The municipal refuse contains a large quantity of organics, such as garbage which can be composted and reclaimed to farmland. Thus, the method of composting has gained attention; however, the composting of the municipal refuse is not widespread yet though no less than thirty composting plants are operated in Japan at present. This is because the compost product containing large quantities of impurities such as plastics cannot be accepted by farmers. The separation of materials unsuitable for composting from the unsorted municipal refuse suffers from high operating costs and the remaining contamination by plastics in spite of excellent separators used.

Composting of plastic materials along with other organic wastes will help the society to usefully recycle and divert more of its solid waste from landfill or other less desirable waste management options. Accordingly, many kinds of biodegradable plastic materials have been developed so far, and those biodegradable plastics are expected to be effective for promoting composting of organic waste.

 CCC 1022-1360/98/$ 17.50

Some test methods have been designed to determine the degree and the rate of aerobic degradation of plastic materials on exposure to a controlled-composting environment under laboratory conditions, and one of the excellent methods is ASTM D-5338-92 (Ref. 1), based on measuring CO_2 released by test materials when mixing with a matured compost. In real composting, however, biodegradation occurs in a fresh waste. Thus, the degradability of biodegradable plastics was examined by mixing fresh waste in this study. We tried to investigate the optimum temperature and the effect of inoculum on degradation of biodegradable plastics by using a bench-scale reactor (Ref. 2) under well-controlled laboratory conditions.

MATERIALS AND METHODS

Poly(ß-propiolactone) (PPL), $(-OCH_2CH_2CO-)_n$, of M_n 162 800 and M_w 317 500, as particles 0.15-1 mm in diameter, was used throughout the experiments.

Commercial dog food with a trade name VITA-ONE soft (Japan Pet Food Co., Tokyo), which is uniform in composition, was used as a composting raw material in order to obtain reproducible data (Ref. 3). The dog food was first minced and then mixed with saw dust as a bulking agent, an inoculum sold for acceleration of garbage composting, and PPL particles in the ratio of 10:9:1:10 on dry weight basis. The commercial inocula used were of two types, A and B. It was ascertained that a considerable difference existed between the two inocula in concentrations and types of microorganisms. The blank run of composting was carried out without addition of PPL, and the degree and the rate of PPL degradation were determined from the difference in the CO_2 evolution. The weight of the raw mixture with and without PPL were ca. 2910 and 3490 g (moist), respectively. At the start of all experiments, pH and moisture content were adjusted to 8.2 and 50 wt.-%, respectively.

Composting

Nine composting runs were carried out varying composting temperature and types of inocula. The experimental conditions for all the runs are listed in Table 1.

Figure 1 shows a schematic diagram of the experimental apparatus (Ref. 2). A bench-scale composting reactor, 300 mm in diameter and 400 mm deep, was used. The composting material was charged into the reactor and temperature was kept constant by regulating the air feed rate. The exhaust gas from the reactor was passed through a conical flask with H_2SO_4 solution to absorb NH_3 and then introduced into an infrared analyzer (RI-550A, Riken Co., Tokyo) to monitor the CO_2 concentration. For the experiments, the CO_2 evolution rate was calculated (mol CO_2 per unit time per unit of dry solid weight of the material).

Table 1. Experimental conditions for composting

Run No.	Temperature, °C	PPL addition	Inoculum type	pH control
A40-1	40	–	A	–
A40-2	40	+	A	–
A50-1	50	–	A	–
A50-2	50	+	A	–
A60-1	60	–	A	–
A60-2	60	+	A	–
B50-1	50	–	B	–
B50-2	50	+	B	–
B50-3	50	+	B	+

The conversion of carbon, X_C, which corresponds to the degree of the organic matter decomposition is defined as a molar ratio of carbon loss as CO_2 to the carbon of the dog food in the raw material. The X_C at a certain time was estimated by cumulative CO_2 evolved up to the given time. The composting experiments were terminated after 8 days. During the experiments, samples were periodically drawn from the reactor for pH measurement.

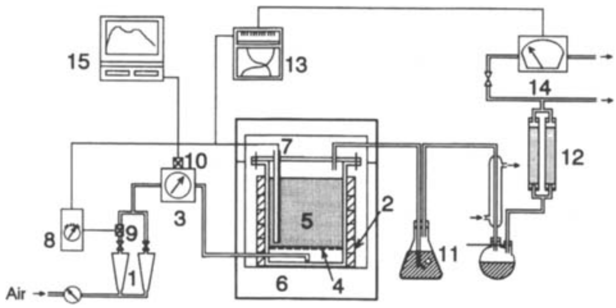

Fig. 1 Schematic diagram of experimental apparatus

1 flow-meter, 2 ribbon heater, 3 gas meter, 4 perforated plate, 5 reactor, 6 Styrofoam insulator, 7 thermocouple, 8 temperature controller, 9 solenoid valve, 10 pulse transmitter, 11 ammonia trap, 12 silica gel adsorber, 13 recorder, 14 CO_2 analyzer, 15 microcomputer

RESULTS AND DISCUSSION

Influence of temperature on the course of composting

The time courses of the CO_2 evolution rate, conversion of carbon, temperature, and pH for runs A50-1 and A50-2 are compared in Fig. 2. The temperature decreased immediately after turning over the composting solid material, but recovered soon, keeping the set temperature for both runs.

A clear difference in the CO_2 evolution rate and carbon conversion between runs A50-1 and A50-2 can be also observed in Fig. 2.

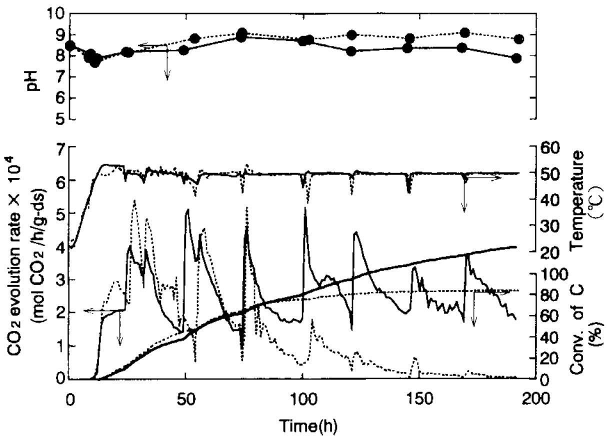

Fig. 2
The courses of the CO_2 evolution rate, carbon conversion, temperature and pH for runs at 50 °C
A50-1 (----)
A50-2 (—)
(ds = dry solid)

The difference in the CO_2 evolution rate became larger at later stages of composting. In addition, the final conversion of carbon in run A50-2 reached 125.3 %, which is by 41.1 % larger than that in run A50-1. The conversion of carbon could be larger than 100 % if the PPL was decomposed to CO_2 because it was calculated on the basis of carbon in the dog food. These results indicate that the PPL was decomposed in the composting and the decomposition occurred vigorously at later stages.

The final value of pH for run A50-2 was smaller than that for run A50-1. It seems that some intermediates of the PPL degradation were produced and accumulated in the composting material.

A similar comparison for runs A60-1 and A60-2 is given in Fig. 3.

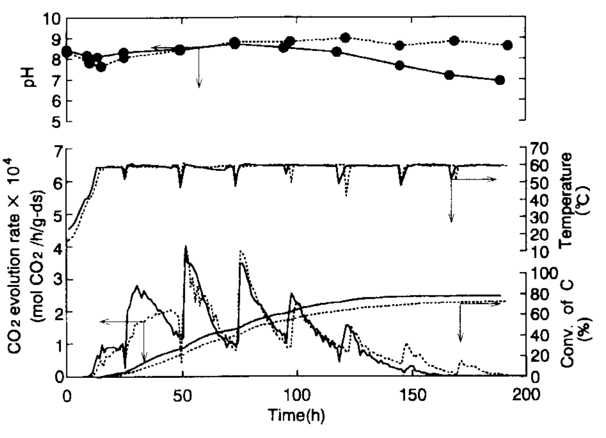

Fig. 3
The courses of the CO_2 evolution rate, carbon conversion, temperature and pH for runs at 60 °C
A60-1 (----)
A60-2 (—)
(ds = dry solid)

The CO_2 evolution rate and the carbon conversion for both runs were similar, although the changes in pH were different. These results suggest that the decomposition of PPL to CO_2 was extremely small compared with the 50 °C composting.

Influence of temperature on the degree of PPL degradation

Calculation of the degree of PPL decomposition for the 50 °C composting is shown illustratively in Fig. 4. The cumulative CO_2 evolution measured during composting in runs A50-1 and A50-2 are 20.6 and 30.9 mol, respectively. The difference of these values, 10.3 mol can be thought to correspond to the amount of PPL degradation. When the PPL in the raw material of run A50-2 is decomposed completely to CO_2, 26.5 mol of CO_2 must be generated. Thus, the degree of PPL degradation was calculated as 39.1 %.

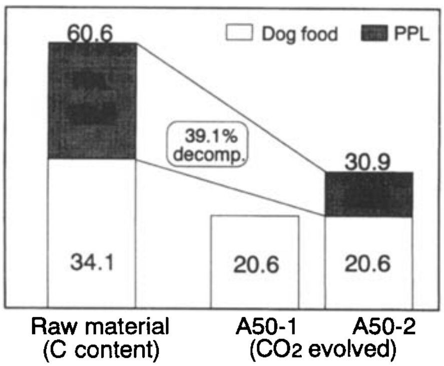

Fig. 4
Estimation of the degree of PPL decomposition for the 50 °C composting (in molar units)

Similar calculations were used for the 40 and 60 °C composting and the results including 50 °C composting are listed in Table 2. The degree of the PPL decomposition in the 60 °C composting was only a few per cent and hence much less effective than at 40 and 50 °C where ca. 40 % of PPL was decomposed.

Table 2. PPL decomposition in composting at different temperatures

Temperature	Total CO_2 evolved, mol		CO_2 from PPL	Degree of PPL
°C	with PPL	without PPL	mol	decomposition, %
40	29.2	19.2	10.0	37.7
50	30.9	20.6	10.3	39.1
60	19.2	17.8	1.4	5.1

Effect of inoculum used for composting

The courses of composting in runs B50-1 and B50-2 are compared in Fig. 5. pH in run B50-2 fell after 120 h. Although approximately 15 g of powdered lime was added at a later stage, pH dropped again immediately and could not be kept at a higher level (7-8.5). No significant difference was seen in the CO_2 evolution rate and carbon conversion for runs B50-1 and B50-2 indicating that the decomposition of PPL seems to have been interrupted in the composting when using inoculum B.

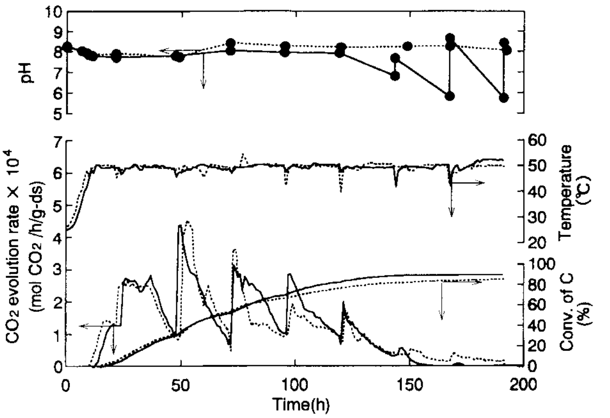

Fig. 5
The courses of the CO_2 evolution rate, carbon conversion, temperature and pH for runs at 50 °C
B50-1 (----)
B50-2 (—)
(ds = dry solid)

The courses of composting in runs B50-1 and B50-3 are compared in Fig. 6. The pH drop was prevented by introducing NH_3 gas along with air (ca. 3000 ppm) into the reactor after 120 h from the start and pH was kept around 8.5 throughout in run B50-2. The difference in the CO_2 evolution rate between runs B50-1 and B50-3 became larger at a later stage of composting, though being smaller than that with inoculum A (cf. Fig. 2).

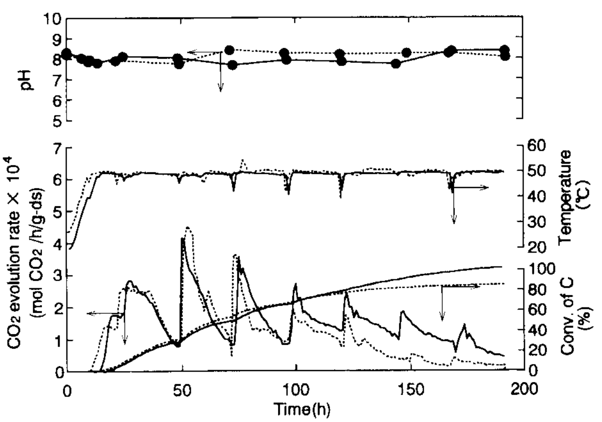

Fig. 6
The courses of the CO_2 evolution rate, carbon conversion, temperature and pH for runs at 50 °C
B50-1 (----)
B50-3 (—)
(ds = dry solid)

The final conversion of carbon in run B50-3 became larger than that in run B50-1. These results reveal that the decomposition of PPL occurred in this composting, too.

Table 3 presents the degree of PPL degradation, which is calculated in the same way as described above. A clear difference was observed in the degree of PPL decomposition between two different types of inocula. The biodegradability obtained using inoculum B was about half of that with inoculum A (cf. Table 2). It can be concluded that the biodegradability of PPL strongly depends on the type of inocula used for composting.

Table 3. PPL decomposition in composting using different types of inocula

Inoculum type	Total CO_2 evolved, mol		CO_2 from PPL	Degree of PPL
	with PPL	without PPL	mol	decomposition, %
A	30.9	20.6	10.3	39.1
B	25.5	20.9	14.6	17.4

CONCLUSIONS

The influence of temperature on the degradation of PPL was investigated at 40, 50, and 60 ^{o}C, and the optimum temperature was found to be at 40-50 ^{o}C. The effect of inoculum on the degradation of PPL in the 50 ^{o}C composting was then examined and it was concluded that the biodegradability of PPL depends on the type of inoculum used for composting.

Using the biodegradable plastics must not promote a throw-away habit. It is, therefore, necessary to carefully investigate their use, for example, in the biodegradable garbage bags for promoting the reclamation of the garbage by composting. It is also necessary to develop application of biodegradable plastics to a material for packaging the garbage is difficult to be sorted on the spot, such as food-package materials. Biodegradable plastics are expected to be a significant tool for reclaiming the garbage in the municipal solid waste which is considered to be most difficult to reclaim.

REFERENCES

1. ASTM D5338-92 : Standard Test Method for Determining Aerobic Biodegradation of Plastic Materials under Controlled Composting Conditions. 1993 Annual Book of ASTM Standards, American Society for Testing and Materials, Villanova (Pa), USA
2. K. Nakasaki, M. Sasaki, M. Shoda, H. Kubota: Appl. Environ. Microbiol. 49, 37 (1985)
3. K. Nakasaki, N. Uehara, M. Kataoka, H. Kubota: Compost. Sci. Util. 2, 88 (1994)