Novel anaerobic process for the recovery of methane and compost from food waste

S.-K. Han*, H.-S. Shin*, Y.-C. Song, C.-Y. Lee*** and S.-H. Kim***

* Department of Civil Engineering, Korea Advanced Institute of Science and Technology, 373–1 Kusong-dong, Yusong-Ku, Taejon 305–701, Korea (E-mail: *skhan003@hotmail.com*)

** Department of Environmental Engineering, Korea Maritime University, 1 Dongsam-Dong, Youngdo-Ku, Pusan 606–791, Korea

*** R&D Team, Institute of Technology, Engineering & Construction Group, Samsung Corporation, 428–5, Gongse-Ri, Giheung-Eup, Yongin-City, Kyunggi-Do 449–900, Korea

Abstract Multi-step sequential batch two-phase anaerobic composting (MUSTAC) process was used to recover methane and composted material from food waste. The MUSTAC process consists of five leaching beds for hydrolysis, acidification and post-treatment, and an upflow anaerobic sludge blanket (UASB) reactor for methane recovery. This process involves the combined methods of sequential batch operation and two-phase anaerobic digestion for simple operation and high efficiency. Rumen microorganisms are inoculated due to their enhanced cellulolytic activity. Each leaching bed is operated in a sequential batch mode. Five leaching beds are operated in a multi-step mode with a two-day interval between degradation stages. Acidified products in the leachate from the leaching beds are converted to methane in the UASB reactor. The MUSTAC process demonstrated that it was capable of removing 84.9% of volatile solids (VS) and converting 85.6% of biochemical methane potential (BMP) into methane at 10.9 kg VS/m^3·d in 10 days. Methane gas production rate was 2.31 m^3/m^3·d. The output from the post-treatment of residues in the same leaching bed without troublesome moving met the Korean regulation on compost, indicating that it could be used for soil amendment.

Keywords Compost; food waste; methane; multi-step mode; MUSTAC; sequential batch operation; two-phase anaerobic digestion

Introduction

The organic waste problems in Korea have attracted public attention due to environmental concerns, coupled with urbanization and industrialization since 1970s. The proper management of the waste is so essential that the waste generation control and the effective waste recycling has been at the center of public interest. The generation of municipal solid waste (MSW) amounts to approximately 44,583 tons per day, of which 26.5% is food waste from restaurants, markets, institutions and households (MOE, 2001). Food waste is the main source of decay, odor and leachate during collection and transportation due to its high volatile solids (VS) and moisture content. Most food waste has been landfilled together with other wastes, resulting in various problems such as emanating odor, attracting vermin, emitting toxic gases, contaminating groundwater and wasting landfill capacity. The landfilling of food waste will be prohibited in 2005, but Kimpo landfill receiving the wastes from Seoul metropolitan area rejected raw food waste from July 2000 (MOE, 2001). The research on the recycling technology for food waste is, therefore, a major field of waste management.

Food waste can be nutrient sources to other living organisms or an alternative energy source. Resource recovery from food waste using proper technologies contributes to environmental preservation by decreasing the consumption of natural resources. Aerobic composting usually used for the treatment of food waste requires energy input to provide aeration whereas anaerobic digestion can achieve dual benefits of resource recovery and

Water Science and Technology **Vol 45 No 10 pp 313–319** © IWA Publishing 2002

Downloaded from https://iwaponline.com/wst/article-pdf/424788/313.pdf
by guest

waste stabilization. The application of anaerobic digestion has, therefore, been increased for the efficient treatment of food waste in Korea.

The aim of this study is to assess the performance of a novel high-rate anaerobic process for treating food waste. This novel process was devised with rational configuration and operating methods for resource recovery as well as waste stabilization.

Process description

Figure 1 shows the schematic diagram of the newly devised process, called multi-step sequential batch two-phase anaerobic composting (MUSTAC). The MUSTAC process consists of two main parts: five leaching beds (5×35 L) for hydrolysis, acidification and post-treatment, and an upflow anaerobic sludge blanket (UASB) reactor (225 L) for methane recovery. Five leaching beds are operated in a multi-step mode with a two-day interval between degradation stages as shown in Table 1. Acidified products in the leachate from four leaching beds are converted to methane in the UASB reactor. The different sizes of shaded portion in the leaching beds (Figure 1) indicate the volume reduction of food waste according to the degradation stages. The post-treatment of residues produces soil amendment in the same leaching bed without troublesome transferring. The effluent from the UASB reactor recirculates through the leaching beds as dilution water. A portion of the effluent is exchanged periodically so that inhibitory materials do not concentrate in the dilution water.

Each leaching bed is operated in a sequential batch mode as shown in Figure 2. Rumen microorganisms (5% v/v) are inoculated into the leaching bed due to their enhanced cellulolytic activity (Song, 1995). Cellulosic materials (i.e. vegetables) amount to about 50% of

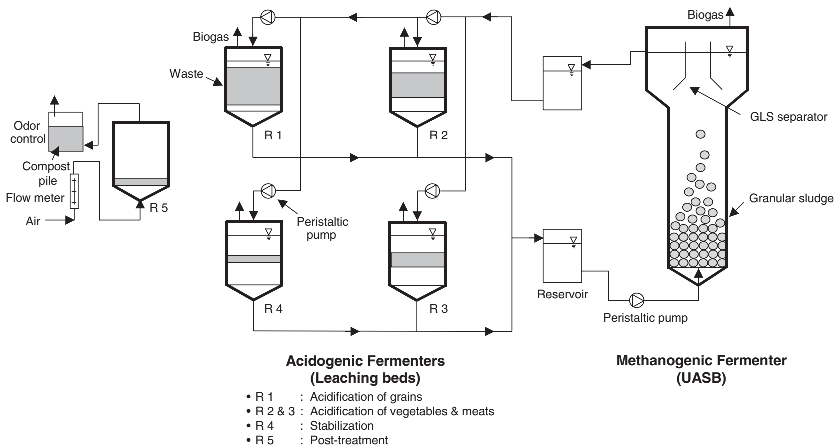

Figure 1 Schematic diagram of the MUSTAC process

Table 1 Operating method of five leaching beds using a multi-step technique

Day	Reactor 1	Reactor 2	Reactor 3	Reactor 4	Reactor 5
1–2	Stage 1	–	–	–	–
3–4	Stage 2	Stage 1	–	–	–
5–6	Stage 3	Stage 2	Stage 1	–	–
7–8	Stage 4	Stage 3	Stage 2	Stage 1	–
9–10	Stage 5	Stage 4	Stage 3	Stage 2	Stage 1
11–12	Stage 1	Stage 5	Stage 4	Stage 3	Stage 2

Stage 1: Acidification of grains (D rate = 2.1 d^{-1}), Stages 2 and 3: Acidification of vegetables and meats (D rate = 0.7 d^{-1}), Stage 4: Stabilization (D rate = 0.7 d^{-1}), Stage 5: Post-treatment

Downloaded from https://iwaponline.com/wst/article-pdf/424788/313.pdf
by guest

food waste. After 6 hr of acclimation, dilution water is provided to a leaching bed in order to transfer the acidified products to the UASB reactor. Dilution rate (D rate; d^{-1}) is defined as Q (flowrate of dilution water; l/d)/V (effective reactor volume; L). The proper control of dilution rate (2.1 → 0.7 d^{-1}), depending on the state of the fermentation, can eliminate environmental constraints in the fermentation (Shin *et al.*, 2000). Rapid acidification of grains in the early stage is likely to result in VFA accumulation and pH drop, and retards the degradation of other components (Han, 2001). Initial D rate (2.1 d^{-1}) is, therefore, relatively high to move produced VFA to the UASB reactor quickly. D rate, after 2 days, is lowered from 2.1 to 0.7 d^{-1} in order to increase retention time (from 0.48 to 1.43 d) for the enhanced degradation of vegetables and meats, which are not degraded at low retention time. Acidogenic fermentation of 8 days is reasonable considering operation time and efficiency (Song, 1995), which is followed by the post-treatment. The residues are dewatered in the leaching bed for 6 hr and then treated by blowing air at 15 L/min through the bottom of the reactor for 42 hr.

Materials and methods

Food waste was collected from a dining hall and then fed into the leaching bed after separating out clamshells, animal bones and other impurities. The distribution of grains, vegetables and meats in the waste was 41.8 ± 3.7, 48.1 ± 6.3 and 10.1 ± 3.8%, respectively. The moisture content, VS/TS and C/N of food waste were 80.0%, 0.95 and 12.6, respectively. Rumen microorganisms (1.8 L), obtained from the stomach of a cow, were inoculated into the leaching bed, while granular sludge (46 L) from an anaerobic plant treating brewery wastewater was seeded to the UASB reactor. The pH, VS/TS and alkalinity of inocula were 6.5, 0.63 and 4.0 g/L (as $CaCO_3$) for rumen microorganisms, and 7.8, 0.76 and 3.1 g/L (as $CaCO_3$) for granular sludge, respectively. The samples of the leaching beds and the UASB reactor were collected daily during the experiment. The composition of VFA and biogas was measured by HP 5890A gas chromatography (GC) and GowMac series 580

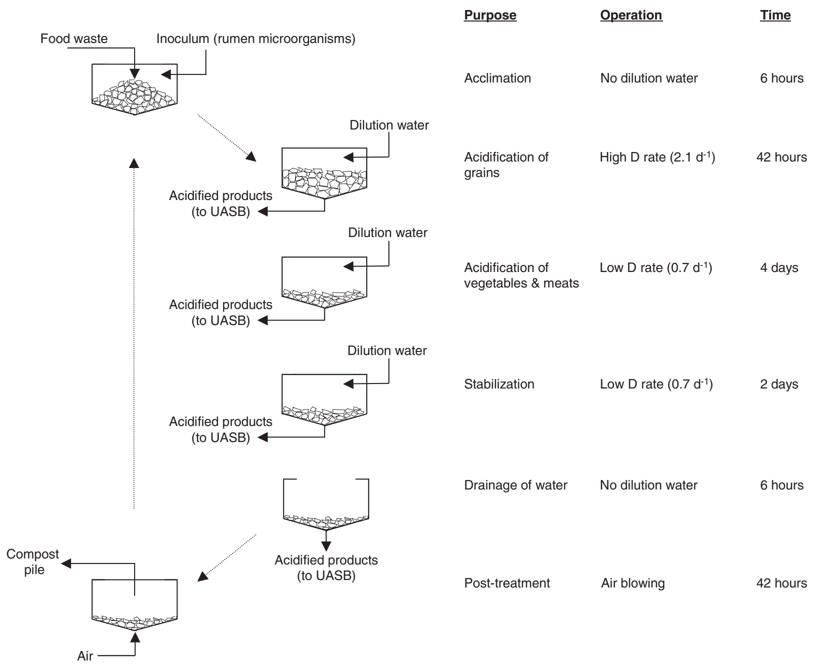

Figure 2 Operating method of a leaching bed using a sequential batch technique

Downloaded from https://iwaponline.com/wst/article-pdf/424788/313.pdf
by guest

Table 2 Operating conditions of the MUSTAC process

Item	Unit	Value
Acidogenic Fermentation		
Temperature	°C	37 ± 1
Organic loading rate	kg VS/m^3·d	10.9 ± 0.4
SRT	d	8
D rate	d^{-1}	$2.1 \pm 0.1 \rightarrow 0.7 \pm 0.1$
Methanogenic Fermentation		
Temperature	°C	37 ± 1
Organic loading rate	kg COD/m^3·d	7.8 ± 0.4
HRT	d	1.5 ± 0.1
Post-treatment		
Temperature	°C	20 ± 4
SRT (d)		2
Air flow rate (L/min)		15 ± 2

GC, respectively. Other parameters were determined according to *Standard Methods* (APHA, 1995). Table 1 shows the operating conditions of the MUSTAC process.

Results and discussion

Acidogenic fermentation

There were typically two increases in the VFA concentration of the leachate over the operation period due to the various components of food waste. In the initial stage, rapidly degradable grains were likely to cause VFA accumulation (over 200 mmol/L) and pH drop (below 5.0), which severely inhibited the acidogenic fermentation of food waste by rumen microorganisms (Song, 1995). Initial D rate was, therefore, controlled so that the pH of the leaching bed could be in the optimum range of rumen microorganisms (6.0–7.0) (Shin *et al.*, 2000). Figure 3 shows that initial VFA and pH were maintained in the range of

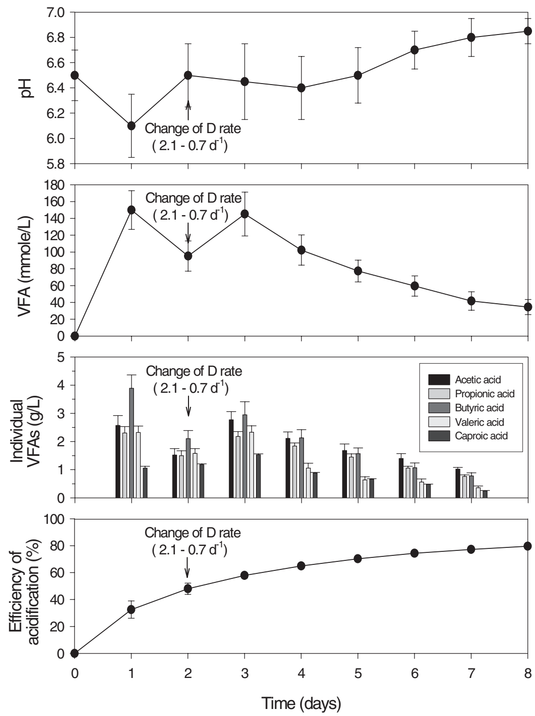

Figure 3 Performance of acidigenic fermentation

Downloaded from https://iwaponline.com/wst/article-pdf/424788/313.pdf
by guest

95–150 mmol/L and 6.1–6.5, respectively, at 2.1 d^{-1} in the first two days. The most abundant acid was butyric acid, indicating that the main reaction in the early stage was the degradation of grains (Han, 2001).

The reduction of grains after 2 days could cause the decrease of VFA production and the increase of pH (Shin *et al.*, 2000). It was reported that the degradation of cellulose increased with retention time, while protein decomposed faster with retention time and at neutral pH (Han, 2001). For this reason, D rate was reduced from 2.1 to 0.7 d^{-1} in order to improve the degradation of other components. Retention time increased from 0.5 to 1.4 days, and pH ranged between 6.5 and 7.0. These meant that the second peak of VFA concentration resulted from the enhanced degradation of vegetables and meats. Moreover, the production of acetic acid increased and then the most abundant acid shifted from butyric to acetic acid from day 5, indicating that protein and cellulosic materials were degraded efficiently (Han, 2001). Therefore, the control of theD rate, depending on the state of the fermentation, was effective in improving the low acidification efficiency.

The theoretical VFA of food waste was 4370.0 g COD (that is, 3800.0 g VS × 1.15 g COD/g VS), and the actual VFA produced in the fermentation on day 8 was 3516.1 g COD. Accordingly, the fermentation efficiency was 80.5%, which was higher than that (65.2%) using mesophilic acidogens (Song, 1995). This meant that the acidification efficiency could be improved by employing rumen microorganisms and controlling the D rate depending on the state of the fermentation.

Methanogenic fermentation

Table 3 shows the operating results of the methanogenic fermenter. The pH and alkalinity of the effluent were 7.9 and 3.4 g/L (as $CaCO_3$), respectively. The efficiency of chemical oxygen demand (COD) removal was over 97% at 7.8 kg COD/m^3·d. The process effluent was replaced with prepared dilution water by 40% once a month since day 60. This was intended to prevent the occurrence of inhibition and to minimize the generation of the effluent that required further treatment. The concentrations of total and free ammonia, and Na^+ in this study were maintained in the range of 520–905, 30–60, and below 1,700 mg/L, respectively, which were below the reported inhibitory concentrations (Han, 2001). The biogas production varied between 640.1 and 707.5 L/d. Methane content of 77.2% was recorded. The exhaust gas met the legal emission limits (MOE, 2001). Methane gas production rate was 2.31 m^3/m^3·d, while methane yield was 0.27 m^3/kg VS.

Post-treatment

Residues were treated in the same leaching bed without troublesome transferring. They were dewatered for 6 h and then composted by blowing air at 15 L/min through the bottom of the reactor for 42 h. Table 4 shows that VS reduction increased to 84.9%. The remaining acids in the residues were volatilised. Organic matter (OM), OM/N and heavy metal concentrations of the output met the Korean regulation standards of the compost as presented

Table 3 Performance of methanogenic fermentation

Parameter	Unit	Value
pH		7.9 ± 0.1
Alkalinity	g/L as $CaCO_3$	3.4 ± 0.2
COD removal efficiency	%	98.6 ± 1.2
CH_4 percentage	%	77.2 ± 1.6
CH_4 gas production rate	m^3/m^3·d	2.31 ± 0.14
CH_4 yield	m^3/kg VS	0.27 ± 0.01

Downloaded from https://iwaponline.com/wst/article-pdf/424788/313.pdf
by guest

Table 4 Characteristics of waste feedstock: before fermentation, after acidogenic fermentation and after post-treatment

Characteristics	Unit	Value		
		Input feedstock	Residues after acidification	Output after post-treatment
Moisture content	%	80.0 ± 5.3	86.2 ± 6.1	57.3 ± 8.1
TS	%	20.0 ± 5.3	13.8 ± 6.1	42.7 ± 8.1
VS/TS		0.95 ± 0.01	0.78 ± 0.02	0.70 ± 0.02
VS	g	3800.0 ± 215.8	742.2 ± 58.6	573.8 ± 37.6
pH		6.5 ± 0.2	6.9 ± 0.2	7.3 ± 0.2
VS reduction	%	–	80.5 ± 2.7	84.9 ± 1.9

Table 5 Output characteristics and the Korean regulation standards of the compost

Item	OM[a] (%)	OM/N	Heavy metals (mg/kg)					
			As	Cd	Hg	Pb	Cr	Cu
Standard	>25	<50	<50	<5	<2	<150	<300	<500
Value	28.9	8.2	ND	ND	ND	ND	ND	18.1

[a]organic matter

in Table 5 (MOAF, 2001), indicating that the output could be used for soil amendment. It improves the economics and the environmental benefits of this technology.

Mass balance

Figure 4 shows the mass balance of COD in the MUSTAC process treating food waste of 20 kg in 2 days (10 kg/d). Approximately 80.5% of input COD was recovered in the biogas of 0.67 m^3/d, of which the methane content was 77.2%.

Overall performance

Table 6 shows the performance data from various anaerobic processes. The MUSTAC process demonstrated excellent performance as it removed 84.9% of VS and converted 85.6% of BMP into methane at high organic loading rates (10.9 kg VS/m^3·d) in a short SRT (10 days). Methane gas production rate was 2.31 m^3/m^3·d. Biochemical methane potential (BMP) of food waste was 0.32 m^3/kg VS, while methane yield was 0.27 m^3/kg VS. Therefore, the methane conversion efficiency was 85.6%. These data were superior to those in other processes (O'Keefe *et al.*, 1993; Cho *et al.*, 1995; Han, 2001). The output

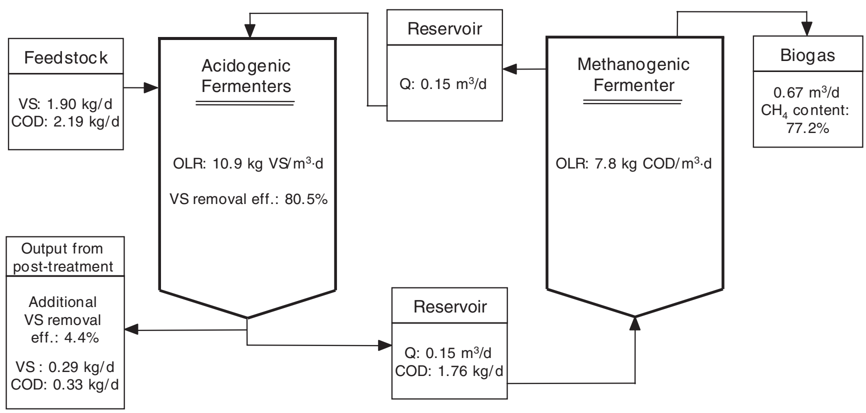

Figure 4 Mass balance of COD in the MUSTAC process

Downloaded from https://iwaponline.com/wst/article-pdf/424788/313.pdf
by guest

Table 6 Comparison of performance data from various anaerobic processes

Item	Value			
	MUSTAC	SEBAC	MSWAD	VALORGA
Operating conditions				
Temperature (°C)	37	55	37	37
OLR (kg VS/m^3·d)	10.9	6.4	3.4	13.7
SRT (d)	10	21	17	15
Operating results				
VS reduction (%)	84.9	36	89.8	45
CH_4 gas production rate (m^3/m^3·d)	2.31	1.02	1.22	2.6
CH_4 yield (m^3/kg VS added)	0.27	0.16	0.36	0.23
BMP (m^3/kg VS)	0.32	0.2	0.47	–
Methane conversion eff.* (%)	85.6	80.0	76.6	–

* the ratio of CH_4 yield to BMP

from the post-treatment could be used for soil amendment. The MUSTAC process proved stable, reliable and effective in resource recovery as well as waste stabilization.

Conclusions

- The MUSTAC process showed simple operation and high efficiency due to the combined methods of sequential batch operation and two-phase anaerobic digestion.
- Large VS reduction (84.9%) could be achieved by employing rumen microorganisms and controlling D rate depending on the state of the fermentation.
- Methane gas production rate was 2.31 m^3/m^3·d. The methane conversion efficiency was 85.6% from the ratio of CH_4 yield to BMP.
- The output from the post-treatment of residues met the Korean regulation standards for compost, indicating that the output could be used for soil amendment.
- The principal advantages of this process are: (1) the enhanced performance due to the rational configuration and the operating method of the process, (2) the elimination of instability that plagues single-stage digesters by separating the phases, (3) the simple operation by using batch reactors, (4) no need for agitation by employing the leaching beds, and (5) the ease of treating residues in a same reactor without the need for troublesome transfers.

References

Cho, J.K., Park, S.C. and Chang, H.N. (1995). Biochemical methane potential and solid state anaerobic digestion of Korean food waste. *Bioresource Technol.*, **52**, 245–253.

Han, S.K. (2001). *Bioenergy Generation and Leachate Treatment by Anaerobic Digestion of Organic Waste*. PhD Thesis. Korea Advanced Institute of Science and Technology, Taejon, Korea.

Ministry of Agriculture and Forestry (2001). Internet homepage of Ministry of Agriculture and Forestry. http://www.maf.go.kr.

Ministry of Environment (2001). Internet homepage of Ministry of Environment. http://www.me.go.kr.

O'Keefe, D.M., Chynoweth, D.P., Barkdoll, A.W., Nordstedt, R.A., Owens, J.M. and Sifontes, J. (1993). Sequential batch anaerobic composting of municipal solid waste (MSW) and yard waste. *Wat. Sci. Technol.*, **27**(2), 77–86.

Shin, H.S., Han, S.K., Song, Y.C. and Hwang, E.J. (2000). Biogasification of food residuals. *Biocycle*, **41**(8), 82–86.

Song, Y.C. (1995). *High-rate Methane Fermentation of the Organic Solid Waste*. PhD Thesis. Korea Advanced Institute of Science and Technology, Taejon, Korea.

Standard Methods for the Examination of Water and Wastewater (1995). 19th edn, American Public Health Association/American Water Works Association/Water Environment Federation, Washington, DC, USA.

Downloaded from https://iwaponline.com/wst/article-pdf/424788/313.pdf
by guest

Downloaded from https://iwaponline.com/wst/article-pdf/424788/313.pdf
by guest