

EVALUATION OF BIOGAS POWER POTENTIAL FROM CO-DIGESTION OF FOOD WASTE AND PALM OIL MILL EFFLUENT

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ABSTRACT

Nigeria's growing population has significantly increased the country's ongoing need for a conveniently available, renewable energy source. In order to produce biogas and produce electricity, food waste and palm oil mill effluent were co-digested in this study. The materials used in this study include food waste, palm oil mill effluent, plastic bottle bio-digester, and mercury-in-glass thermometer. Using a 25-liter plastic container as the batch reactor, the fresh ground POME and food waste were co-digested and digested at a mesophilic temperature range of 29 to 37°C. The hydraulic retention time was 25 days, according to the results. In other words, the first seven days of anaerobic digestion without biogas yields and 25 days of continuous biogas yields spaced two days apart. On the 25th day, minimum biogas yields were attained. On the 21st day, however, the highest biogas yield was achieved. The completion of digestion was the cause of the decrease in biogas production on the 25th day. According to the examination of biogas yields, food waste, POME, and co-digested POME and food waste produced an average of 0.00707 m³, 0.00724 m³, and 0.00965 m³ of biogas. Therefore, the maximum increased biogas yield is provided by the co-digested feedstock. Likewise, the average amount of electricity produced by the co-digested feedstock is 0.01516 kWh. Therefore, a portion of Nigeria's energy and waste issues can be resolved with the appropriate use of biogas technology.

Keywords: Biogas, Food Waste, Effluent, Co-digestion, Electricity, Mesophilic Temperature.

I. INTRODUCTION

The demand for energy consumption and waste generation in Nigeria necessitates the adoption of technologies that promote renewable energy and the conversion of wastes into viable commodity [1-6]. The biogas technology is one of such systems and has been found to be cost effective and environmentally sound [7-10]. The anaerobic digestion (AD) process is a green technology involving the generation of methane rich biogas via the biological degradation of available biomass from organic waste such as cow dung, water hyacinth, and food waste [11-14]. It is an efficient process for treatment and utilization of organic waste because it has proven to be a promising method for waste reduction and energy recycling [15-18]. The AD system is widely adopted by Germany, Sweden, China, USA, and Denmark, which have implemented rigorous waste disposal legislation. Since 2000, annual power generation from digester projects in USA has increased almost 25- fold from 14 million kilowatt-hours (KWh) to an estimated 331 million kWh per year [19, 20].

Furthermore, the standard of waste management in Nigeria is at its lowest with poor documentation of waste generation rates, inefficient storage and collection system, and the under-utilization of disposal sites [21-24]. Nigeria's urban cities are today struggling to clear heaps of solid waste from its environment. Strategic centres of attraction in Nigeria are now taken over by the messy nature of unattended heaps of solid waste emanating from the society [25-28]. City officials appear unable to combat unlawful dumping of house-hold and industrial waste, which is a clear violation of the clean air and health ethics in our environmental sanitation laws and regulations in Nigeria [29-32]. Solid waste management is the most pressing environmental challenge faced by urban and rural areas of Nigeria. Despite a host of policies and regulations, solid waste management in the country is assuming alarming proportions with each passing day [33-38]. However, large percentage of solid waste generated and dump indiscriminately in an open dump site can be useful to us if properly harnessed [38-46]. One best method to achieve this is the adoption of the biogas technology [47-50]. This technology involves

the conversion of organic fraction of solid waste into useful fuel like biogas, which can be used to generate electricity [51-55].

Similarly, from the viewpoint of soil and water pollution, palm oil production provides serious problems. Palm oil mill effluent (POME) exists in forms of high solid, oil, and grease and includes biochemical oxygen demand (BOD) and chemical oxygen demand (COD) in richness. These are major concerns in environmental pollutant due to their adverse effects to many forms of life. The direct discharge of POME in the environment is a matter of concern for both toxicological and esthetical reasons. The majority of the palm oil mills use the addition of water during the extraction process of crude palm oil (CPO) from the fresh fruit bunch (FFB). As a result, a considerable amount of wastewater was generated and stored in ponds. However, POME can be digested and co-digested to produce useful energy instead of indiscriminate dumping in our environment. The aim of this research is therefore the evaluation of biogas power potential from co-digestion of food waste and palm oil mill effluent. To ensure that the aim of this research work was achieved, the amount of biogas produced, and the quantity of electricity that can be generated from the biogas produced was determined.

II. MATERIALS AND METHODS

2.1 Materials

Plastic bottle bio-digester, food waste, palm oil mill effluent, and mercury-in-glass thermometer are the materials employed in this investigation. The fresh ground POME and food waste were co-digested and digested at a mesophilic temperature range of 29 to 37°C using a 25-liter plastic bottle as the batch reactor. The mesophilic temperature range is advised in this study because thermophilic and psychrophilic bacteria carry out anaerobic digestion more slowly than mesophilic bacteria [50,57]. Furthermore, maintaining anaerobic digestion facilities in psychrophilic temperature conditions is difficult due to the low process temperature. Furthermore, it is commonly recognized that thermophilic bacteria require costly process management and monitoring due to their acute sensitivity to disturbances [16, 50, 58]. The optimal mesophilic temperature frequently leads to shorter HRT (higher biogas generation) because more methanogenic bacteria are working on the substrate [27, 28, 59]. A water collector and displacement bottle were attached to the digesters as recommended by [27]. Rubber tubing was used to connect the displacement bottles to the reactors. Each of the three batch reactors received a manual addition of the same amount (15 kg) of substrates in a 2:1 water-to-substrate ratio. By meticulously observing the biogas produced over a 25-day period, the maximum biogas yield among the three (3) batch reactors was ascertained. Figure 1 shows the experimental setup.

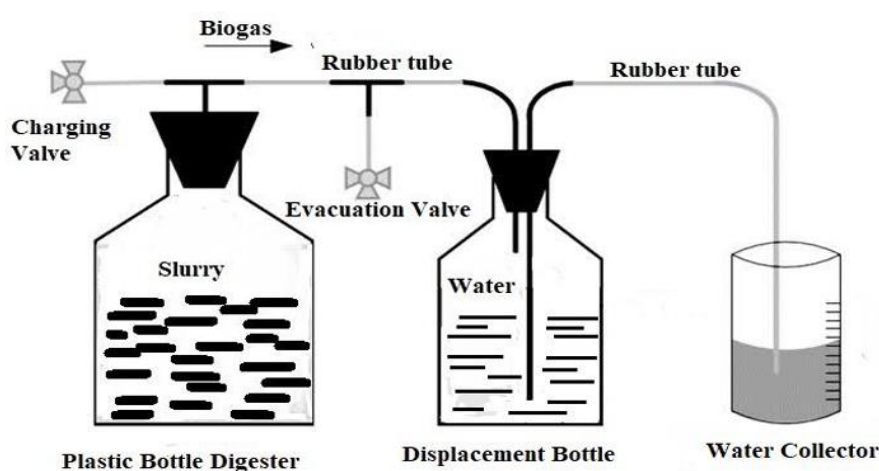


Figure 1. Experimental Setup [27]

2.2 Methods

The following methods were adopted.

2.2.1 Collection of Feedstock

The palm oil mill effluent and food waste were collected from palm oil processing mill and household in Agbarho, Delta State, Nigeria.

2.2.2 Preparation and Charging of Feedstock

The collected feedstock was sorted, and a grinding machine was used to grind it for the formation of slurry. The reason for grinding is to increase the surface area of contact for the microbial activity so that biogas production would begin within the shortest possible time [14]. During the preparation of the feedstock, 25% of palm oil mill effluent was mixed with 75% of food waste, as shown in Figure 2.



Figure 2. Preparation of Feedstock

The mixture was introduced into the digester and observed for 25 days hydraulic retention time. The temperature and pH were monitored using mercury in glass thermometer and analogy pH meter respectively. The experiment was conducted within a pH range of 6-7.2 and mesophilic temperature range of 29°C-37°C.

2.2.3 Determination of the Quantity of Electricity Generated from Biogas Production

To determine the quantity of electricity that can be generated from biogas yields, [56] procedures for energy equivalent was adopted.

Energy equivalents as proposed by [56].

$$1 \text{ Watt} = 1 \text{ joule second}^{-1}$$

$$1 \text{ Wh} = 1 \times 3600 \text{ joules (J)}$$

$$1 \text{ kWh} = 3600000 \text{ J}$$

$$1 \text{ kWh} = 3.6 \text{ MJ}$$

$$22 \text{ MJ (1m}^3 \text{ biogas)} = 22/3.6 \text{ kWh} = 6.1 \text{ kWh}$$

$$\text{Electrical conversion efficiency} = 35\%$$

Therefore,

$$1\text{m}^3 \text{ biogas} = 2.14 \text{ kWh (electricity)}$$

III. RESULTS AND DISCUSSION

3.1 Results of Biogas Production

The amount of gas produced was measured at 2-day intervals after the first seven (7) days using the displacement method. In other words, gas was released from the digester through the valve control into a 1000 cm³ water level of the measuring cylinder. The measuring cylinder was then inverted with the gas pressure displacing an equal amount of water, and the readings were recorded. This procedure was repeated to ascertain the total volume of biogas produced. The volumes recorded are as tabulated below (Table 4.1).

Table 1. Volume of biogas produced

No	Days	Temperature (°C)	Volume (m ³)		
			Palm oil effluent	Food waste	Co-digestion of Food waste and palm oil effluent
1	7	32.00	0.0068	0.0071	0.0085
2	9	29.00	0.0067	0.0073	0.0087
3	11	31.00	0.0069	0.0074	0.0090

4	13	34.00	0.0070	0.0076	0.0092
5	15	37.00	0.0076	0.0078	0.0095
6	17	31.53	0.0069	0.0080	0.0098
7	19	36.00	0.0071	0.0081	0.0099
8	21	37.00	0.0079	0.0085	0.010
9	23	36.00	0.0075	0.0092	0.0109
10	25	37.00	0.0063	0.0095	0.0110
Σ		340.53	0.0707	0.0724	0.0965
Average		34.053	0.00707	0.00724	0.00965

Figure 3 shows the plot of volume of biogas yields against days of production. The results showed that the hydraulic retention time was 25 days. That is, 25 days of continuous biogas yields in intervals of two days and the first 7 days of anaerobic digestion without biogas yields. Minimum biogas yields were achieved on the 25th day. However, maximum biogas yield was obtained on the 21st day. The drop in production of biogas on the 25th day was a result of the completion of digestion. Also, the production rate was not uniform, and this was as a result of differences in mesophilic temperature (Table 2).

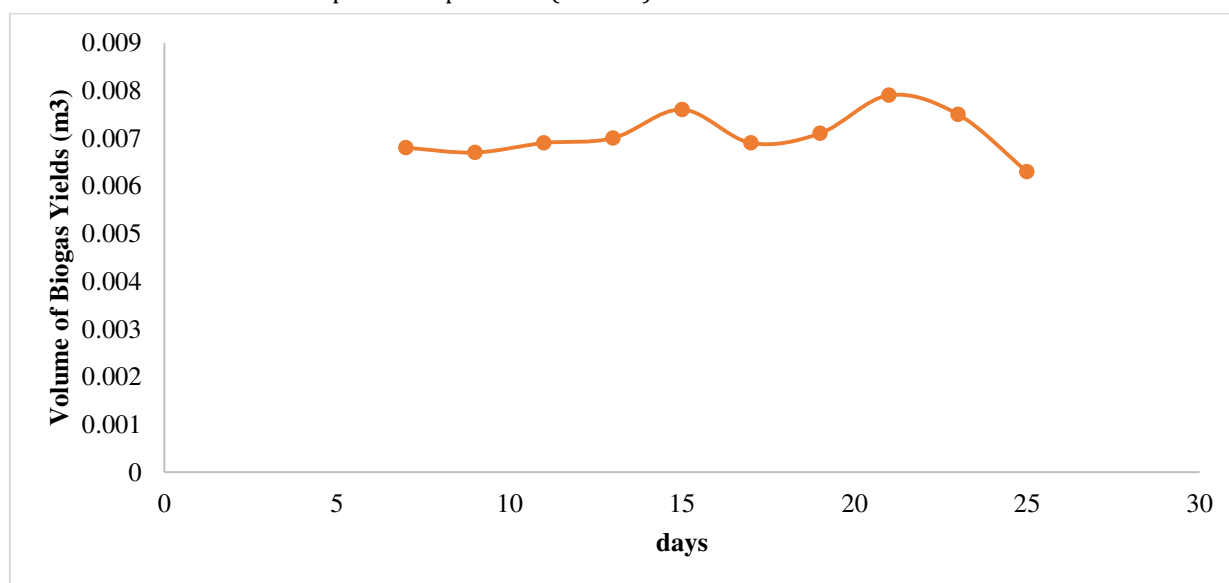


Figure 3. Evaluation of volume of biogas yields from palm oil effluent

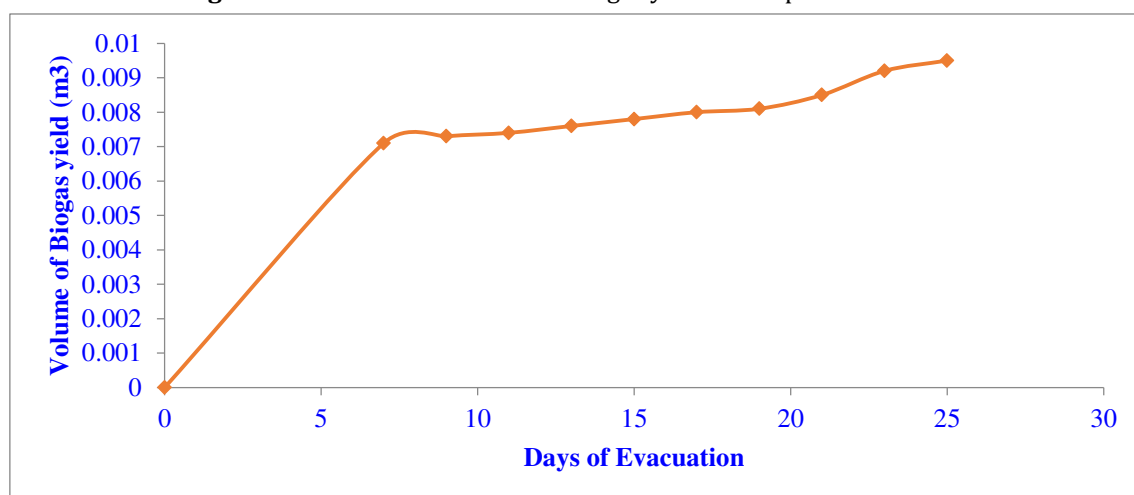


Figure 4. Evaluation of volume of biogas yields from food waste

Co-digested feedstock offers the highest enhanced biogas yield, as illustrated in Figure 5. Anaerobic co-digestion improves biogas production and process stability by combining different organic substrates, which results in better nutritional balance, more microbial variety and activity [9, 27, 28, 60], and a more favorable C/N ratio [59]. Higher methane yields, improved volatile solid (VS) utilization [61], and neutralization of inhibitory chemicals found in specific substrates are the outcomes of this synergistic impact, which also makes the process more resilient and effective than mono-digestion [27, 28].

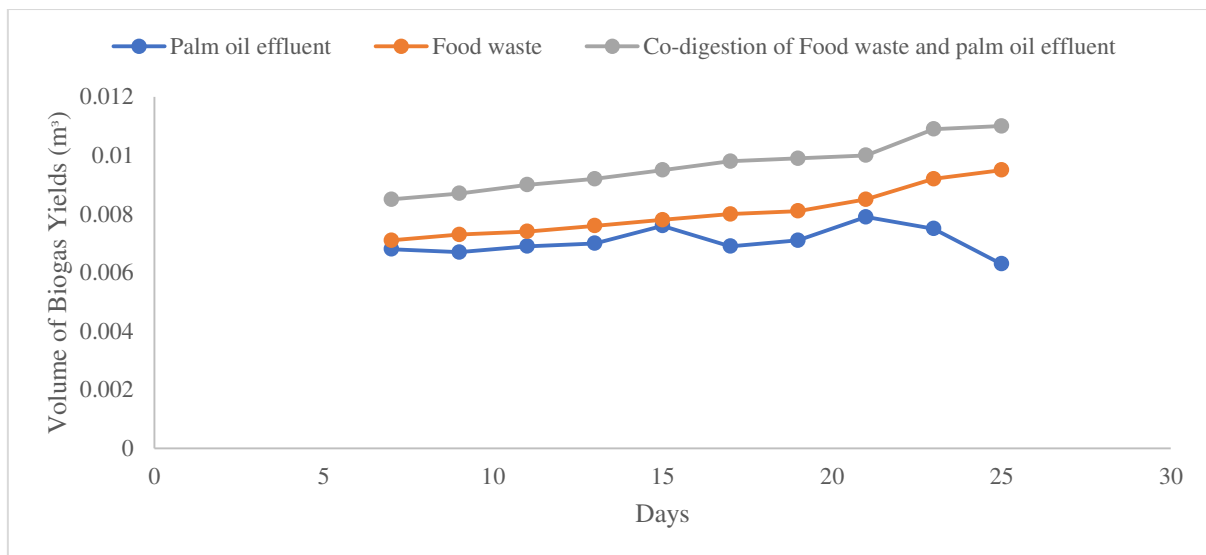


Figure 5. Comparative analysis of volume of biogas yields

According to [50], optimum biogas yields are obtained within mesophilic temperature range of 36°C-37°C. A good look at Figure 6 (bar-chart) showed that better and improved biogas yields were obtained at an optimum mesophilic temperature range of 36°C-37°C. Therefore, the research work agrees with the work of [50].

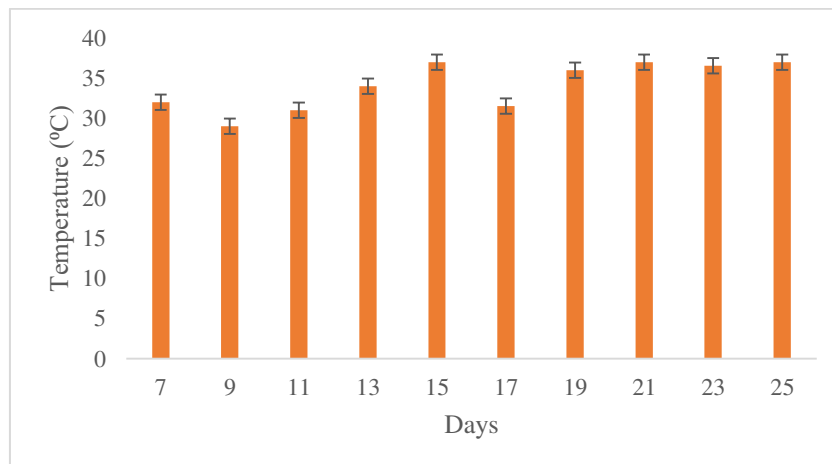


Figure 6. Plot of Temperature against number of days

3.2 Result of Electricity that can be Generated from Produced Biogas

Applying [56] Energy equivalents, the following amount of electricity was determined from the co-digested feedstock (Table 2).

1m³ biogas = 2.14 kWh (electricity) [56]

Thus, the electricity generation from biogas yields was calculated for a period of 25days in two days' intervals. The results obtained showed that electricity can be generated on daily basis from mixed substrates.

Table 2. Results of Electricity that can be Generated from Produced Biogas

S/N	Volume (m ³)	Electricity Generation (KWh)
7	0.0068	0.0146
9	0.0067	0.0143
11	0.0069	0.0148
13	0.0070	0.0150
15	0.0076	0.0163
17	0.0069	0.0148
19	0.0071	0.0151
21	0.0079	0.0170
23	0.0075	0.0161
25	0.00063	0.0135
Σ	0.0707	0.1516
Average	0.00707	0.01516

IV. CONCLUSION

The investigation was completed effectively, and it was discovered that temperature had an impact on the best biogas production. On the 25th day, minimum biogas yields were attained. On the 21st day, however, the highest biogas yield was achieved. The completion of digestion was the cause of the decrease in biogas production on the 25th day. Additionally, more biogas was produced from co-digested feedstock, indicating adequate microbial activity in the digester. While pressure loss was observed on some days, this was caused by modifications to the operating conditions for the best microbial growth and, as a result, the production of biogas. Anaerobic co-digestion, which effectively addresses the drawbacks of mono-digestion (using single substrates) through increased biogas yield, improved process stability, and balanced substrate characteristics, provides a better and more sustainable method of waste management by turning organic waste into biogas, a renewable energy source, and valuable byproducts. The construction of a biorefinery for a more sustainable future is supported by this cooperative approach, which also lowers greenhouse gas emissions, mitigates pollution, and promotes the circular economy.

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