Journal of Basic and Applied Research International

Volume 30, Issue 3, Page 11-34, 2024; Article no.JOBARI.12138
ISSN: 2395-3438 (P), ISSN: 2395-3446 (O)

Design Analysis and Production of Biogas Using Local Feedstock "Elephant Grass"

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Authors' contributions

This work was carried out in collaboration between all authors. Author BUO designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author MCO managed the analysis of the study, arranged and documented all reports structurally. Authors UVO, CSI and KCA managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.56557/jobari/2024/v30i38728

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://prh.ikprress.org/review-history/12138

Original Research Article

Received: 24/03/2024
Accepted: 30/05/2024
Published: 10/06/2024

ABSTRACT

The study was aimed at constructing a biodigester and determining the efficiency of using a mixture of cow dung and elephant grass as feedstock for biogas production. The volume of the biodigester was 126 litres ($0.126m^3$) and it was constructed using mild steel with a thickness of 5mm and a maximum allowable stress of $1.74\ N/mm^2$ to withstand high pressures that could be generated within the digester. 6 kg of elephant grass was mixed with 6 kg of cow dung and 12 litres of water and poured in the biodigester and left for a period of 21 days with a temperature range of 35°C - 44°C. Graphs of temperature (°C) against retention period (days) and daily biogas produced (litres) against retention period (days) were obtained. The daily biogas yield was measured by calculating

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Cite as: *Okonkwo, B. U., M. C. Osuagwu, U. V. Opara, C.S. Ike, and K. C. Aladum. 2024. "Design Analysis and Production of Biogas Using Local Feedstock 'Elephant Grass'". Journal of Basic and Applied Research International 30 (3):11-34. https://doi.org/10.56557/jobari/2024/v30i38728.*

the volume increase of the storage device which is a car tyre tube in this case. Elephant grass serves as an effective substrate for biogas production. To enhance its efficiency in the digester, it is recommended to mechanically pre-treat the grass by breaking it into smaller particles.

Keywords: Biodigester; elephant grass; renewable energy; sustainable energy.

1. INTRODUCTION

Biogas presents a competitive and viable energy option with strong sustainability credentials. The suitability of this technology stems from the abundant availability of cost- effective raw materials and its versatility in various applications, such as heating, power generation, and serving as sustainable inputs for chemical production, including hydrogen, carbon dioxide, and biofuels. The capacity for electricity generation from biogas has witnessed substantial growth in the past decade, with global biogas-based power capacity increasing from 65GW in 2010 to 120GW in 2019, signifying an impressive 90% rise [1]. Across the globe, countries share common energy drivers, namely, environmental protection, energy security, and economic growth. As the sources of fossil fuels, such as coal, gas, and oil, are expected to diminish within the coming century, there is an increasing urgency to investigate alternative energy sources [2]. Energy plays a pivotal role in fostering global prosperity, as it is indispensable for domestic purposes (e.g., cooking and heating water), industrial applications (e.g., furnace heating and running electric motors), and transportation needs.

Furthermore, it plays a pivotal role in driving economic and social progress [3] and is essential for fulfilling the fundamental everyday needs of humanity. Many countries, especially developing ones like Nigeria, are grappling with energy crises due to an excessive reliance on fossil fuels. The worldwide energy shortage has made it necessary to explore new and sustainable energy opportunities. Fossil fuels currently account for approximately 86% of the world's energy consumption [4]. Fossil fuels are burdened with numerous problems, including high costs, price fluctuations, increased demand, supply disruptions, and, most notably, environmental pollution. The latter presents a significant concern linked to their utilization. With growing environmental concerns about greenhouse gas emissions and climate change resulting from fossil fuel usage, there has been a notable surge of interest in biogas as a feasible and renewable energy alternative [5]. Growing interest in using biomass resources as renewable feedstock for a variety of uses, such as electricity generation, fuel production, chemical processing, and hydrogen production, has also been sparked by the escalating environmental concerns and the implementation of policies [6]. To address environmental pollution, such as greenhouse emissions, there is a notable trend of diverting agricultural residues and grass litter to be used as domestic fuel, displacing the need for fossil fuels and reducing overall environmental impact. More than two-thirds of the world's population engages in agriculture as their main economic activity, and it is essential to human survival [7]. In many developing countries, smallholder agriculture and its related sectors form the backbone of their economies, directly or indirectly supporting approximately 82% of the global population [7].

For many developing countries, getting access to modern energy services is a huge challenge. For instance, 836 million Indians did not have access to these services in 2012 [8]. To ensure sustainability in food and energy production, it is vital to focus on the development and adoption of resource and income-conserving technologies in agriculture [7]. Fossil fuels like coal, oil, and gas currently contribute approximately 60% of global electricity generation. However, renewable energy sources have been gradually increasing their share, rising from 26% to 28% in the first quarter of 2020, with variable renewables, such as solar and wind, growing from 8% to 9% during the same period [9].

Since 1990, the share of renewable energy in the world's power generation has increased at a 2% yearly rate, outpacing the 1.8% annual growth in electricity demand. Among renewables, biogas has shown the third-highest annual capacity growth globally at 11.5%, trailing behind solar PV at 36.5% and wind at 23.0%. Biomass, including biofuels, has also maintained a significant average annual growth rate of 9.7% since 1990 in global electricity generation [9]. This emphasizes the vital role of biogas in the ongoing energy transition and emphasizes the significance of fostering its production and utilization. Biogas, produced via anaerobic digestion, is a combination of methane and carbon dioxide, resulting from the breakdown of organic waste by bacteria in an oxygen-deprived environment. It also includes minor quantities of hydrogen sulfide and water vapor and burns with a faint blue flame. The calorific value of biogas ranges from 25.9 to 30 J/m3, depending on the proportion of methane in the gas. In many Nigerian cities, biogas production proves to be a profitable method for reducing or even eliminating the challenges posed by urban waste [10]. It is among the various renewable energy sources, along with biomass and biofuel, each at different stages of transformation. Biogas can be generated from various biomasses, such as poultry droppings, agricultural crop waste, and cattle manure, through controlled anaerobic degradation. The produced biogas can undergo additional processing and concentration to yield biomethane, which is suitable for injection into natural gas pipelines [11].

Moreover, since biogas is a byproduct of microbial metabolism, it can be directly used for heat and power generation. Alternatively, it can undergo upgrading to biomethane, enabling value-added chemical production for energy and various industrial applications [6]. Furthermore, biomethane and enriched biogas present opportunities to integrate rural communities and industries into the energy sector transformation. This can be achieved through grid-connected electricity generation and reduced reliance on the grid by producing their own electricity and heat [9]. Biogas can effectively replace natural gas in all energy-consuming applications. Building an anaerobic digester is the first step in the production of biogas. This enclosed tank is used to subject certain organic wastes, such as manure, sewage sludge, municipal solid waste, biodegradable waste, and energy crops, to anaerobic digestion or fermentation. One of the significant advantages of biogas is its cleaner burning properties compared to coal, leading to lower carbon dioxide emissions per unit of energy Moreover, the carbon present in biogas originates from the atmosphere through photosynthesis, and when released, it contributes less overall atmospheric carbon compared to burning fossil fuels. Despite the many advantages of biogas digesters, certain setbacks pose challenges to the widespread commercialization of anaerobic digesters. The specific parameters required by the methanogens, such as temperature and pH, can hinder the implementation of this technology on a large scale.

1.1 Objective of Study

The main aim of this project is the design analysis and production of biogas using local feedstock (elephant grass).

The specific objectives are;

1. The design of biodigester.
2. The actual anaerobic digestion of the feedstock (substrate).
3. The production and flame test of the biogas produced.

1.2 Problem Statement

Global energy crisis and the environmental challenges associated with fossil fuels have given rise to research and search for alternate fuels or green energies. Nigeria, which is one of the Agricultural nations with abundant vegetation, has the potential for clean energy generation. This work focuses on one of the techniques involved in the production of biogas using abundant elephant grass, an abundant vegetation in the Southern part of the country.

1.3 Justification of Study

High cost of energy and perennial wealth challenge occasioned by the use of fossil fuel is a good justification to switch to cleaner or greener energies. Biogas is anticipated to emerge as a crucial energy source in the future, playing a pivotal role in environmental preservation, addressing pollution issues, and fostering improved agricultural and community health.

1.4 Scope and Limitation

This work covers every aspect of biodigester construction, fabrication and biogas production using elephant grass. The cleaning of gas residue such as hydrogen sulphide is not covered by this work.

2. LITERATURE REVIEW

2.1 Biodigester

Biogas production is a controlled process that takes place within biodigesters. The fixed dome design and the floating dome design are the two basic variations of biogas digesters. However, ongoing research and development efforts are concentrated on creating new and improved designs because to the growing demand for affordable, long-lasting, and useful biogas solutions [12]. Despite its potential, global biogas production and utilization have not reached their full capacity due to several factors. The availability of less expensive fossil fuel alternatives, high production costs, and relatively poor conversion efficiency are some of the obstacles preventing the mainstream use of biogas systems [13].

A biodigester is a self-sustained system of bacteria that takes in organic feedstock and produces methane-rich biogas as well as nitrogen-rich fertilizer as effluent [14]. Organic materials such as grass clippings, vegetables, animal wastes, food processing residues, and other carbon- and nitrogen-containing materials are fed into the biodigester. These materials are broken down by the bacteria in the digester through anaerobic processes, producing biogas as a byproduct. According to Yerima [15], biogas is a colorless mixture primarily made up of methane and carbon dioxide with traces of hydrogen sulfide. When biogas is produced spontaneously in nature, it is commonly known as:

1. Marsh gas, which bubbles up through stagnant water or swamp.
2. Landfill gas, which is produced from organic domestic waste or
3. Sewage gas when it is produced from sewage or animal waste.

The conversion of biogas into heat energy is its main objective. It can be used in gas engines to produce both heat and electricity. The waste product obtained from the biogas production process, known as slurry, can be composted and applied as fertilizer to farmlands, offering an eco-friendly waste management solution. The calorific value of biogas ranges from approximately 6.0 to 6.5 KWh/m3, contingent on the percentage of methane present, which typically falls within the volume range of 55% to 70% [16]. The effectiveness of the biogas burners and other equipment used during the biogas processing has an impact on the net calorific value of the gas.

To produce 1m3 of biogas, approximately 10 kg of biowaste (measured in wet weight) is required. This volume of biogas contains roughly 6 KWh (equivalent to 21.6 MJ) of energy [17]. These figures provide valuable insights into the energy content and potential of biogas as a renewable energy resource for various applications.

2.2 Classification of Biodigesters

2.2.1 Fixed dome

The fixed dome type of biodigester is designed to be constructed underground and gets its name from its immovable and dome-shaped structure. This type of biodigester consists of a feedstock inlet and a displacement pit. As biogas is produced, it is stored in the upper part of the biodigester. There is a closed outlet gas valve that is used to control the gas pressure inside the digester. Gas pressure increases as gas production increases, pushing the slurry into the displacement pit. The gas pressure drops when the gas valve is opened for gas use, allowing a certain quantity of slurry to flow back from the compensating tank into the digester. As a result, the rate of gas generation and consumption determines the constant fluctuation in gas pressure.

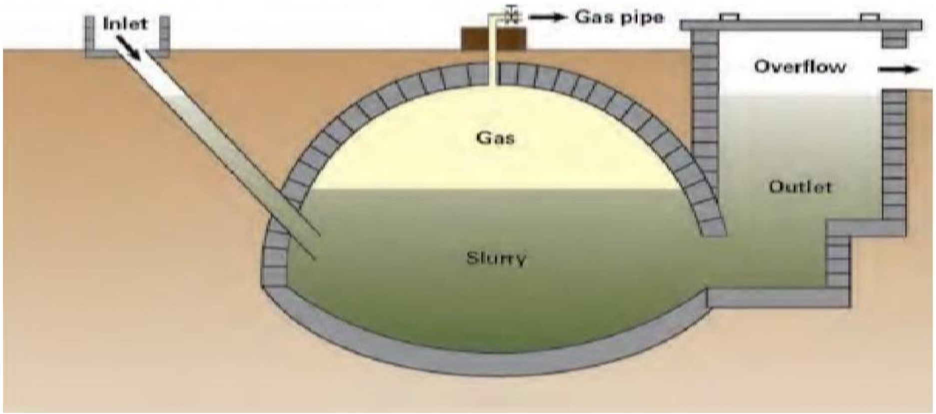


Fig. 1. Schematics of a fixed dome biodigester
(Source: Yvonne et al., [17])

Table 1. Typical composition of biogas from biowaste

Components	Symbol	Concentration (Vol-%)
Methane	CH4	55-70
Carbon dioxide	CO2	35-40
Water	H2O	2(20°C) – 7(40°C)
Hydrogen sulphide	H2S	20 – 20000 ppm (2%)
Nitrogen	N2	<2
Oxygen	O2	<2
Hydrogen	H2	<1
Ammonia	NH3	<0.05

Source: Yvonne et al., [17]

The underground construction of the fixed dome biodigester provides several benefits. Biogas provides insulation against low temperatures during the night and cold seasons, ensuring the efficiency of the anaerobic digestion process, even in colder climates. This design also helps maintain a relatively stable temperature inside the biodigester, promoting efficient biogas production throughout the year.

2.2.2 Flowing drum

The cylindrical digester with a movable drum as the gasholder is another common design for biogas systems. In this setup, the digester is shaped like a cylinder, and the gasholder is represented by a moveable drum. The drum's upward movement is directly linked to the quantity of gas produced in the digester. It is intentionally designed to be slightly smaller than the tank opening [18]. As biogas is generated in the digester, it accumulates within the drum, causing the drum to rise. The rising movement of the drum serves as a visual indicator of the biogas volume being produced. When gas is generated in the digester, the gasholder rises hence giving a signal that gas should be harvested from the plant and lowers where there is no gas [8]. Additionally, the drum's movement allows for the collection of the generated biogas through piping systems that are attached to the drum. Once collected, the biogas can be directed to various applications, including cooking, heating, or electricity generation. This cylindrical digester with a movable drum design is a practical and efficient way to store and utilize biogas, offering a straightforward mechanism for gas collection and usage. It provides a cost-effective and environmentally friendly solution for converting organic waste into valuable energy resources.

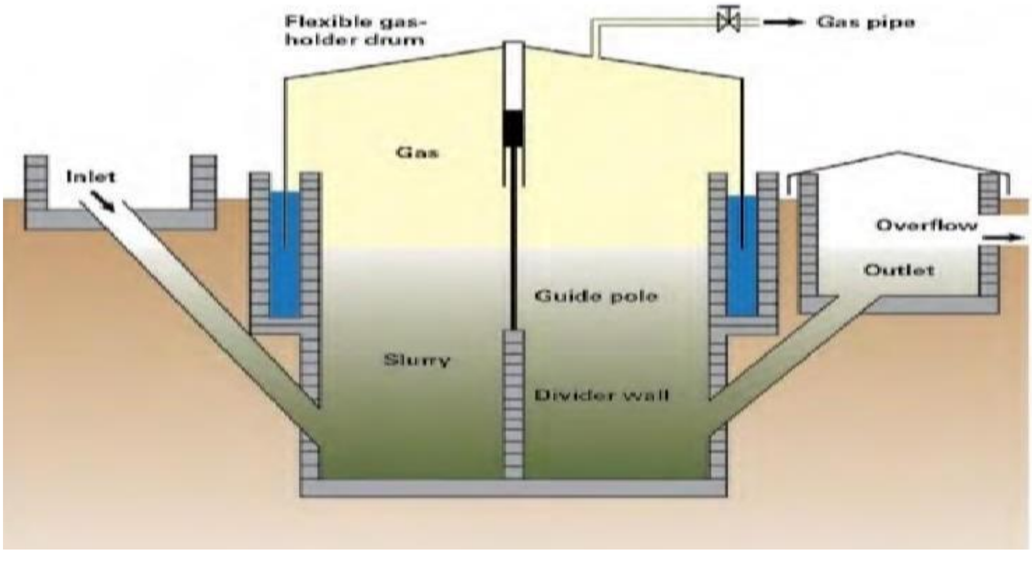


Fig. 2. Schematics of a floating drum biodigester
(Source: Yvonne et al., [17])

2.2.3 Tubular biodigester

A tubular biodigester is a unique design that combines the functions of both the digester and the gas holder into a single weather-resistant plastic or rubber bag, often referred to as a balloon. This longitudinal-shaped balloon serves as both the container for anaerobic digestion and the storage space for the biogas produced. The balloon's surface is directly connected to the intake and outflow pipes. The longitudinal design of the tubular biodigester helps to prevent short-circuiting, which happens when the feedstock passes through the digester too quickly and reduces the efficiency of biogas production.

However, tubular digesters generally lack a stirring device, which limits active mixing of the contents inside. As a result, efficient mixing may not be achieved, and the biogas production rate might be affected (Yvonne et al., 2014. To increase gas pressure inside the tubular biodigester, weights can be placed on the balloon. However, caution should be exercised not to damage the balloon while doing so. Proper management of the gas pressure is essential to maintain optimal biogas production and storage. The tubular biodigester design offers a simple and cost-effective solution for small- scale biogas production, especially in areas where weather-resistant materials are readily available. While it may have some limitations in terms of active mixing, it remains a viable option for converting organic waste into biogas and utilizing it for various energy applications.

2.3 Utilization of Biogas Slurry

Indeed, besides biogas, the slurry produced during the anaerobic treatment process is another valuable product. The slurry is the waste product resulting from the fermentation process and holds significant agricultural benefits. For household digesters that treat only kitchen waste, the resulting slurry is safe for reuse in the garden and serves as an excellent organic fertilizer. It possesses a lower viscosity, which allows it to penetrate the ground more quickly, facilitating nutrient absorption by plants. The chemical composition of the slurry from anaerobic digestion makes it an excellent fertilizer. The slurry obtained from household digesters treating kitchen waste contains all essential plant nutrients, including Nitrogen, Phosphorus, and Potassium, as well as vital trace elements necessary for plant growth. These nutrients are vital for healthy plant development, and their relative ratios play a crucial role in improving soil fertility and nutrient availability [17].

By recycling the slurry as a natural fertilizer, the anaerobic digestion process not only generates biogas but also contributes to sustainable agriculture. It helps to close the nutrient loop, making beneficial use of organic waste materials and reducing the dependence on synthetic fertilizers. This practice promotes a more environmentally friendly and resource-efficient approach to agriculture, which is essential for the long-term health of our ecosystems and food production systems.

2.4 Challenges of Biogas Development

The adoption of biogas technology faces several challenges that hinder its widespread penetration and optimal utilization. These challenges include:

1. **Poor maintenance and management**: It is crucial to give proper attention to managing and maintaining the digester and associated zero-grazing units for livestock. Unfortunately, farmers often prioritize their efforts towards other farm tasks, neglecting the digester's management. As a result, this can lead to low biogas production and a failure to realize the full value of their biogas investments.
2. **Lack or low technological awareness**: Without understanding the working principles of the technology, it becomes challenging to operate, maintain, and service the digesters effectively. This lack of knowledge leads to suboptimal biogas production since the essential requirements for achieving optimal output are not met.
3. **The high installation cost**: The high cost of biogas technology acts as a deterrent to its widespread adoption. The scarcity of technicians and artisans skilled in biogas installation, coupled with a shortage of specific installation materials, further compounds the issue.
4. **System failures and underperforming biogas digesters:** This contribute to a negative perception of the sustainability of biogas technology. These issues may arise due to various factors, and addressing them is essential to enhance the overall perception and effectiveness of biogas solutions.

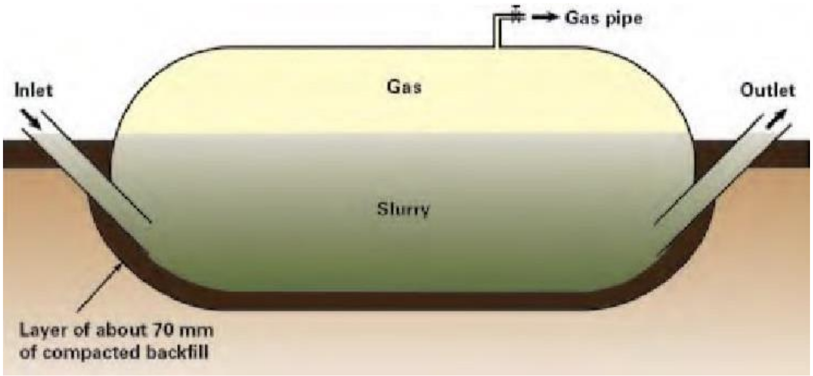


Fig. 3. Schematics of a tubular biodigester
(Source: Yvonne et al., [17])

5. **Poor post-installation support:** The scarcity of technicians and artisans with sufficient knowledge of biogas technology leads to inadequate post-installation support. Once the initial "12-month guarantee period" expires, the support may diminish, leaving farmers or operators with little guidance on maintaining the systems effectively. This lack of ongoing support can hinder the long-term sustainability and successful operation of biogas systems.
6. **Standards**: The absence of well-defined standards to regulate biogas technology poses a challenge in ensuring proper quality control measures are implemented. Having clear and established standards is essential for maintaining consistency, safety, and reliability in biogas systems, as well as promoting broader acceptance and adoption of the technology.

2.5 Biological Stages of Anaerobic Digestion

Anaerobic digestion, which involves the breakdown of diverse organic components, is the method used to produce biogas. It is a sequence of processes by which micro-organisms breakdown biodegradable material in the absence of oxygen [19]. The process is used for industrial or domestic purposes to manage waste or to produce fuels. Much of the fermentation used industrially to produce food and drink products, as well as home fermentation, uses anaerobic digestion. Anaerobic digestion is widely used as a source of renewable energy. The process produces a biogas, consisting of methane, carbon dioxide, and traces of other ‘contaminant’ gases. A variety of bacteria must cooperate in a symbiotic environment in order for the anaerobic digestion of biomass to produce biogas to be a complex microbiological process [20].

The following categories can be used to group the steps of biogas production: pretreatment, hydrolysis, acidogenesis, acetogenesis, and methanogenesis. The efficient functioning of the diverse microbial community involved in each stage is crucial for the overall process of biogas production. Proper feedstock pretreatment and balanced conditions in each stage are essential to maximize biogas production and ensure a stable and effective anaerobic digestion process [21].

2.5.1 Pretreatment stage

Pretreatment is essential for increasing substrate breakdown and raising the anaerobic digestion process' overall effectiveness for producing biogas. There are various methods of pretreatment, including chemical, mechanical, thermal, and enzymatic processes, all aimed at accelerating decomposition and breaking down complex organic compounds, making them more accessible for microbial digestion [22]. However, it is important to note that pretreatment does not necessarily lead to higher biogas production; rather, its primary goal is to facilitate the breakdown of complex compounds for better digestion.

Feedstock cleaning, which involves washing the material and removing non-biodegradable contaminants such plastic, glass, eggshells, ceramics, bones, and sand, is frequently the first step in the pretreatment process in the manufacture of biogas. These contaminants may result in solid deposits at the digester's bottom, which would reduce available digestion area and hinder the production of biogas [13]. In order to eliminate magnetic contaminants and protect the system's moving parts from erosion and damage, magnetic traps can also be used.

Pretreatment accelerates the breakdown of complex organic compounds into smaller and more easily digestible molecules, thereby enhancing reaction rates and increasing biogas yield. This process generates a broader array of new substrates that can be readily utilized during anaerobic digestion. As a result, biomass pretreatment makes the substrate more accessible for microbial action, leading to the partial or complete degradation of the feedstock. This degradation results in the formation of fermentable sugars and reduces the resistance of lignin and the crystalline structure of cellulose [2].

2.5.2 Hydrolysis

Hydrolysis plays a vital role in the anaerobic digestion process for biogas production. It entails breaking down large organic compounds into smaller compounds by adding water. Complex chemical compounds like proteins, lipids, and carbohydrates are disassembled into simple sugars, fatty acids, and amino acids during this phase [23]. This procedure lays the groundwork for additional anaerobic digestion stages that will result in the creation of more biogas. Bacterial hydrolysis is the first stage of anaerobic digestion, which involves the breakdown of biopolymers into soluble forms like sugars, fatty acids, and amino acids by certain fermenting bacteria such bacteroides, Clostridia, and bifidobacteria [24]. Acetate and hydrogen, which are the main byproducts of hydrolysis, are essential for the later phases of anaerobic digestion, where methanogens transform them into methane, the principal component of biogas.

Although hydrolysis generates smaller soluble compounds, many of these products are still relatively large molecules that require further breakdown through the acidogenesis process to produce methane [25]. Acidogenesis is the subsequent stage in the anaerobic digestion process, where acid-forming bacteria convert the hydrolyzed products into volatile fatty acids (VFAs) and other intermediate compounds, which are then utilized in the final stage, methanogenesis, to produce methane.

The overall reaction for hydrolysis is represented by the equation:

$$C12H22O11 + H2O \rightarrow 2C6H12O6$$

This equation illustrates the breakdown of a complex carbohydrate (sucrose) into two simple sugar molecules (glucose). The process of breaking down complex organic compounds into simpler forms, starting with hydrolysis prepares the feedstock for further degradation in the anaerobic digestion process. This step-by-step breakdown eventually leads to the production of biogas, which primarily consists of methane and carbon dioxide.

2.5.3 Acidogenesis

The creation of biogas by anaerobic digestion, which comes after hydrolysis, is dependent on the acidogenesis stage. The simple molecules (monomers) that were created during the hydrolysis step are further broken down by acid-forming bacteria during acidogenesis. Acidogenesis takes place in an acidic environment that fermentative bacteria produce. In this phase, the hydrolyzed monomers are further broken down into a variety of products, such as alcohols, organic acids, organic-nitrogen compounds, carbon dioxide, and organic-sulfur compounds. As they operate on the hydrolysis byproducts, the acidogenic bacteria generate ammonia, carbon dioxide, hydrogen sulfide, carbonic acid, and shorter-chain fatty acids. Other trace compounds might potentially be produced, depending on the composition of the substrate and the hydrolysis products [24]. This acidogenesis step prepares the feedstock for the final stage, methanogenesis, where methane is produced as the primary end product.

The Acidogenesis leaves behind still-large molecules that are not the best for producing methane. As a result, they need to undergo further degradation through the acetogenesis process, where they will be converted into acetate and hydrogen, which are more suitable for the final step of anaerobic digestion – methanogenesis [26].

The overall reactions for acidogenesis are represented by the following equations:

$C6H12O6 \rightarrow 2CH3CH2OH + 2CO2$ (ethanol and carbon dioxide production)

$C6H12O6 \rightarrow 2CH3CHOHCOOH$ (propionic acid production)

The acidogenesis stage is a critical step in the anaerobic digestion process, as it produces intermediate products that are further converted into methane during the final stage of methanogenesis, completing the biogas production process.

2.5.4 Acetogenesis

Acetogenesis is the third stage of anaerobic digestion. In this phase, acetogenic bacteria convert volatile fatty acids and alcohols into acetic acid, carbon dioxide, and long-chain fatty acids. These acetogenic reactions are an important intermediate phase in the entire anaerobic digestion process, laying the groundwork for the production of methane as the main byproduct during the following stage, methanogenesis.

Acetogenesis is a crucial step that creates acetate, primarily from acetic acid (A. Karlsson et al., 2014). During this process, the products generated in the acidogenesis stage, which include various fatty acids, are further broken down by acetogenic microorganisms to produce acetic acid, hydrogen, and carbon dioxide. Acetogenesis acts as an intermediary step between acidogenesis and the final stage of methanogenesis.

By converting the byproducts of acidogenesis, such as fatty acids, alcohols, and volatile fatty acids, into acetic acid and other chemicals, acetogenic bacteria serve a critical part in the anaerobic digestion process. This transformation creates an environment suitable for the subsequent action of methanogenic bacteria. Methanogens then utilize the products of acetogenesis, along with some other compounds from earlier stages, to produce methane, which is the primary component of biogas [26]. This multi-step process involving different groups of microorganisms is essential for efficient biogas production from organic waste materials.

The overall reactions for acetogenesis are represented by the following equations:

1. $CH3CH2COOH + 2H2O \rightarrow CH3COOH + CO2 + 3H2$
2. $CH3CH2CH2COOH + 2H \rightarrow 2CH3COOH + 2H2$
3. $CH3CH3OH \rightarrow CH3COOH + 2H2$

Acetogenesis is a crucial step in the anaerobic digestion process, as it prepares the intermediate products generated in the previous stages for further conversion into methane, ultimately leading to the production of biogas.

2.5.5 Methanogenesis

The third stage of anaerobic digestion, known as methanogenesis, is where methanogenic bacteria turn the leftovers of the preceding phases of acidogenesis and acetogenesis—hydrogen and carbon dioxide—into the gas methane (CH4). Methanogens are highly sensitive to environmental conditions, including temperature, pH, and the presence of oxygen. They thrive in anaerobic (oxygen-free) environments and play a pivotal role in the production of biogas by generating methane, which is the primary component of biogas. Maintaining appropriate conditions for the growth and activity of methanogens is crucial for efficient biogas production from organic waste materials.

During methanogenesis, the methanogenic bacteria act on the products of acetogenesis, such as acetic acid, and further convert them into methane gas. The overall reactions for methanogenesis are represented by the following equations:

1. $CH3COOH \rightarrow CH4 + CO2$ (methane and carbon dioxide production from acetic acid)
2. $2CH3CH2OH \rightarrow CH4 + 2CH3COOH$ (methane and acetic acid production from ethanol)
3. $4H2 + CO2 \rightarrow CH4 + 2H2O$ (methane production from hydrogen and carbon dioxide)

Methanogens play a crucial role in biogas production, as they are responsible for the generation of methane, the primary component of biogas.

2.6 Factors Affecting Digester's Efficiency and Performance

Understanding and managing these factors are crucial to achieve higher efficiency and optimal performance of the anaerobic digestion process.

a. **Carbon/Nitrogen (C/N) ratio:** It describes the proportion of carbon to nitrogen in the organic substance that is being digested. Promoting microbial activity and effective methane production depend on a balanced C/N ratio. The digestion process may be negatively impacted and production of biogas may be less than ideal if the C/N ratio is too high or too low. For the anaerobic digestion process to be successful and to produce the most biogas, the C/N ratio must be maintained appropriately. The recommended C/N ratio falls within the range of 20:1 to 30:1, where carbon content should be 20 to 30 times higher than the nitrogen content. Too much carbon or too little nitrogen can slow down microbial activity and limit biogas production, while too much nitrogen can lead to the production of ammonia.

b. **Temperature**: Temperature is an important factor for determining the efficiency of anaerobic digestion process. The process can be operated under three temperature ranges; Thermophilic (40^0C – 70^0C), Mesophilic (25^0C – 40^0C), Psychrophilic (below 25^0C). Rise in temperature aids increased gas production but results in lesser methane content and increased percentage of CO2 leading to lower heating value of biogas. Hence, the optimum temperature was found to be 32^0C – 35^0C for efficient and continuous biogas production [27].

   The choice between mesophilic and thermophilic digestion depends on the natural climatic conditions of the digester's location. Methane-forming bacteria thrive best at temperatures that are not too extreme, making mesophilic methanogens more suitable for many applications.

c. **The hydrogen ion concentration, or pH value**: is a crucial parameter that significantly influences the stability of the anaerobic digester and the biogas yield. A sustained anaerobic digestion process and high biogas generation depend on maintaining the ideal pH range. The ideal pH range for effective anaerobic digestion and the production of biogas is typically between 6.5 and 7.5. The activity of the microorganisms involved in digestion might be significantly impacted by deviations from this range, which can result in decreased biogas output and possible system instability. Monitoring and controlling pH levels within the recommended range are essential for ensuring the success and sustainability of anaerobic digestion systems. Different stages of anaerobic digestion have different pH requirements, with hydrolysis and acidogenesis occurring at lower pH levels (pH 5.5-6.5) and methanogenesis at higher pH levels (pH 6.5-8.2) [28].

d. **Hydraulic Retention Time (HRT):** In the construction and maintenance of biogas digesters, HRT is a crucial factor. It shows how long liquid and soluble substances typically remain inside the digester before being expelled. HRT is computed by dividing the biodigester's volume by the input feedstock or substrate's flow rate. This parameter influences how long organic material stays in the digester, which affects how effectively anaerobic digestion occurs and how quickly biogas is produced. A well-adjusted HRT is essential for optimizing biogas yield and ensuring stable operation of the biogas system. The HRT required for complete anaerobic digestion varies based on different factors such as technology, process temperature, and waste composition. In mesophilic digesters, the recommended HRT ranges from 10 to 40 days, while in thermophilic digesters, lower retention times of a few days may be sufficient.

Hydraulic Retention Time, HRT = V/Q

Where;

V = Reactor Volume (m^3) Q = Flow rate (m^3/day)

e. **Loading Rate:** The amount of feedstock delivered to the digester with each feeding and the frequency of these feedings are referred to as the loading rate. In order to avoid overloading in biogas digesters, proper loading rate management is essential. When the digester can't effectively process the input feedstock, overloading happens. Fatty acids may build up as a result, acting as inhibitors and negatively reducing microbial activity and methane production.

f. To avoid overloading, loading rates must be carefully managed and adjusted based on the digester's capacity and the characteristics of the feedstock. Both batch and continuous flow processes can be employed to regulate the loading rate and maintain an optimal environment for biogas production. By ensuring proper loading rate management, biogas systems can achieve higher biogas yields and stable operation.

g. **Mixing:** Mixing ensures uniformity of the feedstock concentration, temperature, and environmental conditions within the digester. It reduces the chances of scum formation and solid deposition, leading to increased fermentation efficiency.

h. **Feedstock Particle Size:** The feedstock should have digestible particles, which can be achieved by grinding, crushing, or shredding the material. The rate of biogas production and the feedstock's capacity for biodegradation are both accelerated by smaller particle sizes because they increase the surface area that is available for microbial activity, particularly by methanogens.

2.7 Operational Techniques of Biodigesters

There are various operating techniques for biogas production, and two commonly used methods are batch-wise digestion and digestion in a continuous process.

Batch Process: The batch process in biogas production involves charging the biodigester tank once with substrate, along with starting microorganisms and sometimes chemicals to maintain the reactor pH. After sealing the biodigester, fermentation is permitted to continue for a certain number of days. In this procedure, the biodigesters are entirely filled and then, after a predetermined retention period, entirely emptied. As a result, after the retention days, the daily gas output steadily decreases to its minimum level [29]. Although the quality and quantity of the biogas produced might vary significantly, the batch approach makes it relatively simple to handle the substrate. Three to four digesters can be run concurrently but filled at various intervals to reduce the erratic gas generation. By doing this, it will be possible to produce gas more steadily over time. The maximum substrate material degradation is one of the benefits of the batch process, and if the retention time is long enough, all degradable material can be effectively converted to biogas.

Continuous Process: Between 1 and 8 times per day, substrate materials can be added to and removed from the continuous biogas generation process. This method maintains a constant volume in the digester by periodically pumping substrate material into it and expelling an equivalent volume of digested material. With this method, continuous substrate feeding is allowed, making the production of biogas more reliable and even than with the batch method. For digesting systems with a limited capacity, feedings often take place once or twice each day. However, larger digesters can be operated more continuously, with feeding intervals of less than one hour. Insuring a steady-state functioning by regular feeding and substrate removal results in more consistent and predictable biogas output. Due to its capacity to make effective use of the digester's capacity and ability to maintain a steady gas production rate, the continuous process is preferred for bigger biogas facilities and industrial- scale operations.

2.8 Benefits of Biodigesters

The environmental benefits of biogas production are numerous and contribute to a more sustainable and healthier society. Some of the key environmental benefits of biogas can be summarized as follows:

1. **Sustainable Energy and Fertilizer**: Biogas provides a renewable and sustainable source of energy for various applications, including heating, electricity generation, and cooking. Additionally, the digestate produced during biogas production serves as a nutrient-rich fertilizer, supporting sustainable agriculture practices.
2. **Waste Treatment and Pathogen Reduction**: Biogas production offers a sustainable method for treating organic waste, including sewage sludge, agricultural residues, and food waste. The anaerobic digestion process helps sterilize the waste, reducing the presence of harmful pathogens.
3. **Waste Recycling and Landfill Reduction**: Biogas production reduces the need for landfill space and minimizes disposal costs. Organic waste that would otherwise end up in landfills is converted into valuable energy and fertilizer through the biogas process.
4. **Greenhouse Gas Emissions Reduction**: Biogas production plays a crucial role in mitigating greenhouse gas emissions. By utilizing biogas as a clean energy source, it helps avoid the release of methane (a potent greenhouse gas) from open waste deposits and reduces reliance on fossil fuels, thus contributing to overall climate change mitigation.
5. **Supporting Agriculture and Land Space**: Biogas production offers a sustainable disposal route for organic farm wastes, reducing the pressure on land space and enhancing agricultural practices
6. **Health Benefits**: Biogas usage leads to improved indoor air quality since it eliminates the need for direct burning of traditional biomass sources like charcoal and wood. This reduction in indoor air

pollution contributes to a significant decrease in respiratory and other smoke-borne diseases, thereby improving public health.

7. **Sanitation Improvement**: The use of biodigesters for toilet connection improves sanitation in homes and communities, reducing the need for pit latrines and promoting cleaner waste management practices [30].

Overall, biogas is a green, sustainable energy resource that not only helps in waste management but also offers a range of environmental and health benefits, making it a valuable component in the transition to a decarbonized and environmentally friendly society. With approximately two million deaths annually attributed to pneumonia, lung cancer, and chronic lung diseases caused by the combustion of traditional fuels indoors, the adoption of biogas can offer a cleaner and safer energy solution. Biogas, being a cleaner and more sustainable fuel source, produces lower emissions when used for cooking, heating, and other energy needs in households. By replacing traditional fuel sources with biogas, especially in rural areas where indoor air pollution is prevalent, the number of deaths related to such pollution can be substantially reduced [31].

Biogas offers several socioeconomic benefits, positively impacting individuals, communities, and the overall economy. Some of the key socioeconomic benefits of biogas can be summarized as follows:

1. **Cost Savings on Fuel**: Biogas provides a cost-effective and renewable energy source, reducing expenditures on traditional fossil fuels and electricity. This cost-saving benefit is particularly significant for households and industries using biogas for cooking, heating, and electricity generation.
2. **Time Savings**: With biogas fulfilling their energy needs, individuals and communities save time that would otherwise be spent collecting firewood or other traditional fuels. This time can be utilized for other income-generating activities or personal development.
3. **Soil Productivity**: The use of bioslurry, a byproduct of biogas production, as an organic fertilizer enhances soil fertility and productivity. This can lead to increased agricultural yields and improved livelihoods for farmers.
4. **Reduction in Chemical Fertilizers**: By utilizing bioslurry as a natural and nutrient-rich fertilizer, the dependency on chemical fertilizers is reduced. This not only saves costs for farmers but also helps promote sustainable agricultural practices and reduces the environmental impact of chemical fertilizers.
5. **Improved Health and Reduced Expenditures**: As biogas eliminates the need for burning traditional fuels like wood and charcoal, it significantly reduces indoor air pollution, which is linked to various respiratory and health issues. This leads to reduced health expenditures and improved overall well-being in communities.
6. **Job Opportunities**: The biogas sector creates both direct and indirect job opportunities. Directly, there are job opportunities in the construction, operation, and maintenance of biogas plants. Indirectly, the increased agricultural productivity resulting from the use of bioslurry can lead to additional employment in the agricultural sector.

2.9 Elephant Grass (*Pennisetum purpureum*)

In our experiment, elephant grass was used as the main biomass for the production of biogas. Elephant grass originated from sub-Saharan tropical Africa [32]. It has been introduced as forage into most tropical and subtropical regions worldwide. It was introduced into the USA in 1913, in the 1950s into Central and South America and the West Indies, and the 1960s into Australia. It is commonly naturalized and sometimes become invasive [33]. It can withstand drought conditions and is a pioneer species in arid lands such as the Galapagos Islands [33]. Elephant grass is a useful resource for many uses, including biogas production and other agricultural and environmental benefits, thanks to its vast distribution and quick growth. Due to its distinct qualities, elephant grass makes a desirable alternative source of renewable energy. It is renowned for its high productivity and photosynthetic capacity, which implies that it effectively uses photosynthesis to turn sunlight into biomass. This makes it a very effective plant for producing biomass.

Fig. 4. Elephant grass (*Pennisetum purpureum)*

2.9.1 Morphology

Elephant grass is a robust, rhizomatous, tufted perennial grass. It has a vigorous rot system, developing from the nodes of its creeping stolons. The culms are coarse, perennial, and may be up to 4-7m in height, branched above. Elephant grass forms dense thick clumps, up to 1m across. The leaves are flat, linear, hairy at the base, up to 100-120 cm long and 1-5cm wide, with a bluish-green colour. The leaf margin is finely toothed and the leaf blade has a prominent midrib. The inflorescence is a stiff terminal bristly spike, up to 15-20cm in length, yellow-brown to purplish in colour. Spikelets are arranged around hairy axis, and fall at maturity. Spikelets are 4-6 mm long and surrounded by 2 cm long plumose bristles. There is little or no seed formation. When seeds are present they are vey small (3 million seeds/kg) [33].

Elephant grass is very similar in appearance to sugarcase (*saccharum officinarum*) but its leaves are narrower and its stems are taller [34].

2.9.2 Habitat

Pennisetum purpureum, commonly known as elephant grass, is a widespread weed that can be found in various environments. It is often observed in agricultural fields, pastures, and alongside roadsides, where it can quickly establish itself and compete with other vegetation. Additionally, it thrives in water-rich areas, making it a common sight in waterways, wetlands, floodplains, riverbanks, and swamps. Even in less hospitable conditions, such as waste grounds, elephant grass can persist and grow, especially in wet sites. Its adaptability to different habitats and rapid growth make it a resilient and prevalent species in numerous regions [35]. As a result, it is essential to manage its growth to prevent it from outcompeting native vegetation and disrupting ecosystem dynamics. Hence it has gained prominence as one of the main forage species used for biomass production.

2.9.3 Environmental requirements

Elephant grass exhibits its resilience in terms of soil adaptability by flourishing in a variety of soil types. Both sandy soils with too much drainage and poorly drained clay soils can support it. The grass can grow in situations with soil pH levels varying from 4.5 to 8.2, demonstrating its flexibility to a variety of conditions. However, rich, well-drained soils are where it performs at its best in terms of growth. It does well in places where temperature range from 25^{0}C to 40^{0}C [36] and where annual rainfall is over 1500 m. The benefits of using Pennisetum Purpureum as a feedstock for biodigesters include:

1. It grows rapidly colonizing new areas and it is easily available.
2. It can grow on diverse kinds of soil and climatic conditions.

3. MATERIALS AND METHODS

Various materials can be used for design of biodigesters and these should be materials with good tensile and compressive strength and gas tightness. The materials include clay, plastics and metals. Clay and plastic materials do not last long and would not be able to withstand very high pressures thus steel was opted for our design as it can be used for decades without any damage. The idea of using mild steel was also preferred as mild steel can withstand corrosion and attacks of hydrogen sulphide, a minute constituent of biogas. Our design incorporates the idea of a fixed dome digester system filleted at both the top and bottom edges to reduce areas of stress concentrations.

3.1 Components of the Design

1. **Inlet pipe:** This would be used for inserting the organic material into the digester. It is adequately sealed to prevent air from entering into the system.
2. **Outlet pipe:** It is fixed at the base of the digester for collection of waste at the end of digestion. It has a ball valve for opening and closure.
3. **Stirrer:** As was explained earlier, proper mixing is essential for optimal yield of

3.2 Design Considerations and Calculations

Table 2. Main parameters for evaluation and comparison of different anaerobic digestion system performances

Operational Parameter	Formula	Description	Unit
Hydraulic Retention Time (HRT)	HRT = V/Q	**HRT:** Hydraulic Retention Time **V:** Reactor volume **Q:** Flow rate	 days m^3 m^3/day
Organic Loading Rate (OLR)	OLR = Q*S/V	**OLR:** Organic Loading substrate(VS)/ Rate day **Q:** Substrate flow rate **S:** Substrate concentration In the VS/m^3 flow **V:** Reactor volume	Kg m^3 reactor & m^3/day Kg m^3
Gas Production Rate (GPR)	GPR =Qbiogas/V	**GPR:** Gas production rate **Qbiogas:** Biogas flow rate **V:** Reactor volume	m^3 biogas/m^3 reactor & day m^3/day m^3
Specific Gas Production (SGP)	SGP: Qbiogas/Q*S or GRP/OLR	SPG: Specific Gas Production vs fedmaterial Qbiogas: Biogas flow rate Q: Inlet flow rate S: Substrate concentration	m^3 biogas / kg m^3/day m^3/day kg

Source: Mata-Alvarez, [37]

biogas. The stirrer is incorporated for mixing of the contents in the digester to prevent temperature gradients in the digester and scum layer formation on the surface that could inhibit easy passage of gases in the system.

4. **Bevel gear:** This was attached in order to necessitate the movement of the stirrer.
5. **Gauges:** The gauges installed were pressure gauge and temperature gauge. The pressure gauge is to check and regulate the pressure whereas the temperature gauge is used to be able to analyze temperature variation in the system and find out the temperature of maximum biogas yield.

The estimated quantity of gas to be generated by the digester is put into consideration when debating the size of the digester. Depending on the use of the gas, it may be for domestic use, community use, electricity generation plant, and other industrial heat energy source. The size of the biodigester and the volume of the required gas should be known in other to determine the volume of biomaterial that can generate such quantity of gas.

The size of the biodigester, or its volume, is determined based on the chosen retention time and the daily input quantity of substrate. Retention time refers to the duration required for the substrate inside the digester to be sufficiently degraded, leading to the production of biogas. In this case, we are working with a retention time of twenty-one days, meaning the substrate will remain inside the digester for twenty-one days before being fully degraded into biogas.

With the addition of 2kg of cow dung as a starting culture, and mixing this with water in the ratio1:2, our flow rate, Q i.e. the daily total quantity of diluted feedstock therefore amounts to 6 L (i.e. 2 + (2 * 2)) using the approximation that 1kg is equivalent to 1lire.

As shown in Table 2, the volume of the biodigester, V= HRT * Q.

Converting 6 Litres to m^3 gives $6 * 10^{-3} = 0.006$ m^3 Therefore, $Q = 6$ L $= 0.006$ m^3

Hence, $V = 21 * 0.006 = 0.126$ m^3 = 126 L

3.3 Dimensions of Volume and Height

The radius of the digester should be large for optimal production of biogas as this would achieve a better flow rate of the gases. With this, a radius of 0.22 m was selected.

A simple basic geometric formula is used to determine the straight cylindrical height of the digester. The shape of the digester is a cylinder closed by hemispherical ends on both top and bottom ends and it has the equation:

$$V = \pi r^2 h + {}^{4}\frac{\pi r^3}{3}$$

Where

V = Volume (m^3),
h = Straight height of cylinder (m) and r = radius of the hemisphere (m)

Therefore, $0.126 = \pi*0.22^2*h + 4\pi*\underline{0.22^3}$ – 3
h = 0.54m

Other dimensions:

Internal diameter of cylinder, d = 114 cm = 1.14 m Thickness of cylinder, t = 5 mm = 0.005 m

$\frac{1}{10} * d = \frac{1}{10} * 1.14 = 0.114$ m Since $t < d/10$, the biodigester is classified as a thin shell pressure vessel and would be suitable for use since the pressures developed within the vessel are not very high.

3.3.1 Stresses in the biodigester due to an internal pressure

The following presumptions are used in assessments of stresses created in a thin cylindrical shell.

1. The cylinder wall's curvature and its impact are disregarded.
2. The tensile strains are equally distributed throughout the walls' portion.
3. The impact of the pressure vessel's heads acting as a restraint is overlooked.

The biodigester is likely to fail in one of two ways since it is under internal pressure:

1. It could rupture circumferentially (i.e. along the longitudinal section), causing the cylinder to divide into two troughs as depicted in Fig. 5.
2. It might break the cylinder into two cylindrical shells by failing longitudinally across the transverse section, as depicted in Fig. 6.

The longitudinal stress is typically half of the circumferential stress (hoop stress) in cylindrical pressure vessels like tanks or pipelines. The geometry and load distribution of cylindrical structures under internal pressure lead to this connection. The longitudinal stress runs the length of the cylinder, whereas the hoop stress acts circumferentially around the cylinder. The longitudinal stress is less than the hoop stress because the cylinder is symmetrical. The maximum stress, in this case the hoop stress, must be taken into account while designing pressure vessels.

3.4 Circumferential or Hoop Stress

The circumferential or hoop stress is the tensile stress operating in a direction tangential to the circumference of a thin cylindrical shell under internal pressure as depicted in Fig. 7.

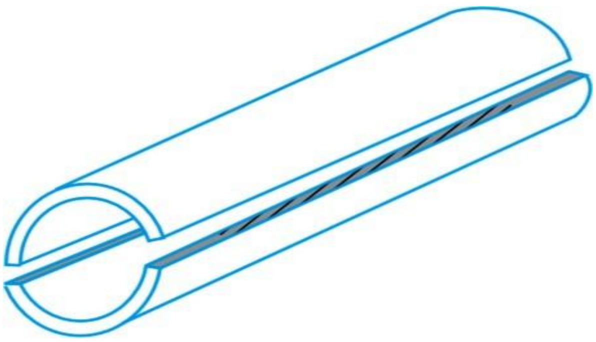


Fig. 5. Failure of cylindrical shell along the longitudinal section

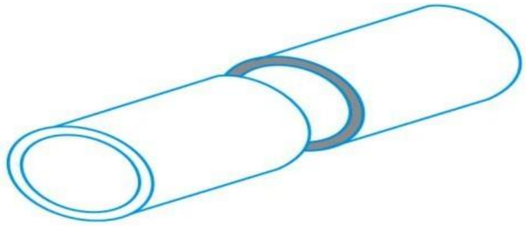
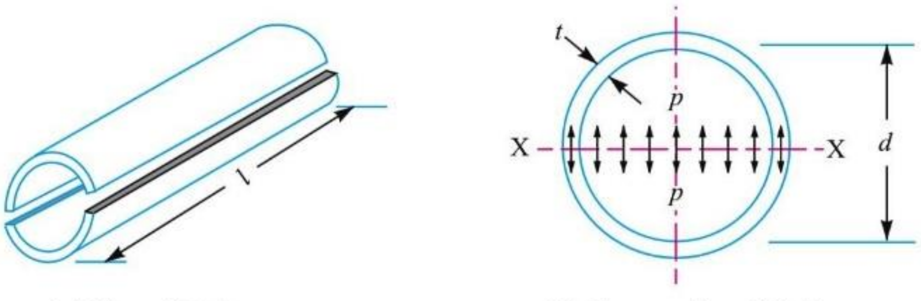


Fig. 6. Failure of cylindrical shell along the transverse section



(a) View of shell.

(b) Cross-section of shell.

Fig. 7. Circumferential or hoop stress

Let

p = Intensity of internal pressure,
d = Internal diameter of the cylindrical shell,
l = Length of the cylindrical shell,
t = Thickness of the cylindrical shell, and
σtl = Circumferential or hoop stress for the material of the cylinder shell.

$$\sigma+1 = p*d/2t$$

Therefore, the intensity of internal pressure of the biodigester is given as;

$$p = \sigma tl * 2t/d$$

For mild steel, the hoop stress, σtl is given as 0.8 * Yield point stress (247Mpa)

$\sigma tl = 0.8 * 247Mpa = 198Mpa = 198N/mm^2$ $p = 198 * (2*5)/1140 = 1.74N/mm^2$

Therefore, the maximum allowable pressure of the biodigester is $1.74N/mm^2$.

3.5 Methods

During the first loading of the digester, inoculation would be carried out. Inoculation involves introduction of a culture of methane-producing organisms (methanogens) i.e. the micro- organisms that would be needed to initiate the biological process. These microbes exist naturally in animal dung that is why diluted cow dung would be used as the starting material. The cow dung would be mixed with water with a ratio of 1:2 then poured into the digester via the inlet pipe and be left for a period of two days in the digester. Proper inoculation of the biodigester with cow dung is essential for the successful start-up and functioning of the anaerobic digestion process. Typically, a minimum of 10% of the total biodigester volume is recommended for good inoculation with cow dung [17]. However, it is important to note that using more cow dung for inoculation can have even better results.

It is essential to gradually acclimatize the bacterial population to the feedstock during the startup phase. The daily feeding load is gradually increased during this procedure to provide the microorganism population enough time to attain a stable state. To prevent overloading the digester, which could be harmful to the anaerobic process, progressive acclimatization is required. When there is a disproportionate amount of biodegradable organic matter present compared to the active population of microbes that can break it down, this is known as overloading. This can happen due to factors such as feeding too much feedstock too quickly or abrupt changes in digester conditions, such as a sudden temperature change, accumulation of toxic substances, or an increase in flow rate. The consequences of overloading are particularly problematic for methanogenic bacteria, as they are more sensitive to changes in their environment. When a biogas digester is overloaded, acidogenic bacteria, which are more resilient and can tolerate higher substrate loads, continue to work and produce organic acids. As a result, the digester becomes acidified, leading to a decrease in pH levels. The activity of methanogenic bacteria, which are in charge of creating methane gas (biogas) during anaerobic digestion, is suppressed by the digester's acidity. Methanogens are more sensitive to changes in pH and require a more stable environment to function effectively. The imbalance between acidogenic and methanogenic bacteria disrupts the normal microbial ecosystem within the digester. The reduction in methanogens' activity and the accumulation of organic acids can lead to digester failure and a decline in biogas production.

To prevent overloading and maintain the proper balance of microbial populations, it is essential to gradually acclimate the digester to increasing feedstock loads, as discussed earlier. This approach allows the microbial community to adjust and maintain a stable and efficient anaerobic digestion process, ensuring consistent biogas production over time. Proper management and monitoring of the digester's performance are also crucial in preventing overloading and maintaining its functionality [17]. By the end of this period, the bacteria would have fed on the cow dung and would need more materials to digest, and this is where the elephant grass would come in.

Feedstock pre-treatment is a crucial step in the anaerobic digestion process, especially when using materials like elephant grass. Pre-treatment prepares the feedstock for efficient digestion and enhances the degradation of volatile solids, ultimately increasing biogas yield [38]. There are several aspects to consider during feedstock pre- treatment:

1. **Sorting:** Non-biodegradable materials such as metals, plastic, and glass need to be removed from the feedstock as they can clog pipes and have no contribution to biogas production. Manual separation or magnetic separation can be used for this purpose.
2. **Removal of impurities**: Grit, sand, and other impurities should be removed from the organic material before feeding it into the digester. These impurities can precipitate in the digester and reduce the available volume for biogas production.
3. **Particle size reduction**: To prevent obstruction of the inflow pipe and to promote microbial decomposition, it is crucial to minimize the particle size of the feedstock. By breaking up the feedstock into minute particles, more surface area is created, which gives microorganisms more places to adhere and effectively break down the substance.
4. **Moisture addition**: The feedstock may require the addition of water to achieve the optimum moisture content for anaerobic digestion. Adequate moisture levels are essential for the microbial activity and overall efficiency of the process.

By carefully implementing pre-treatment procedures, the feedstock can be prepared to ensure smooth and efficient digestion, leading to higher biogas yields. Efficient pre- treatment not only improves biogas production but also helps in maintaining the long-term stability and performance of the anaerobic digester system [17,39].

After the pre-treatment process, the grass was mixed with water in a ratio of 1:2 and added to the digester on a daily basis, a process known as continuous loading. Gases would be produced on a daily basis and with the aid of the pressure gauge, the pressure within the system would be monitored. The valves would be open and would be channeled to the storage vessel which would be used for cooking or for other purposes. During the start-up phase of an anaerobic digester, the gas produced is initially dominated by carbon dioxide (CO2). This is because the microbial populations responsible for methane production (methanogens) take some time to establish and grow in sufficient numbers. As a result, the gas initially contains a higher proportion of CO2, which is not flammable.

However, as the digestion process progresses and the methanogenic bacteria become more established, the methane content of the gas starts to increase. Methanogens are sensitive to environmental conditions, and their growth is influenced by factors like temperature, pH, and the availability of suitable organic matter. As conditions become more favorable for methanogenesis, the production of methane begins to outpace the production of carbon dioxide.

After a few days to weeks, depending on the specific conditions and feedstock used, the methane content of the gas reaches a level that can sustain a flame. At this point, the biogas is of higher quality and can be considered usable for various applications, such as cooking, heating, or electricity generation.

It's important to note that the start-up phase can vary in duration, and it's essential to monitor the process closely during this period. Proper management and control of factors like feedstock composition, temperature, and pH can help promote the growth of methanogens and accelerate the development of high-quality biogas. Once the digester system reaches a stable and balanced state, it can consistently produce usable biogas over an extended period.

3.5.1 Leakage test

After construction, we carried out a pressure test to verify if there were any leakages in the welds, connections, seals, etc., and any other areas of possible gas leakage, by brushing the digester with a soap solution, in order to indicate by bubbles or foam whether there is any leakage. We then sealed all the joints and openings completely, and compressed air via the gas outlet opening. From the test, there was no leakage which showed that the digester was completely air-tight.

3.5.2 Maintenance of the biodigester

After making use of the biodigester, the slurry should be completely removed and the digester should be rinsed properly with neat water. If the digester is not used for a long period, the gears should be properly lubricated and the stirrer occasionally turned within that period.

3.5.3 Proposed design of the biodigester

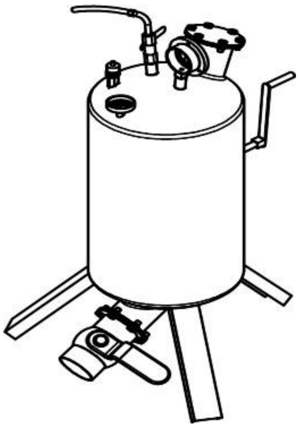


Fig. 8. Proposed design of the biodigester

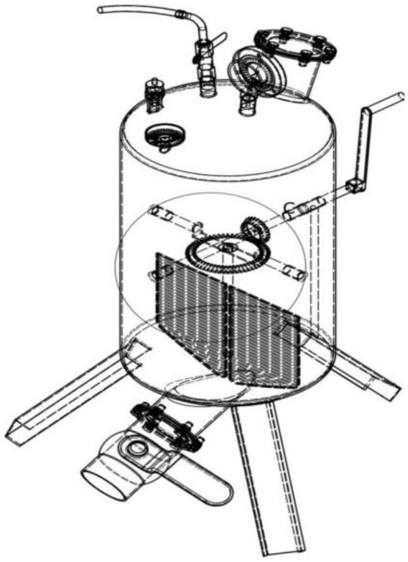
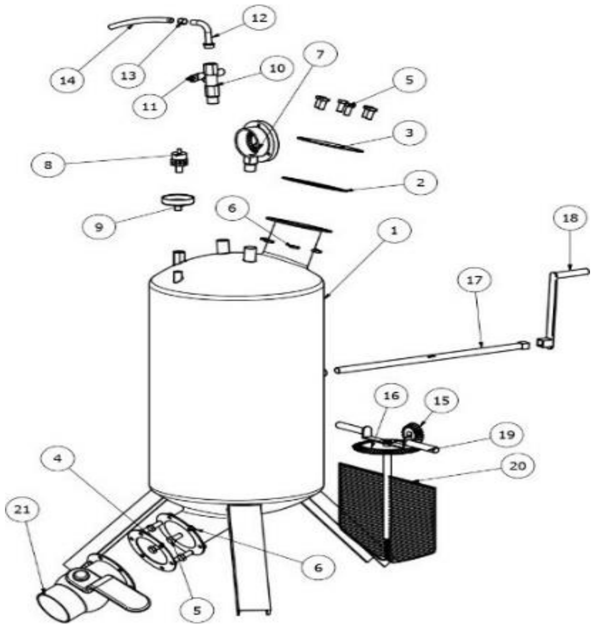


Fig. 9. Internal View of the Biodigester



PARTS LIST		
ITEM	QTY	PART NUMBER
1	1	MIXING CHAMBER
2	1	TOP SEALING RING
3	1	TOP INLET COVER
4	1	BOTTOM SEALING RING
5	12	ISO 4017 - M14 x 30
6	12	ISO 4035 - M14
7	1	PRESSURE GAUGE
8	1	PRESSURE RELEASE VALVE
9	1	TEMPERATURE GAUGE
10	1	GAS OUTLET FAUCET
11	1	GAS OUTLET FAUCET HANDLE
12	1	ELBOW JOINT FITTING
13	1	LINK NUT
14	1	TRANSPARENT HOSE TUBING
15	1	BEVEL GEAR 1
16	1	BEVEL GEAR 2
17	1	BEVEL GEAR 1 SHAFT
18	1	STIRRING HANDLE
19	1	BEVEL 2 HOLDER
20	1	BEVEL GEAR 2 DRIVE SHAFT & STIRRER
21	1	SOLID WASTE OUTLET FAUCET

Fig. 10. Exploded view and part lists of the Biodigester

4. RESULTS AND DISCUSSION

Fresh cow dung was collected from Gariki abattoir in Obinze, Imo State, Nigeria. Fresh elephant grass was also obtained from the school environment, washed with water to remove debris, manually chopped and grinded at Ihiagwa market, Imo State, Nigeria. The proportion of the mixture was as follows:

Dry weight of grass = 6 kg

Dry weight of cow dung = 6 kg Volume of water = 12 L

The grass, cow dung and water were perfectly mixed and the mixture was then introduced into the biodigester, air tightly sealed and left for a period of 21 days. Daily results of temperature and pressure were obtained from a thermometer and pressure gauge respectively that were inserted in the digester. The daily amount of biogas produced was also recorded. The experiment was carried out in FUTO Mechanical Engineering workshop.

4.1 Results

The quantity of biogas produced from the slurry (dung + elephant grass + water) over a period of 21 days at temperatures ranging from 35°C - 44°C is shown in Table 3. From the table, it was observed that biogas production started at about 4 days after loading the slurry into the digester. The biogas yield reached its maximum on the 14th day after loading and then declined gradually.

Flame Test: The biogas generation process included the combustion test. The storage unit was disconnected from the digester and connected to a Bunsen burner to conduct the test. In the beginning, no combustible gas was created. A few days later, we carried out the procedure once more, and the gas ignited. The gas burned with a clear, blue flame that was free of soot.

Table 3. Results obtained from the experiment

DAY	TEMP. (°C)	Daily Biogas Produced (L)
1	40	0
2	36	0
3	40	0
4	38	0.1
5	35	0.1
6	41	0.2
7	44	0.5
8	43	0.7
9	38	0.7
10	36	1
11	42	3
12	40	3
13	38	4
14	40	6
15	44	6
16	39	3
17	41	2
18	43	1
19	38	1
20	36	1
21	42	1

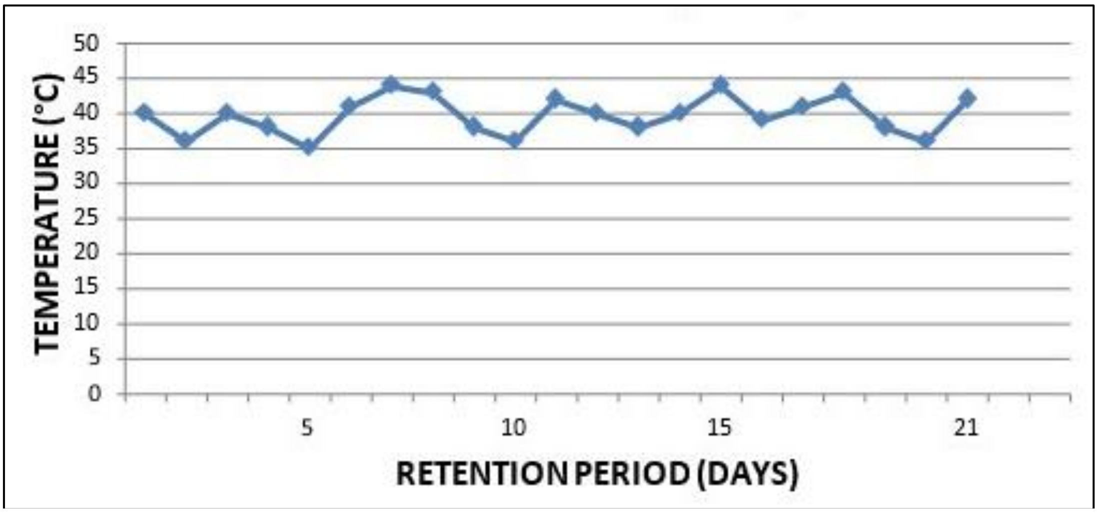


Fig. 11. A graph of temperature (^{0}C) against retention period (Days)

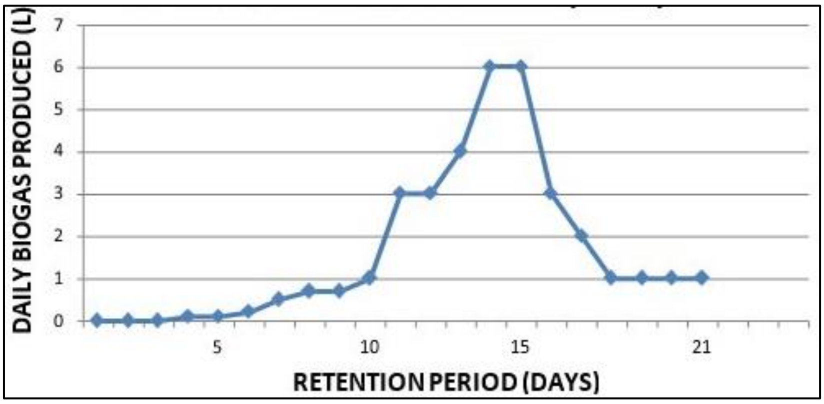


Fig. 12. A Graph of daily Biogas produced (L) against retention period (Days)

Fig. 13. Biogas burning with a blue flame

5. CONCLUSION

The average temperature of the digester was 40°C which corresponds to the temperature suitable for mesophilic bacteria. We ensured adequate temperatures by conducting the experiment under a shade that prevented direct sunlight from heating the digester. Also, the average daily biogas production was 1.6 litres (0.0016 m^3). The flame test was carried out using a Bunsen burner connected to our storage vessel and the flame burned with a bright blue flame. The use of elephant grass as shown is a good organic material and can be used to obtain biogas. Biogas technology offers a range of advantages that make it a viable and sustainable option for renewable bioenergy production. Its versatility in utilizing various feedstocks, from cheap and abundant organic waste to agricultural byproducts, allows for widespread adoption and implementation worldwide. The ability to produce biogas on different scales, from small-scale community digesters to large-scale industrial units, makes it adaptable to various contexts and needs.

The economic benefits of biogas technology are substantial. It provides a source of renewable energy that can be harnessed for heating, power generation, and as a clean fuel for various applications. By utilizing agricultural waste and other organic materials that would otherwise be discarded, biogas production helps in waste management and reduces disposal costs. Moreover, the generation of extra income streams from selling excess biogas or the byproduct slurry as organic fertilizer can boost the economic prospects of farmers and rural communities.

In terms of the environment, biogas technology is crucial for lowering greenhouse gas emissions and preventing climate change. Biogas plants reduce the emission of methane, a powerful greenhouse gas, into the environment by absorbing and using it from organic waste.

Additionally, the substitution of biogas for fossil fuels in various applications helps reduce reliance on finite and polluting energy sources, contributing to a more sustainable energy mix.

Furthermore, biogas technology brings health benefits by reducing the harmful effects of traditional biomass burning for cooking and heating. Indoor air pollution from burning wood, charcoal, or other solid fuels is a major health concern, leading to respiratory illnesses and premature deaths. Biogas offers a cleaner and safer alternative, reducing the health risks associated with indoor air pollution.

In rural areas, the implementation of biogas plants can create job opportunities, both in the construction and maintenance of the digesters and in the supply chain of feedstock and by products. This can help alleviate unemployment and promote sustainable rural development.

Overall, the adoption and expansion of biogas technology hold immense promise in contributing to a greener, more sustainable energy future. It can have a positive impact on various sectors, from agriculture and waste management to energy production and rural development, making it a valuable component of the transition to a low-carbon economy and a more environmentally friendly society.

6. RECOMMENDATION

The cost of production of biogas is quite cheap since most of the raw materials used are waste products that are normally discarded. If the idea of biogas production is properly looked into and improved, it could be a good alternative to the conventional fuels used in Nigeria. Biogas can also be converted to electricity and can be used to improve our Nation's energy grid therefore; the Nation should start investing in biogas as a source of renewable energy.

With respect to this project work, other areas can be looked into, which include:

1. Better methods should be adopted in the design stage for proper lubrication of the meshing gears in the biodigester.
2. Other experiments can be carried out with various organic materials and their corresponding results should be compared to this to obtain (if any) a more efficient system for biogas production.
3. The percentage composition of the constituent elements of the gas can be obtained and methods of cleaning the gas from impurities should be employed.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Moses Jeremiah Barasah Kabeyi, Oludolapo Akanni Olanrewaju. Biogas Production and Applications in the Sustainable Energy Transition. Hindawi Journal of Energy. 2022;22:Article ID 8750221, DOI: https://doi.org/10.1155/2022/8750221, 2022.
2. Azam A, Rafiq M, Shafique M, Yuan J. Renewable electricity generation and economic growth nexus in developing countries: An ARDL approach. Economic Research Ekonomska Istraživanja. 2021;34(1):2423–2446.
3. Elsaeidy EA. Technology Fundamentals of Briquetting Cotton Stalks as Biofuel an unpublished Ph.D. Thesis, Faculty Agriculture and Horticulture, Humboldt University, Germany; 2004.
4. Kaliyan N, Morey RV. Factors Affecting Strength and durability of densified Biomass products. Biomass and Bioenergy. 2009;33:337-359.
5. Stevens DJ. Hot gas conditioning: recent progress with larger-scale biomass gasification systems, National Renewable Energy Lab. (NREL), USA; 2001. Available:https://www.osti.gov/ biblio/786288-hot-gas- conditioning-recent-progress-largerscale-biomass-gasification-systems- update-summary recent-progress.
6. Pasternak G. Chapter 9- Electrochemical approach for biogas upgrading, in Emerging Technologies and Biological Systems for Biogas Upgrading, N. Aryal, L.

D. M. Ottosen, M. V. W. Kofoed, D. Pant, Eds, Academic Press. 2021: 223–254.

7. Sarkar S, Skalicky M, Hossain A, et al. Management of crop residues for improving input use efficiency and agricultural sustainability. Sustainability. 2020;12(23):9808– 9824.
8. Kabeyi MJB, Olanrewaju OA. The Potential of grid power generation from municipal solid waste for Nairobi city 2nd African International Conference on Industrial Engineering and operations management, Harare, Zimbabwe; 2020. Available:http://ieomsociety.org/harare2020/papers/81.pdf
9. International Energy Agency, Outlook for biogas and biomethane: prospects for organic growth, International Energy Agency, Paris; 2020. Available:https://www.iea.org/reports/outlookfor-biogas-and-biomethane- prospects-for-organic-growth/an-introduction-to-biogas-and- biomethane
10. Akinbami JFK, Ilori MO, Oyebisi TO, Akinwuni IO, Adeoti O. Biogas Energy use in Nigeria: current status, future prospects and policy implications. Renew. Sustain. Energy. Rev. 2001;5:97-112.
11. Abanades S. A critical review of biogas production and usage with legislations framework across the globe. International Journal of Environmental Science and Technology. 2022;19(4):3377–3400.
12. Hahn H. Economic and ecological evaluation of biogas plant configurations for a demand oriented biogas supply for flexible power generation; 2015.
13. Jain S. Global potential of biogas, World Biogas Association, London, United Kingdom; 2019.
14. Corey B, Kyle G, Sherman P. Turning waste into heat: Designing an anaerobic digester to extend the growing season for small scale urban farmers. B.Sc Thesis, Worcester Polytechnic Institute, USA. 2014;5.
15. Yerima M, Rahman A, Ekwenchi N. Effect of Buffering on Biogas Fermentation of Chicken Droppings. Nigeria Journal of Renewable Energy. 2001;9(1&2):47-49.
16. Deublein D, Steinhauser A. Biogas from waste and renewable resources: An introduction. Carlifornia, USA: Wiley; 2011.
17. Yvonne V, Christian R, Amalia G, Stefa D, Christian Z. Anaerobic digestion of biowaste in developing countries: Practical Information and case studies. Swiss Federal Institute of aquatic science and technology (Eawag), Dubendorf. Switzerland. 2014;12,22-28,33-36,65.
18. Istok J. Push-pull tests for site characterization. In: Lecture notes in earth system sciences. Springer, Berlin. 2013;444.
19. NNFCC. Anaerobic Digestion. NNFCC Renewable Fuels and Energy Factsheet. National Non-Food Crops Centre; 2011.
20. Kigozi R, Aboyade A, Muzenda E. Biogas Production Using the Organic Fraction of Municipal Solid Waste as Feedstock. International Journal of Research in Chemical, Metallurgical and Civil Engineering (IJRCMCE). 2014;1:107-114.
21. Kabeyi MJB, Olanrewaju OA. Geothermal wellhead technology power plants in grid electricity generation: A review, Energy Strategy Reviews. 2022;39:article 100735.
22. Achinas S, Achinas V, Euverink GJW. A technological overview of biogas production from bio waste, Engineering. 2017;3(3):299–307.
23. Murphy J, Polaficio M. Anaerobic Digestion: Decision Support Software. Department of Civil, Structural and Environmental Engineering. Ireland; 2007.
24. Kour D, Rana KL, Yadav N, et al. Technologies for biofuel production: Current development, challenges, future prospects, Springer, Cham; 2019.
25. Mohammad M, Mohamad Ishak WW, Mustapa SI, Ayodele BV. Natural gas as a key alternative energy source in sustainable renewable energy transition: A mini review. Frontiers in Energy Research. 2021;9.
26. Bond T, Templeton MR. History and future of domestic Biogas plants in the developing world Energy for sustainable Development. 2011;15(4):347–354.
27. Al Mamun MR, Torii S. Enhancement of Production and Upgrading of Biogas using Different Techniques-A Review. International Journal of Earth Sciences and Engineering. 2015;8(2):877-892.
28. Khalid A, Arshad M, Anjum M, Mahmood,T, Dawson L. The anaerobic digestion of solid organic waste - Review. Waste Management. 2011;31(8):1737–1744.
29. Nicaguna BT. Biogas technology. New age International (P) Ltd, Publishers, Daryayanj, New Delhi, India. 2002;243-24.

30. Abokyi E, Konadu PA, Sikayena I, Abayie EFO. Consumption of Electricity and Industrial Growth in the Case of Ghana. Journal of Energy. 2018;2018:Article ID 8924835:1–11.
31. Mengistu MG, Simane B, Eshete G, Workneh TS. A review on biogas technology and its contributions to sustainable rural livelihood in Ethiopia, Renewable and Sustainable Energy Reviews. 2015;48:306–316.
32. Clayton WD, Govaerts R, Harman T, Williamson H, Vorontsova M. World checklist of Poaceae. Richmond, UK: Royal Botanic Gardents, Kew; 2013.
33. CABI. Invasive species compendium Wallingford, UK: CAB International; 2014.
34. Daff. Elephant grass dept: Agric, fish, forest, queenland Gov. Australia. 2014; 67.
35. Langeland K, Cherry H, McCormick C, Craddock B. Identification and Biology of Non-native Plants in Florida's Natural Areas. Gainesville, Florida, USA: University of Florida IFAS Extension; 2008.
36. FAO. Grassland index a search catalogue of grass and forage legume. Italy: FAO. 2015;22-28.
37. Mata-Alvarez J. Biomethanization of the organic fraction of municipal solid wastes. London: IWA publishing; 2003.
38. Tiehm, et al. Ultrasonic waste activated sludge disintegration for improving anaerobic stabilization. Water Research. 2001;35:2003–2009.
39. Schnürer A, Jarvis A. Microbiological Handbook for Biogas Plants. Swedish Waste Management U2009:03 Swedish Gas Centre Report. 2010;207.

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