Experimental determination of a critical temperature for maximum anaerobic digester biogas production

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Abstract

This paper presents an experiment anaerobic digester system. The objective was to evaluate the optimal temperature for maximization of the biogas production through optimal constraining of the mesophilic temperature between log phase for the best fission of methanogenic bacteria. The temperature was varied over time over several days and the biogas production is recorded every after 24 hours(1 day) . Based on the experiment setup, the results show a higher biogas production proportional to the rise in temperature, though critical a temperature should not be reached that denatures the bacteria. This model has potential in the application for energy production especially in remote areas and communities.

Keywords: Anaerobic; Digester ;Optimal production; Biogas ;Substrate; Homoacetogenic bacteria; Methanogenic bacteria

Nomenclature	
$P_e^g(t)$	the total electrical production of the digester kWh/day
$P_t^g(t)$	the total thermal production of the digester kWh/day
CH_4	Methane

1. Introduction

Distributed renewable energy system such as biogas are promising options for energy supply in rural off-grid locations and for institutions such as hospitals, clinics,prisons, hotels and schools especially in areas where grid connection is impossible or not economic. One of the advantages of biogas systems is the fact that the feedstock is readily available in most rural areas and also at schools, hospitals, hotels and other isolated institutions. Biogas systems can meet both electrical and thermal energy requirements of such institutions.

Typically a turbine or engine running on biogas is utilized to generate power. The power generated by the biogas engine is used to meet the load during periods at night all times [1]. Biogas is 25 times more potent than CO_2, when you burn it and convert it to CO_2 which in fact minimizing the harmful GHG effects by 25% [2, 3, 4].

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Anaerobic digestion is a complex process that involves two stages, In the first stage, decomposition is performed by fast-growing, acid-forming (homoacidogenic) bacteria and In the second stage, most of the organic acids and all of the H_2 are metabolized by methanogenic bacteria [5, 6]. The process occurs in an anaerobic (oxygen-free) environment through the activities of acid- and methane-forming bacteria that break down the organic material and produce methane (CH_4) and carbon dioxide (CO_2) in a gaseous form known as biogas. These systems are designed to optimize the growth of the methane forming (methanogenic) bacteria that generate CH_4. Typically, using organic wastes as the major input, the systems produce biogas that contains 55% to 70% CH_4 and 30% to 45% CO_2.

It is crucial for research and development efforts in renewable energy technologies such as biogas CHP systems for institutional and community energy generation applications to continue in order to ensure universal access to energy for people living in marginalised and remote areas where it is difficult or uneconomic to extend the grid. In order to ensure supply reliability of these systems, more research effort should be put in areas such as performance improvements, optimal sizing and dispatching strategies among others. Biomass is a composition of different organic and inorganic materials. Optimization of biogas requires multidimensional approach; the production technology, the chemical composition, the operational parameters such as substrate loading rate, optimal digester temperature, pH etc., bioaccessibility, biodegradability, bioavailability as well as characterization of substrates is crucial. Substrate flowrate and temperature inside the digester are the main factors for the maximization of biogas production. In literature, the optimal control [7, 8, 9] these two important biogas operational constraints is lacking. Hence, this paper proposes the first attempt on applying optimal control on substrate flow rate and digester temperature to maximize the conducive environment for the methanogenic bacteria action.

2. Model formulation and experimental setup

2.1. Anaerobic bacteria reaction

Anaerobic digestion system shown in Figure 2 has a natural process in which bacteria convert organic materials into biogas [10, 11]. The biochemical reaction has several stages and process of biodegradability which is dependent on the composition of the substrate/feedstock. The seven common compounds of biomass reaction are given below:

Glucose breakdown stages which represent monosaccharide given in equation (1),equation (2) and equation (3) below:

$$C_6H_{12}O_6 + 2\,H_2O = 2\,CH_3COO^- + 2\,H^+ + 2\,CO_2 + 4\,H_2 \tag{1}$$

$$C_6H_{12}O_6 = 4\,CH_3CH_2COO^- + 2\,CH_3COO^- + 6\,H^+ + 2\,CO_2 + 2\,H_2O \tag{2}$$

$$C_6H_{12}O_6 = CH_3CH_2CH_2COO^- + H^- + 2\,CO_2 + 2\,H_2 \tag{3}$$

The other biomass component that composes of long chain fatty acids and palmitate are given in equation (4) and equation (5) respectively:

$$(CH_3CH(NH_3^+)COO^- + 2\,CH_2(NH_3^+)COO^- + 2\,H_2O = 3\,CH_3COO^- + CO_2 + 3\,NH_4^+ \tag{4}$$

$$CH_3(CH_2)_{14}COO^- + 14\,H_2O = 8\,CH_3COO^- + 7\,H^+ + 14\,H_2 \tag{5}$$

While the break down of a short chain acids called butyrate is given in equation (6).

$$CH_3CH_2CH_2COO^- + 2\,H_2O = 2\,CH_3COO^- + H^+ + 2\,H_2 \tag{6}$$

The other biomass component palmitates are the most common fatty acids found in animals, plants and microoganisms. Valerate is a synthetic shown in equation (7), steroidal estrogen and an estrogen ecetate (shown in equation (9) and propionate is a small salt given in equation (8).

$$CH_3CH_2CH_2CH_2COO + 2\,H_2O{=}CH_3CH_2COO^- + CH_3COO^- + H^+ + 2\,H_2 \tag{7}$$

$$CH_3CH_2COO^- + 2\,H_2O{=}CH_3COO^- + CO_2 + 3\,H_2 \tag{8}$$

Finally the methane and carbon dioxide gas production in the anaerobic digester are given in equation (9) and equation (10) respectively.

$$CH_3COO^- + H^+{=}CH_4 + CO_2 \tag{9}$$

$$4\,H_2 + CO_2{=}CH_4 + 2\,H_2O \tag{10}$$

2.2. Energy model of the digester

This model has been adopted from [12] The total electrical production:

$$p_e^g(t) = Q_G E_{CH4} H_c \eta_e, \tag{11}$$

The total thermal production:

$$p_t^g(t) = Q_G E_{CH4} H_c \eta_t, \tag{12}$$

where;

Q_G is the biogas production in m^3/day
E_{CH4} is the methane content (%),
HC calorific value of methane ($kWhNm^3$)
η_t and η_e thermal and electrical efficiency respectively.

2.3. Experimental setup of the biogas

The 20 litre Manzi Valley[1] container was used in this experimental setup. Other materials used were a half inch polypipe which was used to connect the container to the excrete container, the gas container and the feeding pipe, the half inch nonreturn valve was used not to allow the biogas back to the fermentation container. After the non return valve (NRV) a tee adaptor was connected to allow another passage of the biogas to the outlet. Along the outlet pipe a gate valve was used for opening and and closing the outlet pipe. Just before connecting to the container a pressure gauge was connected to monitor the pressure in the gas collection tank.

Most of the commercial biogas plants use conventional continuous anaerobic digestion process. By conventional it is meant fully mixed, semi-continuous or continuous load and unload reactor at mesophilic temperature range thus between 20C to 40C. In this case, the substrate was loaded to the reactor once a day after collecting the results. A separate preparation tank, was provided were the substrates was mixed and prepared for the loading. The HRT was 40 days.

The foreign materials like sand, earth, gravel, sawdust, soap, detergents, or any unwanted materials were sieved just before the waste is put into the hydrolysis tank so that no such matter should enter the reactor. The feedstock was weighed before mixed with water through a process called hydrolysis to make a slurry that was eventually pumped into the reactor. But before that, the slurry was fully stirred manually with a piece of wood until there were no lumps. The feedstock was then transferred to the poly made digester. The digester was stirred every after four hours by shacking it since its of a small weight.

[1] www.manzivalley.com

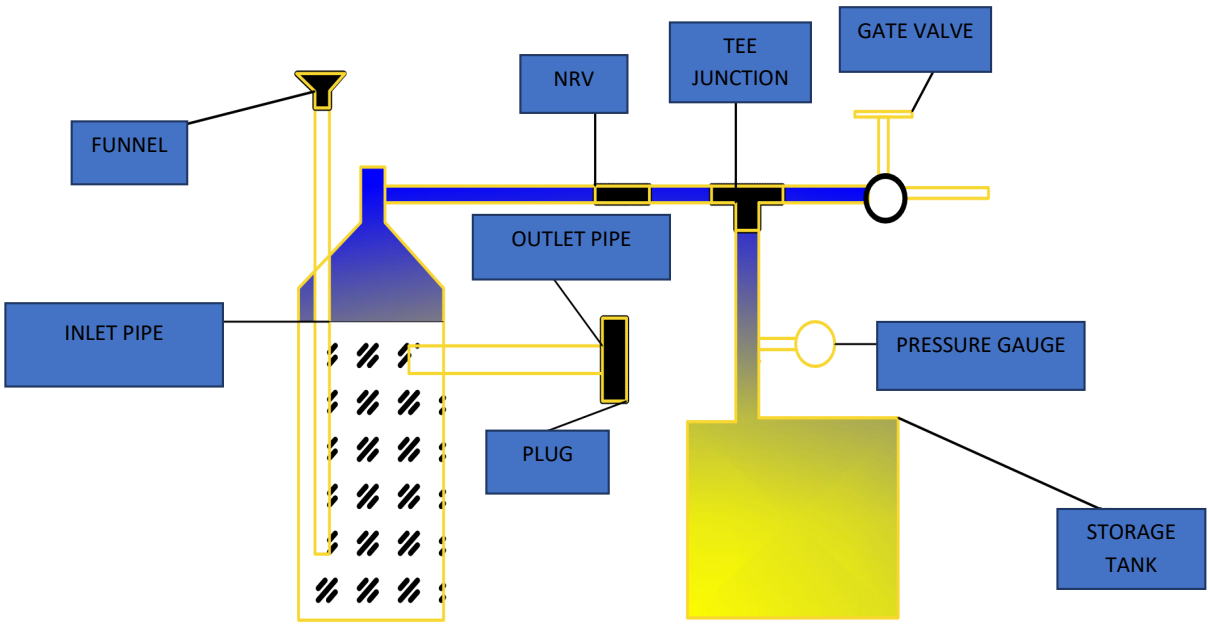

Figure 1: Experimental setup of the biogas layout

A pH meter was used to monitor that the pH values were maintained at optimal values of 6.8 to 7.2 every week. The daily temperatures of the slurry were monitored using a normal clinical thermometer since the expected temperatures are mesophilic which normally range from 20C to 40C. Two thermometers were used one to monitor the surrounding temperatures and another for the slully temperature. The Gas yield was collected using the pressure gauge that was connected to the collection tank then the values changed into volume in m3. 5kg cow dung was mixed with 5kg water (2.1 littres). The results are as shown in section 3.

3. Results and discussion

The data collected shows that maximum production of biogas takes place at 380 C. this means that at mesophilic temperatures for you to obtain maximum gas production temperatures should be kept within 37 to 39 degrees thus proving exactly to what happen in the stomach. This also shows that bacteria production or multiplication increases as the temperatures rises but stops multiplying when it goes beyond 40 degrees. And according to the experiment optimum production of bacteria takes place at 38 degrees.

Table 1: Experimental biogas production per temperature rise

S.No	TEMPERATURE (OC)	VOLUME COLLECTED (m3)/Day
1	20	1.10
2	24	1.20
3	25	1.25
4	26	1.28
5	28	1.30
6	30	1.32
7	32	1.35
8	34	1.45
9	36	1.62
10	38	2.10
11	40	0.20
12	42	0

In the figure....

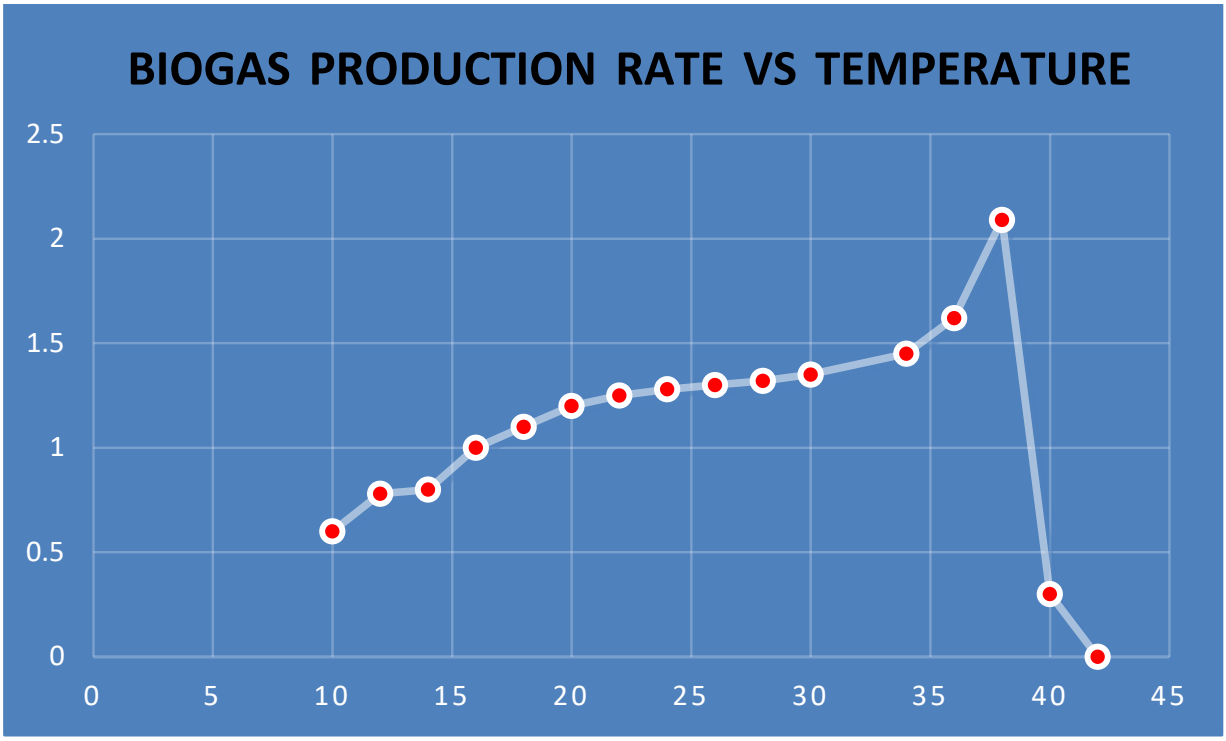

Figure 2: Experimental setup of the biogas layout

4. Conclusions

In conclusion it has been shown that the optimal temperatures to be kept constant for us to obtain maximum biogas at mesophillic temperatures is 380C. this is the exact temperature of a human body that means that the fermentation of the waste material was perfect. The variations in the graph are due to the temperatures that could not be kept constant because the source of heat was not embedded into the biodigester.The blowing wind would disturb the flow of heat directly to the container.

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