Pilot-scale Study of Horizontal Anaerobic Digester for Biogas Production using Food Waste

Yongsei Lee, Hyunsu Park, Youngseob Yu, Heechan Yoo and Sungin Yoo*

***Abstract*—**A horizontal anaerobic digester was developed and tested in pilot scale for Korean food waste with high water contents (>80%). The hydrogen sulfide in the biogas was removed by a biological desulfurization equipment integrated in the horizontal digester. A mixer of the horizontal digester was designed to easily remove the sediment in the bottom and scum layers on surface in the digester. Experimental result for 120 days of operation of the pilot plant showed a high removal efficiency of 81.2% for organic substance and high stability during the whole operation period were acquired. Also food waste was treated at high organic loading rates over 4 kg•VS/m3·day and a methane gas production rate of 0.62 m3/kg•VSremoved was accomplished.

The biological desulfurization equipment inside the horizontal digester was proven to be an economic and effective method to reduce the biogas desulfurization cost by removing hydrogen sulfide more than 90% without external desulfurization equipments.

***Keywords*—**Biogas, Biological desulfurization, Horizontal anaerobic digester, Korean food waste

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I. Introduction

THE average production of food waste in Korea is 15,000 tons per day in 2008 status quo, it reaches to 1/7 of total food quantity and daily production quantity is expected as 17,000 tons per day in 2012 [1]. In Korea, the more than 90% food waste has been converted to livestock feedstuff or compost since the landfill of food waste was prohibited in 2005. But the demands for feedstuff and compost made of food waste are very low due to the low quality and poor sanitary condition. In addition, there is a problem of producing secondary contaminant, wastewater or leachate of food waste during the process of making the resources [2]. On the other hand, food waste has a potential of remarkably high production of biogas compared with other organic waste resources such as livestock wastewater and sewage sludge, because its organic substance contents and degradation efficiency are usually much higher. However, it is more difficult to treat Korean food waste with anaerobic digestion due to the high loading rate of organic substance, low pH with very high organic acids contents, high nitrogen content, high salt and fat concentrations. Therefore, development of efficient and stable treatment technologies for food waste using anaerobic digestion was urgently required in Korea as a promising alternative for the traditional recycling methods of food waste.

The anaerobic digestion is a series of complex and symbiotic microbial processes to produce methane and carbon dioxide finally through the hydrolysis, acidogenesis, and methanogenesis by various groups of microorganism. Anaerobic digestion processes are classified into wet type and dry type processes depending on the solid concentration of raw material or contents inside the digester. The wet type process adopting wastes usually within 10% of solids contents as a base was the main system until the middle of 1980s, but the dry type process digesting more than 20% of wastes in its solid contents has been developed rapidly since 1990s in EU [3].

The dry type anaerobic process has an advantage of minimizing wastewater production because it is not required to add water for dilution to reduce high organic loads of food waste. The thermal energy to maintain a designed temperature of the dry type digester is far less than the wet type process as it treats smaller volume with high concentrations of organics [4]. As commercialized dry type anaerobic digestion processes, DRANCO process [5], VALORGA process [6], and KOMPOGAS process [7] are representative. These processes usually treat solid wastes (TS > 20%) such as agricultural remainings, urban solid wastes and sludge cakes mainly in Europe and other countries with Western living environment. So, there were some difficulties to treat Korean (and Asian) food wastes with higher contents of water, fat, and salts.

Accordingly, we developed a horizontal anaerobic digester and operated in pilot scale to treat Korean food waste efficiently and stably in consideration of characteristics of waste. Also, to decrease equipment and operation costs for external desulfurization facilities, a biological desulfurization equipment was installed on whole wall above surface inside the digester. For the removal of hydrogen sulfide in biogas, only air is added to the headspace of the digester.

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II. Materials And Methods

A. Characteristic of Substrate and Microorganism Seeding

The pilot plant was constructed at a food waste recycling company in Ansung-city, Korea to receive food waste easily. The crushed and sorted food waste in the recycling company was pumped through pipes and it was stored in a storage tank of the pilot plant. The maximum hydraulic retention time (HRT) of the storage tank was not over 3 days. The food waste in the storage tank was added to the horizontal digester every 6 hours (4 times per day) and the same quantity was discharged from the horizontal digester to an effluent tank when the food waste was added. The average characteristics of input food waste was shown in table I.

Sludge of anaerobic digesters and dehydrated sludge cake from Ansung sewage treatment plant and cow manure from a livestock farm were mixed and used for seed materials of the horizontal digester. The concentration of seeding sludge was 2.8% for TS, pH 7.5, and 9,250 g as $CaCO_3$/L for alkalinity.

TABLE I
CHARACTERISTICS OF FOOD WASTE USED IN THIS STUDY

Parameters	Food-waste
pH	4.3 (0.36)
Alkalinity (mg/L)	
Total organic acid (mg/L)	10,315 (689)
TS (mg/L)	199,047 (11,641)
VS (mg/L)	165,088 (4,235)
SS (mg/L)	127,498 (4,709)
CODcr (mg/L)	234,959 (37,181)
TN (mg/L)	7,433 (1,344)
NH_4 (mg/L)	1,128 (170)
TP (mg/L)	2,537 (352)

( ) : standard deviation

B. Horizontal Digester

The horizontal anaerobic digester has a total volume of 15 m^3 (working volume of 12 m^3) and the section of lower part of the digester was round-shape to avoid sludge precipitation in the dead space (Fig. 1). A device for removing the sediment was equipped in the bottom of the digester and the media for attachment of sulfur-oxidizing microorganisms was installed on whole wall above surface inside the digester to greatly enhance the biological desulfurization. The vertical impellers on a horizontal axis were designed to mix waste inside and remove scum on surface in the digester. The agitating speed was adjusted at 4 rpm.

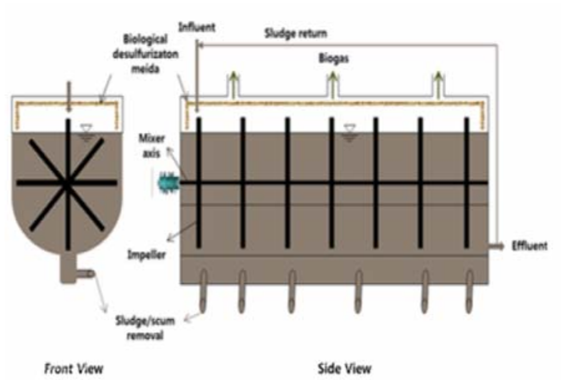

Fig. 1 Schematic diagram of the horizontal anaerobic digester

C. Operation Condition

The storage tank was not heated to prevent excessive acidification and aerobic decomposition, but the horizontal digester (15m^3, working volume 12m^3) was maintained at 37-38 ℃. No chemical for adjusting pH was added in the digester. Food waste of 120 L/day, HRT of 100 days, was added for initial 11 days of operation. Until the next 25 days of operation, 220 L/day (HRT 55 days) of food waste was added. Then, influent amount was increased to 300 L/day (HRT 40 days) for the third period and to 350 L/day (HRT 34 days) for the last period. All the input amounts were divided by 4 and added to the digester with 6 hours of interval. The produced biogas was stored in a membrane type gas storage bag (biogas holder) through the biological desulfurization equipment installed inside the horizontal digester to remove hydrogen sulfide and water-trap for the removal of moisture (Fig. 2). Stored biogas was used for heating the horizontal digester using a biogas boiler and remained biogas was discharged into the air. Media was installed in headspace of the reactor for easy attachment of desulfurization microorganisms which oxidized hydrogen sulfide in biogas by injecting air. Plant operation was also monitored and controlled through internet.

The pH, alkalinity, TS, VS, SS, CODcr, TN, NH_4^+ and TP were measured according to the standard methods for the examination of efficiencies of the horizontal digester treating food waste.

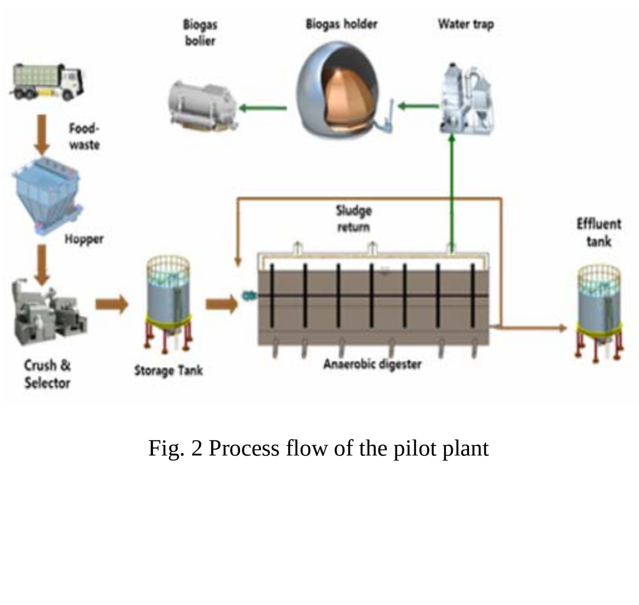

Fig. 2 Process flow of the pilot plant

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III. Results And Discussion

A. Horizontal Anaerobic Digester

The changes of alkalinity, total organic acid, and pH depending on HRT were shown in Fig. 3. The influent was increased gradually during the operation period and the HRT of the digester was changed to 100 days, 56 days, 40 days, and 34 days accordingly. Average values of pH and total organic acid content were 7.97 and 740 mg/L, respectively. These parameters were maintained during the total operation period with a small deviation. The alkalinity was increased above 25,000 m/L from about 10,000 mg/L in the initial. All of these parameter indicated that a high stability was maintained in the digester treating food waste during the whole operation period.

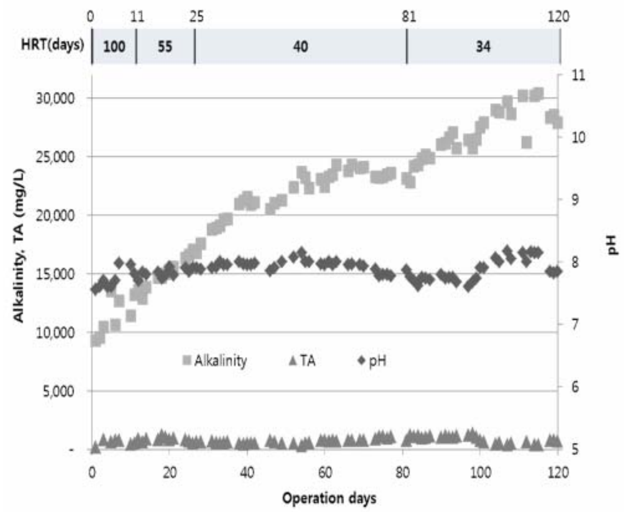

Fig. 3 Changes of alkalinity, total organic acid, and pH

The removal efficiency of organic materials was shown in Fig. 4 through measuring TS and VS of influent and effluent with operation time. The averages for TS and VS concentrations of influent were 199,047 mg/L, 165,088 mg/L, respectively. In the summer season (after 70 day of operation), however, TS and VS of raw food waste decreased by about 15%. The organic loading rate was 4.1 kg•VS/m^3•day for the period of HRT 40 days and 4.3 kg•VS/m^3•day for the period of HRT 40 days. The removal efficiency of organic materials was 81.2% at the HRT of 40 days and 73.7% at the HRT of 34 days. About 10% reduction of the removal efficiency would be caused by the decrease of HRT and a higher content of cellulosic organics in food waste due to a seasonal dietary condition of Korea.

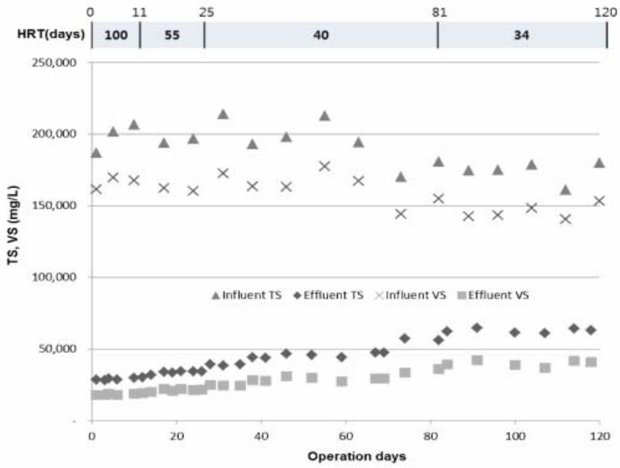

Fig. 4 Changes of solids (TS and VS) contents in influent and effluent

The concentration changes of total nitrogen (T-N) and NH_4^+-N of influent and effluent were shown in Fig. 5. For the influent, only about 15-20% of T-N was NH_4^+-N. On the other hand, around 75% of T-N was NH_4^+-N in the effluent for the latter half period of operation. This indicated that most of organic nitrogen in the influent was converted to inorganic nitrogen as most of organic material was decomposed in the digester. Generally, the nitrogen is not removed through the anaerobic digesting process but only biochemical forms of nitrogen are changed. For the latter part of operation, NH_4^+-N concentrations in the digester were about 6,000 mg/L. Free ammonia concentrations for this period would be about 600 mg/L because about 10% of NH_4^+-N concentration exists in the form of free ammonia at this digester condition, pH 8 and 37. Although the 600 mg/L of free ammonia is known to be above toxic level for anaerobic digestion, any inhibitory effect was not found in this study.

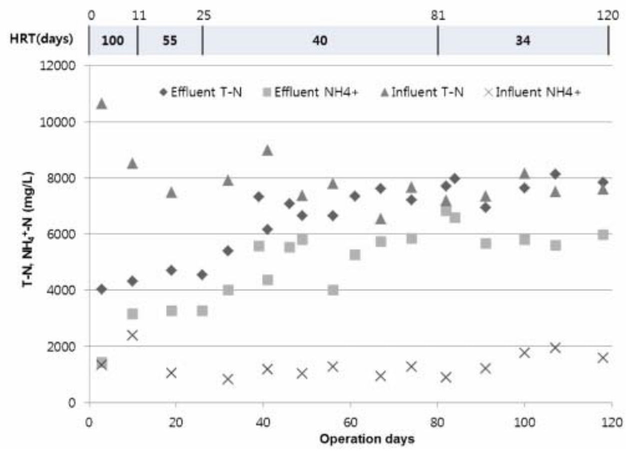

Fig. 5 Changes in concentrations of T-N and NH_4^+-N

B. Biogas and Biological Desulfurization

The biological desulfurization equipment was installed inside the digester and used to remove hydrogen sulfide in biogas in this experiment. While many conventional cylindrical digesters have a similar biological desulfurization equipment inside the digester, few horizontal digesters have this

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equipment. The average concentration of hydrogen sulfide for the first half part of operation before injecting air in the biological desulfurization equipment inside the digester was about 1,700 mg/L, but its concentrations were started to decrease by biological desulfurization activity (Fig. 6). After 90 day of operation, hydrogen sulfide concentrations were maintained at around 100 mg/L without any other treatments. This level of hydrogen sulfide is low enough for the operation of most generators without further pretreatment. We activated biological desulfurization by injecting only 3-5% air of biogas volume produced.

Methane contents of biogas produced from the digester were in the range of 60-70% with an average of 65% during the total operation period.

The biogas production from the digester during the experimental period was shown in Fig. 7. The production of biogas increased consistently and reached to about 40 m^3/day just after the beginning of the third period of operation at HRT 40 days. The daily production of biogas decreased as organics contents reduced in the summer season after 60 day of operation, which was described above (Fig. 4). With the increase of organic loading rate (decrease of HRT), however, the daily production of biogas increased to about 38 m^3. The biogas production rate was 0.97 m^3/kg•VSremoved for the period of HRT 40 days and 0.99 m^3/kg•VSremoved for the period of HRT 34 days. With the consideration of methane contents in biogas, the methane production rate was 0.62 m^3/kg•VSremoved for HRT 40 days and 0.65 m^3/kg•VSremoved for HRT 34 days.

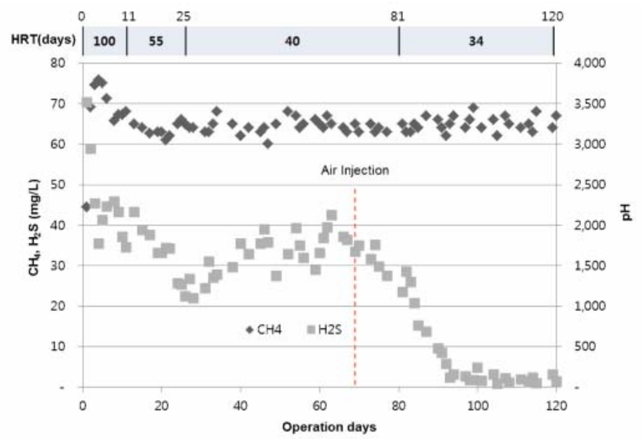

Fig. 6 Changes in methane and hydrogen sulfide concentrations

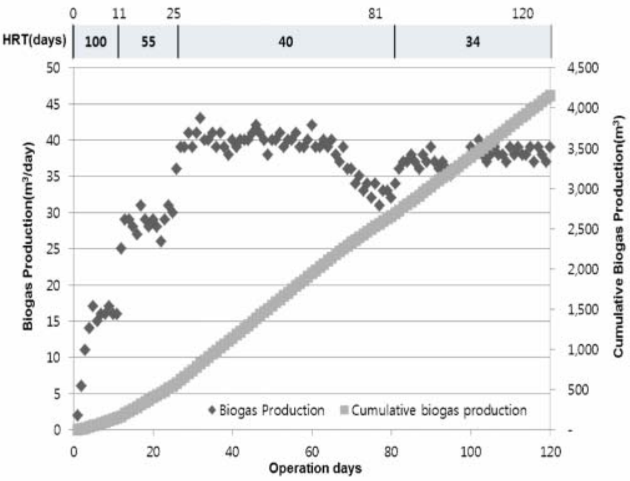

Fig. 7 The daily and cumulative biogas productions during the total operation period

IV. CONCLUSION

The treatment of Korean food waste using the horizontal digester developed in this study was successful and all parameters and factors analyzed indicated high efficiency and stability of this digestion system. The following conclusions were obtained.

1) The horizontal digester developed in this study was highly efficient and stable by the effective mixing, minimized precipitation and removal of sediment in the bottom, and easy removal of scum.

2) The horizontal digester treated food waste at high loading rate more than 4 kg•VS/m^3•day and accomplished methane gas production rates of 0.62-0.65 m^3/kg•VSremoved at HRTs of 40-34 days.

3) The biological desulfurization equipment inside the digester removed more than 90% of hydrogen sulfide and it was thought that this equipment could be an economic alternative for saving the desulfurization cost of biogas.

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