

Anaerobic Digestion of Water Hyacinth for Sustainable Biogas

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ABSTRACT

Water hyacinth (*Eichhornia crassipes*), an invasive aquatic weed, poses serious environmental and ecological challenges due to its rapid growth and clogging of water bodies. This study investigates the potential of utilizing water hyacinth as a sustainable feedstock for biogas production through anaerobic digestion. The collected biomass was mechanically pre-processed, size-reduced, and mixed with cow dung as an inoculum to enhance microbial activity. The substrate was digested under controlled mesophilic conditions in a laboratory-scale anaerobic digester. Key parameters such as pH, temperature, total solids (TS), volatile solids (VS), retention time, and gas yield were monitored throughout the digestion period. The results indicated that water hyacinth has a significant biogas generation potential due to its high cellulose and hemicellulose content. The produced biogas, rich in methane, was tested for its suitability as a cooking fuel. Overall, the study demonstrates that anaerobic digestion of water hyacinth not only provides a renewable source of clean energy but also offers an effective method for managing aquatic weed infestation. This approach contributes to environmental sustainability, waste utilization, and rural energy solutions.

Keywords: Biogas, Water hyacinth, Anaerobic digestion, Renewable energy, Biomass, Methane production.

1. INTRODUCTION

Energy demand is increasing globally due to industrialization and population growth. Conventional fossil fuels are limited and contribute to environmental pollution. Biogas technology has emerged as an effective solution for converting organic waste into clean and renewable energy through the process of anaerobic digestion. Among various biomass resources, *Eichhornia crassipes*, commonly known as water hyacinth, has gained attention as a potential feedstock for biogas production. Water hyacinth is one of the fastest-growing aquatic plants in the world and is widely regarded as an invasive species. Its uncontrolled growth in water bodies leads to serious environmental issues such as blockage of waterways, reduction of dissolved oxygen levels, disruption of aquatic ecosystems, and increased water pollution.

Despite these challenges, water hyacinth possesses high cellulose and hemicellulose content, making it rich in organic matter suitable for anaerobic digestion. Utilizing this invasive aquatic weed for biogas production not only generates renewable energy but also contributes to effective waste management and environmental restoration. Water hyacinth (*Eichhornia crassipes*) is one of the fastest-growing aquatic plants, often considered a nuisance due to its rapid spread in water bodies. It blocks sunlight, reduces oxygen levels, and affects aquatic life. However, its high cellulose and hemicellulose content makes it an ideal feedstock for biogas production. This project aims to investigate the feasibility of producing biogas from water hyacinth through anaerobic digestion. By converting an environmental problem into a valuable energy resource, the study highlights a sustainable approach that addresses both energy scarcity and ecological concerns.

2. METHODOLOGY

The increasing demand for sustainable and renewable energy sources has encouraged the exploration of organic waste materials for biogas production. The production of biogas through anaerobic digestion is an effective and eco-friendly method of converting organic waste into renewable energy. Water hyacinth, an invasive aquatic plant, grows rapidly in water bodies and often creates environmental problems such as blockage of waterways and reduction of dissolved oxygen. However, due to its high organic and cellulose content, it can serve as a suitable raw material for biogas

production. Buffalo dung, on the other hand, is rich in anaerobic microorganisms that help initiate and accelerate the digestion process. By combining water hyacinth with buffalo dung in a controlled anaerobic digester, biogas rich in methane can be produced efficiently. The process not only generates renewable energy in the form of methane-rich biogas but also provides nutrient- rich digestate that can be used as organic fertilizer, thereby promoting waste-to-energy conversion and environmental sustainability. The following procedure describes the systematic steps involved in the collection, preparation, digestion, monitoring, and safety measures adopted for successful biogas generation using these materials.



Flow Chart: 1

2.1 Collection of Raw Materials

Fresh water hyacinth was collected from nearby ponds and lakes where it grows abundantly as an invasive aquatic plant. The collected biomass was thoroughly washed with clean water to remove mud, sand, and other foreign particles that might affect digestion efficiency. Buffalo dung was collected fresh from local dairy farms and transported in sealed containers to prevent contamination. The dung served as a microbial inoculum due to its high population of methanogenic bacteria essential for anaerobic digestion.

2.2 Pre-treatment of Water Hyacinth

The washed water hyacinth was manually chopped into small pieces measuring approximately 1–3 cm in length. Chopping increases the surface area of the biomass, enhancing microbial accessibility and accelerating the hydrolysis process. The chopped material was then partially dried under direct sunlight for 1–2 days to reduce excessive moisture content. Partial drying also helps concentrate organic matter and improves slurry preparation.

2.3 Preparation of Slurry

The slurry was prepared by mixing chopped water hyacinth and fresh buffalo dung in a 5:1 ratio by weight. The dung acts both as a nitrogen source and microbial starter culture. Sufficient water was added gradually while mixing to achieve a semi-liquid, uniform consistency suitable for anaerobic digestion. The mixture was stirred thoroughly to ensure homogeneity and prevent formation of lumps, which could hinder microbial activity.

2.4 Digester Setup

A plastic water tank was modified to function as a fixed-dome batch anaerobic digester. The system consisted of:

- An airtight digestion chamber
- An inlet for feeding slurry
- A gas outlet pipe fitted with a valve
- A gas collection system (balloon or gas bag)

All joints and openings were sealed using appropriate sealants to prevent air entry and gas leakage. Maintaining strict anaerobic conditions was essential for effective methane production.

2.5 Charging the Digester

The prepared slurry was carefully poured into the digester until it reached approximately 70–80% of the total capacity. Leaving headspace is important for gas accumulation and pressure regulation. After loading, the inlet was tightly sealed to prevent oxygen infiltration, which could inhibit methanogenic bacteria.

2.6 Anaerobic Digestion Process

The digestion process was carried out under mesophilic temperature conditions ranging between 30–35°C for a retention period of 30–40 days. The anaerobic digestion process occurred in four main stages:

- **Hydrolysis:** Complex organic compounds such as cellulose were broken down into simpler soluble molecules.
- **Acidogenesis:** Simple sugars were converted into volatile fatty acids.
- **Acetogenesis:** Volatile fatty acids were further converted into acetic acid, hydrogen, and carbon dioxide.
- **Methanogenesis:** Methanogenic bacteria converted these products into methane (CH₄) and carbon dioxide (CO₂).

Proper environmental conditions were maintained throughout to optimize microbial activity.

2.7 Gas Collection and Measurement

The gas outlet pipe was connected to a gas collection balloon to capture the biogas produced. Gas production was monitored daily. The volume of biogas was measured using either the water displacement method or a calibrated gas flow meter. Gas accumulation was recorded to determine production trends over the digestion period.

2.8 Monitoring of Parameters

Key parameters were monitored regularly to ensure optimal digestion:

- **Temperature:** Maintained within the mesophilic range (30–35°C).
- **pH:** Maintained between 6.5 and 7.5 to support methanogenic activity.
- **Daily Gas Production:** Recorded to evaluate performance and peak production period. Adjustments were made if pH fluctuations were observed, such as adding buffering agents if necessary.

2.9 Observations

Initial gas production began within 3–5 days, indicating active microbial fermentation. A significant increase in biogas production was observed between days 15–20, representing the peak digestion phase. After 25 days, gas production gradually decreased due to depletion of biodegradable organic matter. The trend followed a typical batch digestion curve.

2.10 Safety Precautions

Strict safety measures were followed throughout the experiment:

- The digester was kept completely airtight.
- Regular inspection was done to detect gas leaks.
- Open flames and sparks were strictly avoided near the setup due to methane's flammability.
- Protective gloves and masks were worn while handling slurry and digestate. These measures ensured safe and uninterrupted operation.

2.11 Output and By-products

The biogas produced contained approximately 55–65% methane (CH₄), 30–40% carbon dioxide (CO₂), and traces of other gases such as hydrogen sulfide (H₂S). The methane-rich biogas can be used for cooking, heating, or electricity generation. The residual slurry, known as digestate, was collected after completion of the digestion period. It was nutrient-rich and used as an organic fertilizer, enhancing soil fertility and promoting sustainable agriculture.

3. MATERIALS REQUIRED

3.1 Water hyacinth: Water hyacinth (*Eichhornia crassipes*) is a free-floating aquatic macrophyte belonging to the family Pontederiaceae. It is one of the fastest-growing invasive aquatic plants, capable of doubling its biomass within 7–15 days under favorable conditions.

The plant contains high moisture content (90–95%) and significant amounts of cellulose (18–30%), hemicellulose (25–35%), and low lignin content (5–10%), making it suitable for anaerobic digestion. Its organic composition provides an adequate carbon source for microbial degradation during biogas production.

Water hyacinth has a moderate C:N ratio (20–30:1), which supports efficient methane generation when co-digested with animal dung. Due to its rapid growth and high volatile solids content, it is considered a promising renewable biomass feedstock for sustainable biogas production while simultaneously addressing aquatic weed management and water pollution problems.



Figure: 1

3.2 Buffalo Dung: Buffalo dung is an organic waste material rich in anaerobic microorganisms, making it an effective inoculum for biogas production. It contains a balanced microbial consortium, including hydrolytic, acidogenic, acetogenic, and methanogenic bacteria necessary for anaerobic digestion.

Fresh buffalo dung typically contains total solids (TS) of 16–20% and volatile solids (VS) of 70–80% (of TS), indicating high biodegradable organic matter. It has a C:N ratio of 20–25:1, which is close to the optimum range for methane production. The presence of naturally occurring methanogens accelerates the start-up phase of digestion and improves overall biogas yield. Chemically, buffalo dung consists of:

- Cellulose and hemicellulose (partially digested plant fiber)
- Proteins
- Carbohydrates
- Trace nutrients (N, P, K)

Due to its buffering capacity, buffalo dung helps maintain pH stability (6.5–7.5) during digestion, preventing process failure. When co-digested with water hyacinth in a 5:1 ratio, it enhances microbial activity, improves substrate balance, and increases methane production efficiency.

4. RESULTS and DISCUSSION

4.1 Experimental Data Table

Day	Temperature (°C)	pH	Biogas Produced (L)
1	30	7.0	0
4	31	6.8	2
8	32	6.7	5
12	33	6.5	8
16	34	6.5	15
20	34	6.8	25
24	33	7.0	30
28	32	7.2	20
32	31	7.3	10

4.2 Biogas Production Trend

The experimental investigation was conducted to evaluate the efficiency of biogas production using a mixture of water hyacinth and buffalo dung in a 5:1 ratio under batch digestion conditions. The variation in biogas production over a period of 30 days clearly indicates the different phases of anaerobic digestion.

At the initial stage (Day 1), no measurable biogas production was observed, which represents the lag phase of microbial activity. During this period, anaerobic microorganisms adapt to the substrate and environmental conditions inside the digester.

Biogas production commenced on Day 4 with a yield of 2 L, indicating the beginning of microbial degradation. From Day 4 to Day 20, a significant increase in gas production was recorded. The production reached 5 L on Day 4, 8 L on Day 8, and further increased to 15 L by Day 12. This phase corresponds to the active digestion stage, where hydrolysis, acidogenesis, and methanogenesis occur simultaneously.

The maximum biogas yield of 30 L was observed on Day 20, which indicates peak microbial activity and efficient conversion of organic matter into methane-rich gas. This stage is dominated by methanogenic bacteria that convert intermediate products such as volatile fatty acids into methane.

After Day 20, a decline in biogas production was observed. The output decreased to 20 L on Day 24 and further reduced to 10 L on Day 32. This decline can be attributed to substrate depletion, reduced microbial activity, and accumulation of inhibitory by-products. Thus, the digestion process clearly follows the typical pattern of lag, exponential, and decline phases.

4.3 Influence of Temperature on Biogas Production

Temperature is one of the most critical parameters affecting anaerobic digestion. In this study, the temperature was maintained within the range of 30°C to 34°C, which falls under the mesophilic range (25°C–40°C).

The data shows that biogas production increased with a rise in temperature. During the period from Day 1 to Day 12, the temperature gradually increased from 30°C to 34°C, and a corresponding increase in gas production was observed. The highest biogas yield was recorded when the temperature was around 33–34°C, indicating optimal conditions for microbial growth.

After Day 20, the temperature slightly decreased to 31–32°C, which coincided with a reduction in gas production. This demonstrates that even small temperature variations can affect microbial efficiency. Therefore, maintaining a stable mesophilic temperature is essential for maximizing biogas yield.

4.4 Effect of pH Variation

The pH of the digester slurry plays a vital role in maintaining microbial stability. In this experiment, the pH values ranged from 6.5 to 7.3, which is considered suitable for anaerobic digestion.

Initially, the pH decreased from 7.0 (Day 1) to 6.5 (Day 8), indicating the formation of organic acids during the acidogenesis stage. This drop in pH is a normal phenomenon and is caused by the breakdown of complex organic matter into simpler compounds.

As the digestion process progressed, the pH gradually increased and stabilized around neutral values (7.0–7.3) between Day 16 and Day 30. This stabilization indicates effective methanogenic activity, where acids are converted into methane and carbon dioxide.

The highest gas production observed around Day 20 corresponds to a pH close to neutral, confirming that optimal pH for biogas production lies between 6.8 and 7.2. Extreme pH variations were not observed, which indicates that the system remained stable throughout the experiment.

4.5 Discussion

This study presented a practical welding defect detection system based on the YOLO11s model. The system achieves real-time detection with moderate accuracy under realistic data constraints, demonstrating its applicability for industrial inspection support.

5. CONCLUSION

The study demonstrates that water hyacinth, when combined with buffalo dung, can be effectively utilized for biogas production through anaerobic digestion. The process successfully converted invasive aquatic biomass into methane-rich biogas under mesophilic conditions within 30–40 days. Biogas production began within a few days, reached peak levels during the mid-digestion period, and gradually declined as the organic matter was consumed.

The results confirm that water hyacinth is a viable alternative substrate for renewable energy generation when properly pre-treated and mixed with suitable inoculum. In addition to producing 55–65% methane-rich biogas, the process also generated nutrient-rich digestate that can be used as organic fertilizer. Therefore, this method not only provides a sustainable energy source but also helps in environmental management and waste utilization, making it an eco-friendly and cost-effective solution for rural and semi-urban areas.

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