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# Biogas production from cafeteria waste by anaerobic digestion

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**Abstract.** The world's reliance on non-renewable energy sources is unsustainable, and biogas production from organic waste materials is a promising renewable energy source. However, there is a lack of technology and understanding surrounding biogas production and utilization. This study aimed to produce biogas at laboratory scale using cafeteria waste and to examine the processes of biogas production for variable factors such as retention time, pH level, and addition of bases. The findings showed that a mixture of papaya peels, water, cow manure, and a base produced an impressive 80.75% methane yield within 75 days under mesophilic conditions with a specific pH and temperature range. However, maintaining optimal pH and vacuum in a biogas chamber presents challenges, such as leakages and pH fluctuations. The optimal ratio for biogas production is a mixture of 45-50% organic matter and 55-60% water, with careful regulation of base addition to ensure maximum biogas production and optimal biogas quality. This study provides insights into biogas production and its potential as a viable biofuel alternative.

## 1 Introduction

The management of waste has become a major environmental challenge due to the increasing urbanization and rise in waste production. Food waste, in particular, is a significant contributor, generated by various sources such as commercial and household kitchens, cafeterias, and restaurants. According to the Food and Agricultural Organization (FAO), more than 1.3 billion tons of food, including fresh fruits, vegetables, meat, bread, and dairy products, are wasted throughout the food supply chain. The expected economic and demographic growth, particularly in Asian countries, will likely increase the amount of food waste generated in the next 25 years. For example, the amount of urban food waste generated annually in Asian countries is projected to increase from 278 to 416 million tons between 2005 and 2025. These trends pose significant challenges for cities, institutions, and various industrial sectors, highlighting the need for effective waste management strategies. [1]–[7]

The pH level is a crucial factor that greatly influences the efficiency and sustainability of an anaerobic digester. This is because microorganisms are highly responsive to changes in pH. The reason behind this is that each bacterial group has a unique pH range for optimal growth [8]. In particular, the most favorable pH range for hydrolysis, acetogenesis, and methanogenesis is approximately 6.0, 6.0-7.0, and 6.5-7.5, respectively [9].

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The anaerobic digestion (AD) process can be classified as either wet or dry digestion depending on the total solid concentration in the food waste (FW). When the total solid concentration of the FW is between 20% and 40%, it is referred to as a dry process, while a wet process is used for FW with a total solid concentration of less than 15% [10] . According to Kothari et al. (2014), most AD plants constructed in the 1980s relied on the wet system, whereas in recent years, new plants have mostly been based on the dry process.

Co-digestion, which involves the simultaneous digestion of multiple organic waste streams, has been shown to increase biogas production by providing a diverse range of nutrients and energy sources to the microorganisms involved in the digestion process [11], [12]. This process also enhances the stability of the digestion process, reducing the risk of process failure due to the presence of inhibitory compounds. In addition, co-digestion has the potential to lower the overall cost of biogas production by utilizing locally available organic waste materials [13]. Despite these benefits, improper mixing ratios of feedstocks can lead to organic overloading, acidification, and system failure, causing negative impacts [14]. To mitigate these issues, it is crucial to characterize the heterogeneous organic compounds in the digester feedstocks and understand their intrinsic biodegradability patterns [12]. According to Xu et al. (2018) [15], animal manure is a potential co-substrate for anaerobic digestion due to its abundant nutrient content and strong buffering capacity. The addition of animal manure as a co-substrate can increase the maximum organic loading rate (OLR) to up to 10 kg VS/m3/day and provide a stable environment for anaerobic microorganisms.

Due to the challenges associated with controlling various parameters such as temperature, pH, and substrate composition, there is a growing need for cost-effective methods for biogas production from waste. In this study, we aimed to investigate the potential of utilizing a range of agricultural wastes, including papaya peels, bottle gourd, pumpkin, and rice, common food waste in Bangladesh, for the production of biogas using readily available two-liter bottles. In addition, we examined the compatibility of these substrates with cow dung for co-digestion. To control the pH of the mixture, we added urea. Our objective was to develop an affordable and sustainable method for biogas production that can be easily replicated in resource-limited settings. Our results demonstrate the feasibility of using these low-cost substrates for biogas production with co-digestion, opening up possibilities for waste valorization in developing countries. This study contributes to the body of knowledge on alternative sources of energy and provides insight into the potential for utilizing agricultural waste as a sustainable resource for biogas production.

## 2 Experimental methodologies

### 2.1 Construction of the anaerobic digesters

The anaerobic digesters were constructed using a plastic bottle with a capacity of 2 liters, which measures 12.4 inches (31.5 cm) in height and 4.33 inches (11 cm) in diameter as shown in Fig. 1. The bottle is equipped with two directional control valves and a fully sealed cap to prevent biogas from escaping into the surrounding air.

### 2.2.Substrate collection

For the current study, different types of vegetable peels and rice were gathered from the cafeteria of the Islamic University of Technology (IUT), while cow manure was obtained from nearby cattle ranches. The pH of the substrate was regulated using potassium hydroxide (KOH), sodium hydroxide (NaOH), and urea, which were procured from local chemical stores.

## 2.3. Slurry preparation

The slurry was composed of 85% vegetable peel or rice, 10% cow manure, and 5% urea blended with cow manure. Fig. 2 depicts slur prepared with leftover rice and slur prepared from papaya peel is shown in Fig. 3.

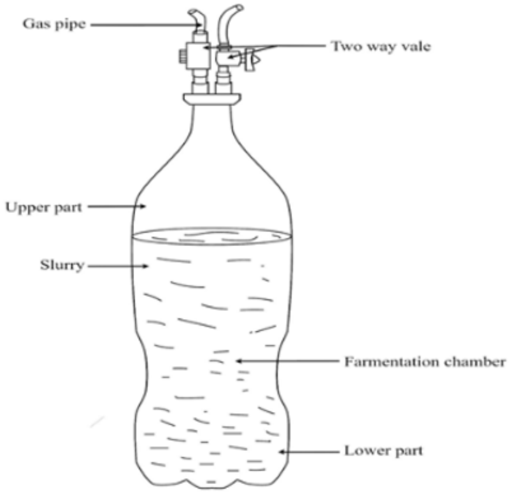


**Fig 1.** Schematic Diagram of the Digester Setup

**Fig 2.** Leftover rice slur in the digester

**Fig 3.** Papaya peel slur in the digester.

## 2.4. Feeding and operation

After the slurry was prepared, it was transferred into the digester, valves were installed, and a suction pump was utilized to eliminate all air and create a vacuum inside the container. The

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digester was then placed in a room where a constant temperature was maintained, and it was covered with black cloth to prevent any light from entering.


**Fig 4.** Gasboard-3200 plus gas analyzer with its components.

**Fig 5.** Measuring pH with a pH meter.

## 3. Result and discussion

This experimental study involved constructing small-scale anaerobic biogas digesters using leftover rice and vegetable peels in different proportions, with cow manure utilized for co-digestion.

### 3.1. Papaya peel and water (1:1) setup, including 10% cow manure, and 20 g urea

The graph depicting methane and carbon dioxide vs. hydraulic retention time (HRT) appears to depict the results of a biogas production experiment. The horizontal axis shows the number of days (HRT), and the vertical axis shows the percentage of biogas produced from the mixture at each time point. The data in Fig. 6 shows that there was an initial lag period of 9 days, during which little to no biogas is produced and the $CO_2$ level is 65% at this time the pH level is 5 as shown in Fig. 7, which suggests that the biogas digester was producing biogas. Initially 50 ml 2 Molar KOH was added to the set up.

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However, after 13 days, at day 29 the biogas production began to increase; the $CO_2$level is 49.7% and the pH level is 6.5, which suggests that the microorganisms are still active and producing biogas. The setup was supplemented with 10 ml of 3 moles of NaOH. The methane percentage increased up to 62.58% within 61 days, reaching a peak of 80.75% at day 75.
At day 75, the CO2 level was 15% and the pH level remained at 7, indicating that the microorganisms were close to completely consuming the organic matter, resulting in low $CO_2$production. By day 92, the $CO_2$level had risen to 17.62%, suggesting that the microorganisms were producing biogas, although not as much as in the initial stages. Subsequently, the biogas production gradually declined, with the final measurement showing 45.15%.

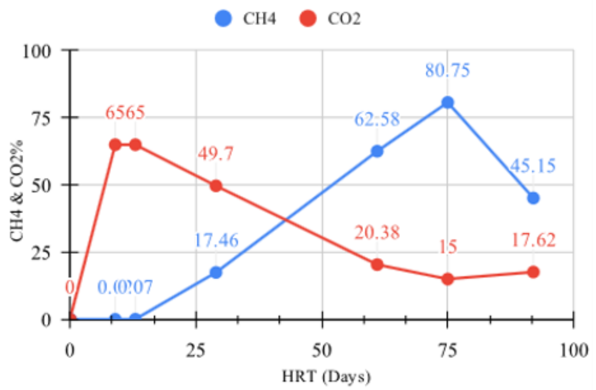


**Fig 6**. $CH_4$ and $CO_2$ production with time from papaya peel and water (1:1) setup.

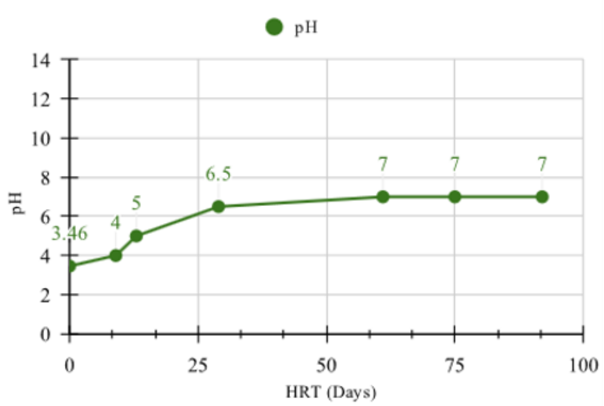


**Fig 7.** pH profile of papaya peel and water (1:1) setup.

### 3.2.Papaya, bottle gourd and water (1:1) setup, including 20% cow manure, and 15 g urea

The utilization of a combination of papaya and bottle gourd peel, 20% cow manure, and 15 g urea in a setup with equal amounts of water, led to the production of methane with a yield of 4.61% in only 17 days as shown in Fig. 8, owing to the ideal pH range as shown in Fig. 9. This suggests the potential for methane production from this setup.

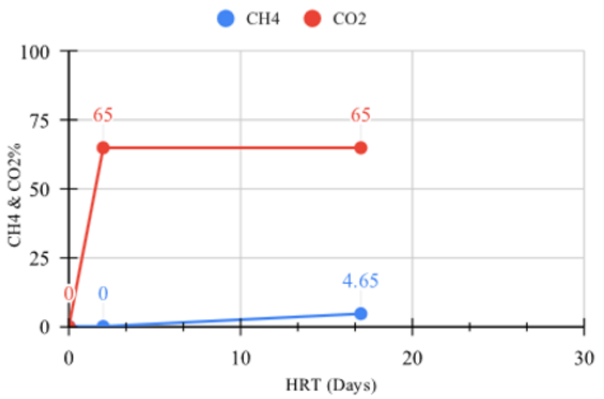


**Fig 8.** $CH_4$ and $CO_2$ production with time from papaya, bottle gourd and water (1:1) setup.

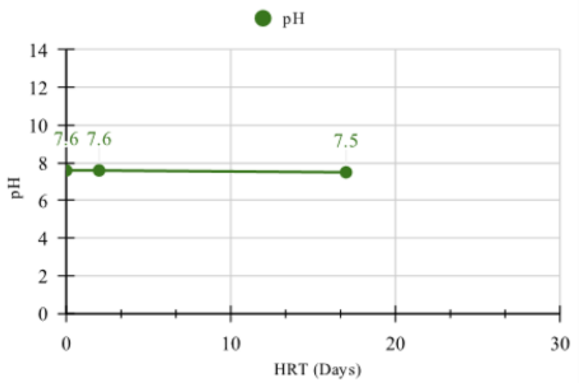


**Fig 9.** pH profile of papaya, bottle gourd and water (1:1) setup.

### 3.3.Pumpkin and water (1:1), including 20% cow manure, and 15 g urea

The mixture yielded 0.03% CH4 and 65% CO2 in the biogas as shown in Fig. 10 after two days of anaerobic digestion. As a result, it may be inferred that methane production was minimal and the anaerobic digestion process was still in its early stages. After 17 days of anaerobic digestion, the biogas produced from the mixture contained 1.1% CH4 and 65% CO2. This indicates that the anaerobic digestion process was more advanced and that a significant amount of methane was produced.

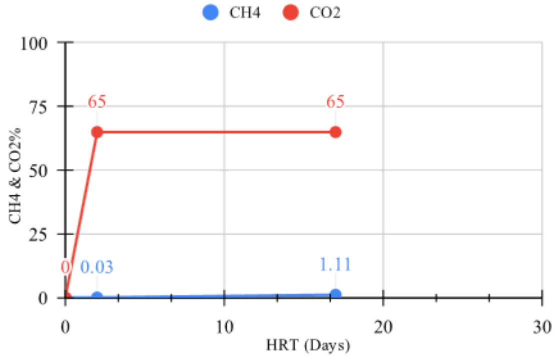


**Fig 10.** CH4 and CO2 production with time from pumpkin peel and water (1:1) setup.

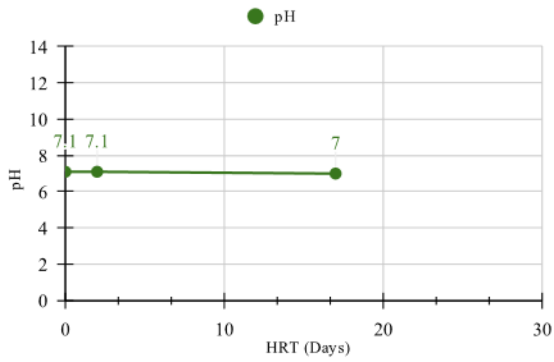


**Fig 11.** pH profile of pumpkin peel and water (1:1) setup.

### 3.4. Rice and water (1:1), including molasses and yeast

Another experiment involved mixing rice with water in a 1:1 ratio, adding 15 g urea, and including either 25 mL molasses or 4 g yeast in separate setups. Although methane was not initially produced, the CO2 level rose to 65% within 17 days in both setups. However, maintaining the pH in the ideal range would require further investigation to achieve positive results.

### 3.5. Discussion

The results of this study demonstrate that papaya peels have the potential to be a suitable substrate for biogas production, but the percentage of methane yield may be influenced by various factors, including temperature, pH, and microbial population. Further investigation is needed to optimize the biogas production process using papaya peels and other waste materials.

Maintaining a pH range of 5.5 to 7.3 [16] is crucial for efficient digester operation under mesophilic conditions. To adjust the pH level, NaOH and KOH bases were initially used, but large quantities were required, as indicated by the high amounts used in the papaya setup. As a result, urea was used as it only requires 20 g to achieve the desired pH range. Urea acts as a nitrogen source for the microorganisms that degrade organic matter in the digester, which promotes biogas production rates. Additionally, urea is more cost-effective and less corrosive compared to NaOH and KOH bases.

## 4 Conclusion

A comprehensive experiment at laboratory scale was performed for biogas production from substrates made of cafeteria waste. The processes of biogas production were carefully examined for variable factors such as retention time, pH level, addition of bases of different types, and so on. Acid-producing bacteria can become dominant if the pH drops below 5.5, and methane-producing bacteria can be inhibited if the pH rises above 8.0, resulting in a lack of methane production. The optimal ratio for biogas production is generally a mixture of 45-50% organic matter, such as food waste, and 55-60% water.

Maintaining a vacuum and optimal pH in a biogas chamber can present challenges, including:

(a) Leakages: A leak-proof system is required to maintain a vacuum. Any leaks can disrupt anaerobic conditions and reduce biogas production.

(b) pH fluctuations: Changes in the composition of the feedstock or temperature can cause pH level fluctuations, making it challenging to maintain the optimal pH range for biogas production. It is crucial to note that adding too much base can have adverse effects. Thus, it is essential to carefully regulate the amount of base added to the biogas plant to ensure maximum biogas production and optimal biogas quality.

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