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Enhancement of biogas production from food waste using yeast as biocatalyst

Abayomi O. Olatunde[1,*], **Olusiji A. Adeyanju**[2] and **Oluwasola Oribayo**[1]

[1] Department of Chemical Engineering, University of Lagos, Akoka, Yaba, Lagos, Nigeria

[2] Department of Petroleum and Gas Engineering, University of Lagos, Akoka, Yaba, Lagos, Nigeria

*E-mail address: aolatunde@unilag.edu.ng

ABSTRACT

The increasing demand for sustainable energy and effective waste management has intensified interest in biogas production from organic residues. Food waste represents a readily available and highly biodegradable substrate for anaerobic digestion, yet its potential remains underutilised in many developing regions. This study investigates the enhancement of biogas production from food waste through the application of yeast as a biocatalyst and the use of an iron oxide scrubber for gas purification. Anaerobic digestion experiments were conducted using laboratory scale digester operated under mesophilic conditions for a period of 40 days. Key operational parameters, including pH, temperature, and daily biogas yield, were monitored throughout the digestion process. Two experimental setups were evaluated: a catalysed system containing yeast and non-catalysed control system. Results showed that the yeast addition significantly improved the rate of biomethanation and reduced lag phase of microbial activity. The total biogas yield obtained from the catalysed system was 13,088 cm^3, compared to 9,021 cm^3 from non-catalyzed system. Optimal biogas production occurred within a pH range of 6.7-7.3 and at temperatures between 31 and 34 °C. The application of an iron-oxide scrubber further improved biogas quality by removing hydrogen sulphide and other impurities. The findings demonstrate that food waste conversion to biogas, aided biocatalysts, offers a viable approach for renewable energy generation and sustainable food waste management.

Keywords: Biocatalysts, Biogas, Food waste, Mesophilic, Yeast

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1. INTRODUCTION

The increasing global dependence on fossil fuels has contributed significantly to climate change, environmental pollution, and the depletion of non-renewable energy resources. The combustion of fossil fuels releases large quantities of greenhouse gases, particularly carbon dioxide, which increases global warming and threatens environmental sustainability [1].

As population growth and industrialisation continue to drive energy demand, the need for alternative, renewable, and environmentally friendly energy sources has become necessary.

Anaerobic digestion is a biological process in which organic materials are decomposed by microorganisms in the absence of oxygen, resulting in the production of biogas [2-4]. Biogas consists of methane and carbon dioxide, with trace amounts of other gases. Methane, the principal energy carrier in biogas, can be utilised for cooking, heating, electricity generation, and transportation when adequately purified. Unlike fossil fuels, biogas is regaraded as a low carbon energy source because the carbon released during combustion originates from assimilated atmospheric carbon [5].

Food waste constitutes a significant fraction of municipal solid waste and poses serious environmental challenges when disposed of through landfilling or incineration . Landfills emit uncontrolled methane, while incineration leads to the loss of valuable nutrients. Anaerobic digestion offers a sustainable alternative by enabling both energy recovery and nutrient recycling. The digestate produced during the process is rich in nutrients and can be applied as an organic fertilizer, contributing to a circular economy [6-8].

Food waste is particularly suitable for anaerobic digestion due to its high moisture content, rapid biodegradability, and favorable composition of carbohydrates, proteins, and lipids [9-11]. However, challenges such as acidic conditions during early digestion stages, slow microbial adaptation, and the presence of corrosive impurities in raw biogas can limit overall system efficiency. Process optimization techniques, including pH control, temperature regulation, biocatalyst addition, and gas purification, are therefore essential

Biocatalysts have been shown to enhance anaerobic digestion by accelerating the breakdown of complex organic matter and improving microbial activity. In addition, iron oxide based scrubber can effectively remove hydrogen sulphide and other contaminants, thereby improving the quality and usability of biogas. This study focuses on evaluating the effect of yeast as a biocatalyst on biogas production from waste and comparing the performance of catalysed and non-catalyzed digestion systems, while also using an iron oxide scrubber for biogas purification.

2. MATERIALS AND METHOD

2. 1. Experimental Setup

The experimental system comprised a laboratory-scale anaerobic digestion unit consisting of a biodigester, a scrubbing chamber, and a gas collection unit. The biodigester was fabricated from 250 L plastic drum and designed for airtight operation under mesophilic conditions. A 40 L gas holder was connected to the digester through a scrubbing chamber to allow for gas purification and storage.

The digester was equipped with a pressure gauge, thermometer, mechanical stirrer, feed inlet, gas outlet, and effluent discharge value. All connections were carefully sealed to prevent gas leakage. Prior to operation, the system was purged with nitrogen gas to eliminate residual oxygen and establish anaerobic conditions.

Figure 1. Purging of The Biodigester System.

The biogas produced having low density gather at the top of the set-up was released at the top of the mixture and left the biodigester through the gas hose into the scrubbing chamber.

The scrubbing chamber contains a scrubbing agent, iron(III) oxide (in form of iron sponge), this removes the contaminant gases (most especially hydrogen sulphide) by the following reaction:

$$2Fe_2O_3 + 2H_2O + 6H_2S \xrightarrow{yields} 2Fe_2S_3 + 8H_2O \quad (1)$$

The hydrogen sulphide if present in the biogas, alongside water (moisture) gives sulphuric acid (H_2SO_4) which may pose a great danger to its usage due to its corrosiveness [12]. Upon exposure of the spent iron sponge to the air, re-oxidation may occur by an exothermic reaction to iron(III) oxide and elemental sulphur, thus regenerating the iron oxide:

$$2Fe_2S_3 + 3O_2 \xrightarrow{yields} 2Fe_2O_3 + 6S \tag{2}$$

The biomethane leaving the scrubbing chamber is now improved in its energy content per unit volume, but still contains carbon (IV) oxide (25 – 50%) which will later be removed by dissolving inside water in the 40 L plastic container.

Figure 2. Full Set-Up.

2. 2. Feedstock Collection And Preparation

Approximately 100 kg of food waste was collected from hotels, markets, and institutional cafeteries (University of Lagos, Nigeria). The waste included both processed and unprocessed food materials such as rice, yam, cassava, vegetables, fruits, and residual oils. Non-biodegradable materials were manually removed before processing.

The food waste was blended with distilled water to form a homogeneous slurry suitable for anaerobic digestion. Composition analysis comfirmed the presence of adequate proportions of carbohydrates, proteins, fats, and fibres necessary for effective biomethanation.

2. 3. Sterilization And Digester Loading

To minimize the influence of indigenous microorganisms and ensure controlled experimental conditions, the prepared slurry was sterilized in an autoclave for approximately 20 minutes. Following sterilization, the biodigester was purged with nitrogen gas.

Approximately 120 L of the prepared slurry was introduced into the biodigester. Two experimental setups were established: one digester received 20 g of yeast as a biocatalyst, while the second digester served as the control without yeast addition.

2. 4. Anaerobic Digestion Process

The digestion process was carried out under mesophilic conditions, with temperatures maintained between 30 and 40 °C. The slurry was gently agitated every two days to ensure uniform mixing and microbial contact.pH was monitored daily, and sodium trioxocarbonate (Na_2CO_3) was added as required to correct acidic conditions and maintain a pH range favourable for methanogenic bacteria. Biogas production was monitored daily by measuring the volume of gas collection chamber and 50 g of sugar was introduced into the biodigester at interval to enhanced the rate of decomposition. Pressure and temperature readings were recorded throughout the 40 day digestion period.

2. 5. Biogas Scrubbing And Purification

Raw biogas generated in the digester was passed through the a scrubbing chamber containing iron oxide (iron spone) where hydrogen sulphide and other impurities were removed which thus improved the gas quality. The scrubbed gas is then passed through a gas holder, where additional purification took place through water displacement which allowed carbon dioxide to dissolve in water leading to methane rich gas.

3. RESULTS AND DISCUSSION

The results gotten for the yield of biogas for the non-catalysed and catalyzed set-ups are displayed on both Tables 2 and 3 below. These were results gotten during the experiment at different retention time, pH and temperatures for a period of 40 days. The effect of biocatalyst on the rate of production of the biogas was also investigated via a graphical plot.

Table 1 below shows the feed composition and quantity in kg and litres used.

Table 1. Feed Composition Used For This Experimental Study.

FEED COMPOSITION	WEIGHT
Feed slurry	120 liters
Food waste	50 kg
Oily water	50 litres
Water (H_2O)	40 litres

Sugar	50g
Catalyst |(Yeast)	20g

Table 2. Experimental results of the Non-catalysed Setup.

Runs	Temperature (°C)	Total gas observed Without Bio-catalyst (cm^3)	pH	Retention Time (Days)
1	31	0	5.0	2
2	31	0	5.0	3
3	31	0	6.0	4
4	31	0	6.3	5
5	31	120	6.7	6
6	31	391	6.9	7
7	32	906	7.1	8
8	33	1143	7.1	9
9	33	1624	7.2	10
10	33	2281	7.1	11
11	34	2676	7.2	12
12	34	2921	7.2	13
13	34	3433	7.2	14
14	33	4644	7.1	15
15	34	6335	7.1	16
16	34	6712	7.1	18
17	33	7013	7.1	19
18	33	7282	7.0	21
19	33	7476	7.1	23
20	34	7980	7.1	28
21	34	8132	7.1	33
22	34	8524	7.1	37
23	34	9021	7.1	40

Table 3. Experimental Results of the Catalysed Setup.

Runs	Temperature (°C)	Total gas observed Without Bio-catalyst (cm^3)	pH	Retention Time (Days)
1	31	0	5.2	2
2	31	0	5.2	3
3	31	0	6.1	4
4	31	354	6.4	5
5	31	681	6.7	6
6	31	1473	7.0	7
7	33	2664	7.1	8
8	33	3821	7.1	9
9	33	4382	7.2	10
10	33	5869	7.1	11
11	34	6936	7.2	12
12	34	8034	7.2	13
13	34	9226	7.2	14
14	33	10112	7.1	15
15	34	10984	7.1	16
16	34	11023	7.1	18
17	33	11281	7.1	19
18	33	11408	7.0	21
19	33	11698	7.1	23
20	34	12382	7.1	28
21	34	12580	7.1	33
22	34	12830	7.1	37
23	34	13088	7.1	40

3. 1. Biogas Production Performance

Biogas production was monitored throughout the 40 days of digestion period for both non-catalysed and yeast catalysed systems as shown in Tables 2 and 3 respectively. There was a distinction in performance observed between the two setups. Gas production started earlier in the catalysed system, with noticeable biogas detected on the fifth day, while non-catalysed system started producing gas on the sixth day. This earlier onset of gas production in the catalysed system shows that yeast addition reduced the microbial lag phase and accelerated substrate conversion. At the end of the digestion period, the total amount of gas produced in the catalysed system was 13,088 cm^3, while the non-catalysed system yielded 9,021 cm^3. This represents a significant improvement in biogas yield due to the presence of the biocatalyst. The enhanced performance is attributed to the improved hydrolysis and acidogenesis, which encoureged faster availability of intermediate products for methanogenetic microorganisms.

3. 2. Effect of pH and Sodium Carbonate on Biogas Yield

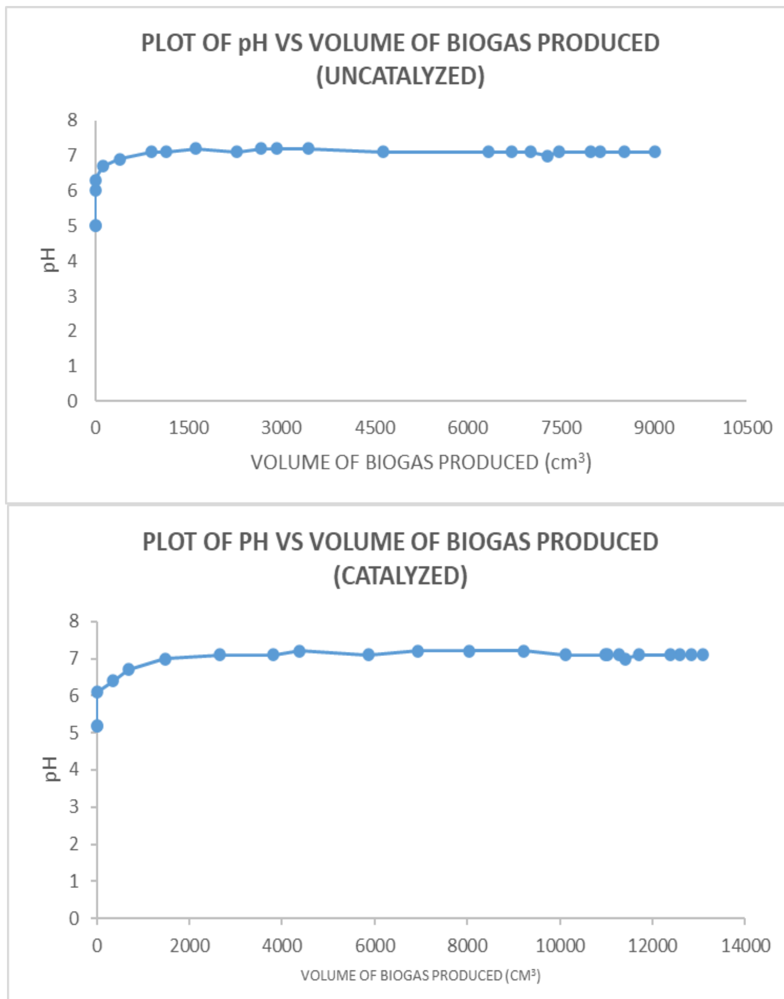

Figure 3. Graph Of pH vs Biogas Produced (Uncatalyzed Set Up And Catalyzed Set Up).

As shown in Figure 3, the pH of the digestion slurry played a major role in determining the efficiency of biogas production. During the initials days of digestion, both systems showed acidic conditions, which inhibited methanogenic activity and delayed gas production. There was no biogas produced during the first three days in catalysed system and the first four days in the non-catalysed system, which is due to unfavourale pH levels. To correct this condition, sodium carbonate was added to both systems to increase the alkalinity. As a result of the pH adjustment, a noticeable increase in biogas production was observed. The pH values gradually shifted from acidic levels of between 5.0 and 5.2 to near neutral conditions between 6.1 and 7.3, which favour methanogenic bacteria. The catalysed system responded more rapidly to pH correction which showed the relationship between the effect of yeast addition and pH optimisation on biomethanation efficiency.

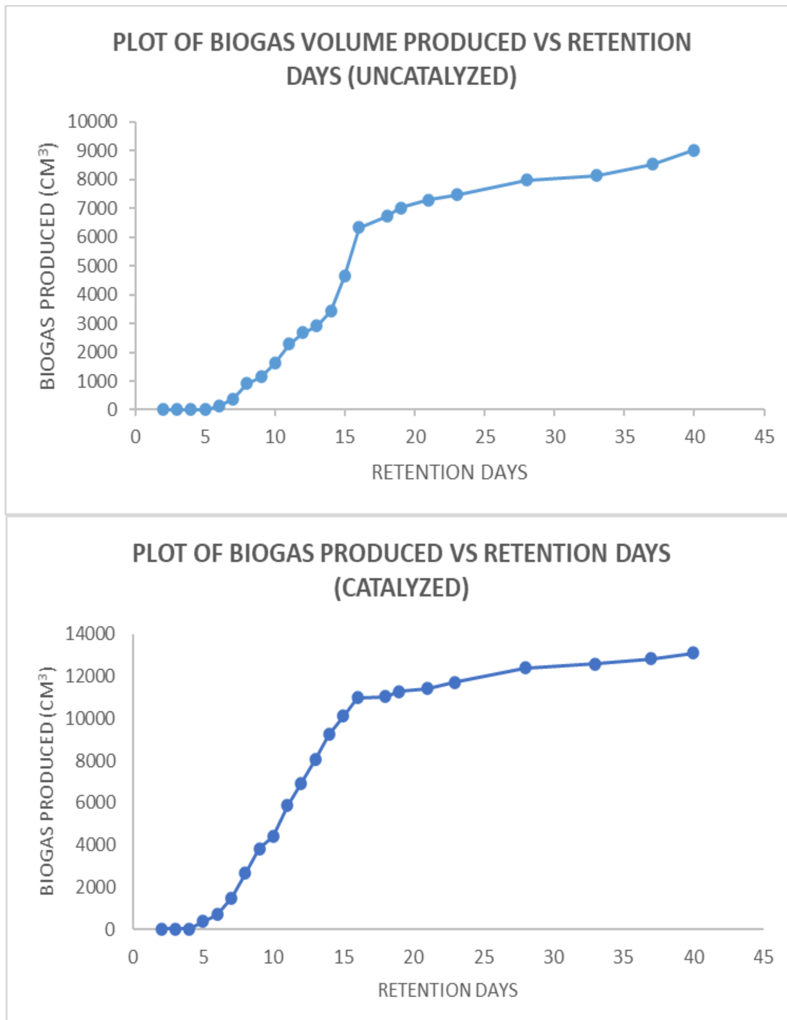

Figure 4. Graph Of Biogas Produced Vs Retention Days (Uncatalyzed Set Up and Catalyzed Set Up).

3. 3. Effect of Retension Time on Biogas Production

Figure 4 showed that the retention time significantly influenced the volume and rate of biogas production. The two systems showed a gradual increase in biogas production during the early phase of digestion, followed by a rapid increase in microbial activity. The catalysed system produced higher daily biogas volume compared to the non-catalysed system throughout the the digestion period.

3. 4. Effect of Temperature on Biogas Production

Temperature variations during the digestion process were studied within mesophilic range of 31-34 °C as shown in Figure 5. These conditions were suitable for the growth and metabolic activity of methanogenic microorganisms. An increase in biogas production was recorded as temperature increases from 31 °C, particularly around the eighth day of digestion. Both systems showed increased gas yield at higher mesophilic temperatures with the catalysed system showing a pronounced response.

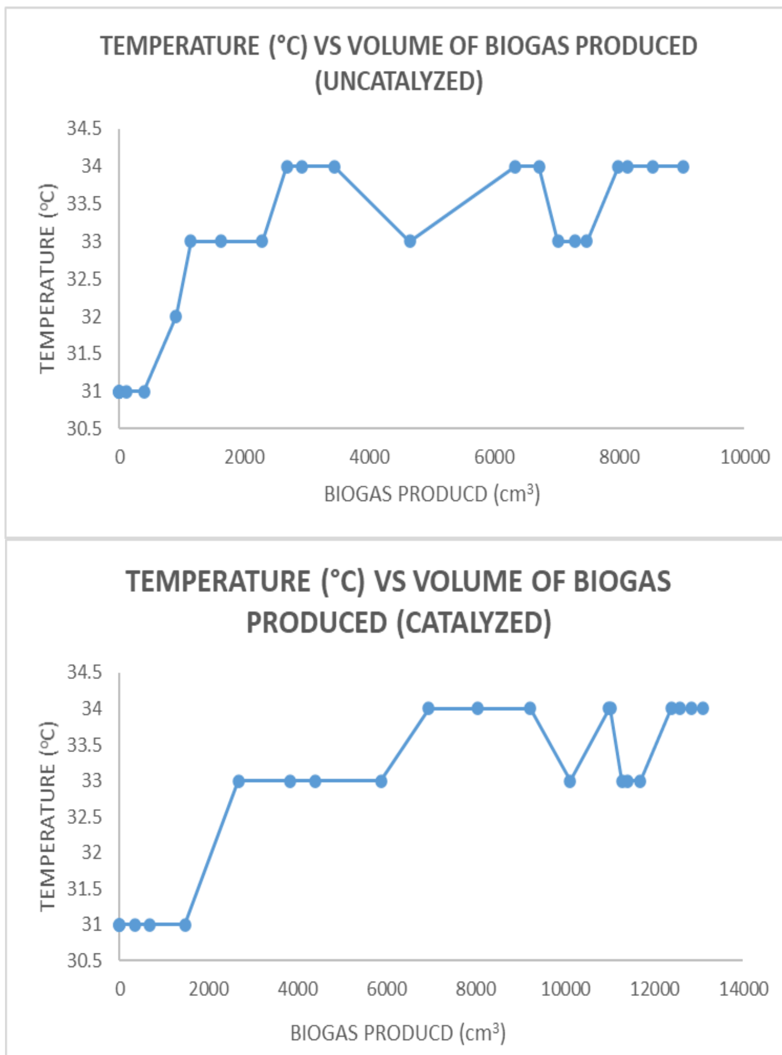

Figure 5. Plot Of Temperature Vs Biogas Produced (Uncatalyzed And Catalyzed Set Up).

3. 5. Effect of Biocatalyst on Efficiency of Biomethanation Process

As shown in Tables 2 and 3., the addition of yeast as a biocatalyst had a significant impact on the biomethanation process. Addition of yeast brought about faster degradation of complex organic compounds into simpler intermediates, which were readily utilized by methanogenic bacteria. This resulted in reduced startup time, higher cumulative gas yield, and improved stability of the digestion process.

Furthermore, periodic addition of small quantities of sugar provided an easily degradable carbon source that stimulated microbial activity and contributed to sustained biogas production. The combined effects of yeast addition, pH regulation, and temperature control resulted in a more efficient anaerobic digestion process.

4. CONCLUSIONS

This study demonstrated the feasibility of enhancing biogas production from food waste through the application of yeast as a biocatalyst and the use of an iron oxide based scrubber for gas purification. The experimental results showed that food waste is a suitable and effextive substrate for anaerobic digestion because it is highly degradable and also high nutrient content.

The yeast catalysed digestion system showed a shorter lag phase, higher biogas production rate, and greater biogas yield compared to non-catalysed system. A total biogas volume of 13,088 cm^3 was produced in the catalysed setup, representing a significant improvement over thhe 9,021 cm^3 of non-catalysed setup which acted as a control system. It showed that optimal biogas production occurred under mesophilic temperature between 31 and 34 °C and also the pH range of 6.7-7.3 which is close to neutral pH condition, which just shows the importance of controlling operational parameters.

The application of sodim carbonate corrected effectively corrected the acidic conditions and promoted methanogenic activity, while iron oxide scrubber improved biogas quality by removing sulphide and other impurities. These findings indicate that the integration of biocatalysts and simple gas purification techniques can significantly improve both the quantity and quality of biogas production from food waste.

Overall, the study supports the potential of anaerobic digestion as a sustainable approach for renewable energy generation and food waste management. The results provide a basis for further optimisation and scaling of small scale biogas systems, particularly in region seeking affordable and environmentally friendly energy solutions.

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