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Determine the optimal conditions for producing biogas from domestic food waste and measure its properties

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Abstract: A viable and ecologically friendly method of waste management and the creation of renewable energy is the use of food waste to produce biogas. The anaerobic digestion process can be made more efficient overall and the gas generation cycle prolonged by implementing a continuous feeding strategy. In order to increase biogas production, minimize waste disposal, and contribute to a cleaner energy future. The research included the collection of food waste from different sources to conduct the anaerobic digestion process for the production of biogas and calculate the amount of gas produced over time for each type of waste after determining the type of waste most produced for biogas, samples of biogas were taken and several tests were conducted for him, including the thermal energy of gas and gas chromatography. Gas production started to appear a few days after adding raw materials to the anaerobic digester and the production continued to increase gradually until it reached its full production within 15 to 25 days, then gas production started to decrease and eventually stopped after the available raw materials were used up. Biogas produced from household waste has a lower calorific value, as the impurities in the biogas reduced its overall energy production. The best raw material is food waste from the student restaurant as it gave us the highest gas production rate

Keywords: Biogas, digester; heat energy; Zucchini waste ; Eggplant waste

1. Introduction

In the energy sector, "biomass" refers to living biomaterials that were viable until recently and can be utilized for industrial production or as fuel (Léonard *et al*., 2011); (Basu *et al.*, 2018); (Tran, M. H. *et al.*, 2024). Except for organic matter that is ground into coal or oil, biomass can also refer to waste that naturally decomposes and can be burned as fuel. Most biomass is made up of plant materials used as biofuels, but it can also refer to plant or animal materials used to produce fiber, chemicals, or heat (Dahiya, 2014); (Hakeem *et al*., 2014) (Jameel, M. K. *et al*, 2024).

The nature of the product can be determined by the method used in the conversion, there is a wide range of products including ; liquid fuel can be prepared: ethanol, methanol, biodiesel, Fisher Tropch liquid products, while gaseous fuel can represent hydrogen and methane, and biomass can be exploited directly and without complex chemical treatments through direct burning, which is one of the oldest means and techniques adopted by man since ancient times (Demirbas, 2007); (Demirbas, 2006)

(Demirbas, 2006). Biomass represents any organic material that has stored sunlight in the form of chemical energy. Wood, wood debris, straw, sugar cane, manure and other by-products from melty agricultural processes can all be used as fuel. In its narrowest definition, bioenergy is the same as biofuels, which are fuels produced from bio sources. In its broadest definition, bioenergy encompasses biomass, biomaterials used to make biofuels, as well as the social, economic, scientific, and technical domains related to using bio sources as energy sources. As bioenergy is the energy that is taken from biomass, biomass represents the fuel, and bioenergy is the energy that the fuel contains; this is a common misconception [Andrews, 2009]. Methane's gas, which is without any color, odorless, and harmless, makes up the majority of this gas, which is produced when organic matter is broken down by anaerobic fermentation in specially designed digesters. Because of its lighter weight (half that of air), it volatilizes in the air upwards without causing any harm (Roy, 2024); (Kazlauskas, 2005); (Smil, 1985). The generation of biogas from household food waste has garnered significant attention as a sustainable solution to two pressing global challenges: food waste management and renewable energy production. Food waste accounts for a substantial portion of the total waste produced worldwide, with an estimated 1.3 billion tons of food wasted each year, nearly one-third of global food production. Much of this food waste is frequently dumped in landfills, where it breaks down anaerobically without oxygen-producing methane, a powerful greenhouse gas that fuels climate change. However, a potent substitute that can lessen problems with the environment and energy is the anaerobic digestion of food waste to create biogas (Ferdeș *et al*., 2022). Methane and CO_2 make up the majority of biogas, a renewable energy source that can be utilized for transportation, heating, cooking, and even the production of electricity. Anaerobic digestion, which is the biological breakdown of organic materials by microbes without oxygen, is a part of the manufacturing process. The perfect substrate for this procedure is household food waste, such as fruit peels, vegetable scraps, and other organic materials. These organic materials undergo regulated anaerobic digestion to produce biogas, which can be used locally to lessen dependency on fossil fuels and assist in alleviating energy shortages, especially in developing or off-grid locations (Jameel *et al*., 2024); (Mignogna *et al*., 2023). It is clear that this technology has two advantages: it provides a sustainable energy source and lowers the amount of waste that is dumped in landfills. Digestate—the leftover material from the digestion process—is a nutrient-rich material that may be utilized as a natural fertilizer, completing the circle in a circular economy model. This integrated waste-to-energy solution contributes to sustainable waste management practices while reducing the carbon footprint of both energy production and food disposal (Peng *et al*., 2019); (Pal *et al*., 2024). This study for the production of biogas is not the only one, but it is an extension of previous studies in this field, and what encouraged us to do this study is the large number of household food waste or resulting from restaurants, which has spread widely

2. Experimental Method:

2.1 Devices and tools used

1- Digestion bowl with its accessories, figure (1) g
2- Gas stove.
3- Dual-link thermometer.
4- Rubber tubes for storage.
5- Gas Chromatography Device of North Refineries - Baiji Refinery.

2.2 Working procedure

1- The digester is manufactured as shown in the figure (1)
2- Preparation of bacterial crop is done by preparing a diluted solution of 16-20% of herb-free cow dung and left in the digester for 20-30 days for the purpose of bacterial reproduction, after which the digester is ready to work, taking into account that the level of solution in digestion is 60% of the digester volume
3- Feeding the digester is through the preparation of solutions in the form of curd (siliri) from food waste used as a raw material.
4- The waste used is (food waste for the student restaurant, potato waste, eggplant waste, zucchini waste, fish waste).
5- One type of feedstock is placed at a time and we monitor the changes and the time required to produce biogas and calculate the amount of gas by collecting it in containers whose size can be calculated, such as balloons or rubber tubes for tires.
6- Under constant conditions and special fermentation process, the amount of gas produced for each feedstock and the time taken for that are calculated.
7- Samples are sent for analysis using the GC-MAS technics.

Figure (1): The digester

2.3Equation for Flame Temperature to Thermal Energy

In a general sense, if you're focusing on **radiative heat transfer** or the **energy emitted by a flame**, the equation can be related to **Stefan-Boltzmann Law** for blackbody radiation. This law describes how an object emits energy in the form of radiation based on its temperature.

The **Stefan-Boltzmann Law** states that the **power radiated per unit area** (thermal energy per unit time per unit area) from a perfectly black body is proportional to the fourth power of its temperature (Incropera *et al*., 1996); (Cengel *et al*., 2011); (Turns,2006):

$E_{radiated} = \sigma T^4$ ……………………………..1

Where:

$E_{radiated}$ = Power radiated per unit area (W/m²)
σ = Stefan-Boltzmann constant= (5.67×10^{-8} W/m^2K^4)
T = Temperature of the flame in Kelvin (K)

or use the following equation:

$Q = \eta T$ ……………………………..2

Where:

Q: Heat energy emitted by flame (joules/s).

Ŋ : The conversion factor depends on the type of fuel and the intensity of the flame.

T :Temperature measured in (degrees Celsius or Kelvin)

3. Results and Discussion

The result of this study has successfully demonstrated the viability of using various types of food waste—specifically, eggplant waste, potato waste, zucchini waste, fish waste, and food waste from a student restaurant—for biogas production through anaerobic digestion. The findings suggest that food waste from the student restaurant yields the highest gas production, followed by fish waste, potatoes, and, lastly, zucchini and eggplant waste. This result highlights the potential of utilizing food waste, especially from restaurants and food establishments, as a valuable feedstock for biogas generation.

The study's biogas production dynamics, as displayed in tables 1, 2, 3, 4 and 5, clearly illustrate a trend: gas production starts to appear a few days after the feedstock is introduced into the anaerobic digester. Production keeps increasing gradually until it achieves its full output in 15 to 25 days. This is probably because organic molecules were rapidly broken down by microbes in the early stages of the process. However, gas production starts to decrease and eventually stops after the available feedstock is used up. This halt is a sign of feedstock exhaustion, highlighting the necessity of ongoing input to maintain and maximize biogas production.

Table (1) biogas produced from Eggplant waste

Feed stock weight (kg)	gas Volume (cm^3) at1 day	gas Volume (cm^3)at 3 days	gas Volume (cm^3)at 5 days	gas Volume (cm^3)at 7 days	gas Volume (cm^3)at 10 days	gas Volume (cm^3)at 15 days	gas Volume (cm^3)at 20 days	gas Volume (cm^3)at 25 days	gas Volume (cm^3)at 25 days
2	407.2	722.5	1002.88	3147.93	6147.93	7322.51	7322.51	-------	-------
4	567.12	1315.67	2012.087	6423.33	12891.23	13762.23	13764.25	13764.25	---------

Table (2) biogas produced from Zucchini waste

Feed stock weight (kg)	gas Volume (cm^3) at1 day	gas volume (cm^3)at 3 days	gas Volume (cm^3)at 5 days	gas Volume (cm^3)at 7 days	gas Volume (cm^3)at 10 days	gas Volume (cm^3)at 15 days	gas Volume (cm^3)at 20 days	gas Volume (cm^3)at 25 days	gas Volume (cm^3)at 25 days
2	410.1	698.6	1030.31	3368.76	6368.76	7452.21	7454.21	-------	-------
4	589.12	1323.67	2032.08	6383.33	13211.2	13962.2	13964.2	13764.2	---------

Table (3) biogas produced from Potato waste

Feed stock weight (kg)	gas Volume (cm^3) at1 day	gas volume (cm^3) at 3 days	gas Volume (cm^3) at 5 days	gas Volume (cm^3) at 7 days	gas Volume (cm^3) at 10 days	gas Volume (cm^3) at 15 days	gas Volume (cm^3) at 20 days	gas Volume (cm^3) at 25 days	gas Volume (cm^3) at 25 days
2	630.21	812.32	1280.22	3621.51	6721.41	8201.4	8221.4	-------	-------
4	964.12	1423.67	2312.087	6603.33	12971.23	14782.23	14994.25	14974.25	--------

Table (4) biogas produced from Fish waste

Feed stock weight (kg)	gas Volume (cm^3) at 1 day	gas volume (cm^3) at 3 days	gas Volume (cm^3) at 5 days	gas Volume (cm^3)at 7 days	gas Volume (cm^3) at 10 days	gas Volume (cm^3) at 15 days	gas Volume (cm^3) at 20 days	gas Volume (cm^3) at 25 days	gas Volume (cm^3) at 25 days
2	587.32	832.61	1896.21	2602.18	57002.34	8432.34	8437.34	-------	-------
4	786.12	1345.67	3112.087	5302.33	74690.23	15632.23	15982.25	15978.63	---------

Table (5) biogas produced from Food waste of the student restaurant

Feed stock weight (kg)	gas Volume (cm^3) at1 day	gas volume (cm^3) at 3 days	gas Volume (cm^3) at 5 days	gas Volume (cm^3) at 7 days	gas Volume (cm^3) at 10 days	gas Volume (cm^3) at 15 days	gas Volume (cm^3) at 20 days	gas Volume (cm^3) at 25 days	gas Volume (cm^3) at 25 days
2	628.3	829.84	1312.51	4080.21	6987.52	9012.34	9020.11	-------	-------
4	834.23	1482.53	2231.69	7389.51	12791.62	16873.53	16943.31	16947.53	---------

The thermal energy from burning biogas made from domestic garbage is included in Table (7). The information demonstrates that biogas has a calorific value, a crucial measure of its potential for energy production, and can, in fact, ignite a flame. However, as compared to natural gas or other fossil fuels, biogas produced from domestic garbage has a lower calorific value. Impurities in biogas lower its overall energy yield, which is the main cause of this variation in energy content. However, because they are purer and contain fewer contaminants, fossil fuels, such as natural gas, have a higher calorific value and burn more effectively. Home West biogas is still renoable and Sustainable energy source, but because of its lower calorific value, it cannot be used directly in many high -efficiency application. However, biogas can remain a useful alternative energy source for power generation and heating with their right upgrading and purifying a produced. Biogas viability and competitiveness in the energy market can be increased by improving its a quality and energy content through more research and technological development.

Figure 2 illustrate the gas chromatograph spectrum of the biogas produced from household waste. According to the spectrum a significant portion of the biogas is made up of CH4, which is the primary component responsible for its flammability and energy potential. To methane, trans number of combustible gazes such as Bhutan and Ethane are present in the biogas, which further increases its calorific value and stability. However, the spectrum also displays none -flammable gases that are frequently found in biogas, such as CO_2 and N_2, while these gases is do not rise the energy content of the biogas, they can reduce its overall fuel efficiency. Since fossil fuels are mostly made up of methane and have less pollutants biogas ofen has a lower calorific value due to these impurities.

In order to eliminate non-flammable gases and improve the biogas's energy efficiency for usage in real-world applications like heating or power generation, this study emphasizes the gas's composition and the necessity of modernizing and purifying techniques. To guarantee the long-term sustainability and efficiency of biogas generation, the digester's feedstock needs to be routinely refilled. The overall anaerobic digestion process will be stabilized and gas output will be maintained with this continuous feeding technique. It is also necessary to take into account the kind and quality of feedstock because the rate at which gas is produced is influenced by various organic ingredients. According to our research, the food waste from student restaurants is the best feedstock for producing biogas because of its higher organic content.

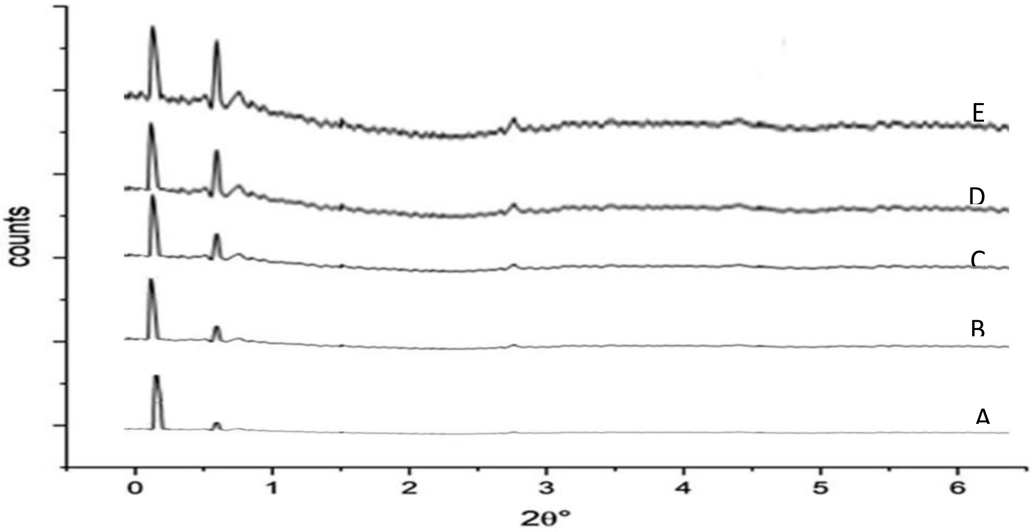

Figure (2): gas chromatograph spectrum of the biogas produced from household waste(student restaurant waste)

To sum up, produce biogas from food waste is a practical and sustainable way to manage trash and give renewable energy. When using a continuous feeding strategy can extend the gas generation cycle and improve the overall efficiency of the anaerobic digestion process. This study lays the groundwork for future investigations into methods to boost biogas production, reduce waste disposal, and aid in the creation of greener energy.

Heat Temperature

By Using a benzen lamp, the change in flame temperature over time, were calculated determined the minimum and maximum limits of the flame temperature, and also calculated the flame energy from knowing the maximum temperature (Q) according to the equation:($Q = \eta\ T$) **Table (6).**

Table (6) Flame heat Temperature gradient over time

Time (sec)	Flame heat Temperature of Kitchen gas (Household gas cooker) ◦ C	Flame heat Temperature of biogas ◦ C
5	23	23
10	58	44
15	119	98
20	229	130
25	354	182
30	436	221
35	411	250
40	444	288
45	479	324
50	520	352
55	555	374
60	594	392
65	630	410
70	630	410

Table (7) Heat Energy calculation by equation (Q = η T)

source	Max Flame heat Temperature ◦C	Heat energy of the flame Q(jol⁄sec)
Household gas cooker (Kitchen gas)	630	441
Biogas produced	410	287

The data demonstrates that biogas has a calorific value, a crucial measure of its potential for energy production, and can, in fact, ignite a flame. However, as compared to natural gas or other fossil fuels, biogas produced from domestic garbage has a lower calorific value that can show in Table (7). Impurities in biogas lower its overall energy yield, which is the main cause of this variation in energy content. Fossil fuels, such as natural gas, on the other hand, have a higher calorific value and burn more efficiently because they are purer and contain less impurities.

Conclusion

The results of the biogas production dynamics we see in this investigation show a distinct pattern: gas production begins to appear a few days after the feedstock is added to the anaerobic digester. Production continues to increase gradually until it reaches its full production within 15 to 25 days, then gas production begins to decline and eventually stops after the available feedstock is used up. This cessation is a sign of feedstock depletion, highlighting the need for continued inputs to maintain and maximize biogas production. The data also show that biogas has a calorific value, a critical measure of its potential for energy production, and can actually ignite a flame. However, compared to natural gas or other fossil fuels, biogas produced from household waste has a lower calorific value. Impurities in biogas reduce its overall energy yield, which is the main reason for this discrepancy in energy content. The best raw material is the food waste resulting from the student restaurant, as it gave us the highest gas production rate. On this basis, samples of the produced biogas were taken for the periods (5, 10, 15, 20, 25).

The biogas production from household food waste presents a sustainable solution to reduce waste, mitigate climate change, and provide renewable energy. As research progresses and technology advances, it is likely that decentralized biogas systems will become an integral part of urban waste management and renewable energy strategies. Through continued innovation and global collaboration, biogas from food waste can play a critical role in achieving more sustainable, circular economies.

A viable and ecologically friendly method of waste management and the creation of renewable energy is the use of food waste to produce biogas. The anaerobic digestion process can be made more efficient overall and the gas generation cycle prolonged by implementing a continuous feeding strategy. In order to increase biogas production, minimize waste disposal, and contribute to a cleaner energy future.

According to the results in tables 1, 2, 3, and 5, the dynamics of biogas production seen in this investigation show a distinct pattern: gas production starts to appear a few days after the feedstock is added to the anaerobic digester. Production keeps increasing gradually until it achieves its full output in 15 to 25 days. This probably because organic molecules were rapidly broken down by microbes in the early stages of the process. However, gas production starts to decrease and eventually stops after the available feedstock is used up. This halt is a sign of feedstock exhaustion, highlighting the necessity of ongoing input to maintain and maximize biogas production.

The thermal energy from burning biogas made from household trash is shown in Table (7). The data demonstrates that biogas has a calorific value, a crucial measure of its potential for energy production, and can, in fact, ignite a flame. However, as compared to natural gas or other fossil fuels, biogas produced from domestic garbage has a lower calorific value. Impurities in biogas lower its overall energy yield, which is the main cause of this variation in energy content. Fossil fuels, such as natural gas, on the other hand, have a higher calorific value and burn more efficiently because they are purer and contain less impurities.

We also note that the best feedstock is food waste resulting from the student restaurant, where it gave us the highest percentage of gas productivity as shown in Table (2), and on this basis samples of biogas produced for the periods (5, 10, 15, 20, 25) were taken and gas chromatography analysis was conducted and gave us spectra (A, B, C, D, E) respectively shown in Figure (2), which shows the effect of the period of stay of feedstock in the digester on the amount of biogas production.

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