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Short communication

Laboratory composting of extruded poly(lactic acid) sheets ☆

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Abstract

Composting of extruded poly(lactic acid) (PLA) in combination with pre-composted yard waste in a laboratory composting system was studied. Yard waste and PLA mixtures containing 0%, 10%, or 30% PLA (dry weight basis) were placed in composting vessels for four weeks. Exhaust gases were analyzed for carbon dioxide concentration twice per week. After the first week, significantly greater ($P < 0.05$) amounts of carbon dioxide were generated in vessels with 10% or 30% PLA than in control (0% PLA) vessels. Data indicated that microbial degradation of PLA occurred. There was no significant difference ($P > 0.05$) in carbon dioxide emission between 10% and 30% PLA mixtures. Compost pH dropped (from 6.0 to 4.0) after 4 weeks of composting for 30% PLA, but remained unchanged (6.3) for 0% or 10% PLA. Most likely, in the case of 30% PLA, substantial chemical hydrolysis and lactic acid generation lowered the compost pH. The lowered pH likely suppressed microbial activity, thus explaining the lack of difference in carbon dioxide emissions between 10% and 30% PLA mixtures. Gel permeation chromatography showed a notable decrease in PLA molecular weight as a result of composting. It was demonstrated that PLA can be efficiently composted when added in small amounts (<30% by weight) to pre-composted yard waste.

Keywords: Poly(lactic acid); Composting; Biodegradability; Polymer degradation; Gel permeation chromatography

1. Introduction

Interest in biodegradable, compostable plastics derived from renewable biopolymers continues to grow. Biodegradable plastics are commercially available for selected applications (e.g., disposable plates, cups, cutlery, and drinking straws; agricultural mulch films; packaging bags and films; containers for liquid foods; loose fill packaging; and golf tees) (Doane, 1994). The role of biodegradable plastics in solid waste management is somewhat controversial because of their slow degradation rate and their possible interference with plastic recycling efforts (Brown, 1993). However, composting of biodegradable plastics with other "organic" compostable materials such as yard, food, and agricultural waste can generate much-needed carbon-rich compost (humic material) for solid enrichment (Narayan, 1998).

Starch, an abundant and inexpensive natural polymer, has received the most attention as a feedstock for biodegradable plastics (Otey, 1985). The Novon Division of Warner–Lambert Company in the US and Novamont of the Ferruzzi–Montedison Group in Italy produce starch-based resins that can be extruded, injection molded, or blow molded into consumer goods (Doane, 1994). Products from fermentation of starch or starch-derived sugars also serve as basis of biodegradable polymers. For example, poly(lactic acid) (PLA) is a polyester synthesized by condensation polymerization of free lactic acid or by catalytic, ring-opening polymerization of the lactide (dilactone of lactic acid) (Lipinsky and Sinclair, 1986). PLA has primarily been used in biomedical applications such as controlled drug release and tissue fixation (Zhang et al., 1994). However, there is recent interest in tailoring PLA or copolymers of PLA and glycolic acid to industrial applications such as packaging materials and controlled release agrochemical formulations (Doane, 1994). PLA degradation in water (Li et al., 1990) and in water/acetone solutions (Zhang et al., 1994) has been discussed. However, published

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information on PLA composting is scarce. Our objective was to examine laboratory-scale composting of extruded PLA sheets mixed with garden waste.

2. Methods

2.1. Materials

PLA (EcoPLA™, molecular weight 80,000) resin was obtained from Cargill (Minneapolis, MN) and extruded into sheets (1.5 mm mean thickness) with a C.W. Brabender single screw extruder (model 2802, C.W. Brabender Instruments, South Hackensack, NJ). The sheets were cut into 25×75 mm strips and mixed in composting vessels (inside diameter 125 mm; Fig. 1) with composted (for seven months) yard waste (i.e., grass, wood mulch, and tree leaves in equal parts by weight). Yard waste compost/PLA mixtures of 100%/0%, 90%/10%, and 70%/30% (dry weight basis) were used.

2.2. Composting

The composting vessels were placed in the laboratory composting system (Fig. 2) for 4 weeks. Humidified air was passed through flow meters (mean air velocity 25 ml/min) and then into the composting vessels. External heat was applied to maintain a constant temperature of 52°C. The exhaust air was directed through a two-way valve attached to a gas chromatograph (Perkin Elmer, Norwalk, CT) to measure CO_2 concentration twice per week. Once per week, the compost in the vessels was stirred and compost samples were removed to determine moisture content, which ranged from 49% to 55% (calculated on wet weight basis). Moisture contents of waste composts typically fall within 20–56% (Kinman and Nutini, 1990). Compost pH was measured initially and at the end of the composting cycle. The whole experiment was replicated three times with the treatments (PLA concentrations) randomly assigned to the four available composting vessels over three 4 week-long periods.

2.3. Gel permeation chromatography

Gel permeation chromatography (GPC) testing was performed on samples of PLA resin, extruded PLA, and composted (for 4 weeks; from 70% yard waste/30% PLA mixture) PLA using a Waters Corporation (Milford, MA) high-performance liquid chromatograph. Tetrahydrofuran (THF) was pumped at 0.01 ml/s. A PLA

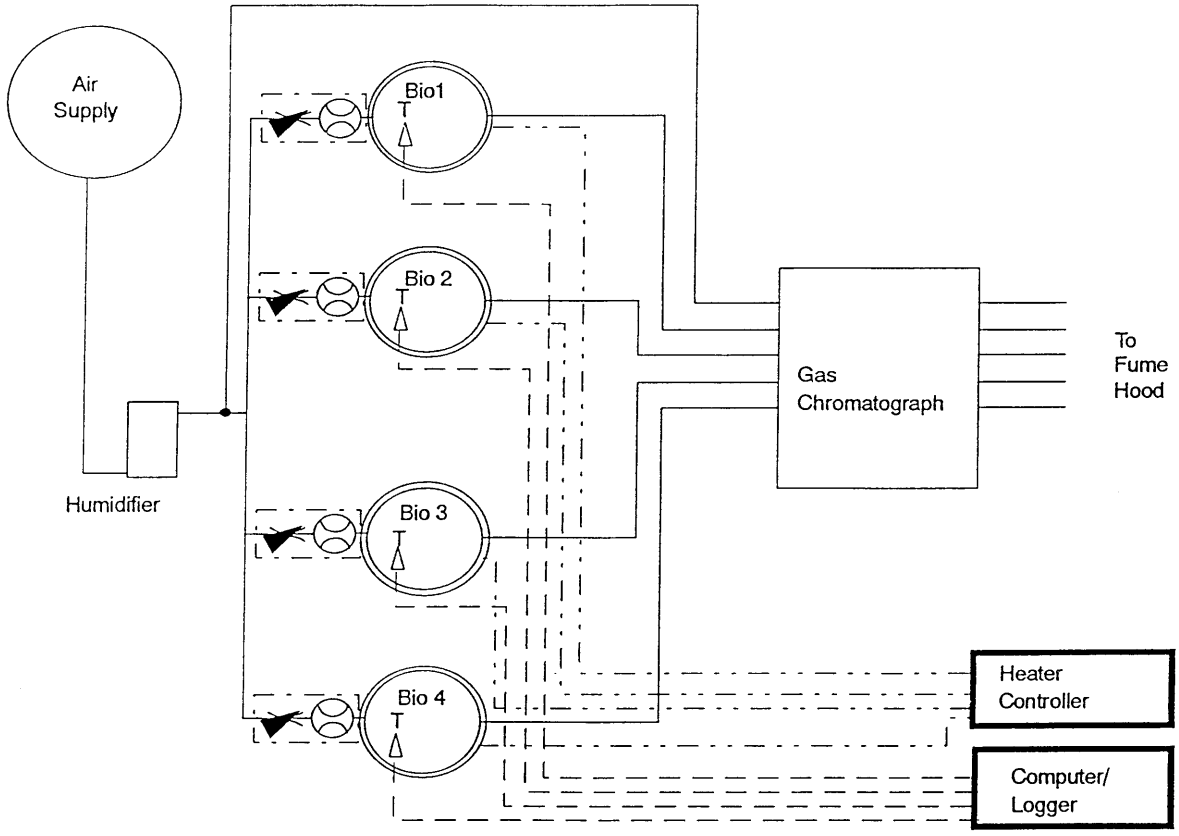

Fig. 1. The laboratory composting vessel.

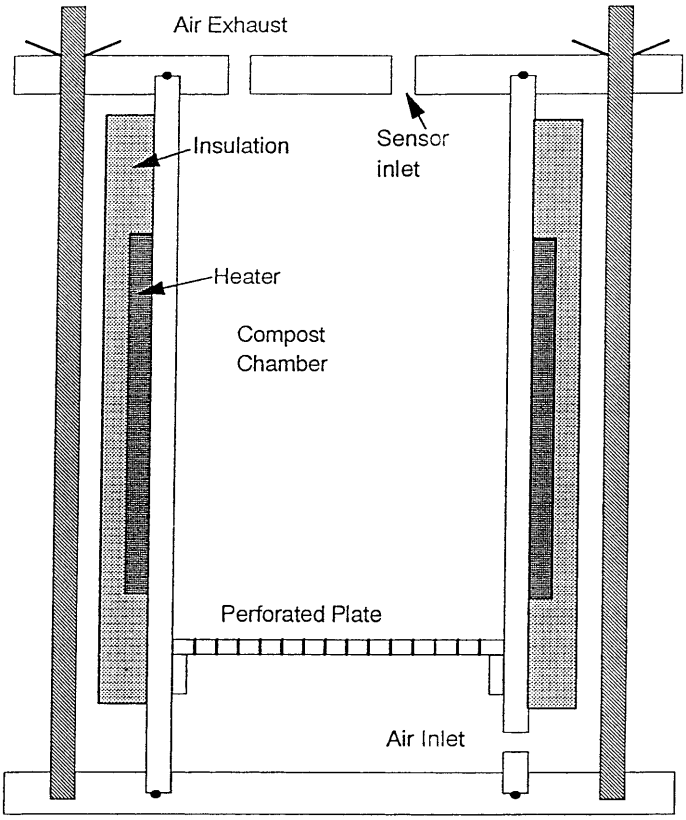

Fig. 2. The laboratory composting system.

sample of 0.075 g was dissolved in 50 ml of THF. A 0.5-ml sub-sample was then analyzed. A Waters differential refractometer was interfaced to a Gateway (North Sioux City, SD) 2000, 486 personal computer. A Keithley instruments (Cleveland, OH) Metrabyte DAS 16 data acquisition board enabled chromatograms to be numerically recorded. The chromatograph was automated with respect to sample injection with the aid of a DDA-06 digital/analog board and in-house software and hardware.

2.4. Statistical analysis

The effects of PLA concentration and composting time on CO_2 generation were determined with the General Linear Models procedure in SAS (Release 6.08, SAS Institute, Cary, NC). Significant differences were determined at the $P < 0.05$ level of significance.

3. Results and discussion

3.1. Subjective observations

Loss of mechanical strength is typical for synthetic polymers subjected to microbial degradation (Dale and Squirrell, 1990). The PLA strips exhibited decreased mechanical strength following one week of composting as evidenced by the fact that strips readily broke apart with application of minimal manual force. Measuring the tensile strength of composted strips was not feasible due to their fragility. Furthermore, the PLA specimens lost most of their transparency after 1 week of composting and appeared "milky" white and opaque after two weeks of composting.

3.2. CO_2 generation and compost pH

Degradation of synthetic polymers proceeds by depolymerization (molecular chain break down) and subsequent mineralization. Depolymerization occurs by hydrolysis and is accompanied by lactic acid generation. As a terminal step, microorganisms mineralize the broken down polymer generating gases (e.g., CO_2, nitrogen, and methane). Therefore, CO_2 emissions may be used to assess polymer degradation. In all cases (0%, 10%, or 30% PLA), the amount of emitted CO_2 significantly increased ($P < 0.05$) as composting time increased (Fig. 3). After the first week of composting, significantly greater ($P < 0.05$) amounts of CO_2 were generated within composting vessels containing 10% or 30% PLA than within vessels without PLA (Fig. 3). Therefore,

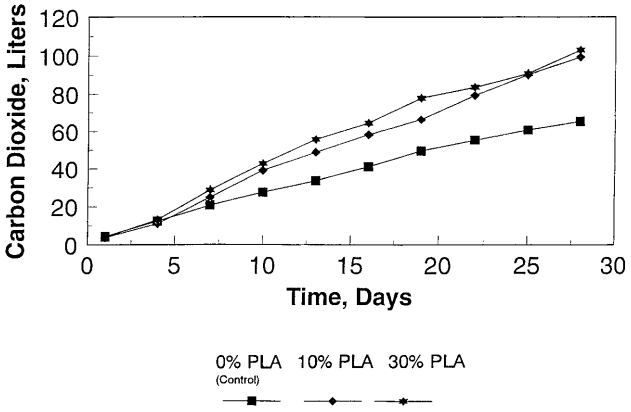

Fig. 3. Generation of CO_2 during composting of yard waste compost/PLA mixtures (100%/0%, 90%/10%, or 70%/30% on dry weight basis).

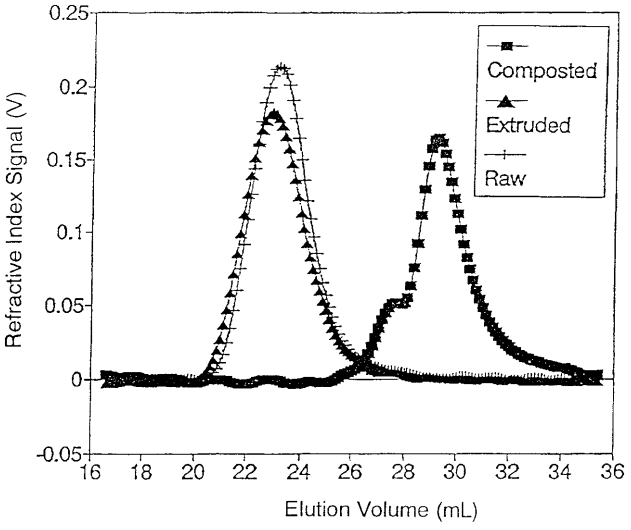

Fig. 4. Gel permeation chromatograms of PLA resin, extruded PLA, and extruded PLA composted for four weeks.

PLA was degraded to some extent. However, there was no significant difference ($P > 0.05$) in CO_2 emission between compost mixtures containing 10% and 30% PLA. This was attributed to the pH decrease in compost mixtures containing 30% PLA. The pH values of mixtures comprised of 70% yard waste compost and 30% PLA at the beginning and end of the composting cycle were 6.0 and 4.0, respectively. In contrast, the initial pH (6.3) of the 100%/0% and 90%/10% yard waste/PLA mixtures did not change during composting. This suggested that substantial lactic acid generation occurred in composting vessels containing 30% PLA with a consequent drop in compost pH. Data suggested that the decreased pH limited microbial activity thus explaining the lack of significant difference in CO_2 emission between 30% PLA mixtures and 10% PLA mixtures (Fig. 3).

3.3. Gel permeation chromatography

Compared to the PLA resin, there was only a minor shift in the refractive index signal versus elution volume curve for extruded PLA (Fig. 4). This indicated that extrusion did not affect substantially the molecular weight of PLA. However, the elution profile of composted PLA was notably shifted to the right (Fig. 4) indicating occurrence of PLA molecular weight reduction (smaller molecules elute later from the packing column).

4. Conclusions

Our exploratory study demonstrated the feasibility of composting PLA in combination with yard waste. However, we noticed that in garden waste/PLA mixtures containing 30% PLA, chemical hydrolysis most likely proceeded faster than microbial degradation. The faster chemical hydrolysis and consequent lactic acid generation seemingly suppressed the degrading action of composting microorganisms. Therefore, it appears that adding PLA to garden waste in small amounts (lower than 30% of the total mixture) is preferable for efficient composting. The possibility that PLA is toxic to composting microorganisms and, in general, the relationship between PLA chemical hydrolysis and microbial respiration merit investigation.

Acknowledgements

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