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Evaluation Of Biogas Production Rate From Agricultural, Sewage And Homemade Wastes

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Abstract
This study investigates the production of biogas using two mini-biodigesters of 120 liters each, within a controlled laboratory environment. The research focuses on evaluating the biogas yield from four distinct feedstocks: sewage waste, pig waste, poultry waste, and homemade waste composed of watermelon and pineapple residues. Each feedstock was used individually and in various combinations to determine their effectiveness as substrates for biogas production. The experimental setup was designed to measure the average daily biogas production rates and methane content over a period of 14 days of maximum production. The results revealed that the average daily biogas production rates (in cubic meters) were as follows: 0.0329 for sewage waste (X1), 0.0372 for pig waste (X2), 0.0354 for poultry waste (X3), and 0.0296 for homemade waste (X4). When combined, the production rates were 0.0362 for sewage and homemade waste (X1+X4), 0.0384 for sewage, pig, and poultry waste (X1+X2+X3), and 0.0410 for the combination of all four feedstocks (X1+X2+X3+X4). In terms of methane content, the findings indicated that the percentages were 54.8% for sewage waste (X1), 58.7% for pig waste (X2), 56.6% for poultry waste (X3), and 51.7% for homemade waste (X4). The combinations showed higher methane content with 68.2% for sewage and homemade waste (X1+X4), 65.5% for sewage, pig, and poultry waste (X1+X2+X3), and 69.3% for the combination of all four feedstocks (X1+X2+X3+X4). These results highlight the potential of utilizing various organic wastes for biogas production, demonstrating that mixed substrates can enhance both the yield and methane content of the biogas. This research contributes to the understanding of biogas production dynamics and provides insights into optimizing feedstock combinations for improved biogas generation.

Keywords: *Key Words: Biogas production, Sewage wastes, Agricultural wastes, Homemade wastes, Optimization Model.*

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I. Introduction

Biogas technology is an innovative and sustainable approach that harnesses the power of anaerobic digestion to convert organic waste into a valuable energy resource [1]. Biogas, primarily composed of methane (CH4) and carbon dioxide (CO2), is produced through the anaerobic decomposition of organic materials such as animal manure, agricultural residues, food waste, sewage sludge, and energy crops [2]. The utilization of biogas technology offers numerous benefits. Firstly, it provides a renewable source of energy that can be used for various applications, including electricity generation, heating, and cooking [3]. Biogas can serve as a cleaner alternative to fossil fuels, reducing greenhouse gas emissions and mitigating climate change impacts [4]. In addition to energy production, biogas technology promotes sustainable waste management [1]. Organic waste that would otherwise decompose and release methane into the atmosphere, a potent greenhouse gas, is captured and converted into biogas. This process not only reduces the environmental impact but also mitigates odors, reduces pathogens, and improves sanitation [5].

The technology behind biogas production involves the controlled anaerobic digestion of organic materials in an oxygen-free environment [6]. Microorganisms break down complex organic compounds, such as carbohydrates, fats, and proteins, into simpler substances, resulting in the production of biogas [2]. The anaerobic digestion process is typically carried out in specially designed biogas plants or digesters, which are engineered to optimize gas production and efficiency [3]. Biogas technology can be tailored to various scales, from small-scale household digesters used in rural areas to large-scale commercial installations [1]. The design and operation of biogas plants depend on factors such as the type and availability of feedstock, climatic conditions, and desired energy output. Advanced technologies, such as co-digestion (combining multiple waste streams), pre-treatment techniques, and digestate utilization, have further enhanced the efficiency and effectiveness of biogas production

[7]. Moreover, biogas technology aligns with the principles of the circular economy. By utilizing organic waste streams as feedstock, it closes the nutrient cycle and promotes resource recovery. The byproduct of the anaerobic digestion process, called digestate, is a nutrient-rich fertilizer that can be used in agriculture, reducing the reliance on synthetic fertilizers [8]. In recent years, biogas technology has gained prominence worldwide as countries seek sustainable energy solutions, waste management strategies, and reduction in greenhouse gas emissions. Governments, industries, and individuals are recognizing the potential of biogas as a valuable component of the renewable energy mix [3].

Biogas technology stands as a versatile and promising solution to the dual challenges of energy generation and waste management, contributing significantly to sustainable development and environmental protection. This innovative technology plays a pivotal role in the transition to a low-carbon future, offering a renewable energy resource that holds great potential for addressing global energy demands while reducing environmental impacts. These continuous advancements in biogas technology are vital in promoting a greener and more sustainable society [9].

One of the key advantages of biogas technology lies in its remarkable versatility. It can be harnessed from a wide range of organic materials, making it an exceptionally flexible energy source [10]. For instance:

i. Agricultural Residues: Biogas can be effectively generated from agricultural residues such as crop residues, straw, and stalks, providing a renewable energy source for farmers while helping manage agricultural waste.
ii. Animal Manure: Livestock operations, including dairy farms and poultry farms, employ biogas technology to convert animal manure into energy. This approach not only reduces the environmental impact of manure disposal but also yields valuable energy resources.
iii. Food Waste: Various entities, including restaurants, food processing plants, and municipalities, utilize biogas technology to process food waste. This proves to be an effective method for diverting organic waste from landfills, ultimately reducing methane emissions.
iv. Sewage Sludge: Wastewater treatment plants make use of biogas from sewage sludge, which reduces the volume of sludge and offsets energy costs for the treatment facility.
v. Energy Crops: In certain regions, specific energy crops, such as maize or switchgrass, are cultivated for biogas production. These dedicated crops can be grown sustainably to produce biogas, contributing to the renewable energy landscape.

Biogas not only serves as a source of renewable energy but also addresses pressing environmental challenges. It notably reduces methane emissions from landfills and wastewater treatment, effectively mitigating the impact of these potent greenhouse gases. Furthermore, biogas technology aids in waste reduction and sanitation improvement, particularly in areas with limited waste management infrastructure. The utilization of biogas technology is in harmony with global efforts to transition to a more sustainable and circular economy. It embodies the principles of waste-to-energy and resource recovery, where what was once considered waste becomes a valuable resource [11].

Moreover, biogas can be seamlessly integrated into decentralized energy systems, especially in rural areas with limited access to centralized power grids. This enables communities to become more self-reliant in terms of energy production and reduces the need for long-distance energy transmission 12]. As technology continues to advance, and as environmental concerns grow, biogas is poised to play an increasingly significant role in the renewable energy landscape. Its unique ability to simultaneously address waste management and energy generation positions it as a powerful tool in the pursuit of a more sustainable and eco-friendly future [13].

II. Materials And Methods

Research Materials

The raw materials used in this research and their classification are as follows.
Sewage Waste or Human feces collected from the septic tank and Agricultural Wastes.

The rationale for choosing these combinations of wastes is that they are easily accessible, especially for middle and low-income dwellers.

Research Methods

A mini biodigester of 120 liters volume which was used in the laboratory to experiment with the production of biogas production from three major types of feedstocks which are Homemade waste feedstock, sewage waste feedstock, and Agricultural waste feedstock. This will involve setting up controlled experiments in a laboratory, measuring and analyzing data, and drawing conclusions about the capacity of different biogas production feedstocks and the best combination of feedstock that will give the maximum production of biogas. The biodigester used for this experiment will have an inlet device that could be opened to feed the plant, a gas collection vent, and a slurry (digestate) evacuation outlet at the bottom of the dome. The anaerobic digesters were fed with different types of feedstocks on different occasions with the Agricultural waste, Sewage waste, and Home-made waste feedstocks individually and in different combinations of the feedstocks respectively and the rate of production of biogas was compared. Biogas yields for each feedstock or combination of feedstocks were monitored for 30 days for each trial.

The following are the methods employed in achieving the objectives of this research:

We designed and constructed 2No 120L Biodigesters which were used in the production of biogas from the different feedstocks (raw materials).

We determined the potential biogas production of each feedstock as well as a combination of different feedstocks by Performing the biochemical methane potential (BMP) tests and afterward calculating the rate of biogas production for the feedstocks.

We derived, tested, and validated an optimization model to determine the optimum combination of these three (3) feedstocks classifications (Sewage waste, food waste, and Agricultural waste) that will produce the maximum yield of biogas in the Anaerobic System (Mini Digesters).

We Determined the Carbon-Nitrogen Ratio of the Raw Materials through laboratory analysis.

We Determined the rate of biogas production from feedstocks through a combination of laboratory testing and mathematical calculations.

Daily Determination of the change in temperature of the biogas plant was determined through measurements and calculation of the temperature change by Subtracting the initial temperature from the final temperature.

Change in Temperature = Final Temperature - Initial Temperature

The temperature of the system was determined at various stages for the different feedstocks.

III. Results And Discussion

Biogas Production Rates, Averages and Biogas Composition

Table 1.0: Summary of the percentage composition of gas in biogas

COMPOSITION	Sample 1(Sewage)	Sample 2 (Pig Waste)	Sample 3 (Poultry waste)	Sample 4 (Homemade food waste)	Sample 5 (Sewage and homemade food waste)	Sample 6 (Sewage, Pig waste and poultry waste)	Sample 7 (Sewage, Pig, poultry, and Homemade food waste waste)
Methane(CH4)	54.8%	58.7%	56.6%	51.7%	68.2%	65.5%	69.3%
Carbon-dioxide (CO2)	39.4%	35.0%	36.5%	41.1%	26.6%	30.2%	25.3%
Hydrogen Sulphide (H2S)	Traces	Traces	Traces	Traces	Traces	Traces	Traces
Ammonia (NH:)	Traces	Traces	Traces	Traces	Traces	Traces	Traces
Water Vapour (H2O)	Traces	Traces	Traces	Traces	traces	Traces	Traces

The graphical representation below underscores the differences in biogas quality.

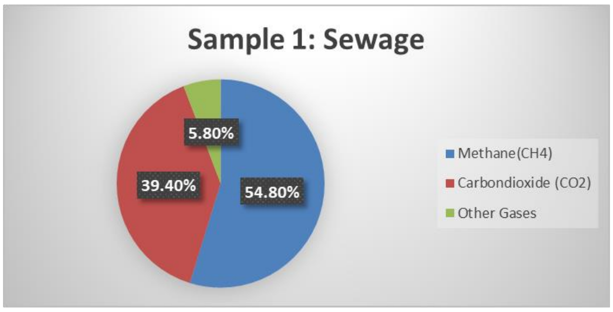

Fig. 3.1: Figure showing the percentage composition of gas in sewage produced biogas.

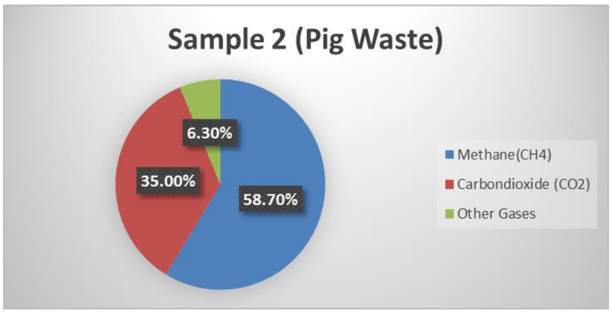

Fig. 3.2: Figure showing the percentage composition of gas in pig waste produced biogas.

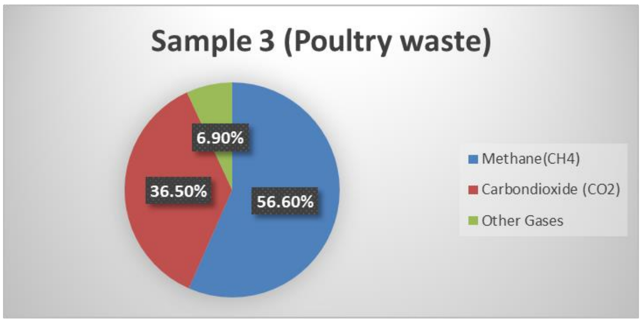

Fig. 3.3: showing the percentage composition of gas in poultry waste produced biogas

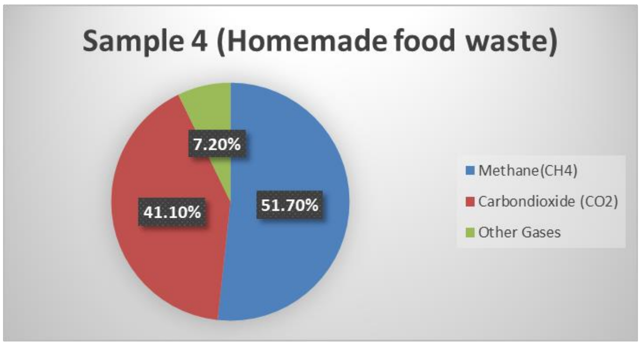

Fig. 3.4: Figure showing the percentage composition of gas in homemade food waste produced biogas.

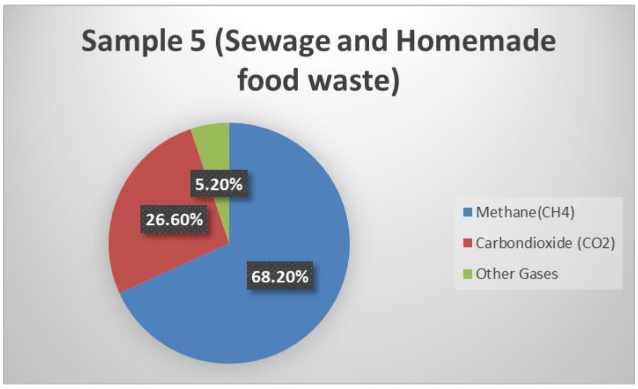

Fig. 3.5: Figure showing the percentage composition of gas in sewage and homemade waste produced biogas.

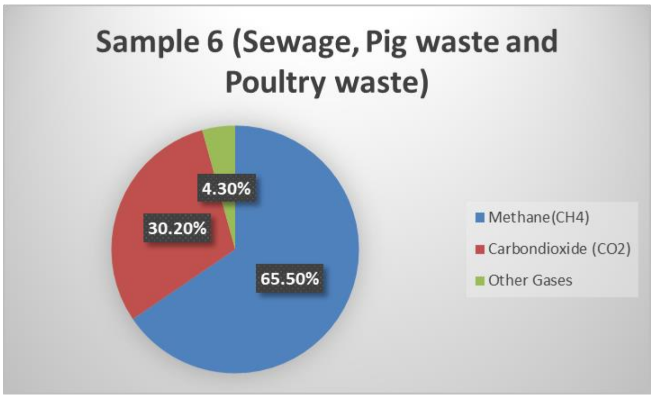

Fig. 4.6: Figure showing the percentage composition of gas in sewage, pig waste and poultry waste produced biogas.

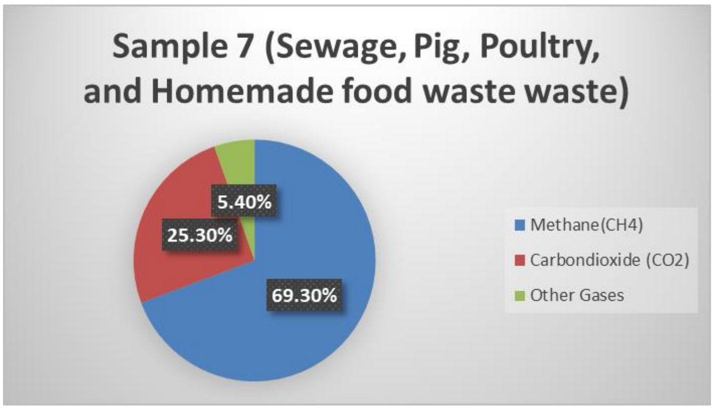

Fig. 4.7: Figure showing the percentage composition of gas in sewage, pig, poultry, and Homemade food waste produced biogas.

Below is a Statistical Comparison of Data for Sewage Waste, Agricultural wastes (Pig and Poultry wastes) Home-made food waste (Pineapple and watermelon peels).

Table 2.0: Table showing summary of Findings from the laboratory work for Sewage Waste

Parameter	Percentage (%)			
	SEWAGE WASTE	PIG WASTE	POULTRY WASTE	HOMEMADE WASTE
Organic Matter	7.8%	20.5%	46.42%	91%
Moisture Content	99%	70%	30.09%	13.5%
Carbon Content	8.64%	58%	36.12%	35.1%
Nitrogen Content	0.32%	5.8%	2.40%	1.3%
Carbon-to-Nitrogen (C/N) Ratio	26:1	10:1	15:1	27:1
Ph	6.7	6.5	6.94	6.3
Temperature	22°C	20°C	20°C	36.4°C

The table 2.0 above, it was seen that all lab tests conducted on the samples were done under standard temperature and pressure; also, the PH falls around the neutral 6.30 to 6.94; the Carbon-Nitrogen ratio is between 10:1 to 27:1.

Biogas Production Rates: The biogas production rate refers to the amount of biogas generated per unit of time from an anaerobic digestion process. The biogas production rate for the feedstocks were measured in cubic meters per day as seen in table 4.6 below.

Table 4.6 summarizing the daily biogas production rates for all feedstocks used is presented below. The data of the daily biogas production rates for all the feedstocks were recorded over a 3-Month Period, also the focus was only on the 14days of maximum production period.

Table 3.0: Daily Biogas Production Rates (m^3/day)

DAYS	X1 (SEWAGE WASTE)	X2 (PIG WASTE)	X3 (POULTRY WASTE)	X4 (HOMEMADE WASTE)	(X1 + X4)	(X1+X2+X3)	(X1+X2 +X3+X4)
1	0.0325	0.0366	0.0348	0.029	0.0356	0.0378	0.0404
2	0.0326	0.0367	0.0349	0.0291	0.0357	0.0379	0.0405
3	0.0327	0.0368	0.035	0.0292	0.0358	0.038	0.0406
4	0.0327	0.0369	0.0351	0.0293	0.0359	0.0381	0.0407
5	0.0328	0.0369	0.0351	0.0294	0.0359	0.0381	0.0407
6	0.0328	0.037	0.0352	0.0294	0.036	0.0382	0.0408
7	0.0329	0.0371	0.0353	0.0295	0.0361	0.0383	0.0409
8	0.0329	0.0372	0.0359	0.0301	0.0367	0.0389	0.0415
9	0.0333	0.0377	0.0358	0.03	0.0366	0.0388	0.0414
10	0.0331	0.0376	0.0357	0.0299	0.0365	0.0387	0.0413
11	0.0332	0.0375	0.0357	0.0299	0.0365	0.0387	0.0413
12	0.0332	0.0375	0.0356	0.0298	0.0364	0.0386	0.0412
13	0.0331	0.0374	0.0355	0.0297	0.0363	0.0385	0.0411

14	0.033	0.0373	0.0354	0.0296	0.0362	0.0384	0.041
TOTAL	**0.4608**	**0.5202**	**0.4950**	**0.4139**	**0.5062**	**0.5370**	**0.5734**
AVERAGE	**0.0329**	**0.0372**	**0.0354**	**0.0296**	**0.0362**	**0.0384**	**0.0410**

Graphical Representations of the Daily biogas production rates: Below are the graphical representations of the above data with respect to the 14 days duration taken: From the Graphs in figures 4.8 to 4.14, it was seen that the volume of biogas produced as the days go by continues to increase until it get to maximum and then begins to decrease after reaching the maximum until the volume produced becomes negligible. The time from the beginning of gas production and the end of production is known as the retention time. Immediately the Retention time is reached the Biodigester's digestate needs to be emptied and new feedstock put in for the process to repeat. Also note that the volume of gas produced tends to increase as the days gets closer to the maximum volume of gas production. Also, after getting to the maximum, the rate of gas production decreases in very slowly as compared to the rate increase before the maximum volumetric rate.

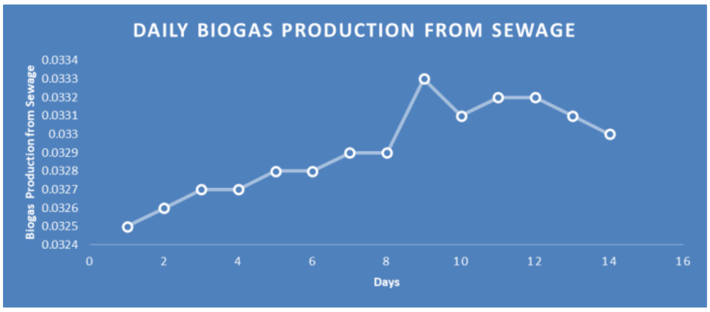

Fig 4.8: Daily Biogas Production Rates from Sewage (m³/day)

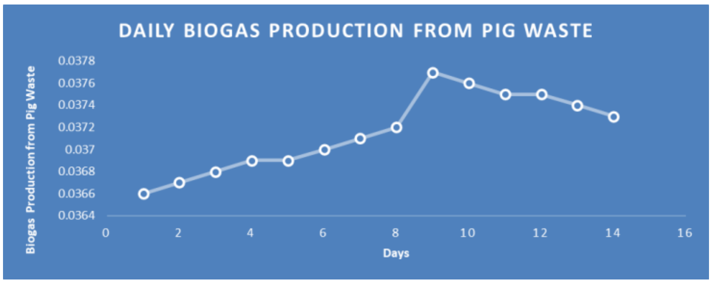

Fig 4.9: Daily Biogas Production Rates from Pig Waste (m³/day)

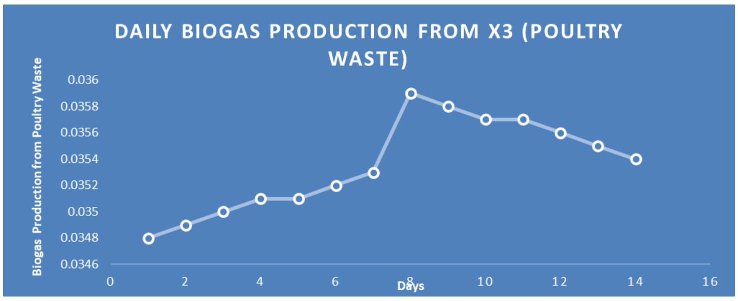

Fig 4.10: Daily Biogas Production Rates from Poultry Waste (m³/day)

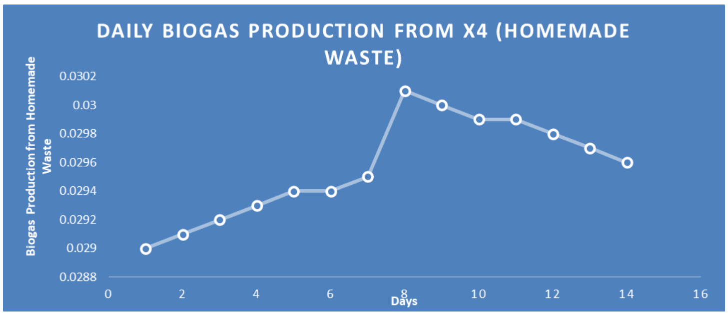

Fig 4.11: Daily Biogas Production Rates from Homemade Waste (m³/day)

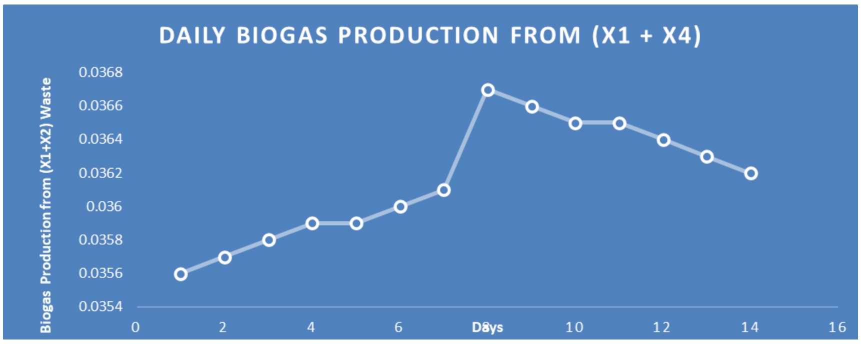

Fig 4.12: Daily Biogas Production Rates from Sewage and Homemade Wastes (m³/day)

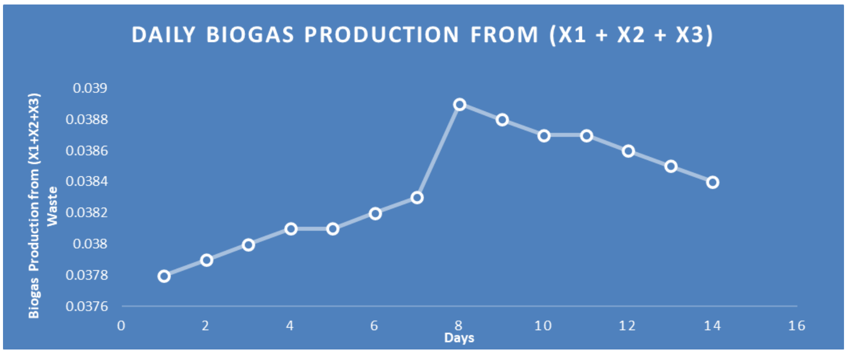

Fig 4.13: Daily Biogas Production Rates from Sewage, Pig and Poultry Wastes (m³/day)

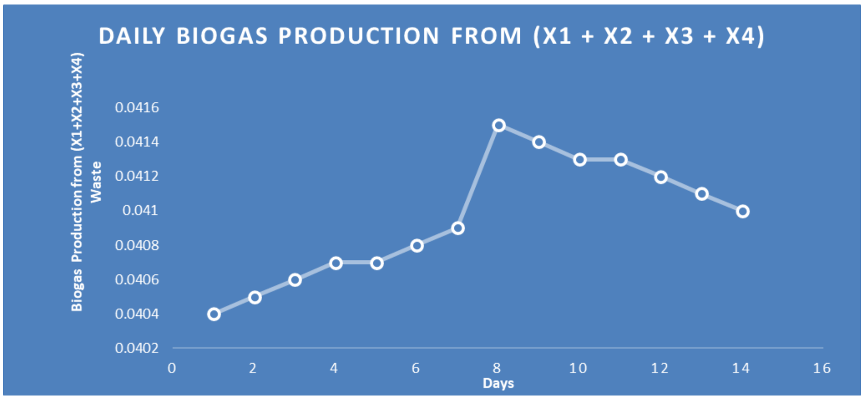

Fig 4.14: Daily Biogas Production Rates from Sewage, Pig, Poultry and Homemade Wastes (m³/day)

IV. Conclusion

The research conducted on the production of biogas using two 120-liter mini-biodigesters in a controlled laboratory environment demonstrates the feasibility and efficiency of various organic wastes as substrates. The study specifically evaluated the biogas yield and methane content from four distinct feedstocks—sewage waste, pig waste, poultry waste, and homemade waste consisting of watermelon and pineapple residues—both individually and in combinations. The results indicated that combining different substrates can significantly enhance biogas production and improve methane content. The highest average daily biogas production rate was achieved with the combination of all four feedstocks (0.0410 liters), while the highest methane content was also observed in the same combination (69.3%). These findings suggest that mixed feedstocks, particularly those that incorporate a variety of organic materials, can optimize biogas yield and quality. The implications of this study are significant for sustainable waste management and renewable energy production. By effectively utilizing organic waste materials, biogas production can serve as a viable solution to waste disposal issues while generating a clean and renewable source of energy. This research highlights the potential benefits of adopting biogas technology in both urban and rural settings, promoting environmental sustainability and energy independence.

Future research should focus on scaling up the biodigester models, exploring long-term stability and performance, and evaluating the economic viability of biogas production from mixed feedstocks. Additionally, investigating the environmental impacts and potential benefits of widespread biogas adoption will further elucidate its role in a sustainable energy future.

Conflicts of Interest
I declare that there are no conflicts of interest regarding the publication of this paper.

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