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Main Factors Affecting the Production of Biogas during Anaerobic Digestion Process

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ABSTRACT

Fossils like coal, natural gas, and oil have been extensively used due to the twentieth century's worldwide economic growth. These fossils were used as fuels and pharmaceutical raw materials. As a byproduct of combustion, the widespread use of fossil fuels has resulted in massive carbon dioxide releases. The so-called "greenhouse effect" can be attributed to carbon dioxide's high infrared absorption rate. Biomass-based sustainable energy sources have recently gained prominence due to a growing movement to at least partly substitute oil usage and, by extension, reduce greenhouse gas emissions from the atmosphere. The manufacturing of chemicals could switch to biofuels as a basic substance. One of these renewables is biogas, produced through the anaerobic digestion of various forms of organic waste into natural gas. Temperature, pH, hydraulic retention time (HRT), and other elements are just a few of the key variables studied in the present study that influence biogas output. A portable closed batch process was utilized. Biogas technology produces energy from biological matter or biological waste (substrate) that also benefits human health and the ecosystem. The water displacement technique was used to measure the biogas generated in laboratory-scale trials to determine the biogas yield. Cow dung, potatoes, onions, lettuce, carrots, and cabbage are some substrates used. For two weeks, mesophilic temperatures supported the biogas generation process.

INTRODUCTION

In anaerobic digestion (AD), anaerobic bacteria decompose (digest) organic substances in the absence of air, producing biogas as a byproduct of their metabolism [1]. In anaerobic digesters, naturally occurring biological processes are used to handle and discard waste materials, stabilize end products, kill pathogens, and produce biogas and a valuable product at a rate of one gram per second. Methane accounted for about 55% to 60% of biogas, carbon dioxide makes up 35%–40%, and other gases like hydrogen, carbon monoxide, nitrogen, water vapor, and hydrogen sulfide are present in very small amounts [2].

Fig. 1 depicts the four stages of the microbial process by which methane is produced when microbes develop and provide the driving energy for the metabolism of organic waste in anaerobic conditions [3]:

- **Hydrolysis:** In the first stage of anaerobic digestion, hydrolytic enzymes generated by the hydrolytic microorganism break down insoluble biopolymers and complex organic matter like lipids, carbohydrates, triglycerides, proteins, and nucleic acids into basic soluble organic molecules. Consequently, the hydrolysis reaction for this fraction of organic waste or municipal solid waste would be:

$C_4H_{10}O_4 + 2O_2\ C_6H_{12}O_6 + 2H_2$ (1)

- **Acidogenesis:** Using acidogenic bacteria to convert a soluble organic substance like volatile fatty acid (VFA) and carbon dioxide.
- **Acetogenesis:** During the process of acetogenesis, volatile fatty acids are oxidized into methanogenic substrates such as acetate and hydrogen.
- **Methanogenesis:** Methanogenic bacteria convert acetate, carbon dioxide, and hydrogen into methane gas.

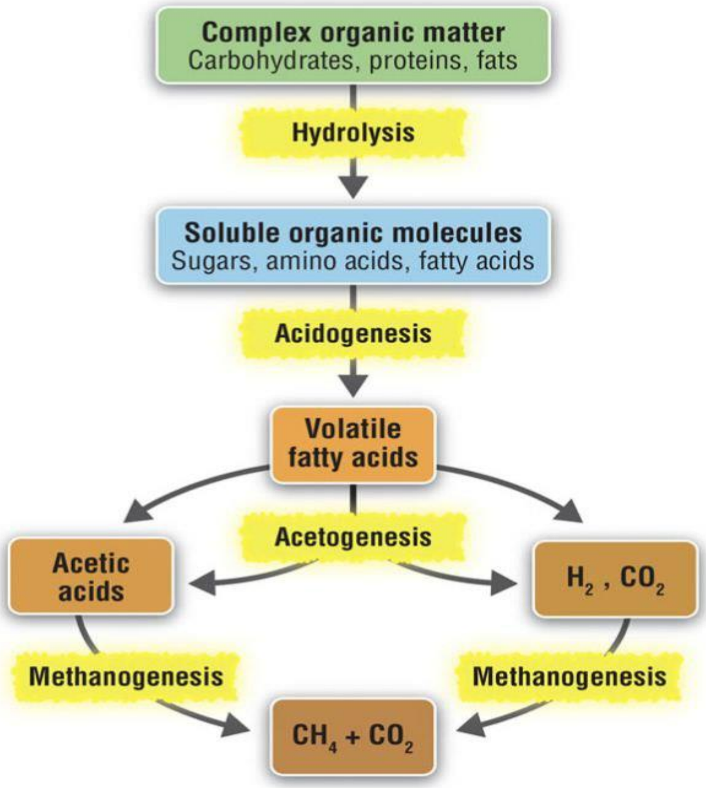

Figure 1: *Anaerobic digestion steps [3].*

BIOGAS PRODUCTION

The breakdown of organic matter by microorganisms in anaerobic conditions results in the production of biogas. According to Table 1 [4], the major components of biogas are 50 to 75% methane and 25 to 45% carbon dioxide. Water, oxygen, nitrogen, and hydrogen sulfide are additional components of biogas. Hydrolysis, acidogenesis, acetogenesis, and methanogenesis are the four steps of digestion [5]. These four stages must occur simultaneously to sustain a steady anaerobic process. The methanogenesis step produces biogas, energy and methane [4].

Substrates (inputs) for creating biogas can be made from various organic components. Food waste from homes and restaurants, residues from the food preparation industry and slaughterhouses, sewage sludge from wastewater treatment facilities, manure, and agricultural leftovers are all common substrates [4]. Pretreatment methods for the substrate before digestion in the digesters at biogas facilities vary according to the substrate's makeup. Crushing or pulverizing to decrease particle size, dispersing to make the substrate more volatile, and eliminating contaminants like plastics, textiles, metals, or gravel are all examples of pretreatment methods [4].

Table 1: *Average Biogas composition [4].*

Constituent	Concentration
Methane	50-75 vol. %
Carbon dioxide	25-45 vol. %
Water	2-7 vol. %
Hydrogen sulphide	20-20,000 ppm
Nitrogen	< 2 vol. %
Oxygen	< 2 vol. %
Hydrogen	< 1 vol. %

PARAMETERS AFFECTING BIOGAS PRODUCTION

Temperature

The temperature inside the digester strongly influences the rate at which biogas is produced. When it comes to temperatures, anaerobic fermentation can be performed in a variety of conditions. These ranged from the psychrophilic (<30ºC) to the mesophilic (30–40ºC) to the thermophilic (50–60ºC) temperatures. However, the mesophilic and thermophilic temperature regions are where anaerobes are most active. Temperature affects how long the fermentation process lasts. Methanogenic bacteria, which aid in biogas production, are extremely susceptible to temperature changes, and the ideal temperature for the gas to function is between 33 and 38 degrees Celsius.

Biogas production is slowed at lower temperatures while biogas-producing bacteria are killed off at higher temperatures. As a result of this low temperature, the structure for biogas production is typically constructed underground so that the temperature remains as constant as feasible. Increases in temperature, especially sudden ones, can kill certain types of bacteria crucial to bio-methane generation and thus should be avoided if possible.

Biomethane production tests can be performed in a chamber with a thermostat or with the reactors submerged in a water bath kept at a controlled temperature. Since temperature is crucial in deciding digestion and retention rates, measurements of both atmospheric and slurry temperatures were taken. Due to the outer sides of the digester area coming into direct contact with the atmosphere, the atmospheric temperature influences the rate of digestion. So, the digester walls either take in or release heat based on the temperature difference between the digester and its surroundings [6].

pH

The optimal pH range for methane formation is between 7.0 and 8.0, but methane formation occurs within a limited pH range of 6.5 to 8.5. pH values below 6.0 or above 8.5 significantly slow down the process. The degradation of proteins results in a rise in pH due to the accumulation of ammonia, while the aggregation of volatile fatty acids (VFA) results in a decline in pH. Because of the substrate's buffer capacity, VFA buildup does not necessarily lead to a decrease in pH. Alkalinity is abundant in animal manure, keeping the pH steady even as volatile fatty acids (VFAs) build-up. In large concentrations, volatile fatty acids (VFA) can inhibit methanogenesis and serve as a crucial intermediary. Even though acetic acid is present in greater concentrations than other fatty acids, methanogens are effectively inhibited by propionic and butyric acids. The undissipated form has a connection to inhibition. Therefore, systems with a low pH value are particularly susceptible to the inhibiting impact of VFAs. Chemicals are introduced to the organic substrate to offer a buffer capacity [7] and prevent the pH from dropping. The four most common forms of sodium are bicarbonate, hydroxide, and carbonate [6].

Carbon/ Nitrogen Ratio

The C/N ratio significantly impacts organic matter's (OM) potential for anaerobic digestion. A large C/N ratio indicates a low nitrogen concentration for microbial development. Therefore, methanogens absorb nitrogen for protein synthesis, resulting in carbon waste, and, in the end, a low biogas yield [8]. Ammonia and nitrogen buildup from a low C/N ratio can inhibit anaerobic digestion [8]. According to Gerardi [9], a C/N ratio of 25:1 is ideal for efficient biogas generation. It was determined that a C/N ratio of 20–35:1 is optimal for the efficient operation of the bi-digester [10]. To reduce the likelihood of ammonium inhibition at elevated temperatures, a greater C/N ratio is required [11]. Maximum biogas yield was achieved with the following C/N ratios for various feedstocks: 25:1 for grass hay, 15:1 for chicken manure, 47:1 for rice stalks, and 13:1 for cattle manure [12]. A better methane yield can be attained with the right C/N mix.

Moisture Content

The substrate's moisture content impacts anaerobic digestion. At 60-80% humidity, according to Equation 1, the highest methane yield has been recorded [13]. The experimental findings of 70% and 80% moisture revealed that the former produced the most biogas, 83 ml CH_4 per gram of dry matter, as opposed to the latter, which produced 71 ml CH_4 per gram of dry matter [13].

$$\%MC = \frac{weight\ of\ the\ sample - weight\ of\ sample\ after\ dring}{weight\ of\ sample} \times 100 \qquad (1)$$

Organic Loading Rate (OLR)

The organic loading rate (OLR) is the mass of organic material added to the digester volume per unit of time or per unit of the substrate's biological conversion capability. Gas output is primarily affected by OLR. The biogas yield is affected by the OLR because it is proportionate to the number of volatile particles that will be placed in the digester. The amount of gas created increases as OLR decreases. The OLR equation stated by Rohstoffe is presented in the following equation [14]:

$$OLR = \frac{m * C}{V_R * 100}\ (\text{kg oDM m}^{-3}\ \text{d}^{-1}) \qquad (2)$$

In which:

m = amount of substrate fed per unit of time (kg/d),

C = concentration of dry organic matter (%oDM), and

V_R = volume of the reactor (m^3).

Hydraulic Retention Time (HRT)

The amount of time that biodegradable material spends inside the reactor is referred to as its hydraulic retention time (HRT). Internal digester temperature, food composition, and technological implementation all play a role in HRT. HRT in a thermophilic digester is 14, while in a mesophilic digester; it ranges from 10 to 40 days. If the retention time is too brief, the bacteria might be flushed out of the digester before they multiply, leaving it inactive. The reactor's volume rises as retention time increases. Methane gas production can be maximized by maintaining the optimal loading rate, which minimizes retention time and reactor volume. The below calculation shows that the optimal time for lignocellulosic material to decompose and produce biogas is between two and three weeks [15].

$$HRT = \frac{VR}{V}\ (d) \qquad (3)$$

In which:

V_R = reactor volume (m^3), and

V = reactor's substrate volumetric daily feed rate (m^3/d).

MATERIALS AND EXPERIMENTAL PROCEDURE

The study was conducted at the Environmental Engineering Department of Mustaniriyah University laboratories. The waste materials used for the study were leftover onion waste, carrots, cabbage, cow dung, and distilled water.

Figure 2: *Mechanical pretreatment of leftover vegetable waste.*

Figure 3: *Cow dung preparation.*

This study made extensive use of a variety of equipment. A weighting balance was utilized to estimate the waste samples. A measuring cylinder was used to measure the distilled water volume added to the anaerobic digester. Lastly, a big plastic container for mixing agricultural waste with distilled water and cow dung.

Digester Setup

The anaerobic digester was fabricated from a plastic container of cylindrical shape with a total volume of 5 litres (a working volume of 4 litres). All the processes involved in producing biogas happen inside it. Two covers of Teflon were used, one on the bottom and the other on top of the digester. Four openings were drilled on the top cover of Teflon, as shown in Fig. 4. Each opening is designed for a specific function. The first and second openings were input and output pipes for withdrawal samples, the third opening for the pH probe, and the fourth opening for biogas. It is attached to an autoclave glass bottle used for water displacement.

Figure 4: *Top Teflon cover.*

A laboratory pH meter was utilized for measuring the pH of the digestive system throughout the entire digestion process. This instrument was calibrated with commercial pH standard solutions of 4.0, 7.0, and 10.0. A one-litre glass bottle was used, and the cover was drilled into two openings, as shown in Fig. 5. The first one is connected to a biogas pipe located at the top cover of the digester. Another opening was extended to a graduate beaker to measure the milliliters of biogas from the digester. Fig. 6 displays the complete setup of the digester.

Figure 5: *Autoclave bottle.*

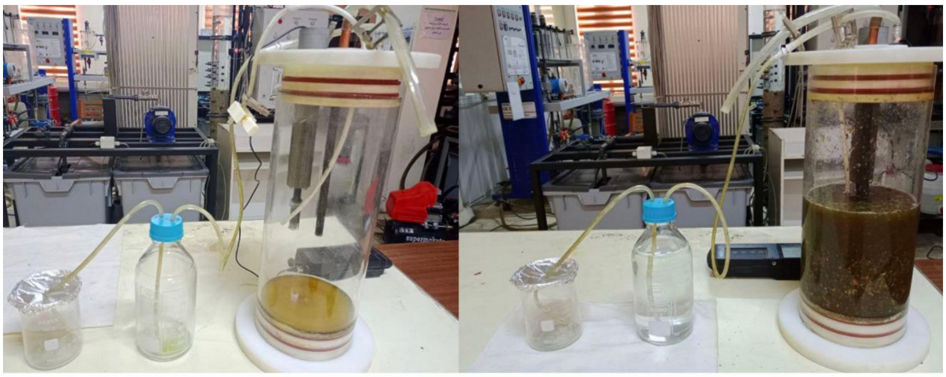

Figure 6: *Anaerobic digester before and after feeding.*

Biogas Daily Yield

There was a need to withdraw samples from the digester to determine the number of volatile solids and conduct ash analysis. The samples were withdrawn at different weights daily during anaerobic digestion. The amount of residue left in the evaporating dish after the ignition of an oven-dried sample at 105°C was weighed. Oven-dried, moisture-free samples were weighed and placed in muffle furnaces at 550°C for an hour. The same procedure was followed daily, as shown in Fig. 7.

Figure 7: *Steps of samples' withdrawal from the anaerobic digester (left to right).*

The volatile solids were calculated using the following equation:

$$VS = W_d - W_i \quad (4)$$

Where:

W_d = weight of the dried sample (g)

W_i = weight incinerated sample (g)

RESULTS AND DISCUSSION

1740 g of vegetable waste was added to the digester. A 20% cow dung mixture, equal to 348 g of vegetable waste and 2 liters of distilled water, was mixed with cow dung before adding it to the digester. The pH value was measured and was 6.4. The pH value was adjust in all experiments during the digestion process by using sodium bicarbonate $NaHCO_3$ .The digester was closed tightly on August 21, 2022, and placed in a water bath at a controlled temperature of 35 °C. Table 2 and Fig. 8 show the values of biogas produced daily.

Table 2: *Biogas daily yield (ml/ g VS).*

Dates of Withdrawal Samples	**Weight of Empty Evaporation Dish (g)**	**Weight of Samples (before drying)(g)**	**W_d (A)**	**W_i (B)**	**VS = A-B (g)**	**Milliliters of Water Displacement**	**Biogas Daily Yield (ml/g VS)**
Monday 22/8/2022	69.8	3.1	0.4	0.1	0.3	500	1666.6
Tuesday 23/8/2022	18.8	2.6	0.3	0.1	0.2	600	3000
Wednesday 24/8/2022	22.9	2.4	0.3	0.1	0.2	800	4000
Thursday 25/8/2022	26	2.1	0.2	0.1	0.1	900	9000
Sunday 28/8/2022	20.8	2.2	0.3	0.1	0.2	800	4000
Monday 29/8/2022	16.4	0.7	0.2	0.1	0.1	400	4000
Tuesday 30/8/2022	15.5	2.7	0.2	0.1	0.1	400	4000
Wednesday 31/8/2022	26	3.1	0.3	0.1	0.2	200	1000
Thursday 1/9/2022	20.8	3.7	0.4	0.1	0.3	100	333.3
Sunday 4/9/2022	16.4	1.4	0.4	0.1	0.3	100	333.3

Fig. 8 shows that biogas production starts on the second day. It continued increasing and reached its maximum production on the fourth day, measuring 9000 ml/g vs. at 35 Celsius. After that, the biogas production decreases dramatically, reaching 1000 ml/g VS on the eleventh day. The biogas production continued to decrease and ceased on the fifteenth day

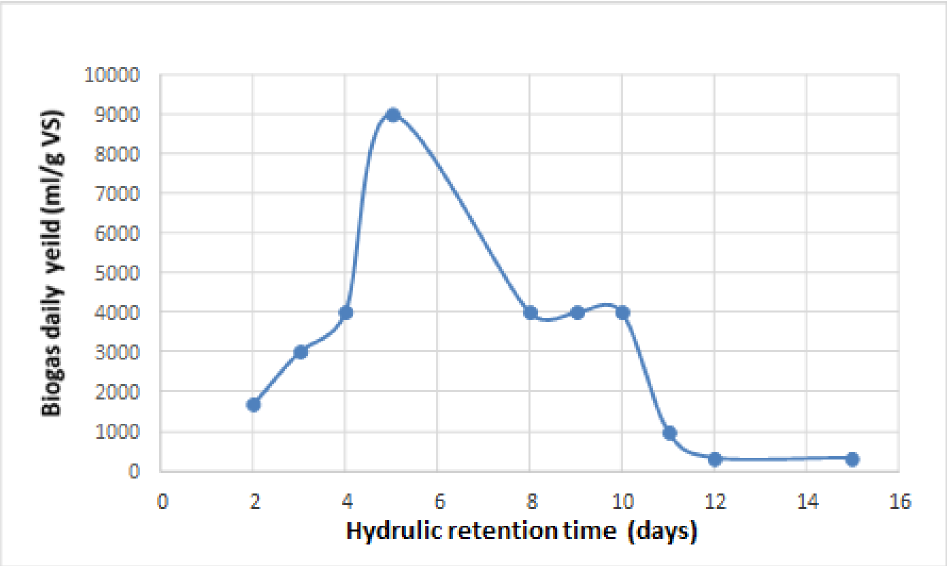

Figure 8: *Biogas daily yeild.*

Table 3: *Parameters of the second experiment.*

Date	**Sunday/ 9/10/2022**
Weight of agricultural waste	1500g
Cow dung weight	60% of agricultural waste
Distilled water	1.8 L
Temperature	50°C
pH	7.2

Table 4: *Biogas daily yield (ml/ g VS).*

Date of Withdrawal Samples	Weight of Empty Evaporation Dish (g)	Weight of Sample (before drying)(g)	Weight of Sample (after drying) (g) (A)	Weight of Sample After Burning (g) (B)	VS = A-B (g)	Milliliters of Water Displacement (ml)	Biogas Daily Yield (ml/g VS)
Monday 10/10/2022	69.8	6.4	0.5	0.1	0.4	200	500
Tuesday 11/10/2022	18.8	2.8	0.2	0.1	0.1	300	3000
Wednesday 12/10/2022	22.9	2.4	0.2	0.1	0.1	500	5000
Thursday 13/10/2022	26	2.6	0.4	0.1	0.3	500	1666.6
Sunday 16/10/2022	20.8	3.8	0.6	0.1	0.5	300	600
Monday 17/10/2022	16.4	1.9	0.4	0.1	0.3	100	333.3
Tuesday 18/10/2022	15.5	3.4	0.4	0.1	0.3	100	333.3
Wednesday 19/10/2022	18.8	3.8	0.5	0.1	0.4	100	250
Thursday 20/10/2022	20.8	4.1	0.5	0.1	0.4	100	250

Fig. 9 shows that biogas production started to form on the second day and increased rapidly, reaching its maximum on the fourth day. The biogas production was 5000 ml/g. A sudden decrease in biogas production started after the fourth day. This decrease continued until the eleventh day. Later, it stopped after the twelve day.

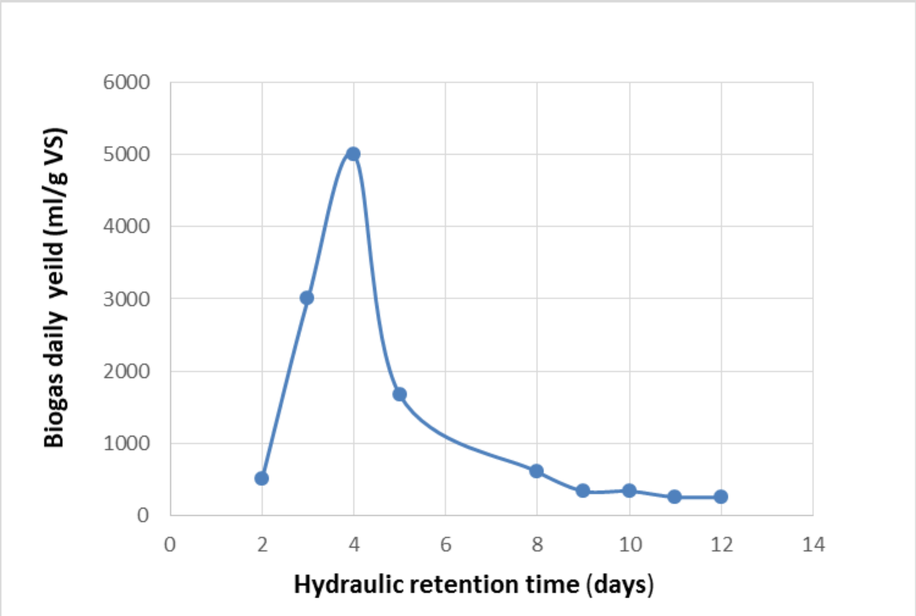

Figure 9: *Biogas daily yield.*

CONCLUSIONS

This study demonstrated that vegetable waste could be used in anaerobic digestion to create biogas and that the pH range plays a significant part in biogas yield. The process of turning biomass into biogas could have benefits for both the environment and people. Greenhouse gas emissions have decreased because of the change, as have pollution levels in the air, water, and soil. Former California governor Arnold Schwarzenegger said, “The future is green energy, sustainability, and renewable energy.” Using renewable energy sources is essential for a problem-free existence. After the trial is applied, many findings emerge as a result. The findings were as follows:

- Cow dung was added only to speed up the biogas production process.
- pH 6.4 is the best value to achieve maximum biogas for the mixture.
- The amount of methane depends on pH, which heat content depends on.
- The pH value in the mixture of ingredients reduced rapidly due to the accumulation of the ingredients’ volatile fatty acid (VFA) and buffer capacity.
- Digest ingredients produce gas directly.
- Biogas production was obtained at a temperature of 35 ^{o}C greater than the temperature of 50 Celsius.

Our motivation for future work is to reduce the emission of greenhouse gasses by proposing or making a strong framework.

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Ethical approval

This work did not require ethical approval under the research governance guidelines operating at the time of the research.

Consent to participate

My participation is completely voluntary. My right to withdrawal from the study at any time without any implications to me. The risks including any possible inconvenience, discomfort or harm as a consequence of my participation in the research project.

Consent to publish

I, give my consent for the publication of identifiable details, which can include photograph (s) and/or details within the text ("material") to be published in the above Journal and Article.

Author contribution

The author confirm contribution to the paper as follow: study conception, design, data collection, analysis, interpretation of results and draft manuscript preparation: Raghad Maher Wadi is a master student and Seroor Atalah Khaleefa Ali is thesis supervisor.

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Competing Interests

The authors declare that they have no competing interests

Availability of data and materials

No data supporting this study due to the results of tables and graphs were created according to the experimental work which is monitor in a laboratory my college Al-Mustansiriyah University and did not used third party.