Production of Biogas by Anaerobic Digestion of Food Waste and Process Simulation

Faisal Kader[*], Abdullah Hil Baky, Muhammad Nazmul Hassan Khan, Habibullah Amin Chowdhury

Islamic University of Technology, Gazipur, Bangladesh
*Corresponding author: mfaisaliut@yahoo.com

Abstract Anaerobic Digestion is a biological process that takes place naturally when microorganisms break down organic matter in the absence of oxygen. In an enclosed chamber, controlled anaerobic digestion of organic matter produces biogas which is predominantly methane. The produced methane then can be directly used for rural cooking; or after certain conditioning, can be used in onsite power generation, heating homes or as vehicular fuel. Besides, food waste is increasingly becoming a major problem in every society imposing serious economic and environmental concerns. For this reason, many contemporary researches are emphasizing in finding sustainable solutions to recycle and produce energy from such waste. In this context, this paper aims to study and optimize the production of biogas from food waste (rice). For the experiment, an existing wet digestion biogas plant installed in Islamic University of Technology was used. The food waste (rice) for the research was collected from the cafeteria of Islamic University of Technology. Furthermore, a process simulation was performed by PROII software to estimate the methane production rate. Eventually, the simulated and experimental results were compared. The duration of the study period was 120 days. The experimental results showed that an average specific gas production of 14.4 kg-mol/hr can be obtained for 0.05 kg-mol/hr of starch loading rate. In case of the simulated results, the gas production was found to be 19.82 kg-mol/hr for the same loading rate of starch. The percentage of methane and CO_2 obtained in the biogas plant was 69% and 29% respectively.

Cite This Article: Faisal Kader, Abdullah Hil Baky, Muhammad Nazmul Hassan Khan, and Habibullah Amin Chowdhury, "Production of Biogas by Anaerobic Digestion of Food Waste and Process Simulation." *American Journal of Mechanical Engineering*, vol. 3, no. 3 (2015): 79-83. doi: 10.12691/ajme-3-3-2.

1. Introduction

Concerning the treatment of solid waste, the anaerobic digestion of solid waste has been studied in recent decades, trying to develop a technology that sum up advantages for volume and mass reduction as well as for energy and sources recovering. Anaerobic digestion, besides aerobic composting can be an alternative strategy for the reduction of MSW. In contrast to aerobic composting, anaerobic digestion of solid waste does not require air and produce biogas with high volumetric fraction of methane (50-70%). Furthermore the anaerobic digestion processes are best applicable for wet waste and the area requirement are satisfactory [1,2]. Until 1970's the anaerobic digestion (AD) was commonly used only for wastewater treatment [3]. Due to continuous increase of generated solid waste and the large environmental impacts of its improper treatment, its management has become an environmental and social concern. In Dhaka the main source of municipal solid waste are domestic, streets, market places, commercial establishment clinics and hospitals. At present, Dhaka City generates about 3500-4000 tons of solid waste per day, the per capita generation being 0.5kg/day. The density of solid waste is reported to be 600 kg/m³ (JICA

2005). According to a study conducted by Japan International Corporation Agency (JICA 2005), as of 2004, the total waste from domestic source was estimated to be 1945 t/d out of a population of 5.728 million with average generation rate of 0.34 kg/day per person. The total solid waste from business sources was estimated to be 1035 t/d and by cleaning the streets, the amount of waste generation was predicted to be 200 t/d (0.365 t/kmx550 km=201 t/d), making the total estimated waste generation of about 3200 t/d.

By 2025 the demand of energy is expected to increase by 50%. Hence there is an ongoing search to develop renewable energy sources which gives sustainable, affordable, environmentally friendly energy [4,5]. Biofuels are renewable and environmentally clean which significantly decreases the fossil fuel consumption [6].

For anaerobic digestion food waste is a highly degradable substrate because of its biodegradability and high nutrient content. A typical food waste contains 7-31 wt. % of total solid and the biochemical methane potential of the food waste is estimated to be 0.44-0.48 m² CH4/kg of the added volatile solid [7,8,9].

Therefore the aim of this study was to investigate the potential of anaerobic digestion for biogas production using only rice as food waste. The production of methane was simulated using process simulation software PROII.

Then the simulated results were verified by the experimental data.

2. Materials and Method

2.1. Sample Collection

The food waste (rice) for the research was collected from the cafeteria of Islamic University of Technology. The water was collected from the main water supply line of the university. The rice waste was fed into the digester by diluting with water. The waste was manually mixed with water without shredding or any pretreatment.
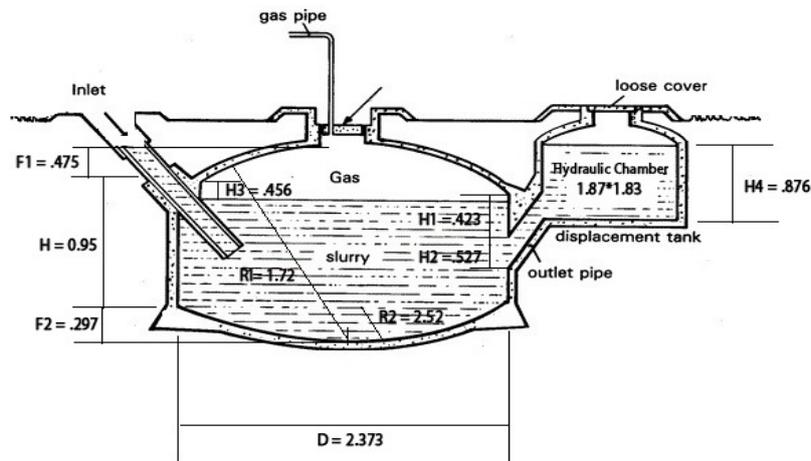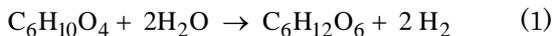
2.2. Experimental Setup

A fixed dome wet-digestion plant was constructed in the IUT campus. The schematic diagram of the plant is shown below. The digester consisted of three major parts: inlet chamber, fermentation chamber and a hydraulic chamber. The inlet chamber was used for charging the feed stock into the fermentation chamber where the fermentation of the feedstock takes place. The fermentation chamber had a fixed non movable gas space. The gas was stored in the upper part of the chamber and collected through the gas-outlet pipe. When the production commences, the pressure of the gas displaced the slurry into the hydraulic chamber. The hydraulic chamber had a volume of 3 m^3 which indicated the maximum gas holding capacity of the digester.

Figure 1. Schematic diagram of a wet digestion plant

3. Analytical Method of Biogas Production

Generally three main reactions occur during the entire process of the anaerobic digestion to methane: hydrolysis, acid forming and methanogenesis. Although AD can be considered to take place in three stages all reactions occur simultaneously and are interdependent.
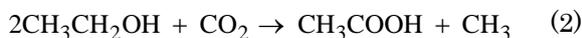
Hydrolysis is a reaction that breaks down the complex organic molecules into soluble monomers. Hydrolysis reaction of the organic fraction of the MSW can be represented by the following reaction: [10]

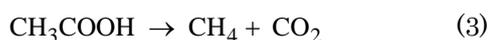$$C_6H_{10}O_4 + 2H_2O \rightarrow C_6H_{12}O_6 + 2H_2 \qquad (1)$$

Acid forming stage comprises two reactions – fermentation and the acetogenesis reactions. Typical reactions occurring during this stage are the conversion of the glucose to ethanol and the conversion of the glucose to propionate. Important reactions during the acetogenesis stage are the conversion of glucose to acetate, ethanol to acetate, propionate to acetate and bicarbonate to acetate.

The reactions that occur during methanogenesis stage are as follows [10]:
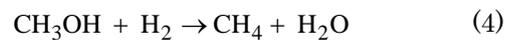
Acetate conversion:

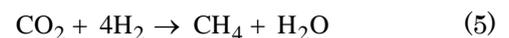$$2CH_3CH_2OH + CO_2 \rightarrow CH_3COOH + CH_3 \qquad (2)$$

Followed by:

$$CH_3COOH \rightarrow CH_4 + CO_2 \qquad (3)$$

Methanol conversion:

$$CH_3OH + H_2 \rightarrow CH_4 + H_2O \qquad (4)$$

Carbon dioxide reduction by hydrogen:

$$CO_2 + 4H_2 \rightarrow CH_4 + H_2O \qquad (5)$$

4. Process Simulation of Methane Production

For process simulation in the PRO II software at first the components needs to be identified. Since ethanol, H_2O, CO_2 were present in the library they were added from the library components and hypothetical components Glucose and Starch were filled up according to the UNIFAC structures since they were not in the system.
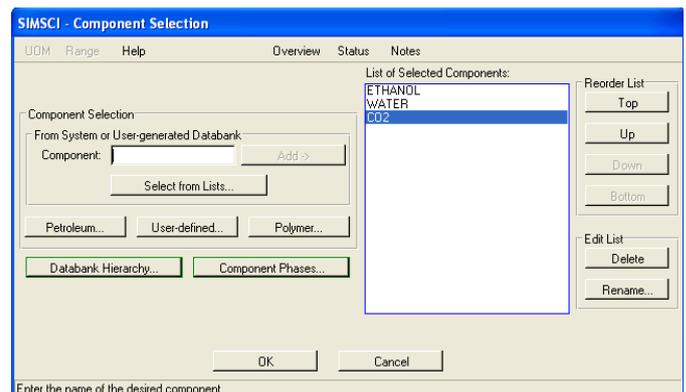

Figure 2. Component selection
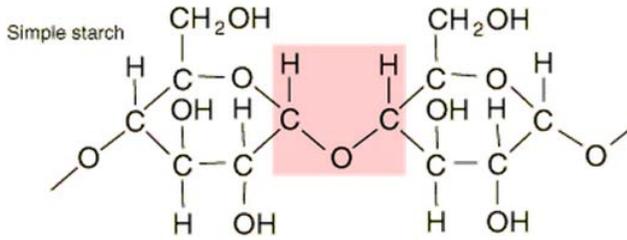
Filling up Glucose and Starch:

Figure 3. Structure of starch

Table 1. Group and number of the components of starch

Category	Group	Number
Alcohols	0200	1600
Alcohols	0277	800
Ethers	0602	1600
Paraffins	0902	2400

Figure 4. Component properties for starch

Table 2. Group and number for glucose

Category	Group	Number
Alcohols	0200	4
Alcohols	0214	1
Aldehyde	0300	1
Paraffins	0902	3

Figure 5. Component properties for glucose

After that the reactions were defined. The reaction set names were provided with the reaction data where the reaction was balanced (Figure 6). All the reactions were balanced likewise.

Figure 6. Reaction set names
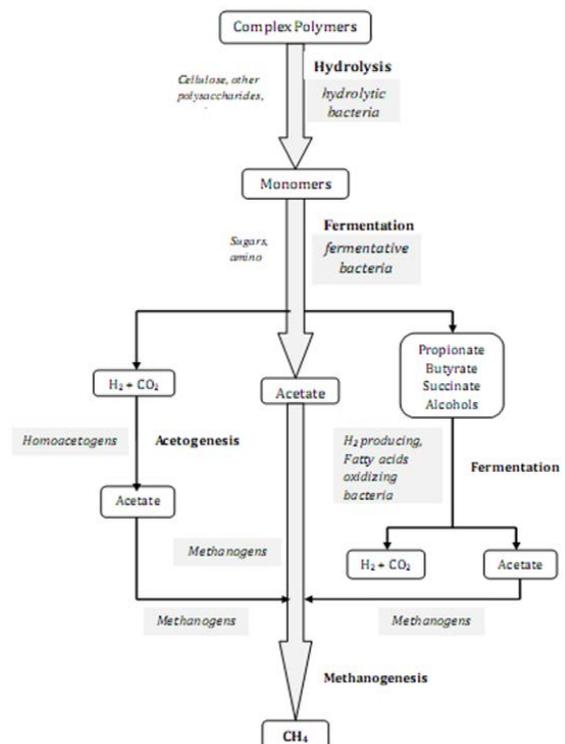

Figure 7. Reaction data

Figure 8. Overall process diagram of AD system

Then the PFD was drawn. It was drawn according to the overall process diagram of the AD system as shown in Figure 8. The production of methane is divided into three streams; three different line of production. The PFD was drawn for each of the three streams from which methane can be obtained separately as shown in Figure 9, Figure 10 & Figure 11. To be explained, in the left stream the

monomer glucose is converted into carbon dioxide and hydrogen which then with acidogenesis reaction turns into acetic acid followed by the methanogenesis reaction, which convert it into methane. Likewise methane is produced from the middle and right stream of the overall process diagram. Each of the PFD consists of some conversion reactors and input and output lines. By clicking on the input lines the conditions like the flow rate and composition for the input substance is defined. Same was done for the conversion reactors for the parameters to be placed. After all the parameters are defined the program was run. The reactors will turn blue if the conditions are set perfectly in the input/output lines and in the reactors. Here, water and starch flow rate was taken as 0.5kg-mol/hr and 0.05 kg-mol/hr respectively. In different reactor the conversion factor for Hydrolysis reaction was set as 0.89 [11].
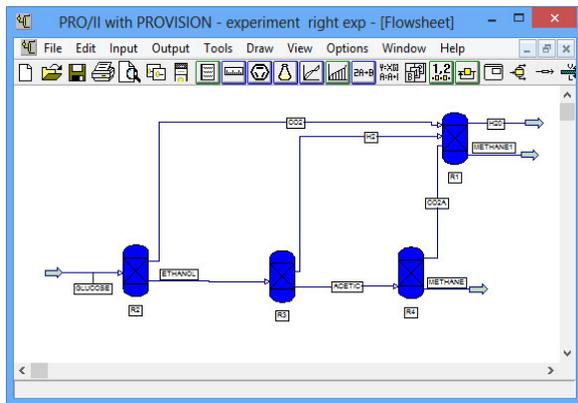

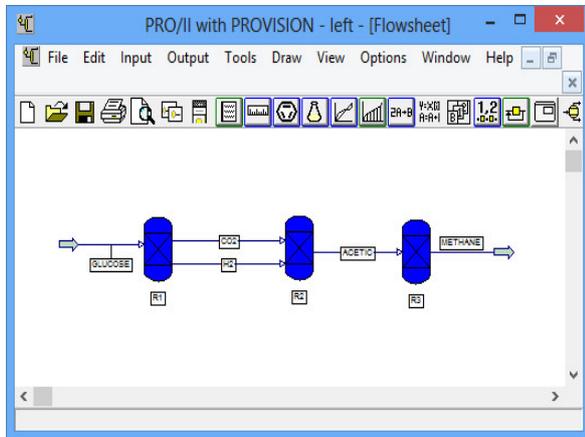**Figure 9.** Flow diagram for right stream of the process diagram

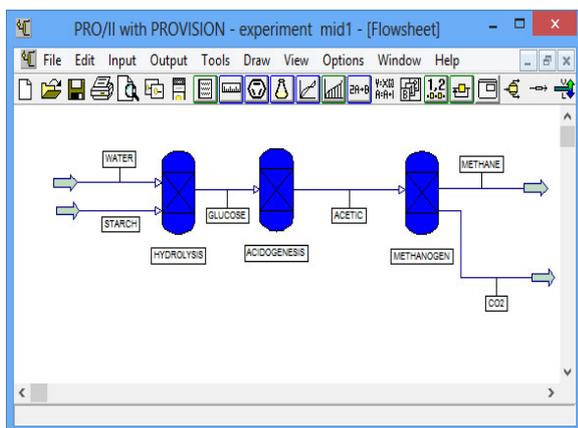**Figure 10.** Flow diagram for left stream of the process diagram

Figure 11. Flow diagram for the middle stream of the process diagram

The flow of methane from three different streams was obtained from the output lines after the simulation was run. From the simulated results, the total flow rate of methane from three different streams was found to be 19.82 kg-mol/hr.

5. Experimental Result

The sample calculation of methane flow rate for starch loading rate 0.05 kg-mol/hr is done using the continuity equation. The density of methane is 0.668 kg/m^3. The output pipe used to collect the methane was of 18 mm diameter. Using the anemometer the velocity of the output methane was calculated. Using these values the mass flow rate for the methane was calculated.

Density of Methane, $\rho = 0.668$ kg/m^3
Diameter of Pipe,   D = 18 mm
Cross sectional area of pipe, $A = \pi/4 D^2 = \pi/4 * 0.018^2$
  $= 2.5 * 10^{-4}$ m^2
Velocity of flow,   V = 24 m/s
Mass flow rate, $m = \rho A V = .668 * 2.5 * 10^{-4} * 24$
  $= 4.00 * 10^{-4}$ kg-mol/s
  $= 14.4$ kg-mol/hr

The comparison between experimental and simulated flow rate of methane with respect to starch loading rate is shown below. The observed deviation of the experimental result might be happened due to conversion factors used in the conversion reactors. A good approximation of the conversion factors might give a better solution. Also no necessary steps were taken to control the pH value in the digester which might have a great effect on the output.
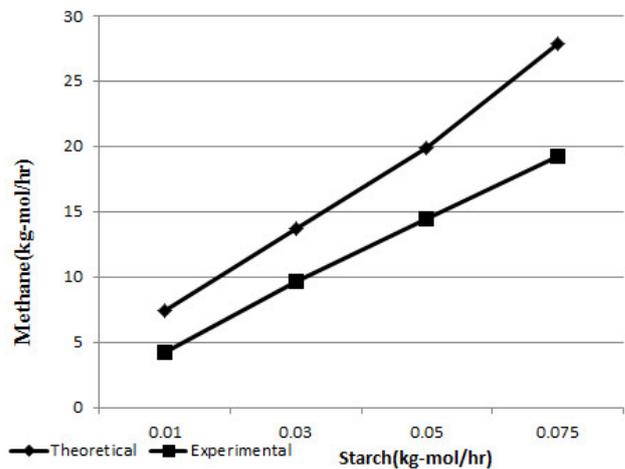

Figure 12. Comparison between starch loading rate vs. Methane flow rate of theoretical and experimental result

In wet digestion plant, gas volume was measured daily by measuring the water displacement in the hydraulic chamber. Each day, gas was released at the prescheduled time and the water level of the chamber was measured before and after the release. The difference between two readings was multiplied with the length and width of the chamber to obtain the gas volume each day in m^3.

The percentage of methane in the biogas obtained from the plant is shown below. Considering the cost of the test, the gas was tested only 3 times during the study period. Each test was done in approximately 3 weeks interval. As the degradation of starch particle continuously increased

with the increase of the methanogenic bacteria, the percentage of methane in the outlet gas also increased. Also, as the food waste is mainly starch, which is a hydrocarbon, the gas obtained from the anaerobic digestion of food waste contains an incredibly high amount of methane. Furthermore, it was observed that gradually the amount of methane in the biogas came to an almost constant value of 69%. This is in accordance with a finding of Bangladesh Council of Scientific and Industrial Research (BCSIR).
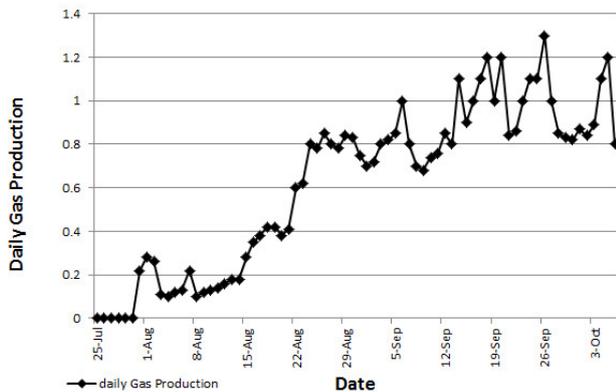

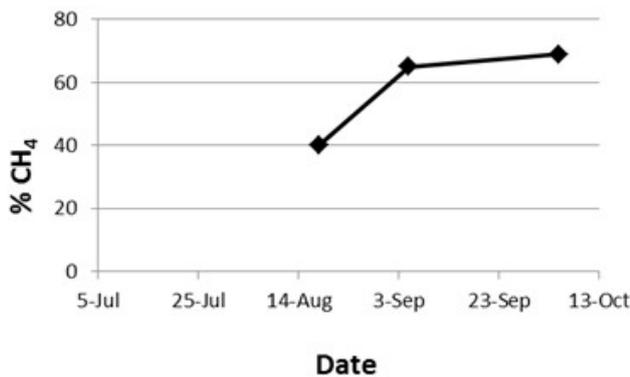**Figure 13.** Daily gas production in, m^3

Figure 14. Percentage of methane, %

6. Discussion

In this research, PROII process simulation software was used to optimize the methane flow rate and comparisons have been done between the experimental and the simulated results. The reason of the observed deviation between the experimental and simulated results was predicted to be the lack of controlled environment and leakage of the gas and rain water out and in to the system respectively which affected the production as the plant was setup in an open space. Since both the flow rate and the percentage of methane in the biogas is important for its different useful usage this experiment was carried out with a view to maximizing both the flow rate and the methane percentage. And using wasted rice was of great response. Its reason remains in rice being a source of starch which is hydrocarbon.

Nomenclature

AD- Anaerobic Digestion
IUT- Islamic University of Technology
GTZ- German Technical Corporation
JICA- Japan International corporation Agency
MCE- Mechanical and Chemical Engineering
MSW- Municipal Solid Waste
PFD- Process Flow Diagram

References

[1] Baldasano, J.M. and Soriano, 2000, "Emission of greenhouse gases from anaerobic digestion processes: comparison with other municipal solid waste treatments. Water science and technology," Vol. 41 (3); 275-282.

[2] Hartmann, H. and Ahring, B.K., 2006, "Strategy for the anaerobic digestion of the organic fraction of municipal solid waste: and overview. Water science & technology." Vol. 53 (8):7-22.

[3] Palmisano, A.C. & Barlaz, Morton A., 1996. "Microbiology of solid waste."

[4] Deublein, D. and Steinhauser, A. (2008). "Biogas from waste and renewable resources: An introduction." Wiley-V CH, Weinheim, Germany.

[5] Khanal, S.K. (2008). "Bioenergy generation from residues of biofuel industries. Anaerobic Biotechnology for Bioenergy Production: Principles and Applications." Wiley-Blackwell, Oxford, UK; John Wiley & Sons, New York, NY, USA, 161-188.

[6] Ersahin, M.V, Gomec, C.V., Dereli, R.K., Arikan, O. and Ozturk, I. (2011), "Bio methane production as an alternative: Bioenergy source from codigesters treating municipal sludge and organic fraction of municipal solid wastes." Journal of Biomedicine and Biotechnology, 8:1-8.

[7] Heo, N., Park, S., Lee, J., Kang, H. and Park, D. (2003). "Single-stage anaerobic codigestion for mixture wastes of simulated Korean food waste and waste activated sludge." Applied Biochemical and Biotechnology, 107: 567-579.

[8] Han, S.-K.and Shin, H.-S. (2004). "Biohydrogen production by anaerobic fermentation of food waste."

[9] Zhang, R., El-Mashad, H.M., Hartman, K., Wang, F., Liu, G., Choate, C. and Gamble, P. (2007). "Characterization of food waste as feedstock for anaerobic digestion." Bioresource Technology, 98: 929-935.

[10] Ostrem, K. & Themelis, Nickolas J., 2004. "Greening waste : anaerobic digestion for treating the organic fraction of municipal solid wastes".
http://www.seas.columbia.edu/earth/wtert/sofos/Ostrem_Thesis_final.pdf.

[11] Rebecca Anne Devis, 2008. "Parameter Estimation for Simultaneous Saccharification and Fermentation of Food Waste into Ethanol Using Matlab Simulink".