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Biogas Production from Dining Hall Waste and Landfill Leachate in a Two Stage R&D Facility

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Abstract

Taking into consideration recovery of dining hall waste from university cafeteria and nutrient reduction of landfill leachate, they were mixed at a temperature of 36±1°C and for a period of 90 days in a two stage biogas production R&D facility with a total volume of 5m^3, and then experiments were done. Experiment-I was performed to engage the second digester as a priority, and Experiment-II was performed to engage the first digester. After the required bacteria formation was ensured, the first digester was daily fed with mixture of dining hall waste with 10% solid matter content and landfill leachate weighing 167 kg in total regularly feeding in Experiment-III. Analyses and measurements of total solids (TS), total volatile solids (TVS), C% and N% percentages, pH, volatile fatty acid (VFA) and inhibitive of the organic waste samples were measured from the feedstock, digesters, and fertilizer tanks. In addition, daily biogas samples were taken and concentrations of CH_4(%) with mass flow rate of the biogas were measured. The results showed that in case dining hall waste and landfill leachate was mixed, the first digester worked at pH values of around 4.5–5.5 and performed the task of hydrolysis and acidification. The second digester performed the task of bio-methanation successfully.

1. Introduction

In developed countries, there has been an increased interest in the improvement of technologies for harnessing renewable energy sources such as biomass either directly or through conversion routes [1]. Valorization of biomass with electricity production or, even better, with cogeneration of heat and electricity are major contributing approaches to sustainable development [2]. Millions of tons of industrial, agricultural and domestic organic waste o are attempted to be decomposed by burying systematically or nonsystematically, transformed into fertilizer by composting or disposed of by burning every year around the world. Organic waste buried non-systematically causes soil and water pollution to a large extent. At the same time, the emerging gas products cause air pollution and global warming [3–5]. During the decomposition of one ton organic solid matter, about 50- 110 m^3 carbon dioxide (CO_2) and 90-140 m^3 methane (CH_4), are released into the atmosphere [6]. CH_4 has thirty times more effective on global warming at a molecular scale compared to CO_2 and its half-life is longer than other gases [3]. Anaerobic digestion process is applied to dispose of this type of organic waste without harming the environment [7]. Anaerobic digestion is a process where complex organic materials are transformed into volatile fatty acids by acid bacteria after the hydrolysis stage, and later to methane gas by methanogen bacteria. Methane fermentation is a complex process, which can be divided up into four phases: hydrolysis, acidogenesis, acetogenesis/dehydrogenation, and methanation. Hydrolytic bacteria bring about initial degradation of complex biopolymers such as cellulose, hemicelluloses, proteins and lipids into dicarboxylic acids, volatile fatty acids (VFAs), ammonia, carbon dioxide, and hydrogen. Methanogenic bacteria which play a key role in the terminal step of anaerobic digestion use only a few compounds like acetate, methanol, methylamine, hydrogen and carbon dioxide [8]. Successful applications of anaerobic technology depend on anaerobic digesters to a large extent [9–11]. In recent years, a series of new digester designs

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continue to be developed and an effort is made to advance from single-stage digesters to two-stage digesters [12]. In two stage biogas production facilities, it is possible to obtain high amounts of stable gas even in high loading ratios and realize production in higher efficiencies compared to that in single stage systems stated in their experimental studies that two stage systems are advantageous compared to single stage systems for domestic waste [13]. For these important reasons, it is foreseen that two stage biogas production systems will become widespread in industrial facilities soon [14]. For two stage systems to be preferable, more experimental studies must be performed, the ease of operation must be ensured and the investment costs must be lowered. Considering these facts, a two stage biogas production R&D facility able to work at actual conditions was designed, produced and installed by Kocaeli University together with the biogas working group of İzaydaş, 100% Kocaeli Metropolitan Municipality participation. . This facility has been developed continually, and biogas production test studies have been conducted with various organic waste. In the studies performed, considering that methane formation process was very slow compared to fast formation of especially volatile fatty acids, the volumes of first digester 1.2 m^3 for hydrolysis and acidogen section, and second digester 3.8 m^3 for methanogen section were foreseen. The total system volume was maximum 5 m^3; when needed, digesters can be operated under the specified volumes, and most suitable operational volumes and hydraulic retention times of both digesters, contents of the used organic material can be determined and adjusted according to operation analyses.

2. Working Method of the Two Stage Biogas Production R&D Facility

The schematic drawing of R&D-purpose two stage biogas production facility consisting of 1.2 m^3 first digester (for hydrolysis and acidification process) and 3.8 m^3 second digester (for the methanation process) is shown in Fig. 1. Disintegrator (1), feed mixer (2), stone, metal, glass retentive filter (4), first digester (3), second digester (5) and organic fertilizer storage tank (7) are connected serially to each other. (8: Gas pipeline, 9: Filter, 10: Gas engine and generator, 11: Main pipelines, 12: Electric control panel)

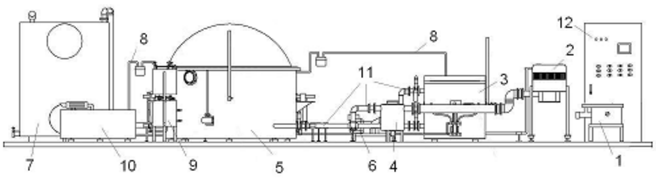

Figure 1. The schematic top view of biogas R&D facility.

The organic materials broken into small parts in the disintegrator were loaded into the feed mixer unit. Water requirement of the organic material loaded into the feed mixer was determined based on analyses and water or wastewater is automatically added into the feed mixing unit in the needed amount, and mixing is performed for certain duration. The product prepared in the feed mixer to be sent into the first digester is passed from the stone, metal, glass retentive filter, and the related pipes and valves on them are opened by the automation system for certain duration to ensure the daily feeding amount, the transfer pump is operated, and the product is transferred to the first digester. After completed the hydrolysis and acidification phases in the first digester, the product is transferred from the first digester to the second digester by means of the transfer pump by opening the related valves in the same amount again. The mixture is used by methane bacteria in the second digester for a longer retention duration and sent to the organic fertilizer storage tank by means of the related valves and transfer pump, and the biogas production process is completed. During the operation, the speed of mechanical mixing of digesters were set by the automation system. Heating system of both digesters operates with hot water passed inside heating pipes embedded within the concrete wall. In the case of any failure occurs in the heating system, concrete serves as thermal accumulator, and the energy stored within the concrete makes for energy losses of the system until the failure is rectified. Biogas is produced continuously within the first and second digester, and the biogas line is connected serially. Biogas coming from the first digester to the second digester combines with the gas produced in the second digester and sent into the gas cleaning unit. In this section, the H_2S, other toxic constituents and water vapor in the biogas are retained and cleaned. For power generation, biogas is sent into the internal combustion engine and thus the engine and generator are operated. With the cooling water of the water-cooled gas engine, temperature of the digesters is kept fixed by means of the automation system.

3. Experimental Study and Results

The experimental study was conducted by using the continuous feed method. Experiments were lasted with the organic materials which can be seen in Table I for 90 days. The first two phases were aimed at engaging, while daily feedings were performed with various mixtures in the subsequent three phases. Due to experimental studies conducted successively, a two stage R&D purpose experiment system was used. Second digester engaging phase took 35 days, and first digester engaging phase operated during 16 days. In subsequent phases, hydraulic retention period of the first digester took 6 days, and that of the second digester took 19 days, and experiments were conducted with different materials and mixture ratios at three separate phases. In experiment III, mixture of dining hall waste and landfill leachate were fed during 29 days. In the two stage R&D facility, in all phases of the experimental study, both digesters were operated at a mesophyllic temperature of 37 ±0.1 ºC. Solid matter percentage of organic waste and landfill leachate were measured by drying with the humidity device at 105 ºC, and that of volatile organic materials were measured by burning at 550 ºC until the solid matter reaches fixed weighing for three hours, from the resulting amount of missing matter. Volatile fatty acids, total kjedhal nitrogen (TKN), ammonium, phosphate, sulphate, sulfide, nitrate and nitrite were analyzed with the Hach-Lange DR 5000 UV/VIS spectrophotometer, and metal and other trace elements with the 7500 CX, ICP-MS device. Samples were taken every day both in the first fed product and the first and second digesters, and once a week from the organic fertilizer storage tank and the total volatile fatty acid amount in the daily period, and variations of inhibitors and trace elements in the weekly period were tracked. Moreover, the amount of biogas produced was measured with biogas flowmeters, daily gas concentration [CH_4(%), CO_2(%), O2(%), N_2(%), CO(ppm), H_2S(ppm)' and LEL(%)] with portable gas data LMS XI multifunction gas analyzer.

3.1. pH Change in the First and Second Digester

pH level of feeding products prepared in amounts 200 kg (mixture of 99 kg dining hall waste and 101 kg leachate), both digesters were measured regularly every day, and the obtained results are given in Fig 2.

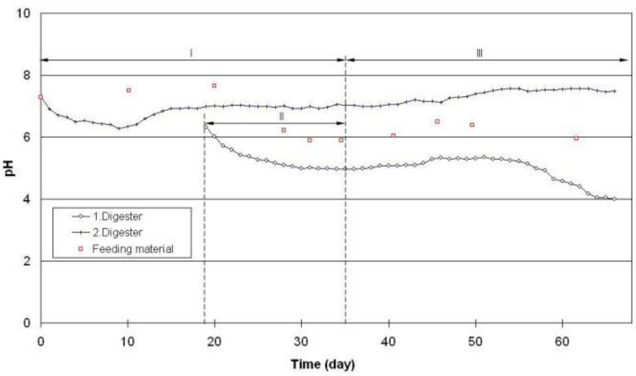

Figure 2. pH change in the feed material and the materials within the first and second digesters.

The pH in the second digester engaged initially with cow, chicken fertilizer, tripe interior, landfill leachate mixture wa ere measured as 7.3 on the first day. This value dropped rapidly to as low as 6.3 at the end of the 9 days, and afterwards, with the increase in methanogen bacteria, started to increase after day 11. In the first digester engaged on day 19, similar to the second digester, first digester pH value dropped rapidly in the beginning; on day 39, in order to slow this drop, feedback was done from the second digester with a pH value of 7 to the first digester. After day 35, when the pH decrease process of the first digester ended and the pH value became stable, 200 kg organic material was loaded regularly every day with dining hall waste and landfill leachate mixture. Beginning from day 35, when daily feedings began, it was observed that pH value of the material within the two digesters. In the engaging phase, average pH was around 5.2 in the 1st digester and 7 in the 2nd digester, respectively. As a result of experiments, it was seen that acidogen bacteria within the first digester in which the hydrolysis and acidogen process occurred produced volatile fatty acid at a pH of about 4– 5.

3.2. Volatile Fatty Acid (VFA) Concentration

Volatile fatty acids in the product within the first and second digesters were measured continuously during 65 days and obtained results are given in Fig. 3.

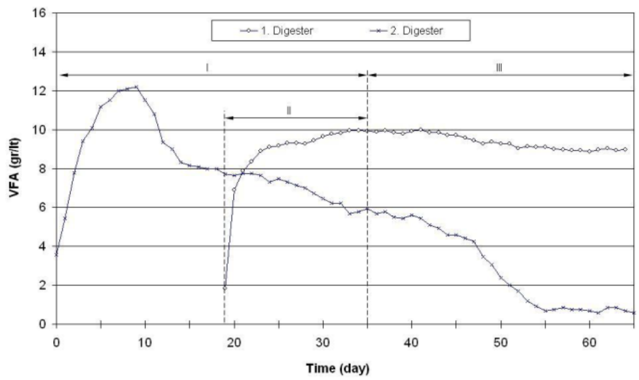

Figure 3. Volatile fatty acid change of the first and second digesters.

As explained above, volatile fatty acid of the product loaded into the second digester engaged first was initially measured as 3.5 g/l. In the first days when the experiment began, acidogen bacteria multiplied and volatile fatty acid value increased within the second digester. In the graphic given in Fig.3, volatile fatty acid amount of the second digester was maximum at 12 g/l on day 9. As numbers and activity of methanogen bacteria increased, so did their acetic acid consumption, and thus the volatile fatty acid value started to decrease. On day 19, initial loading of the mixture given in Table I into the first digester was done gradually. Because of the tripe interior material in the loading menu, it was observed that while pH dropped within the first digester, volatile fatty acid value increased rapidly.

Depending on the properties of dining hall waste and landfill leachate fed as part of the third experiment, it was seen that volatile fatty acids dropped from 10 to 9 g/l slowly in the first digester, and dropped from 6 to 0.5 g/l rapidly in the second digester. In summary, the first digester served as acidifier, and the second digester served as methanizer.

3.3. Methane Production in the First and Second Digesters

In the first digester engaged 19 days after the beginning of experimental study, as a result of the acidogen activity, high rates of CO_2 and volatile fatty acid formation, and low rates of methane formation occurred.

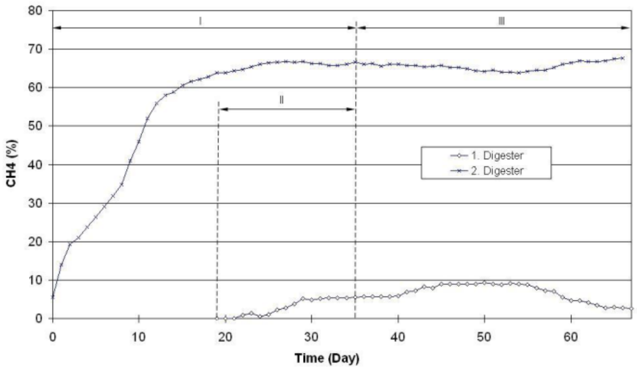

Figure 4. Methane percentage of biogas produced of first and second digesters.

It can be seen in Fig. 4 that on day 45 of the experiment the methane gas in the first digester reached its maximum value of 9 percent. Owing to the activity of acidogen bacteria in the first digester and unsuitability of pH value of the environment for methanogen bacteria, methane bacteria could not be engaged in sufficient activity, and in the subsequent periods of the future, methane was produced at an average level of 2%. The first digester worked for hydrolysis and acidification. In the second digester, naturally, as a result of acidogen activity at the beginning of experiments, high ratios of CO_2 formation was observed, methane gas started to increase rapidly on 8th day, CH_4/CO_2 ratio surpassed 50% on day 12 and reached 68% on day 26. The experiment phase in III, feeding was performed daily from day 35 to day 65 with the loading menu consisting of dining hall waste and garbage seepage water. Methane content of the 29-day biogas production process is 65% on average.

3.4. Daily and Total Biogas Amount Produced in the First and Second Digesters

Daily biogas (methane) production of the first digester seen in Fig. 5 was 0.9 m^3/day (3% CH_4) on average between day 19 and day 35, 2.6 m_3/day (8% CH_4) on average between day 35 and day 65, and 0.9 m3/day (3% CH_4) in the experiment.

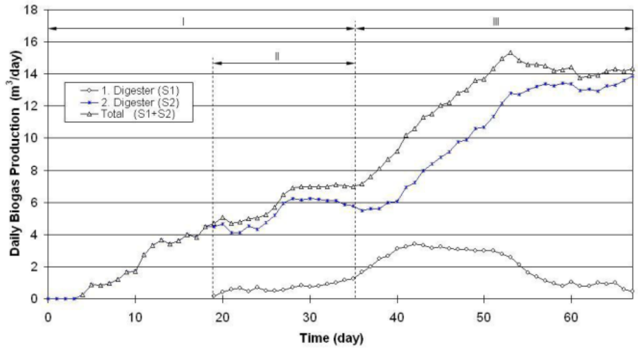

Figure 5. Daily biogas production of the first and second digesters.

Biogas production was 4 m^3/day (51% CH_4) on average from day of engaging the second to day 35; 13 m^3/day (66% CH_4) on average, from 36th day, when daily feeding with dining hall waste and landfill leachate mixture started.

Biogas amounts produced in both digesters were measured separately for 65 days and obtained results are given in Fig. 6. Accordingly, at the end of 65 days, 75 m^3 in the first digester, 389 m^3 in the second digester, and a total of 464 m^3 was produced from the two stage biogas system.

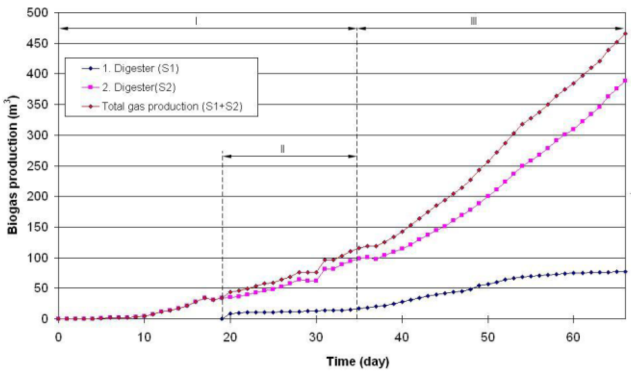

Figure 6. Total biogas production of the first and second digesters.

4. Conclusions

Storage of organic waste is a costly method with its environmental impacts. Biogas production with anaerobic digestion, one of the applicable methods for recovery, has been very important since biogas has a status of renewable energy resource and ensures recycling. Obtaining the landfill leachate that may be needed for using organic waste by decomposing in anaerobic digester from regular storage areas continuing to form landfill leachate will lower purification costs. To this end, various organic materials with non-homogenous feeding conditions, such as dining hall waste, and landfill leachate were mixed and experiments were conducted in the two stage R&D experiment system. As a result of the experiments, it is highly possible to produce biogas by mixing various organic products and landfill leachate in two stage systems. In this process, the first digester served as acidifier, and second digester served as methanizer successfully.

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