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A Novel Process for Anaerobic Composting of Municipal Solid Waste

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ABSTRACT

A novel process has been developed and evaluated in a pilot-scale program for conversion of the biodegradable fraction of municipal solid waste (MSW) to methane via anaerobic composting. The sequential batch anaerobic composting (SEBAC) process employs leachate management to provide organisms, moisture, and nutrients required for rapid conversion of MSW and removal of inhibitory fermentation products during start-up. The biodegradable organic materials are converted to methane and carbon dioxide in 21–42 d, rather than the years required in landfills.

Index Entries: Anaerobic composting, solid wastes; municipal wastes; methane.

NOMENCLATURE

DRANCO	dry anaerobic composting
MSW	municipal solid waste
SEBAC	sequential batch anaerobic composting
VS	volatile solids; dry, ash-free solids
vvd	volumes of methane per volume of reactor per day

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INTRODUCTION

Diversion of the biodegradable fraction of municipal solid waste (MSW) and its treatment by composting is receiving increased attention. If potentially toxic contaminants are removed by source separation or other separation techniques, the residues of composting do not pose an environmental threat and may be disposed of, or even marketed as a compost soil conditioner. Since the biodegradable fraction composes about 67% (wet wt) of a typical MSW stream (*1*), any effective treatment of this fraction in a manner that diverts it from landfills will have a major impact on the MSW problem.

Normally the term "composting" is associated with either in-vessel or out-of-vessel processes in which oxygen is provided by mixing and/or by application of air to enhance decomposition (*2*). Anaerobic composting (more commonly referred to as anaerobic digestion) accomplishes similar extents and rates of decomposition without the need for aeration or mixing (some designs) (*3*). It not only has reduced energy requirements, but also produces the valuable energy product methane.

Anaerobic decomposition in the form of a methane fermentation occurs naturally in landfills; however, decomposition is slow (requiring years) and often incomplete. This slow rate may be attributed to lack of organisms, moisture, and nutrients necessary for a rapid fermentation (*4*). Various digester designs have been developed and tested at different scales for anaerobic composting of MSW. The more attractive options process the feedstock in its high-solids form to minimize reactor size and the energy penalties associated with heating water. These digester designs have included mixed, plugflow, batch, and multistage with leachate recycle.

The novel reactor design described here is of the multistage leachate-recycle type and is referred to as the sequential batch anaerobic composting (SEBAC) reactor. Although it is similar to other systems described (*5–11*), it has a unique combination of design and operating conditions. This paper describes the general design and operating conditions and the results of a series of pilot-scale tests involving two different feedstocks and two different retention times.

DESCRIPTION OF PROCESS

The SEBAC process shown in Fig. 1 employs three stages for conversion of MSW to methane. In Stage 1 (new stage), the biodegradable fraction of MSW (mainly paper, yard waste, and food waste) is coarsely shredded (to about 10 cm), placed into the reactor, and moistened and inoculated by recycling leachate from Stage 3 (old stage). Leachate recycle also removes inhibitory organics (organic acids and other fermentative products) produced in Stage 1 from depolymerization and fermentative

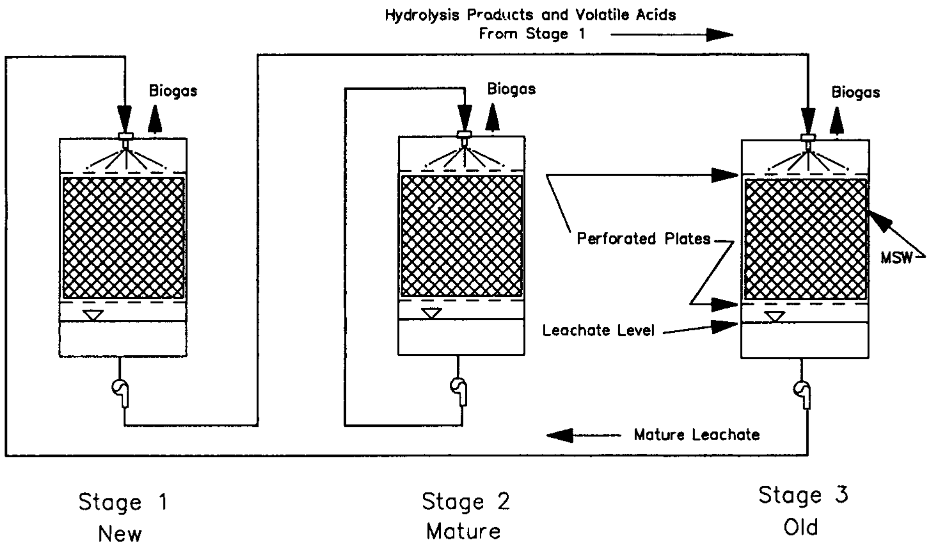

Fig. 1. Schematic diagram of the sequential-batch anaerobic composting (SEBAC) process.

reactions. In Stage 2 (mature stage), the fermentation is active and balanced and thus operated in the batch mode. Stage 3 (old stage) allows for completed conversion of particulates and also serves as an inoculum for the start-up of Stage 1 and conversion of acids pumped out of Stage 1 via leachate.

MATERIALS AND METHODS

Feedstocks

Two sources of feedstocks were used in this study. One (referred to as Sumter Co. feed) was obtained from a commercial aerobic composting facility. The feed is prepared by manual removal of aluminum, ferrous metal, and some plastic, followed by coarse shredding (2–10 cm range) with a hammermill. Fresh feed was obtained the day prior to starting each run.

A second feed (referred to as Levy Co. feed) was prepared by hand removal of the undesired components, including all metal, glass, plastics, and fabrics, from a municipal waste stream. The remaining fraction was coarsely shredded (2–10 cm range) with a hammermill. This feed was also obtained the day prior to startup of a run.

Digester Design, Start-Up, and Operation

The system consisted of three reactors, 0.61 m in diameter×2.4 m. The middle half (about 0.33 m^3) of each reactor contained a bed of feedstock packed in nylon-mesh bags and supported underneath by a plate.

The bags allowed for easy filling and weighing of feed and for removal and weighing of digester residues. The lower quarter of the vessel provided a place for leachate collection and storage. A leachate-recirculation system consisting of PVC pipes and perforated plate facilitated even distribution of leachate. The bed consisted of nine bags of MSW containing a total of 50–100 wet kg (60–80% total solids). The typical initial bulk density for each run was about 178 g/L. The reactors were maintained at 55°C by passing hot water through coils wrapped around the vessel. The vessels were well insulated. Using pneumatic pumps, leachate was pumped from the bottom to the top of interconnected vessels. Thermisters were placed in three locations in each vessel to allow for temperature measurements.

The first run was started up by heavily inoculating a bed of MSW with leachate and active solids from another MSW-fed digester. After this run became active and balanced (low levels of volatile acids), it was used to start up the second run via leachate recycle, as described above. All subsequent runs were started up from a Stage 3 reactor, as described above.

Leachate recycle was done at the same time for 15 min each day, either between reactors for start-up (between Stages 1 and 3) or upon itself (Stage 2). Runs consisted of totals of 42 or 21 d, with 14 or 7 d per stage, respectively.

Sampling and Analysis

Feed and effluent were analyzed for total weight and total and volatile solids. Feed composition, in terms of paper, cardboard, plastic, yard waste, and miscellaneous, was determined. Gas production was measured daily using a specially designed U-tube gas meter that trips a counter every 50 mL. Gas composition was determined daily by gas chromatography. Volatile acids in leachate from the first week of Stage 1 were determined daily and from Stages 2 and 3 weekly by gas chromatography. Using thermisters, temperature was determined in three different locations in all digesters daily.

RESULTS

42-Day Tests

Operational parameters and performance data from four 42-d tests are shown in Tables 1 and 2, and a typical profile of performance data from a typical 42-d run is shown in Fig. 2. These tests were all conducted with Sumter Co. feedstock. During the initial part of Stage 1 (the first 14 d), over 3000 mg/L of volatile acids accumulated and methane production was minimal. Accumulative methane yield and methane gas content rapidly increased after 5 d, indicating developing of a balanced methane fermentation. During this stage, acids were carried via leachate recycle to another reactor, operating in Stage 3, where they were converted to methane and

Table 1
Operational Parameters for Trials with a 42-day Retention Time and Sumter Co. MSW

	Trial 4	Trial 5	Trial 6	Trial 7
Loading Rate: ($g\ VS\ L^{-1}\ d^{-1}$)	3.34	3.17	3.00	3.12
Temperature:	55°C	55°C	55°C	55°C
Feed Characteristics:				
Total Solids (%):	74.1	70.4	66.1	80.2
Volatile Solids (%):	78.4	77.7	79.2	87.9
Dry Composition (%):				
Paper:	60.3	58.8	65.2	43.7
Cardboard:	14.7	14.3	3.8	4.8
Plastic:	7.5	10.9	12.0	11.2
Yard Waste:	----	----	----	3.0
Misc.:	17.5	16.0	19.0	37.3
Bulk Density (g/L)	280	280	280	280

Table 2
Performance Data for Trials with a 42-day Retention time and Sumter Co. MSW

	Trial 4	Trial 5	Trial 6	Trial 7	Mean
Methane Yield (L/g VS added)	0.179	0.182	0.220	0.192	0.194
Methane Production Rate (vvd)	0.64	0.57	0.64	0.60	0.61
Volatile Solids Reduction (%)	51.0	48.9	52.4	46.6	49.7
Volume Reduction (%)	43.2	46.1	42.4	----	43.9

carbon dioxide. Most of the methane was produced in Stage 1. The rate of methane production leveled off in Stage 2. Methane in Stage 3 was produced in part from residual conversion of MSW and in part from volatile acids carried over from another reactor in the start-up process. The pH was in the range of 7.5–8.0, which is abnormally high for anaerobic digestion; no reason could be determined for this.

The actual loading rate for these runs was approx 3.2 g VS $L^{-1}d^{-1}$, calculated on the basis of the bed volume, actual feed added, and residence time. Under these conditions, the mean methane yield was 0.19 L/g of VS added (range, 0.186–0.220), corresponding to a mean VS reduction of 43.9% (range, 42.4–46.0). The mean volumetric methane production rate, based on the bed volume, was 0.61 vvd. It should be recognized that the methane yield is limited by the biodegradation ability of the feed and that further degradation of this feed at longer residence times would be minimal. It is also important to note that loading rates and corresponding methane production rates would be expected to be higher in commercial digesters because of a 55% increase in bulk density (from 176 to 272 g/L), expected in deeper commercial systems. Another important observation is that these runs were very stable by virtue of the removal of inhibitory volatile fatty acids formed during start-up.

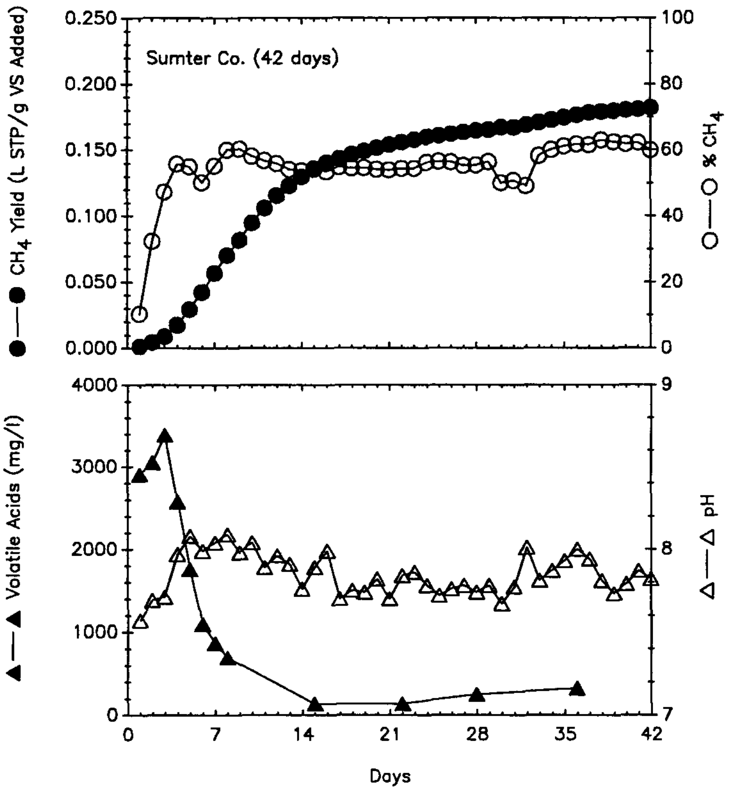

Fig. 2. Performance data from a typical 42-d run (Trial 5) of the SEBAC process receiving the organic fraction of Sumter Co. MSW (T=55°C, bed vol=0.33 m^3, loading=39.7 kg VS).

21-Day Tests

Seven tests were run with Sumter Co. feed and five with Levy Co. feed. The loading rate was about 6.4 g VS $L^{-1}d^{-1}$ for these tests, reflecting operating conditions similar to those of the above tests, except for a reduced loading rate. The performance-data profiles for the two feeds (Figs. 3 and 4) follow trends similar to those of the 42-d test, except that the final level portion of the accumulative methane yield curve is excluded. Recall that each Stage is 7 d, instead of 14, for these runs. These plots, along with tabulated performance data below, suggest that 7 d is sufficient for adequate start-up of this system, but a total of 21 d of retention may not be enough for the desired conversion.

Tables 3–6 summarize operation parameters and performance for the 21-d tests with Sumter Co. and Levy Co. feeds. For Sumter Co. feed, the mean methane yield was 0.163 L/g of VS added (range, 0.132–0.189), corresponding to a mean VS reduction of 39.7% (range, 37.3–42.7). For the Levy Co. feed, the methane yield was 0.191 L/g of VS added (range, 0.171–

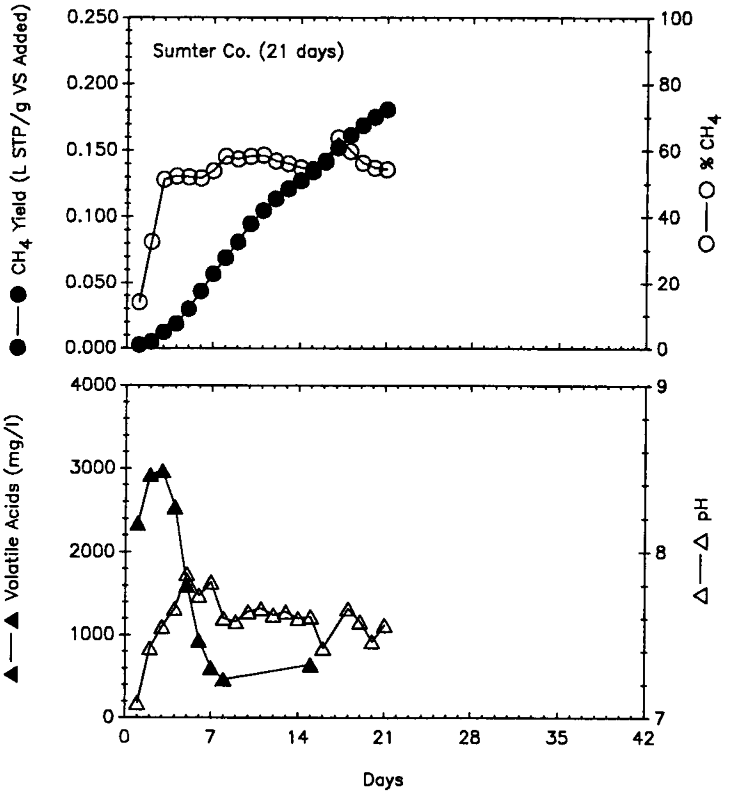

Fig. 3. Performance data from a typical 21-d run (Trial 11) of the SEBAC process receiving the organic fraction of Sumter Co. MSW (T=55°C, bed vol= 0.33 m^3, loading=48.4 kg VS).

0.215), corresponding to a VS reduction range of 42.4–51.1% (three runs are continuing beyond 21 d to determine ultimate biodegradation ability; therefore VS reduction data are not available). For both feedstocks, the methane production rate was about 1 vvd. As for the 42-d runs, loading rates and corresponding methane production rates would be expected to be higher in commercial digesters because of higher expected bulk densities in deeper systems. The higher methane yields and corresponding solids reductions of the Levy Co. feed are attributed to a higher fraction of biodegradable volatile solids.

DISCUSSION

The SEBAC process is effective for conversion of the biodegradable fraction of MSW to methane. Compared to other processes described for anaerobic digestion of MSW (Table 7), methane yields were similar, but

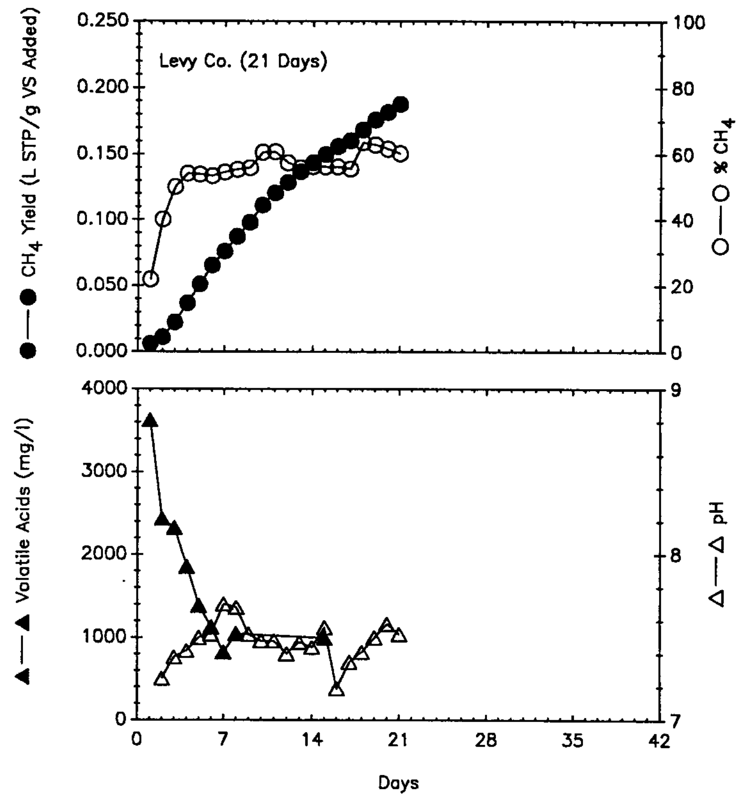

Fig. 4. Performance data from a typical 21-d run (Trial 16) of the SEBAC process receiving the organic fraction of Levy Co. MSW (T = 55°C, bed vol = 0.33 m^3, loading = 33.2 kg VS).

are more a reflection of the ability of the feedstock to be biodegraded than of process-specific factors. The significantly higher loading rates and associated higher methane production rates reported for DRANCO (*12*) and VALORGA (*13*) reflect the lower residence times and higher bulk densities employed in these designs. It should be pointed out that values for loading rate and methane production rate for the SEBAC process would be expected to be higher in a commercial system in consequence of higher bulk densities expected in larger reactors. A comparison of these systems must also take into account other factors, such as simplicity of design and operation, process stability, energy requirements, and overall process economics. This comparison is currently being done for future publication.

The SEBAC design is expected to be competitive because of simplicity of design, high stability, and lack of need for mixing or movement of solids during operation. The design is versatile and could be applied to either in-vessel systems or modified landfill designs. The latter application is compatible with newer landfill designs requiring leachate management and treatment.

Table 3
Operational Parameters for Trials with a 21-day Retention Time and Sumter Co. MSW

	Trial 8	Trial 9	Trial 10
Loading Rate: ($g\ VS\ L^{-1}\ d^{-1}$)	6.45	7.54	6.19
Temperature:	55°C	55°C	55°C
Feed Characteristics:			
Total Solids (%):	73.4	56.5	77.0
Volatile Solids (%):	88.4	87.7	84.6
Dry Composition (%):			
Paper:	57.1	49.3	38.9
Cardboard:	9.2	8.8	11.8
Plastic:	7.0	8.7	4.0
Yard Waste:	0.0	0.0	22.7
Misc.:	26.7	33.5	22.6
Bulk Density (g/L)	280	280	280

	Trial 11	Trial 12	Trial 13	Trial 14
Loading Rate: ($g\ VS\ L^{-1}\ d^{-1}$)	6.98	5.53	6.68	5.86
Temperature:	55°C	55°C	55°C	55°C
Feed Characteristics:				
Total Solids (%):	67.2	72.9	73.0	71.1
Volatile Solids (%):	86.5	85.5	68.4	77.6
Dry Composition (%):				
Paper:	47.6	55.3	22.0	25.1
Cardboard:	29.6	4.2	14.5	0.0
Plastic:	10.5	21.4	10.1	6.3
Yard Waste:	0.6	4.6	7.5	2.0
Misc.:	11.7	14.5	46.0	66.7
Bulk Density (g/L)	280	280	280	280

This research has evaluated the technical feasibility of the SEBAC process for conversion of the biodegradable fraction of MSW to methane and compost. Since yard wastes are kept separated by law in Florida, the feeds tested contained minimal quantities of that fraction. Future research will not only evaluate yard wastes as feeds, but also test the suitability of the residues from treatment of various feeds as compost, including their adherence to environmental standards. A systems and economics analysis of this process will be conducted and its economics compared with those of aerobic composting and other anaerobic digestion options.

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Table 4
Performance Data for Trials with a 21-day Retention Time and Sumter Co. MSW

	Trial 8	Trial 9	Trial 10	Trial 11	Trial 12	Trial 13	Trial 14	Mean
Methane Yield (L/g VS added)	0.132	0.171	0.137	0.181	0.151	0.182	0.189	0.163
Methane Production Rate (vvd)	0.84	1.27	0.85	1.26	0.82	1.21	0.87	1.02
Volatile Solids Reduction (%)	----	----	----	41.4	44.4	37.0	21.1	36.0
Volume Reduction (%)	42.7	40.0	38.9	----	37.3	----	----	39.7

Table 5
Operational Parameters for Trials with a 21-day Retention Time and Levy Co. MSW

	Trial 15	Trial 16	Trial 17	Trial 18	Trial 19
Loading Rate: ($g\ L^{-1}\ d^{-1}$)	5.07	5.27	5.24	6.28	6.94
Temperature:	55°C	55°C	55°C	55°C	55°C
Feed Characteristics:					
Total Solids (%):	62.0	72.5	67.2	64.3	62.1
Volatile Solids (%):	92.5	94.1	91.0	95.3	89.5
Dry Composition (%):					
Paper:	85.0	91.3	95.9	98.5	87.0
Cardboard:	7.0	7.0	3.2	0.4	2.8
Plastic:	0.8	0.0	0.9	0.0	0.0
Yard Waste:	0.0	1.6	0.0	1.1	8.4
Misc.:	7.2	1.8	0.0	0.0	1.8
Bulk Density (g/L)	280	280	280	280	280

Table 6
Performance Data for Trials with a 21-day Retention Time and Levy Co. MSW

	Trial 15	Trial 16	Trial 17	Trial 18	Trial 19	Mean
Methane Yield (L/g VS added)	0.199	0.188	0.171	0.182	0.215	0.191
Methane Production Rate (vvd)	1.00	1.00	1.03	1.13	1.13	1.06
Volatile Solid Reduction (%)	36.7	44.6	not available since runs are continuing			
Volume Reduction (%)	42.4	51.1	not available since runs are continuing			

Table 7
Reactor Performance Comparison for Anaerobic Digestion of MSW (RDF)

Reactor	RefCoM CSRT (14)	SOLCON (15)	DRANCO (12)	VALORGA Mixed (13)	GOSH LBAFR (6)	SEBAC* 42 days Sumter MSW	SEBAC* 21 days Sumter MSW	SEBAC* 21 days Levy MSW
Temp. °C	60	35	50	37	35	55	55	55
Loading, g VS L^{-1} d^{-1}	3.0-9.6	3.2	16	15	1.1	3.2	6.4	6.4
Retention Time d	6-27	18	20	15	90	42	21	21
Methane Yield, L/g VS added	0.13-0.30	0.25	0.28	0.20	0.21	0.18-0.22	0.13-0.19	0.17-0.22
Methane Rate, (vvd)	0.39-2.9	0.80	4.4	3.0	0.24	0.5	1.0	1.0

* This study

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