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Acidulocomposting, an Accelerated Composting Process of Garbage under Thermoacidophilic Conditions for Prolonged Periods

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We propose a new, highly practical process of accelerated high-temperature composting of garbage. This process, which we named acidulocomposting, is autonomously sustained under thermoacidophilic conditions (at pH 3.5–6.5 and 50–70°C) for prolonged periods (more than 2 years). This is in striking contrast with known accelerated composting processes that generally proceed under slightly alkaline conditions (pH 7.5–9). This process emitted only low levels of odor, in contrast to other known composting processes. Thus, acidulocomposting may be a low-maintenance process that can overcome problems associated with conventional accelerated-composting processes, such as low sustainability and odor emission.

Key words: acidulocomposting, garbage, composting, odor, high temperature, thermoacidophilic

1. Introduction

Large quantities of garbage generated by homes, restaurants and food industries cause environmental problems, such as the formation of dioxins, when incinerated[5]. Thus, the establishment of alternatives to treat garbage is an urgent issue, especially in small, overpopulated areas.

Composting, which produces fertilizer, is an effective means of recycling garbage without the formation of dioxins and is an alternative way of garbage management[1,3,6,9]. To date, a variety of apparatuses have been designed to compost garbage from kitchens of homes, restaurants, feeding facilities for school lunch, etc., and they are currently available from many commercial sources in several countries, including Japan. These apparatuses are generally equipped with heating and agitating devices that promote biodegradation of organic materials by thermophilic microorganisms under neutral to alkaline conditions at moderate-to-high temperatures (40–60°C)[1,3,6]. The development of such accelerated high-temperature composting (AHTC) systems has been expected to promote efficient bio-recycling of garbage[6]. Nevertheless, several problems associated with these systems remain. First, composting with these apparatuses tends to emit foul odors[6]. Second, the composting activity by most AHTC gradually diminishes with a decrease in pH of the compost, and, finally, typically 2 to 6 months after the start of the process, the composting activity stops and putrid odor is emitted[6].

To overcome these disadvantages, the AHTC conditions to compost garbage have been examined extensively, and an efficient AHTC process has been observed that proceeds autonomously under acidic conditions for prolonged periods. We here describe this process, which we name here "acidulocomposting", and its general properties to show its practical advantages in the efficient recycling of garbage from a wide variety of sources.

2. Materials and Methods

2.1. Microorganism

Alicyclobacillus sendaiensis strain NTAP-1[8] was a stock culture of Nishino Laboratory, Department of Biomolecular Engineering, Graduate School of Engineering, Tohoku University. The cells were grown at 55°C and pH 4.5 for 48 h with shaking in the ATCC 573 medium containing 0.13% $(NH_4)_2SO_4$, 0.037% KH_2PO_4, 0.025% $MgSO_4 \cdot 7H_2O$, 0.007% $CaCl_2$,0.002% $FeCl_3$, 0.1% glucose and 0.1% yeast extract, and were used as a starter microorganism for acidulocomposting. The cells of strain NTAP-1 were stored at –80°C in broth cultures supplemented with 15% (w/v) glycerol.

2.2. Composting

Figure 1 shows the composting apparatus for acidulocomposting used in this study. It has a maximum capacity of 5 kg (wet wt) of garbage a day. Before the first addition of the substrate (garbage), the culture of *A. sendaiensis* (see section 2.1), typically 1 liter, was mixed with the base material (cedar-wood saw dust, 32 liters) in a vessel by running the machine for 1 h with no substrate. Considering the importance of the practical feasibility and the general applicability of the process to compost garbage, whose composition varies with the source and other factors (e.g., seasons), we did not use "standard garbage" with a specific composition[3,6] as a substrate for composting; instead, we used garbage from a wide variety of sources for evaluation, such as restaurants, homes of different countries, feeding facilities for school lunch, and hospitals. Typical added substrates were food refuse and raw residual materials generated during cooking. All edible materials, fruit rinds, animal skins, fish bones, and eggshells are basically good substrates for acidulocomposting. However, large animal bones, shells, and wood materials were not suitable substrates. Excess water in the fresh garbage was drained by using a basket, and a specific quantity of the substrate was added daily to the vessel of the composting system, which was operated as described in the legend to Fig. 1. Through repeated additions and composting of the substrate, the volume of the product compost in the vessel gradually increased. Excess product was removed to maintain the volume of the compost in the vessel at less than 27 liters. The temperature of the compost in the vessel was routinely measured at 30 cm depth from the surface before each addition of the substrate. Compost (1 g) was routinely sampled and was vigorously suspended in 10 ml distilled water by using a vortex mixer. The resultant suspension was allowed to stand for 30 min at room temperature, and the pH of the supernatant was measured.

2.3. Measurement of odor levels

The odor emission from the acidulocomposting system was quantitatively analyzed by using an odor meter equipped with an electrochemical sensor based on a ZnO_2 semiconductor (KALMOR-Σ, Karumoa, Co., Tokyo, Japan). The Σ value, which could be directly measured by using the odor meter, is an arbitrary value showing a linear relationship with the odor level[2], was measured at the exhaust outlet of the deodorizer and at a position 3 m from the system and was compared with the values measured in a typical kitchen of feeding facilities for school lunch (in Hitachi, Japan).

3. Results and Discussion

Figure 2 shows the results of long-term monitoring of the acidulocomposting process. Garbage from a university restaurant was added every weekday (an average of 4 kg wet wt/day) to the system (Fig. 1) and was treated as described in section 2.1 and legend to Fig. 1. The pH and temperature of the compost were monitored for 2.5 years. The cumulative input of the substrate garbage to this process was 2.2 tons (wet wt; Fig. 2A), from which approximately 0.41 tons of

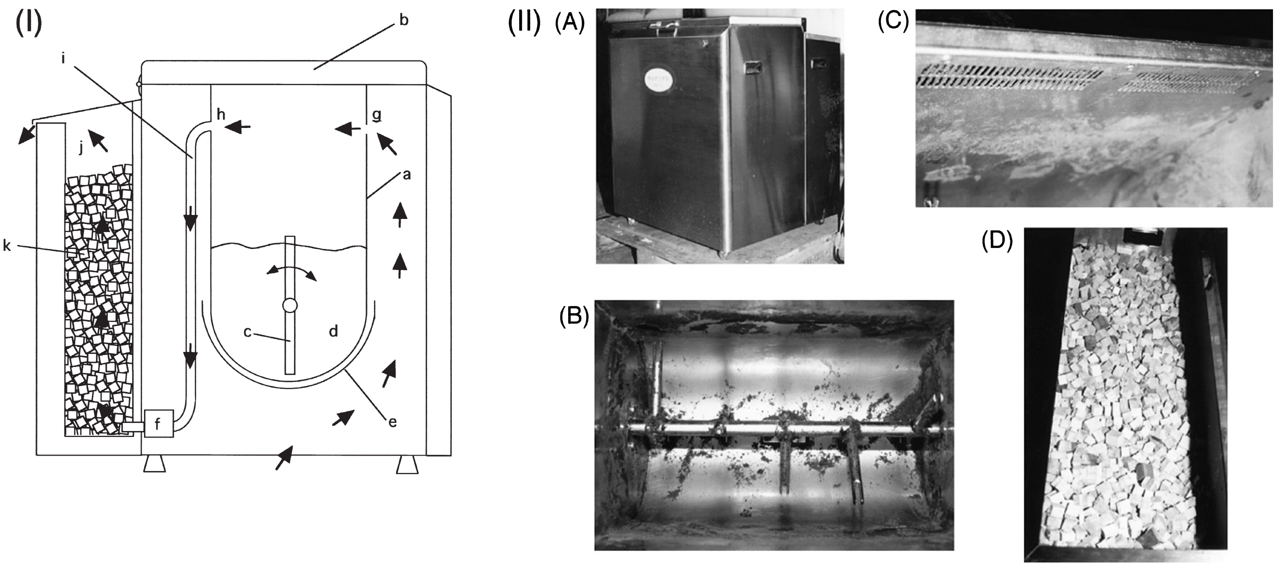

Fig. 1. (I) A cross-sectional drawing (side view) of the composting apparatus used for acidulocomposting. The apparatus had a composting vessel (a) of 500 mm×300 mm×500 mm (the maximum depth) with a top cover (b) and five bars for agitation (c) (see also photograph B). The compost (d) was heated with a sheet-shaped heating device placed below the vessel (e), with a thermostat set at 85°C. The agitation rate was set at 2 rpm, and the direction of rotation of the agitation bars, which are indicated by a double-headed arrow, was reversed every 2 min. An 8-min agitation was alternated with a 24-min interval, and the agitation and heating devices were automatically stopped when the top cover remained closed for over 30 h. Air (arrows) was introduced by suction by using a fan (f) at a flow rate of 0.5 l/min from an air-inlet window (g) into the vessel and escaped from an air-outlet window (h, see also photograph C) through a pipe (i) into a deodorizer unit (j) containing moist wood chips (k, see also photograph D). (II) Photograph of (A) a general view, (B) the empty composting vessel (with agitation bars, top view), (C) air-outlet windows, and (D) deodorizer unit containing moist wood chips (top view).

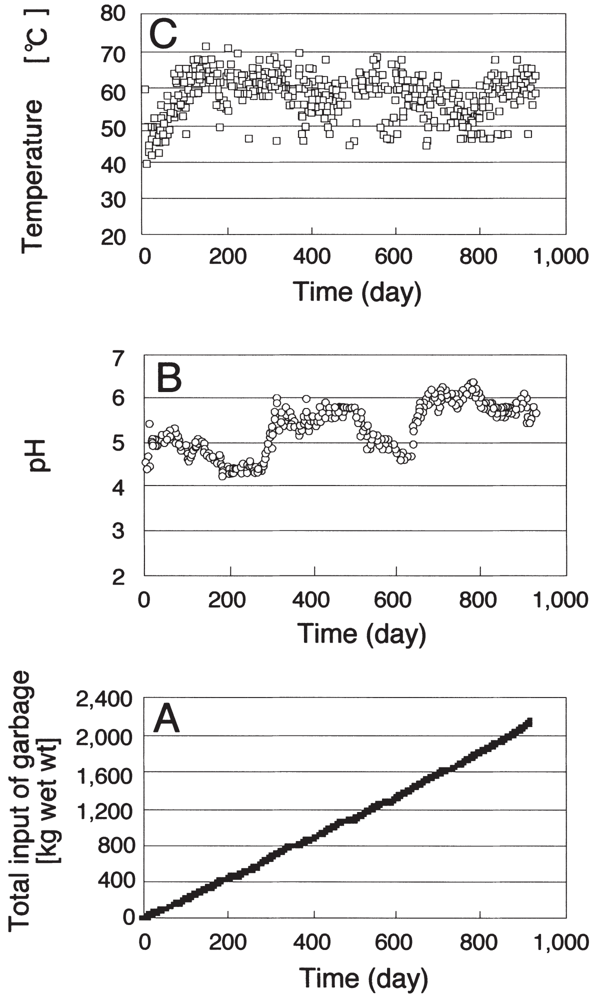

Fig. 2. Long-term monitoring of the course of acidulocomposting of garbage generated from a university restaurant. This study started on January 11, 2000. The substrate garbage (an average of 4 kg wet wt/day) was added every weekday to the system and was treated as described in the text; at intervals, the excess compost was removed. The cumulative input of substrate during this study is plotted in panel (A). The pH and temperature of the compost at a 30-cm depth from the surface are shown in panels (B) and (C), respectively. For further details, see the text.

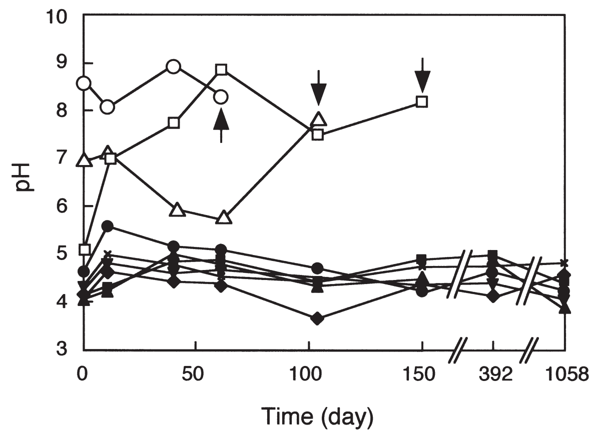

Fig. 3. Comparisons of compost pH and durations of different AHTC systems. An identical composition and amount of garbage, from a feeding facility for school lunch, was subjected to the conventional systems[3,6] from three different commercial sources (maximum capacity, 1 kg/day; indicated by ○, □, and △) and six, identical, independent acidulocomposting systems (maximum capacity, 1 kg/day; indicated by ●, ■, ▲, ◆, ▼, and ×). The composting stopped at the time indicated by arrows.

compost was obtained. The appearance of the product compost was a generally brown pulverulent material. Visual inspection of the compost suggested that the degradation of the added substrate was completed within 24 h at high temperatures (50–70°C, Fig. 2C). Most noticeably, the pH of the compost was autonomously maintained between pH 3.5 and 6.5 throughout the process (Fig. 2B; see Fig. 3 for other examples), in striking contrast to known AHTC processes that generally proceed under alkaline conditions (pH 7.5–9; Fig. 3)[1,3,6]. The acidification of the conventional AHTC process tends to cause malfunctioning of the process[3,4,6]. The process of this study was sustained for a prolonged period (more than 2 years) with no supplementary addition of starter microorganisms. In comparison, most known AHTC processes malfunction within 2–6 months after the start of the process (Fig. 3); in such cases, starter microorganisms must be supplemented to increase the composting activity to restore the process, or the total content of the composting materials must be removed so that the process can be restarted[6]. In our new process, when the substrate was added beyond the capacity of 5 kg/day, biodegradation of organic materials markedly decreased. In such cases, the pH remained at 4–6, and the compost became blackish brown, was slimy, and contained oily substances. However, the ability to degrade garbage and the pulverulent nature of the compost was autonomously restored by operating the system for 1–2 days with no addition of a substrate. These characteristics have generally been identified when using this system to compost garbage from a variety of sources, including Japanese, Korean, Chinese, European and fast-food restaurants, homes of different countries, feeding facilities for school lunch and hospitals. These results suggest that this process should not be specific for the garbage from particular sources, but may be generally applied to garbage from a wide variety of sources and other organic wastes. Thus, this unique AHTC process is named "acidulocomposting" with emphasis on the distinctive acidophilic nature of the process.

Unsanitary vermin, such as cockroaches, flies, and maggots, were not found in the compost product, named acidulocompost. Nitrogen, organic carbon, phosphorus (as P_2O_5), and potassium (as KO_2) of the acidulocompost were measured by official protocols[7]: typical values were 3.4, 39, 0.95, and 0.78 w/w%, respectively. Although these values may vary with substrate garbage, the C/N ratio of the compost was usually 10–12 independently of the source of garbage. For comparison, the nitrogen content and C/N ratio of the composts produced from conventional processes from municipal wastes are mostly 1.5–2% and 20–30, respectively[3,6]. The water content of the acidulocompost during

Table 1. Measurement of odors

Site of measurement	Σ value	
	Measurement 1	Measurement 2
Outlet of deodorizer	375	340
3 m from the system in open air	250	220
Kitchen	330	350
Open air	230	210

composting was 25–40%; however, it decreased to 10% when the garbage was not newly added for several days. The acidulocompost was mixed with soil and was subjected to secondary fermentation for several days, as for the compost produced by traditional non-accelerated composting processes. The resultant soil-mixed compost can be used to cultivate vegetables, flowers, and fruits (T. Nishino and K. Hoshi, unpublished results).

Olfactory examination showed that acidulocompost generally emits a weak burning and caramel-like smell and does not emit an ammonia-like odor. This is in striking contrast to the odor of compost produced by conventional AHTC processes, which is ammonia-like. Moist wood chips are inexpensive, effective deodorizing materials for the process of this study; thus, the acidulocomposting system is regularly equipped with a deodorizer unit containing them (Fig. 1). The odor emission from this system was quantitatively analyzed by using an odor meter equipped with an electrochemical sensor based on a ZnO_2 semiconductor (Table 1). The results showed that the Σ value of the exhaust from the system, measured at the outlet of the deodorizer, was comparable to the value obtained in the kitchen. The Σ values measured at a position 3 m from the system in open air were mainly the same as those in the outdoor air, where almost no odor was detected in an olfactory examination. These results show that acidulocomposting emits only very low levels of odor.

The fact should be noted that detailed microflora analyses of the acidulocomposting process by polymerase chain reaction-denaturing gradient gel electrophoresis, combined with fluorescent in situ hybridization, are currently underway and show the participation of lactic acid producing bacteria during the process. These observations may provide a clue to understand why this process is stably sustained under thermoacidophilic conditions for prolonged periods with very low odor emission. Details of the results of these analyses will be reported in future.

4. Conclusion

Acidulocomposting is a novel method to recycle garbage. It is autonomously sustained under thermoacidophilic conditions for more than 2 years with very low emission of odor and does not require tedious procedures to maintain the process. Therefore, acidulocomposting is a generally efficient and relatively maintenance-free process applicable to bio-recycling garbage from a wide variety of sources.

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