Effect of Temperature and pH Control on the Efficiency of Biogas Production: Converting Food Waste, Poultry Litter and Water Hyacinth to Energy

Sham Vartia
Department of Mechanical Engineering
Rajshahi University of engineering & Technology
Rajshahi,Bangladesh
1702161@student.ruet.ac.bd

Dr. Nirendra Nath Mustafi
Professor,
Department of Mechanical Engineering
Rajshahi University of engineering & Technology
Rajshahi,Bangladesh
nnmustafi@me.ruet.ac.bd

Helal Sarker
Department of Mechanical Engineering
Rajshahi University of engineering & Technology
Rajshahi,Bangladesh
helalsarker98@gmail.com

ABSTRACT

The increasing global energy demand has necessitated a shift towards sustainable and eco-friendly solutions. Consequently, extensive research is being conducted to explore, develop, and enhance new renewable bioenergy sources. This research is critical for addressing the energy crisis and ensuring a more sustainable and environmentally friendly future. This study involved a small-scale experiment integrating water hyacinth with food waste and poultry litter under controlled conditions, including temperature and pH regulation within a continuously stirred reactor in a portable biogas reactor. The experiment was conducted in two phases. In Phase 1, where temperature and pH were not controlled, it took seven days to initiate biogas production, peaking at 1,145 ml on day 22, with a total cumulative output of 12.988 L, which was only 25.97% of the anticipated 50 L. Conversely, in Phase 2, where temperature and pH were controlled within 33-35°C and 6.8-7.5, biogas production began on the sixth day, reaching 2,632 ml on the 16th day. The cumulative production in Phase 2 was 32.683 L, representing 65.36% of the targeted 50 L. This underscores the pivotal role of controlled conditions in achieving faster and more substantial biogas production.

Keywords: Anaerobic digestion, Biogas, Poultry litter, Water hyacinth, Food waste.

1. INTRODUCTION

The global population's growth, particularly in developing nations, has escalated the demand for both food and energy. This surge has strained energy production and consumption, leading to increased greenhouse gas emissions and contributing to climate change [1]. Energy plays a crucial role in meeting daily needs and ensuring human comfort. Historically, biomass served as the primary energy source until the Industrial Revolution ushered in the dominance of fossil fuels like coal, diesel, and natural gas. However, the heavy reliance on fossil fuels, especially in developing countries, has precipitated an energy crisis, leading to a decline in global energy production [2].

If a new energy source is not discovered within the next 50 years, the world may face the exhaustion of fossil fuel-generated energy. This pressing need highlights the urgency of finding a reliable, efficient, affordable, and environmentally friendly energy source with minimal carbon emissions [3].

Agriculture, a primary economic activity for over two-thirds of the global population, plays a vital role in supplying food to humanity. Many developing countries heavily depend on smallholder agriculture and related sectors, which directly or indirectly support around 82% of the world's population [3]. However, a significant challenge in these regions is the limited access to modern energy services. Implementing resource-conserving agricultural technologies is pivotal for sustainability in both food and energy production [4].

Fossil fuels, including coal, oil, and gas, currently contribute to approximately 60% of global electricity production. However, there is a growing shift towards renewable energy sources, with variable renewables witnessing growth from 8% to 9% in the first quarter of 2020 (International Energy Agency, 2020). In response to the surging energy consumption, renewable energy sources such as biogas, derived from agricultural materials like cow dung, poultry litter, household waste, and water hyacinth, have emerged as promising alternatives [5].

Biogas, as a renewable energy source, offers eco-friendliness and economic viability due to its cost-effective feedstock and diverse applications in heating, power generation, and sustainable chemical production [6]. It holds substantial potential for industrial and domestic use, presenting a viable solution to the global energy crisis. In light of concerns surrounding greenhouse gas emissions, climate change, the depletion of fossil fuel reserves, escalating organic waste production, and the looming threat of global warming, interest in anaerobic digestion and biogas resources has grown significantly [7].

Co-digestion, the simultaneous digestion of multiple feedstock within a single digester, can significantly enhance biogas production. This study focuses on the co-digestion of food waste, poultry litter, and water hyacinth, materials that can be co-digested to generate biogas for various purposes such as electricity and heat generation [8]. Poultry litter consists of manure, bedding materials, waste feed, and other by-products from poultry houses. Water hyacinth is a rapidly growing aquatic plant known for its high biomass yield and nutrient-removing capabilities [5]. Organic waste, particularly from food and poultry, contributes significantly to methane emissions and landfill issues. However, co-digesting these waste products with water hyacinth in an anaerobic digester initiates a biological process that breaks down organic matter and generates biogas. This approach offers several advantages, including reducing landfill volumes, enhancing fertilizer quality, and increasing overall biogas production [9]. By harnessing these problematic materials, we can transform them into valuable resources through biogas production.

The demand for sustainable energy has driven interest in biogas production through anaerobic digestion, which efficiently converts organic waste into renewable energy. Food waste, poultry litter, and water hyacinth are promising feedstock for biogas due to their availability and high energy potential. However, the success of anaerobic digestion depends heavily on maintaining optimal temperature and pH.

Temperature significantly influences microbial activity, with mesophilic conditions (30–40°C) being ideal for stable biogas production [10]. Maintaining these conditions, especially under thermophilic digestion (50–60°C), can be challenging due to the energy required [11]. Meanwhile, pH plays a critical role in sustaining the microbial communities that drive biogas production, with a neutral pH (~7) being optimal [12]. Deviations from this range can inhibit the process and reduce biogas yield [13].

Despite the potential of co-digesting food waste, poultry litter, and water hyacinth, the combined effects of temperature and pH on this process are not well understood. This research aims to explore these interactions to optimize biogas production, making it a more viable and efficient energy source.

This research highlights the efficiency and effectiveness of co-digestion as a waste-to-energy solution. It underscores the critical role of advanced technology in optimizing biogas production from a diverse array of organic feedstock.

2. MATERIALS AND METHOD

2.1 Feed Material Selection

2.1.1 Poultry Litter

Bangladesh has a significant poultry industry, comprising 8 grandparent stocks, 100 breeder farms and hatcheries, and over 70,000 commercial layer and broiler farms. This industry produces approximately 2.1 million tons of waste annually, causing complaints about odor and flies from nearby communities [3].

Table. 1. Composition of Different Poultry Products

Parameters	Boiler litter	Broiler Cake [1]	Roaster Litter	Breeder Litter
Moisture (%)	21.5	40.0	22.5	33.5
TS (%)	78.5	60.0	77.5	66.5
Density (lb/cu. ft.) [2]	27	34 [3]	27	35

Among all poultry products, boiler litter has the highest amount of TS content, making it an effective criterion for choosing the feed material.

2.1.2 Food Waste

Bangladesh grapples with a severe food waste crisis driven by population growth and changing eating habits. Recent research reveals an annual household food waste of 10.62 million tons, comprising 68.3% to 81.1% of municipal solid waste [3].Main sources include restaurants, agriculture, and social events. Dhaka disposes of 1,241,133.23 tons of food waste yearly, with Chittagong's annual rate estimated at 421,330.45 tons, varying by season. The best way to manage this waste is to generate energy from it, and generating biogas is an effective waste-to-energy conversion method [4].

2.1.3 Water Hyacinth

Water hyacinth (Eichhornia crassipes) is a widespread aquatic plant in Bangladesh. It can be found in various water bodies, including rivers, lakes, ponds, and canals. The presence and abundance of water hyacinths can fluctuate depending on factors like climate, season, and geographical location. Efforts are ongoing in Bangladesh to manage and control the spread of water hyacinth due to its negative impacts on water quality, biodiversity, and agriculture. Producing biogas from this is the best solution regarding its potential as a feedstock for anaerobic digestion [7].

2.2 Feed Material Preparation

The preparation of feed material is a critical process. Particle size is an important criterion in determining the production rate. Smaller particle sizes significantly improve productivity by increasing the reaction rate. In this experiment, the material was prepared in three phases:

1. The feed materials were cut into smaller pieces of 10-20 mm.
2. The material was then blended, resulting in a particle size of 2-5 mm.
3. After blending, the feed material was mixed at a proportion suited for the mixer.

2.3 Experimental Setup

Design of the biogas reactor

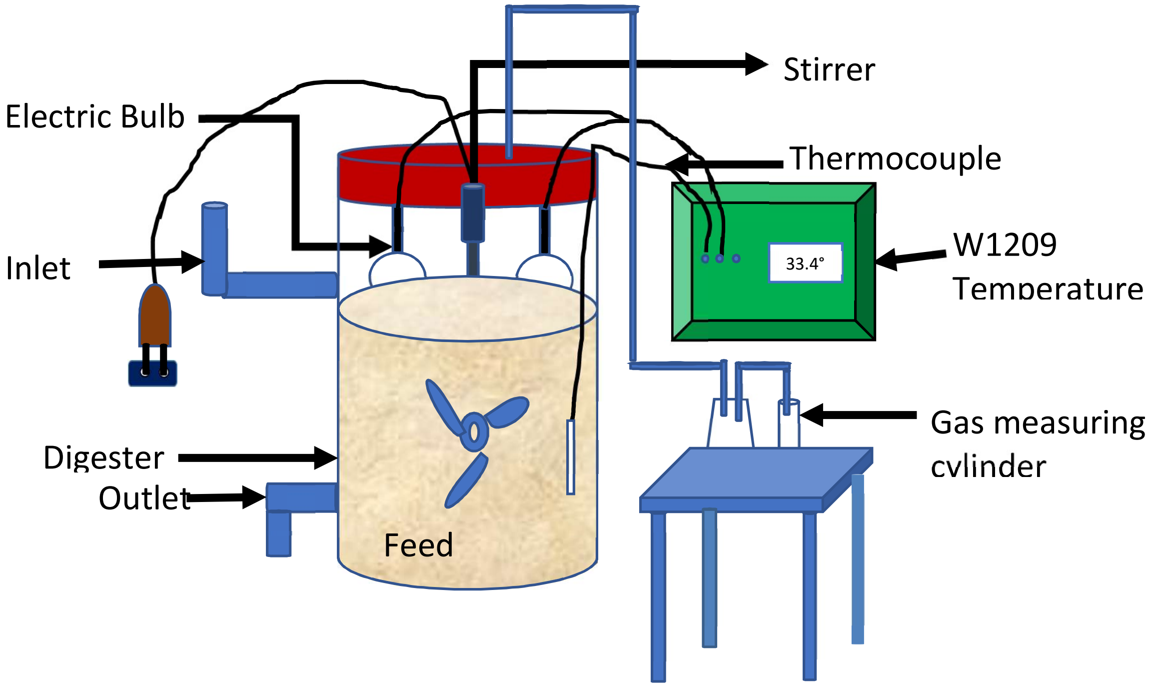

Figure. 1. Design of the biogas reactor

The setup used in this research is a small-scale biogas plant. It was chosen for its advantages, such as cost efficiency and ease of use in experimenting with different feed compositions under various biodegradation parameters. The main components of the biogas plant include:

Inlet/Feeding System: Where organic feedstock (e.g., agricultural residues, food waste, or animal manure) is introduced into the digester.
Digester Tank: The primary vessel where anaerobic digestion occurs, designed to create anaerobic conditions necessary for microbial digestion.
Mixing System: Ensures uniform distribution of microorganisms and nutrients throughout the digester, optimizing the digestion process.

Temperature Control System: Maintains the optimal temperature range for microbial activity, typically between 35°C and 40°C.
Gas Outlet/Piping: Channels biogas from the digester to storage or utilization systems.
Gas Storage: Temporarily stores biogas before it is utilized or distributed.
Digestate Outlet: Removes nutrient-rich liquid residue (digestate) for use as fertilizer or further treatment.
Safety Features: Includes pressure relief valves and gas monitoring systems to ensure safe operation.

The design of the biogas reactor involved careful consideration of factors such as temperature control, pH balance, and the retention time of the feed materials to maximize biogas production.

3. RESULTS AND DISCUSSION

The experiment was carried out in two parts. In the initial phase, biogas was generated without any control. However, in the second phase, we applied a temperature and pH control system. The effect of adjusting these factors was assessed in this experiment.

3.1 Biogas production without controlling the factors

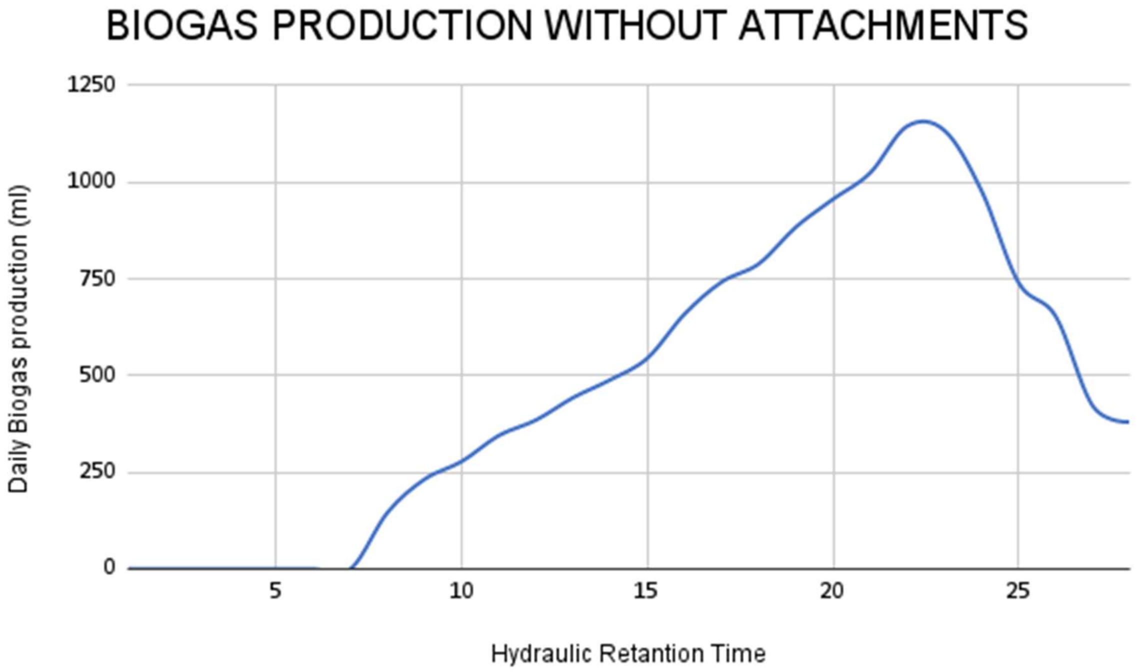

Figure. 2. Biogas production without controlling temperature and pH

In the first part of the experiment, no attachments were utilized to regulate temperature, pH, or stirring. Figure 2 shows that biogas production began on the seventh day and peaked at 1,145 ml on day 22. The entire cumulative production was 12.988 L, or 25.97% of the projected 50 L.

3.2 Biogas Production after using temperature and pH Control system.

Maintaining the digester's temperature between 33 and 35°C was critical for optimal methane generation. This temperature range is optimal for the activity of bacteria that produce methane during anaerobic digestion [1]. In this phase, a temperature control module was employed to regulate the temperature.

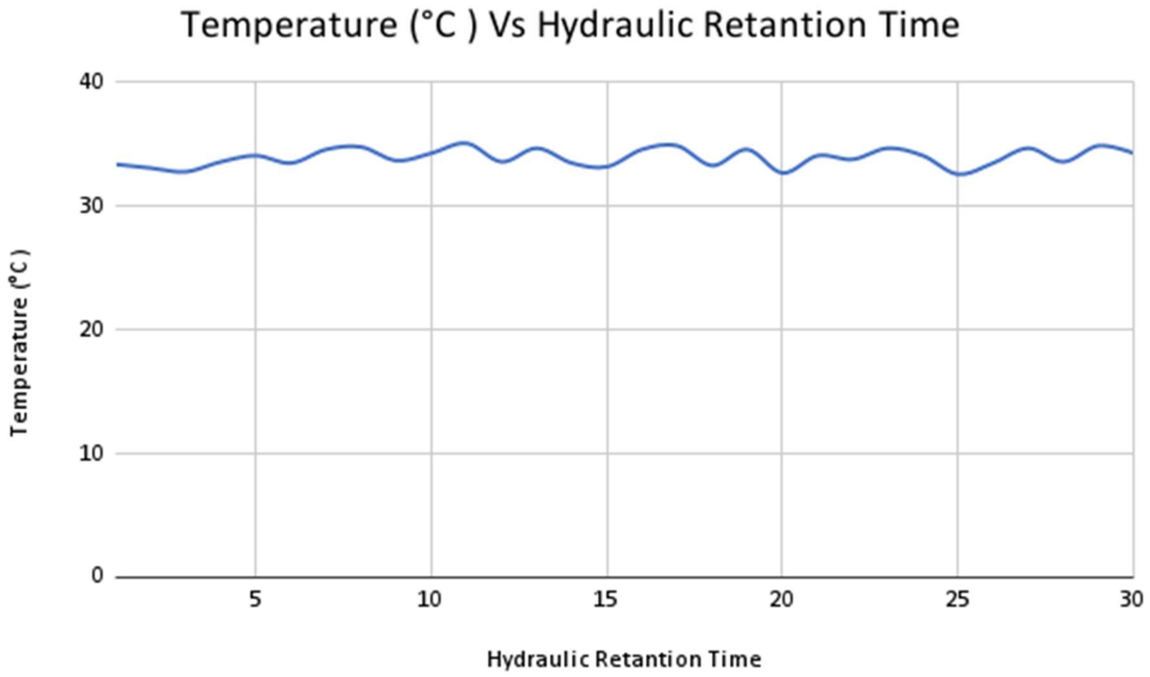

Figure 3. Temperature vs. Hydraulic Retention Time graph.

Figure 3 shows that the temperature of the reactor is controlled between 32 and 35°C. So, utilizing the module, the desired temperature range was achieved.

Another important factor anaerobic digestion is pH. Maintaining the pH level within the range of 6.8-7.5 in the biogas digester was essential for optimizing microbial activity and biogas production. Sodium hydroxide was used to raise pH when it decreased, and sulfuric acid was used to lower pH when it increased [9]. This pH control strategy ensured a stable environment for efficient anaerobic digestion and maximized biogas yield.

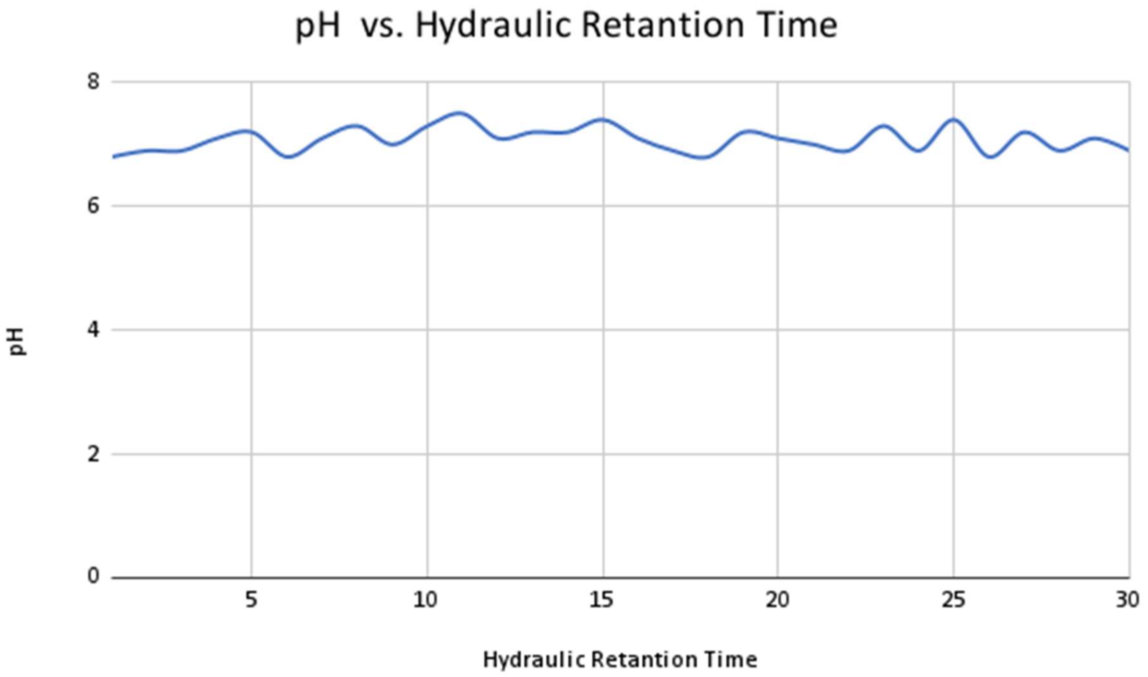

Figure. 4. pH vs. Hydraulic retention Time graph.

Figure 4 shows that the pH of the reactor is controlled between 6.5 and 7.6. So, utilizing the module, the desired pH range was achieved.

By adjusting these variables to optimal conditions, we were able to boost biogas output. The daily production is shown in the graph below.

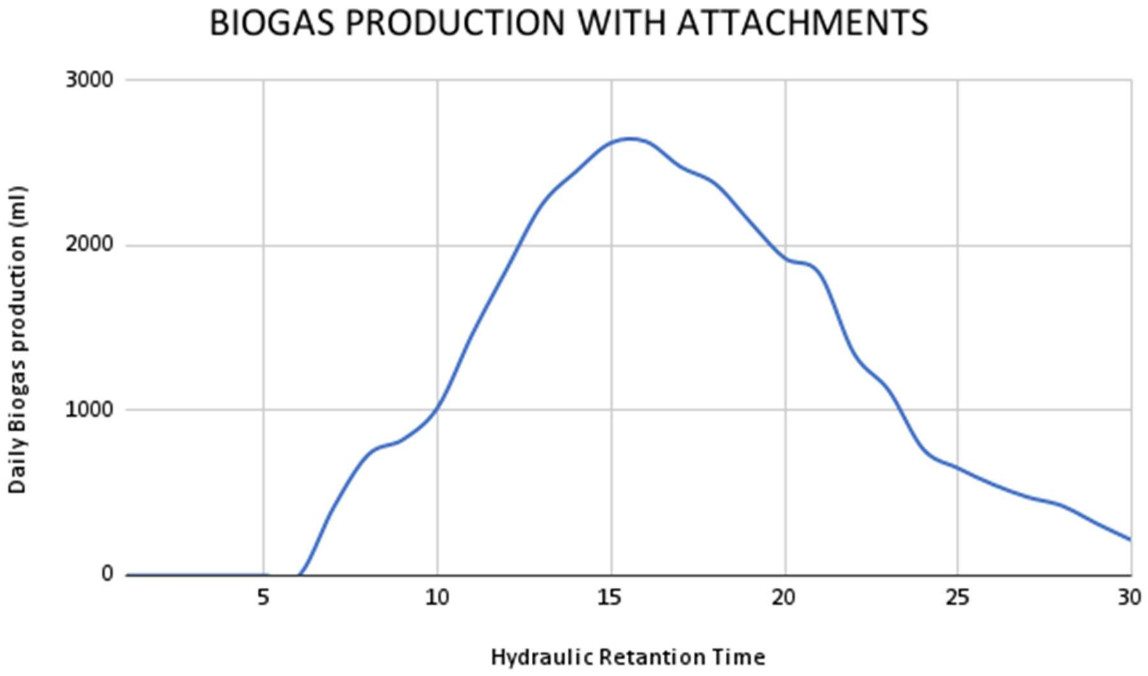

Figure 5. Biogas Production after using temperature and pH Control system.

Attachments were added in the second phase to help regulate temperature, pH, and stirring more efficiently. Figure 3 shows that biogas production began on the sixth day and peaked at 2,632 ml on day 16. The entire cumulative production was 32.683 L, or 65.36% of the predicted 50 L.

3.3 Comparison between Biogas Production with and Without Attachments

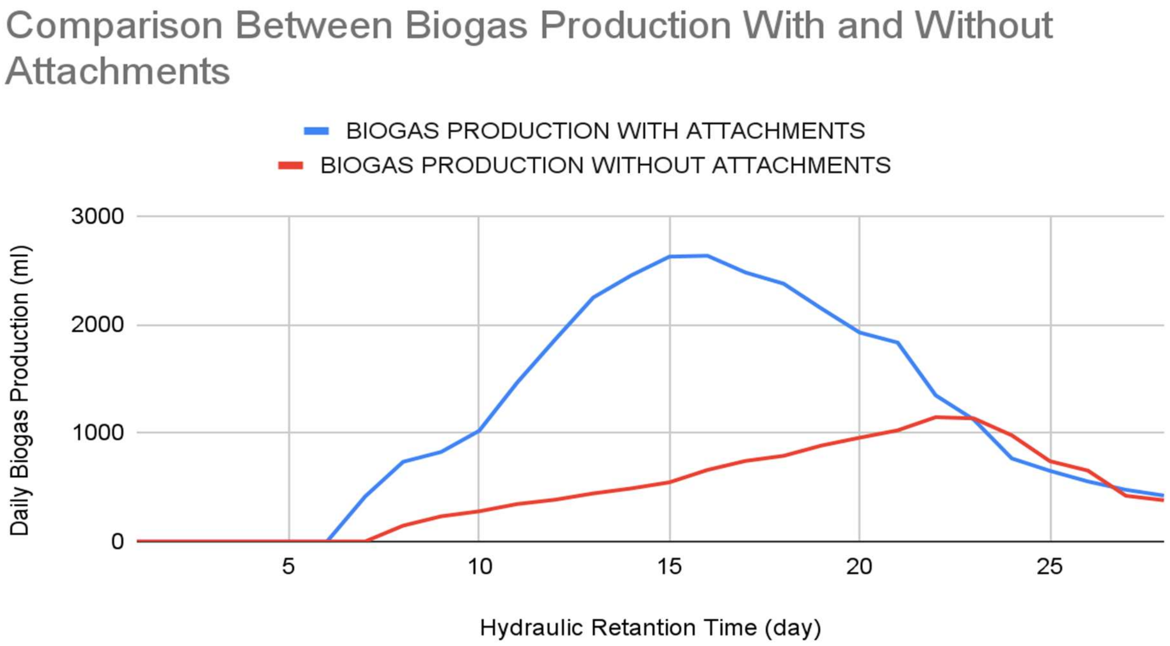

Figure. 4. Comparison between Biogas Production with and Without Attachments

The experiment was conducted in two phases which is compared in figure 6. In Phase 1, biogas production began after 7 days, with a peak production of 1,145 ml on the 22nd day and a total cumulative output of 12.988 L, representing 25.97% of the estimated 50 L. In Phase 2, with temperature and pH control, biogas production began after 6 days, with a peak production of 2,632 ml on the 16th day and a total cumulative production of 32.683 L, representing 65.36% of the estimated 50 L. Therefore the increase in the production of biogas for using attachments is 40.61% of the estimated value.

4. CONCLUSIONS

This experiment utilized a small-scale portable biogas plant with a continuously stirred tank reactor (CSTR). The setup was cost-efficient and suitable for experimenting with different feed compositions under various biodegradation parameters. The effect of controlling temperature and pH has been discussed in this research. We have produced about 40.61% more biogas using the attachments. To assess its commercial potential, further study, as well as techno-economic and environmental investigations, should be undertaken. To ensure the success of future experiments, all types of leakage must be eliminated. The use of high-quality materials for the reactor is recommended to withstand the pressure of biogas production and tolerate thermal stress. Additionally, introducing inorganic additives could facilitate the breakdown of the hydrogen chain in feed materials, boosting methane production. Further pretreatment techniques should also be explored to improve yield.

REFERENCES

[1] H. Hahn, "Economic and ecological evaluation of biogas plant configurations for a demand-oriented biogas supply for flexible power generation," *Renewable Energy*, vol. 83, pp. 19-27, 2015.

[1] International Energy Agency, "Global energy review 2020," *International Energy Agency*, 2020.

[2] C. Gürsan and V. de Gooyert, "The impact of natural gas on energy transition: A systemic analysis," *Renewable and Sustainable Energy Reviews*, vol. 138, p. 110552, 2021.

[3] R. S. Sarkar, M. Skalicky, A. Hossain, *et al.*, "Managing crop residues can improve the efficiency of inputs and promote sustainability in agriculture," *Sustainability*, vol. 12, no. 23, pp. 9808-9824, 2020.

[4] M. Mohammad, W. W. M. Ishak, S. I. Mustapa, and B. V. Ayodele, "Natural gas as an alternative energy source in the transition to sustainability: A mini-review," *Frontiers in Energy Research*, vol. 9, 2021.

[5] S. Achinas, V. Achinas, and G. J. W. Euverink, "A technological overview of biogas production from biowaste," *Engineering*, vol. 3, no. 3, pp. 299-307, 2017.

[6] H. Li, D. Mehmood, E. Thorin, and Z. Yu, "Biomethane production via anaerobic digestion and biomass gasification," *Energy Procedia*, vol. 105, pp. 1172-1177, 2017.

[7] S. Sahota, G. Shah, and P. Ghosh, "Current and future trends in biogas upgradation technologies," *Bioresource Technology Reports*, vol. 1, pp. 79-88, 2018.

[8] B. Afework, J. Hanania, J. Jenden, K. Stenhouse, and J. Donev, "Biogas production and usage: A global review of legislation framework," *International Journal of Environmental Science and Technology*, vol. 19, no. 4, pp. 3377-3400, 2022.

[9] Y. R. Ouahabi, K. Bensadok, and A. Ouahabi, "Chemical pretreatments and ultrasonic disintegration improve wheat straw biomethane production via anaerobic digestion," *Sustainability*, vol. 13, no. 13, p. 7202, 2021.

[10] G. Öztep, T. Güngören-Madenoğlu, G. Özdemir, "Microbial community analysis for anaerobic digestion of water hyacinth with waste sludge at different solid contents and temperatures," *Technology & Innovation*, Elsevier, 2023.

[11] F. Tasnim, S. A. Iqbal, A. R. Chowdhury, "Biogas production from anaerobic co-digestion of cow manure with kitchen waste and water hyacinth," *Renewable Energy*, Elsevier, 2017.

[12] S. M. Khune, "Biogas production from solid food waste and its use for electricity production," *VUT*, 2021.

[13] I. Ashraful, H. Shameem, A. I. Salma, "Upgraded Method of Biogas Production from Waste in Anaerobic Co-Digestion Process," *JES*, 2018.