0273-2289/99/77–79/0585/$12.25

Two-Phase Methanization of Food Wastes in Pilot Scale

JOON PYO LEE, JIN SUK LEE, AND SOON CHUL PARK*

Biomass Research Team, Korea Institute of Energy Research, 71-2 Jangdong Yusonggu, Taejon, Korea, E-mail: bmscpark@kier.re.kr

Abstract

A 5 ton/d pilot scale two-phase anaerobic digester was constructed and tested to treat Korean food wastes in Anyang city near Seoul.

The easily degradable presorted food waste was efficiently treated in the two-phase anaerobic digestion process. The waste contained in plastic bags was shredded and then screened for the removal of inert materials such as fabrics and plastics, and subsequently put into the two-stage reactors. Heavy and light inerts such as bones, shells, spoons, and plastic pieces were again removed by gravity differences. The residual organic component was effectively hydrolyzed and acidified in the first reactor with 5 d space time at pH of about 6.5. The second, methanization reactor converted the acids into methane with pH between 7.4 and 7.8. The space time for the second reactor was 15 d. The effluent from the second reactor was recycled to the first reactor to provide alkalinities.

The process showed stable steady-state operation with the maximum organic loading rate of 7.9 kg volatile solid (VS)/m^3/d and the volatile solid reduction efficiency of about 70%. The total of 3.6 tons presorted MSW containing 2.9 tons of food organic was treated to produce about 230 m^3 of biogas with 70% (v/v) of methane and 80 kg of humus.

This process is extended to full-scale treating 15 tons of food waste a day in Euiwang city and the produced biogas is utilized for the heating/cooling of adjacent buildings.

Index Entries: Anaerobic digestion; two-phase; organic wastes; pilot study.

Introduction

An anaerobic digestion process for food-waste reduction, while producing humus and biogas, has been developed. The process is optimized with regard to several special properties of Korean food wastes. Total amounts of municipal solid wastes (MSW) generated have been reduced in Korea after the source-sorting enforcement of recyclable by the government

*Author to whom all correspondence and reprint requests should be addressed.

since 1991. However, the generation of food waste was hardly reduced; the proportion of food waste in the disposable MSW was gradually increased from 28.5% in 1991 to 31.6% in 1995 *(1)*. Korean food waste has extremely high moisture and salt content, and it is not homogeneous because it is mixed with the other disposable wastes during collection.

When food waste is dumped into the landfill together with the other wastes, it creates odors and leachate that have the potential to pollute streams and underground water. The food waste become converted to methane, a greenhouse gas, and chlorinated hydrocarbon gases polluting the atmosphere around landfill sites. Moreover, Korea—highly urbanized and populated—confronts a shortage of landfill sites. Thus, the government decided to adopt incineration as the main treatment method. However, the high moisture in the food waste prevents effective incineration of wastes. Current incinerators require fuel oil as the combustion aid and the heat recovery is very ineffective with those low-heating-value waste streams containing moistened food wastes.

Anaerobic digestion is considered to be an alternative organic waste treatment in Northern Europe *(2)*. A number of processes using different operation temperatures, solid contents, and types of methanization reactors have been developed. Scores of full-scale plants are in operation, under construction, and in planning *(3)*. The anaerobic digestion of organic fraction of MSW has several advantages when it is integrated with the landfill or the incineration. Problems of landfill disposal of untreated food wastes can be substantially reduced. Heat recovery from incinerator would be much more efficient with low-moisture waste streams. Furthermore, energy is recovered from wet food wastes in the form of methane-rich biogas.

The presorted Korean food waste with 15–30% TS (total solid) shows high volatile solid (VS) content (84–99% of TS), and the ultimate methane yield of those are estimated to be about 0.47 m^3/kg of VS added. Thus the waste is adequate for anaerobic digestion. However, the waste is readily soluble and degradable to volatile fatty acids (VFAs) at the early stage of anaerobic digestion, resulting in a drastic pH drop that inhibits the initiation of methane fermentation without sufficient buffering capacity *(4)*.

Two-phase systems in various scale have been reported to treat refuse derived cellulosics *(5)*, the organic fraction of MSW *(6)*, market garbage *(7)*, and source-sorted organic fraction of MSW (SS-OFMSW). The latest bench-scale experiment with SS-OFMSW *(8)* showed clear advantages of two-phase system for the high biodegradability substrate such as SS-OFMSW, food waste, and so on. Based on experimental results on Korean food wastes, we reached a similar conclusion that the two-phase system is best because the single-phase anaerobic digestion is impossible with this easily degradable substrate *(4)*.

In this study, VFAs produced in the first reactor were fed to the second reactor for methane fermentation. The performance results are presented for this two-phase anaerobic digestion process of 3.6 ton/d scale, with the actual presorted food waste fraction of MSW collected from an apartment complex in Anyang city, near Seoul.

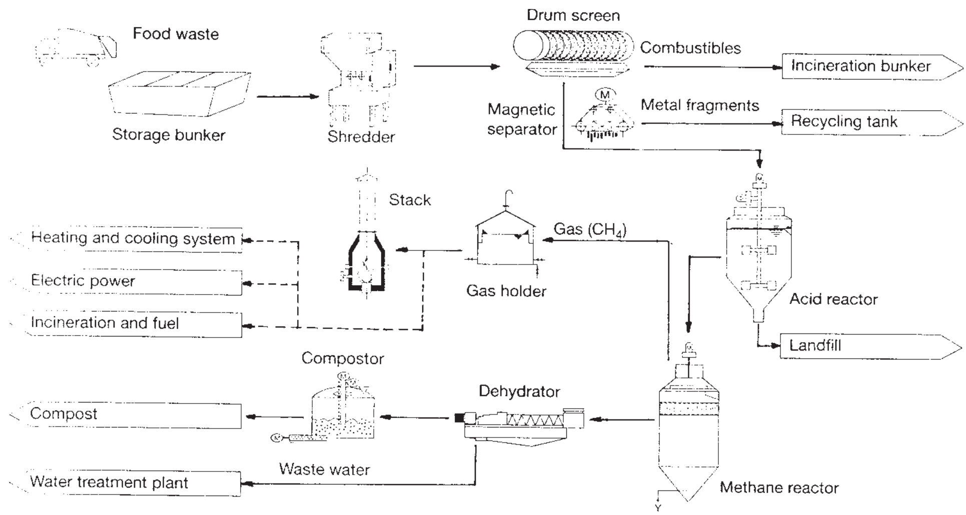

Fig. 1. Schematic diagram of 3.6 tons/d two-phase anaerobic digestion process.

The Process and the Substrate

Whole process consists of four different parts: pretreatment, anaerobic digestion, composting, and gas utilization, as shown in Fig. 1. The first section is the pretreatment step to separate the nondegradables. The food waste in plastic bags is dumped into a container from a collection truck. The waste is put into a shredder, and then moves through a 50 mm drum screen to reject coarse and light fractions such as pieces of plastic bags, cloth, and wood. Subsequently, a magnetic separator removes ferric components such as small pieces of steel. The downstream from the drum screen, which is mainly wet and fine organic fraction, is then fed into the acid reactor (AR).

The composition and properties of wastes as arrived to the plant is listed in Table 1. Those of wastes after the pretreatment (or AR input) is tabulated in Table 2. Although the pretreatment step removes large amounts of inert materials, substantial amounts of inerts still remain in the AR input.

The acid reactor where hydrolysis and acidification of food waste takes place is designed to function also as a separator in this process. The heavy inerts such as pieces of ceramics, glasses, bones, shells, and stainless utensils are settled down and removed from the mildly agitated (<20 rpm) AR. Some fractions of light inert materials that float on the top surface of the reactor are removed by a skimmer.

The pretreated food wastes that are uniformly suspended are hydrolyzed and degraded to VFAs in the AR. The fluid containing high concentration of acids is pumped into the methane reactor (MR) where the subsequent conversion of acids into methane takes place. Overflow of the MR with high alkalinity is recycled to the AR to prevent excessive acidification in the AR.

Table 1
The Composition and Properties
of Source-Sorted Food Waste Upon Arrival

Components	Wet weight (%)	Moisture content (%)	Dry weight (%)	VS (%)[a]
Food organics	65.4	77.6	54.6	89.9
Plastic bags	15.7	64.5	21.1	—
Fabric and papers	12.1	72.5	12.6	—
Bones and shells	2.9	53.7	5.1	—
Miscellaneous	3.9	56.1	6.6	—
Total	100.0	—	100.0	—

[a]Volatile solid (% of total solid [TS]).

Table 2
The Composition and Properties
of Source-Sorted Food Waste After Pretreatment

Components	Wet weight (%)	Moisture content (%)	Dry weight (%)	VS (%)
Food organics	75.4	77.3	66.2	89.9
Plastic bags	6.8	62.2	9.9	—
Fabric and papers	10.3	74.2	10.3	—
Bones and shells	3.6	53.7	6.6	—
Miscellaneous	3.9	52.7	7.0	—
Total	100.0	—	100.0	—

A portion of slowly degrading organic and anaerobic sludge is withdrawn from the bottom of the MR. The sludge becomes dehydrated in a screw press, and then fed to an aerobic composter, where it is further stabilized aerobically to produce the organic fertilizer. The biogas produced from both the MR and the AR is temporarily stored in a gas holder. The gas can be utilized for cooling/heating of adjacent facilities and for the electricity generation using adequate equipment such as absorption coolers, boilers, and gas engines, respectively.

Results and Discussion

The design and construction of an anaerobic digestion plant with the capacity of 3.6 tons of waste/d was completed in July 1996. After eight months of the test operation, the revision of the plant was commissioned for the steady operation in March 1997. Several unexpected problems were encountered during the test operation. Problems were mainly related to the large volume of unexpected foreign and inert materials in food wastes in the plastic MSW collection bag. For example, a large number of bottle openers and fresh intact fruit were not expected (intact fruit is difficult to be

Table 3
Material Balance of Two-Phase Anaerobic Digestion Pilot Plant

Material balance, average	Wet basis (kg/d)	Dry basis (kgTS)	Dry basis (kgVS)
Incoming waste	3,600	892	—[a]
Drum screen reject	–650	–164	—
AR input	(2,950)	(728)	(532)
AR reject	–774	–263	–87
Digested sludge	–1,733	–91	–71
Biogas	–443	–374	–374

[a]kg VS (volatile solid) data are not available for mixed MSW.

digested because of skin) at first. Mechanical problems such as clogging in the conveying line and hoppers were easily adjusted except for the AR bottom clogging by bridged heavy rejects such as stainless spoons, bottle openers, bones and shells, and so forth.

During the test periods, the feed composition of the plant was changed from MSW containing 50–60% food wastes to presorted food wastes containing approx 80% of food component. Those changes were made with the cooperation of the inhabitants providing the waste sample. It should be pointed out that the mechanical sorting of food-mixed MSW is very difficult. During the steady-state operation, the 5 tons/d throughput of food mixed MSW (50–60% food waste) was reduced to about 3.6 tons/d presorted food waste (80% food waste) to adjust the organic loading. Most of the problems were solved by using presorted food waste and by adjusting equipment to adapt to the new food-waste input upon commissioning.

Table 3 shows the material balance of the process during the steady state operation. As shown in Table 3, significant amounts of wastes containing food organic are rejected from both the drum screen (650 kg, 18.1% of incoming waste) and the AR (774 kg, 21.5% of incoming waste). These rejects are to be dewatered and then incinerated or disposed in the landfill. If the plastic bags are not used for food waste collection, the amount of reject will be reduced significantly. However, the law or rules cannot force the individual not to use plastic bags when handling food wastes.

The start-up operation to the steady state was accomplished within 3 wk by seeding 10% of the AR and 50% of the MR by volume with dilute sewage sludge of 3% TS taken from Anyang waste-water treatment plant and then increasing the organic loading gradually to the maximum The steady-state operation of the plant was monitored for 3 mo from March 1997.

Figure 2 shows the steady-state organic loading to the AR and MR. The biogas production during the same periods is shown in Fig. 3.

At the end stage of the steady-state run, the feed rate fluctuated and was insufficient; accordingly, the biogas production rate also fluctuated. However, any time the feeding was increased, the system reacted immediately, resuming biogas production. The methane content of biogas

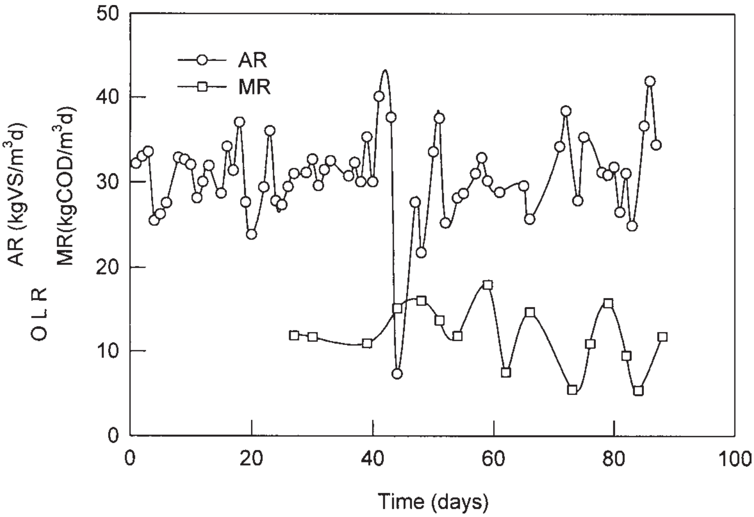

Fig. 2. Organic loading rate to the AR and MR.

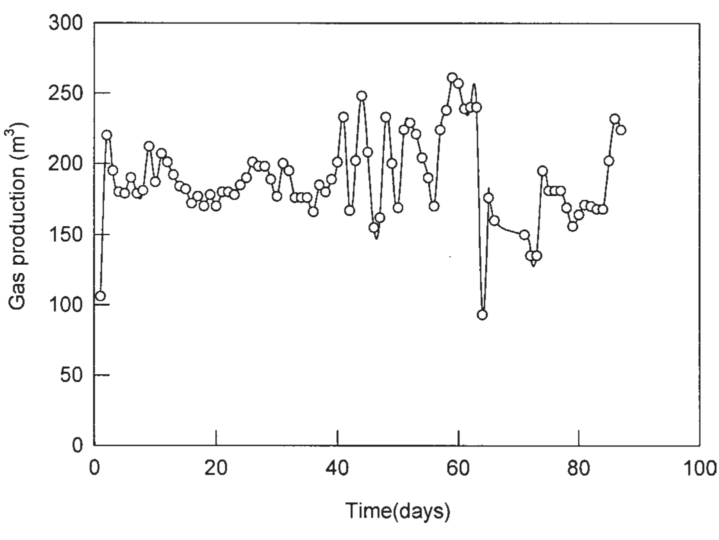

Fig. 3. Biogas production during steady-state operation.

remained constant between 60% (v/v) to 70% (v/v) all the time. This was a little higher than that from a conventional anaerobic digester, because only the biogas produced from the MR was collected. The AR gas containing about 15% of methane was discharged directly to the flare stack.

The main features of the process are listed in Table 4. The AR is a specially designed stirred-tank reactor equipped with an agitator and a skimmer. The agitator rotates slowly enough not to disturb the separation of the light and heavy materials in suspension. The conical bottom of the

Table 4
The Main Features of the Process

Reactors and process conditions			
AR volume, m^3, and pH	17.0		(5.5–6.5)
MR volume, m^3, and pH	58.0		(7.4–7.8)
Process temperature (°C)		35–38	
Loading AR reactor (kg VS/m^3/d)		25–35	
Loading MR reactor (kg COD/m^3/d)		10–15	
Overall organic loading (kg VS/m^3/d)		5.7–7.9 (Avg. 7.1)	
MR effluent recycling (m^3/d)		5.6	

Table 5
Performance of Two-Phase Anaerobic Digestion Pilot Plant

Biogas production (m^3/d)	236
Volumetric productivity (m^3/m^3 reactors/d)	3.2
Organic matter conversion (% of VS input)	70.3
TS in AR (%)	5–6
TS in MR (%)	3.5–4
Total VFAs in AR (mg/L)	9,000–13,000
Total VFAs in MR (mg/L)	4,000–7,000
SCOD[a] in MR (ppm)	25,000–35,000
Methane yield	0.44 m^3/kg VS
Humus production (kg 50% moisture)	80–100

[a]Soluble chemical oxygen demand.

reactor are also mildly agitated to prevent clogging of the bottom valves where heavy inert waste (e.g., stainless steel spoons, bottle openers, etc.) must be withdrawn through. The MR is an anaerobic biofilter with packing filled on the top one third of the reactor volume. This design was based on our previous study *(9)*.

The pH in the AR was changed to the large extent with the feed and process conditions, but it was maintained below pH 6.5. The pH in the MR was maintained fairly constant around 7.6 as shown in Table 4. This indicates that the two reactors maintained two-phase anaerobic digestion system in the steady state. The steady operation of two-phase reactor system was well-maintained by the MR effluent recycling because the pH of AR and the organic loading to the AR and the MR could be easily controlled by recycling. The AR to MR reactor volume ratio was determined for maximum performances based on the results obtained from the laboratory tests *(4)*.

Even though there were large fluctuations of the overall organic loading to the pilot-scale reactors (Table 4 and Fig. 2), the system maintained stability. This is one of the advantages of two-phase system with easily degradable biowastes *(8)*. Table 5 summarizes the performance of the pilot plant system.

From Table 5, it is shown that our result are comparable to the reported commercial process results of 3.0 m^3/m^3 reactors/d volumetric productivity of biogas and percent anaerobic conversion 45% *(10)*. The difference in the waste composition and characteristics between two-countries is believed to be the major reason for the higher conversion of this study. It should be pointed out that the pilot plant results followed closely the performance of our lab-scale process *(11)* except for the humus production. The humus production was expected to be about 180 kg (50% moisture)/d in this pilot scale based on the lab-scale data. However, the pilot-scale solid recovery from the MR effluent was not as effective as in the lab-scale experiments. Therefore, only 80–100 kg of humus was produced from the plant.

The VFAs content and SCOD in MR effluent were too high to treat directly by conventional waste-water treatment methods. However, since the volume of the MR effluent is estimated to be very small (smaller than 1.8 m^3 from the pilot plant) in comparison with the capacity of conventional waste-water treatment plant, the wastewater can be diluted into the public waste-water treatment plants or into the leachate treatment of incinerator plant.

Conclusion

A pilot-scale, two-phase anaerobic digestion system was investigated to treat the biowaste while recovering biogas. The anaerobic digestion proved to be an efficient and practical solution to treat Korean food wastes. The food waste was degraded most efficiently when the anaerobic degradation occurred in two-phases. The separation of acidogenic phase from methanogenic allows both stabilization of the process and improvement of the biogas production with easily degradable organic wastes such as source-sorted Korean food waste.

It was shown that the pretreatment of food waste—shredding and removal of inerts—was troublesome. Substantial amounts of inert and organic (39.6% [w/w]) are inevitably removed and sent to the landfill or incinerator. Thus, the food-waste collection scheme or pretreatment methods to reduce the reject from the digestion must be investigated further. A method to treat the waste water from MR effluent also needs to be developed for an anaerobic digestion plant isolated from waste-water treatment facilities.

The process showed stable steady-state operation with the maximum allowable organic loading rate of 7.9 kgVS/m^3/d and about 70% of the VS reduction efficiency. The total of 3.6 tons of presorted MSW containing 2.9 tons of food organic was treated to produce about 230 m^3 of biogas from 60% (v/v) to 70% (v/v) methane content and approximately 100 kg of humus.

Recently, the process has been extended to a full-scale operation, treating 15 tons of food waste/d in another city (Euiwang). The biogas is then utilized for the heating/cooling of adjacent buildings. Initial investment for this type of plant is estimated to be below $77,000/ton of food-waste treatment/d for a plant with a capacity of over 15 tons/d, excluding waste-water treatment. The operating cost/ton of food-waste treatment was estimated to be around $60/ton, without accounting for biogas and compost utilization credit.

Acknowledgments

This work was supported by a grant-in-aid from the Ministry of Industry and Resources of Korea and Halla Engineering and Heavy Industries Ltd.

References

1. Korea Ministry of Environment (KMOE) (1998), White Book of Environment, pp. 710–712.
2. Fouhy, K. (1993), *Chemical Engineering/May 1993*, 45–48.
3. International Energy Agency (IEA) (1994), Biogas from municipal solid waste, Technical Brochure (IEA Bio-energy Agreement Task XI; MSW conversion to energy ed.).
4. Cho, J. K., Park, S. C., and Chang, H. N. (1995), *Biores. Technol.* **52,** 245–253.
5. Ghosh, S., Henry, M. P., and Sajjad, A. (1983), Novel two-phase anaerobic gasification with solid-bed acid digestion in tandem with fixed-film methane fermentation. *Proc. Int. Gas Res. Conf.*, London, June 13–16, 1983.
6. Anderson, G. K. and Saw, C. B. (1992), *Proceedings of the Symposium on Anaerobic Digestion of Solid Waste,* Venice, April 14–17, 1992, pp. 171–179.
7. Chanakya, H. N., Borgaonkar, S., Meena, G., and Jagadish, K. S. (1993), *Biores. Technol.* **46,** 227–231.
8. Pavan, P., Mussaco, A., Battistoni, P., Mata-Alvarez, J., and Cecchi, F. (1996), in *Management of Urban Biodegradable Wastes*, Hansen, J.-A., ed., James & James Ltd., London, pp. 125–131.
9. Cho, J. K., Kim, B. S., Park, S. C., Choi, Y. S., and Chang, H. N. (1996), *Biomass Bioenergy* **10,** 1, 25–35.
10. Brinkmann, J. and Hack, P. J. F. M. (1996), in *Management of Urban Biodegradable Wastes*, Hansen, J.-A., ed., James & James Ltd., London, pp. 181–192.
11. Cho, J. K., Lee, J. P., Lee, J. S., Park S. C., and Chang, H. N. (1996), *J. Korean Solid Waste Eng. Soc.* **13,** 5, 616–624.