DESIGN AND PRODUCTION OF A CONTINUOUS HOUSEHOLD BIOGAS DIGESTER

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CERTIFICATION

This certificate acknowledges that this project presented to the Department of Mechanical Engineering was conducted by Ikade Samuel, Emiko Laju, Uwuigbe Christian, Obi Emmanuel, Ubah Divine Nmesoma, Onokebhagbe Precious, Iluobe Anselm, Oseghale Genesis, Atsegamhe Oshoke and Adewole James all affiliated with the Department of Mechanical Engineering, University of Benin, Benin City, Edo State, Nigeria, under the guidance and supervision of Professor Dennis Iyeke Igbinomwanhia.

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DEDICATION

We dedicate this project to God, the source of wisdom, knowledge, and understanding, for His enabling support and assistance that allowed us to complete this program successfully. We extend our deepest appreciation to our parents and families for their endless love and support, acknowledging that we have reached this milestone because of their encouragement.

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ABSTRACT

The traditional batch process for biogas production has been dominant, but it often leads to inefficiencies and inconsistent gas output. This project aims to address these issues by designing and producing a continuous household biogas digester, which promises a more stable and reliable method for generating renewable energy from organic waste.

The development of the digester was guided by the design tree process, starting with feasibility studies and progressing through design specifications, conceptual designs, and detailed design phases. The fabrication involved constructing key components such as the inlet system, a 150-liter steel digester tank, and the outlet system. Although most planned components were successfully incorporated, some were excluded due to unforeseen challenges.

The digester demonstrated the potential for continuous biogas production, though improvements are needed. The project concluded with recommendations for enhancing system efficiency and exploring alternative materials to reduce production costs, suggesting that with further refinement, this design could become a viable household solution for renewable energy production.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND STUDY

In today's era, with environmental sustainability and renewable energy taking center stage in global concerns, the quest for alternative energy sources becomes increasingly urgent. Biodegradable waste are commonly found in municipal solid waste as green waste, food waste, paper waste, and biodegradable plastic which often goes unutilized and ends up being discarded. Within households, food waste is a common occurrence, whether in its cooked form or left raw and spoiled.

In many regions, such as Nigeria, the disposal of biodegradable waste primarily involves sending it to landfills, where it undergoes decomposition and releases greenhouse gases into the atmosphere, exacerbating the climate change crisis. As these waste materials degrade in the oxygen-deprived conditions of landfills, they produce biogas, contributing to emissions that harm the ozone layer.

However, there exists a transformative opportunity within this waste stream. Biodegradable waste, including household food waste, holds the potential to be converted into biogas through a process known as anaerobic digestion. This biogas can then be utilized for various household applications, such as cooking and power generation. By harnessing biogas from biodegradable waste, households can reduce their reliance on fossil fuels, thereby alleviating financial burdens associated with energy procurement.

This report embarks on an exploration of the captivating realm of biogas production from biodegradable waste, aiming to illuminate its potential as a sustainable and renewable energy source. Biogas emerges as a versatile solution that not only addresses waste management challenges but also meets the growing demand for environmentally friendly energy alternatives

1.2 PROBLEM STATEMENT

The amount of biodegradable waste produced poses a serious environmental and financial problem, increasing landfill waste and greenhouse gas emissions. Anaerobic digesters play a crucial role in managing organic waste and generating renewable energy, but they encounter various operational and design hurdles that necessitate careful exploration.

This project seeks to explore the practicality and efficiency of producing biogas from readily available household waste. By employing anaerobic digestion, a biological process where microorganisms break down organic matter in the absence of oxygen, we aim to convert biodegradable waste into a valuable source of clean energy. We intend to identify and tackle key challenges related to the performance, optimization, and practicality of anaerobic digesters, and design a continuous biogas digester aiming to improve efficiency, scalability, and overall environmental impact. Through this initiative, we aspire to not only contribute to waste reduction but also harness a locally available, renewable resource that can serve as a cleaner alternative to traditional energy sources.

1.3 AIM AND OBJECTIVES

1.3.1 Aim

To design and construct a continuous biogas production system with feedstock from biodegradable waste suitable for household use.

1.3.2 Objectives

1. To carry-out literature review on biogas production system
2. To prepare design specifications for the system
3. To develop conceptual designs of a biogas production system with feedstock from biodegradable waste, suitable for household use.
4. To select the best conceptual design
5. To carry-out detailed design

6. To prepare manufacturing specifications for the system
7. To construct the biogas plant
8. To test the biogas plant for performance

1.4 SIGNIFICANCE OF STUDY

The significance of the project lies in its potential to address pressing environmental and energy challenges through a sustainable and innovative approach. Here are several key aspects of the project's significance:

1. Waste Reduction and Management:

The project addresses the issue of escalating household waste by providing a practical solution for its management. By converting organic waste into biogas, the project contributes to waste reduction and minimizes the environmental impact associated with traditional waste disposal methods.

2. Renewable Energy Source:

Biogas is a renewable energy source that can be used for cooking, heating, and even electricity generation. Harnessing energy from household waste reduces dependency on finite fossil fuels and contributes to a more sustainable energy mix, aligning with global efforts to transition towards cleaner energy sources.

3. Mitigation of Greenhouse Gas Emissions:

Anaerobic digestion of organic waste in the production of biogas helps mitigate the release of methane, a potent greenhouse gas, into the atmosphere. Methane is a byproduct of decomposing organic matter in landfills, and by capturing it for energy production, the project helps combat climate change.

4. Community Empowerment and Engagement:

Implementing biogas production at the household level fosters community involvement and empowerment. Communities can actively participate in waste segregation, collection, and the production of their own energy, leading to a sense of ownership and environmental responsibility.

5. Economic Feasibility:

The economic feasibility of the project is significant, as it explores the potential for sustainable energy production at a local level. By converting waste into a valuable resource, the project may have economic benefits, including potential cost savings on waste management and reduced reliance on conventional energy sources.

6. Promotion of Circular Economy:

The project aligns with the principles of a circular economy, where resources are used efficiently, waste is minimized, and products are designed for longevity and recyclability. Biogas production from household waste exemplifies a circular approach by closing the loop on organic material utilization.

7. Educational and Awareness Impact:

The project has the potential to raise awareness about sustainable living practices, waste management, and the benefits of renewable energy sources within the community. Educational initiatives accompanying the project can foster a culture of environmental consciousness.

8. Potential for Scaling and Replication:

The project could serve as a model for similar initiatives in other communities. The scalability and replicability of the approach can have a cascading effect, contributing to broader regional and even global efforts to address waste management and energy challenges.

In essence, the significance of the project lies in its holistic approach to environmental, social, and economic challenges, offering a tangible and scalable solution that promotes sustainability and resilience.

1.5 SCOPE OF WORK

The scope of this work involves the research, design, and production of biogas from biodegradable waste from households.

1.6 METHODOLOGY

The methods adopted for achieving the aim and objectives of this work are as follows:

1. Literature review of the research.
2. Feasibility studies
3. Conceptual design and preliminary testing.
4. Detailed design of the prototype
5. Fabrication of the prototype
6. Testing and review of the performance of the prototype
7. Conclusion and recommendation

CHAPTER TWO

LITERATURE REVIEW

In order to achieve our aim, we ought to understand certain important concepts in biogas production and also examine the current state of biogas technology in the world. This would help provide useful insight into the improvement of biogas production technology to ensure sustainable energy in the future.

2.1 REVIEW OF PAST LITERATURE

Explorations performed by Fabien Kenmogne et al “Review, Design, and Artisanal Fabrication of Anaerobic Bio-digester for Biodegradable Waste” (2023): This research work by Fabien Kenmogne and colleagues focuses on the design and fabrication of a bio-digester using HDPE (high-density polyethylene) geomembrane material. The designed bio-digester is effective in recycling biodegradable waste and produces biogas and organic liquid fertilizer.

Going beyond mere theoretical comprehension, research demonstrates the real-world implementation of anaerobic digestion. Works like Neshat S. A. et al.'s “Anaerobic co-digestion of animal manures and lignocellulosic residues as a potent approach for sustainable biogas production” illustrate the potential of combining different feedstocks, unlocking new possibilities for waste valorisation and biogas production. This practical shift underscores the adaptability and versatility of anaerobic digesters, proving their efficacy in diverse contexts.

Similarly, “Design Considerations and Operational Performance of Anaerobic Digesters” (2016): This research paper by Muzafar Ahmad Mir, Athar Hussain, and Chanchal Verma discusses the importance of anaerobic digestion in managing solid waste and producing renewable energy. The paper emphasizes the production of biogas from organic waste due to the decline in fossil fuel reservoirs. The authors also highlight the lack of literature regarding the design considerations of anaerobic digesters.

Works like M. Esmat et al. “A Review of Anaerobic Digestion Bio-kinetics” (2018): This article reviews the experimental kinetic studies of conventional anaerobic bioreactors and anaerobic membrane bioreactors. It emphasizes the importance of kinetics in the design of bioreactors, processes, and process scale-up in anaerobic digestion

2.2 HISTORICAL BACKGROUND OF ANAEROBIC DIGESTION

Anaerobic digestion, a biological process where microorganisms break down organic matter without oxygen, has deep historical roots within human civilization. Early societies, lacking scientific knowledge, noticed organic material decay in environments devoid of oxygen, likely during agricultural activities and waste disposal, such as those of the Mesopotamians and Egyptians.

Scientific exploration into anaerobic processes commenced in the 18th century with scholars like Joseph Priestley and Antoine Lavoisier, who made initial observations on fermentation. However, the significant advancement in understanding anaerobic digestion occurred in the 19th century through scientists such as Joseph Gay-Lussac and Louis Pasteur, who laid the groundwork for modern microbiology and biochemistry. Pasteur's work on fermentation in the absence of oxygen was particularly groundbreaking.

In the late 19th and early 20th centuries, interest in anaerobic digestion grew with the discovery of anaerobic microorganisms by Martinus Beijerinck and others. The practical use of anaerobic digestion began in the early 20th century, notably with the construction of the first documented anaerobic digester in Bombay, India, in 1859 by Sir James Murray. However, widespread adoption and development of anaerobic digestion technology occurred in the mid-20th century.

During the mid-20th century, especially in Europe, research focused on optimizing anaerobic digestion for wastewater treatment and agricultural waste management. The oil crises of the 1970s reignited interest in anaerobic digestion for producing renewable energy, with countries like Germany leading in large-scale biogas production from agricultural residues.

In the late 20th and early 21st centuries, anaerobic digestion technology continued to advance due to concerns about environmental sustainability, energy security, and climate change.

Research intensified to improve digester designs, enhance process efficiency, and expand suitable feedstock. Today, anaerobic digestion is a recognized versatile and sustainable technology applied in wastewater treatment, organic waste management, agricultural biogas production, and renewable energy generation.

Over its history, anaerobic digestion has transitioned from ancient observations to modern engineering achievements, showcasing its ongoing importance in addressing contemporary environmental and energy challenges.

2.3 ANAEROBIC DIGESTION

Anaerobic digestion is a biological process that involves the breakdown of organic matter by certain microorganisms in the absence of oxygen. It stands as an essential headway in the search for renewable energy production but also doubles as a sustainable waste management solution. This mechanism holds the potential to reform our approach to organic waste, simultaneously addressing environmental concerns and contributing to the growing demand for clean energy sources.

Basically, anaerobic digestion entails the activity of various microorganisms that prosper in an oxygen-deprived environment. These microbes collectively break down complex organic compounds—ranging from agricultural residues and sewage sludge to food waste—into simpler substances, yielding a flammable byproduct: biogas. Biogas predominantly comprises of methane (CH4) and carbon dioxide (CO_2), this renewable energy source holds immense promise as an eco-friendly alternative to conventional fossil fuels.

In essence, anaerobic digestion follows the biological processes illustrated below

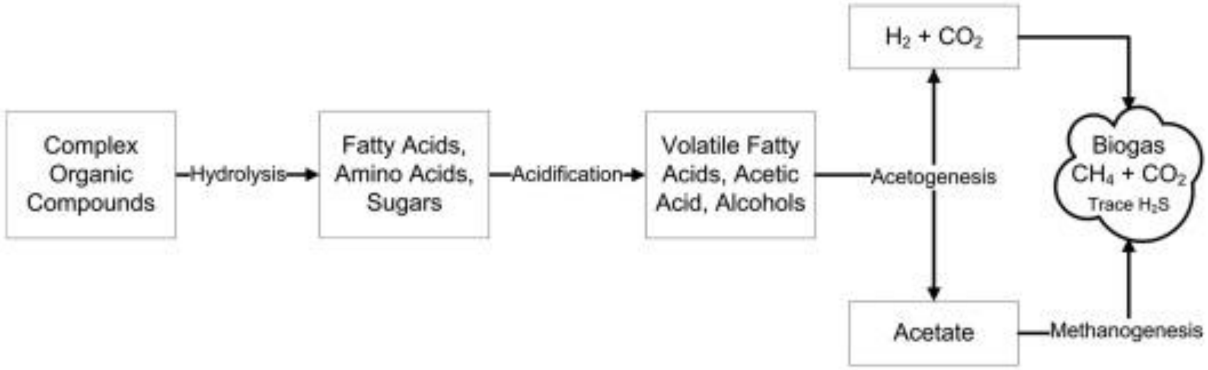


Fig. 2.1 (Anaerobic digestion biological process chart)

2.3.1 Hydrolysis

The word hydrolysis is a combination of two separate words “Hydro” which means water and “Lysis” which means to unbind or to split, so hydrolysis at the very basic level is the breaking down of large organic compound through the action of water (H_2O).

The input feedstock is usually made up of large organic polymers, for the micro-organismspresent in the digester to be able to act on this large carbon chain molecule they have to bebroken down into smaller units or monomers such as simple sugars, fatty acids, and aminoacids which are then available for further breakdown by other bacterial. Bacteria employ extracellular enzymes to dismantle long-chain molecules, yielding fatty acids, amino acids, and glucose.

2.3.2 Acidogenesis

The ensuing step involves acidification by acid-forming bacteria, transforming the produced fatty acids, amino acids, and glucose into volatile fatty acids (VFA).

2.3.3 Acetogenesis

Acetogenesis follows, wherein VFA undergoes a conversion process to generate acetate, hydrogen, and carbon dioxide. During this stage, metabolites from acidogenesis that methanogenic bacteria cannot directly convert to methane are further digested into methanogenic substrates. Alcohols and volatile fatty acids are oxidized to produce acetate, hydrogen, and carbon dioxide, which are methanogenic substrates. The hydrogen produced at this stage is often considered a waste product, and it slows down these bacteria's metabolism.

2.3.4 Methanogenesis

Methanogenesis takes place, converting acetate into methane through a biological process.

The products obtained from the Acetogenesis stage are further acted upon by methanogens (bacteria that create CH_4) to produce mainly carbon dioxide, water, and biomethane in this last stage of the digestion process. Methanogenesis takes place between pH 6.5 to pH 8, and it is sensitive to both high and low pH. Methanogens can be divided into two classes: those that primarily convert acetic acid to CH_4 and those that combine hydrogen and carbon dioxide to produce CH_4. A few exceptional methanogens can do both.

The engineered or controlled environment where anaerobic digestion occurs is called the anaerobic digester.

2.4 BIOGAS

Biogas is a source of renewable energy (Le Mer 2001), it is a mixture of gas produced from anaerobic fermentation of biodegradable materials. Agricultural waste, manure, municipal waste, plant material, sewage, green waste, wastewater, and food waste are some of the raw materials used to produce biogas. Biogas can be produced primarily in two ways, naturally and industrially. It is found naturally in wetland soils, oceans, forest soils, termites, and ruminant animals (Le Mer 2001) and industrially in a biogas digester. The composition of biogas varies according to the nature of the feedstock fed to it and the nature of the conditions of the digester (Temperature, pH, and substrate conditions) (Hafner et al. 2017). It is primarily made up of methane (CH_4), carbon dioxide (CO_2), a small quantity of hydrogen sulphide (H_2S), moisture, and other contaminants (siloxanes, ammonia, and sulphuric compounds). Biogas can find application in various areas of human life such as the by-products of the digestion process can be used by farmers to serve as manure for fertilization of crops, biogas can be used for generating electricity and also for cooking in our contemporary homes.

2.5 BIOGAS DIGESTER

Various types of biogas digesters have been developed to suit different scales and contexts. The fixed-dome, floating-drum, and plug-flow digesters are among the most common. Notable studies by Moller et al. (2018) and Zhang et al. (2016) provide insights into the comparative performance, advantages, and limitations of these designs, offering valuable guidance for selecting the most appropriate technology for household applications.

Biogas digesters come in various designs, each tailored to specific conditions, feedstock availability, and desired outputs. Understanding the nuances of different types of digesters is crucial for selecting an appropriate system for household applications.

2.5.1 Fixed-Dome Biogas Digesters

Fixed-dome digesters, pioneered by Deenbandhu model and the Chinese Dome model, are characterized by a rigid, dome-shaped structure that houses the anaerobic digestion chamber. These digesters typically use a mix of animal manure and kitchen waste as feedstock. The gas storage is integral to the digester, ensuring constant pressure. Research by Parawira (2012) emphasizes the simplicity of construction, affordability, and their suitability for small-scale applications. However, challenges related to gas storage fluctuations and difficulty in temperature control have been identified, requiring careful design considerations.

2.5.2 Floating-Drum Biogas Digesters

Floating-drum digesters, such as the popular Indian design, consist of a cylindrical tank with a movable gas-collecting drum. As organic material undergoes anaerobic digestion, the gas displaces the water in the drum, causing it to rise and collect the produced biogas. This design offers advantages such as ease of gas storage regulation and adaptability to varying feedstock compositions. Studies by Odeh et al. (2014) and Tuan et al. (2018) explore the performance, efficiency, and challenges associated with floating-drum digesters, highlighting their widespread adoption in rural settings.

2.5.3 Plug-Flow Biogas Digesters

Plug-flow digesters, also known as tubular digesters, have a long, narrow design where organic material progresses through the system in a continuous flow. This design facilitates a more controlled digestion process and is particularly suitable for large-scale operations. Authors like Gao et al. (2015) and Guevara et al. (2020) discuss the advantages of plug-flow digesters in terms of efficient gas production, reduced retention time, and better handling of high solid-content feedstock. However, complexity in construction and operation may limit their applicability in certain household settings.

2.5.4 Horizontal-Flow Biogas Digesters

Horizontal-flow digesters, often used in agricultural and industrial settings, have a horizontal orientation where organic material flows through the system horizontally. This design allows for better mixing and retention time control, leading to efficient biogas production. Research by Zhang et al. (2019) and Li et al. (2017) explores the performance and optimization of horizontal-flow digesters, emphasizing their suitability for large-scale applications where more continuous feedstock is available.

2.5.5 Balloon-Type Biogas Digesters

Balloon-type digesters, also known as bag digesters, consist of flexible, gas-tight containers that expand as biogas is produced. These digesters are portable and suitable for locations with limited space or where mobility is required. Studies by Böjti et al. (2019) and Tumwesige et al. (2018) discuss the advantages of balloon-type digesters in terms of simplicity, affordability, and adaptability to varying feedstock types. However, challenges related to durability and gas storage fluctuations require careful consideration.

2.5.6 Hybrid Biogas Digesters

Hybrid digesters combine features of different designs to optimize performance and address specific challenges. For instance, a combination of fixed-dome and floating-drum elements may offer enhanced gas storage and temperature control. Research by Dong et al. (2021) and Kapoor et al. (2016) explores the potential advantages of hybrid designs, showcasing the versatility and adaptability of such systems to diverse household and community needs.

Understanding the strengths and limitations of each type of biogas digester is essential for selecting the most suitable system based on factors such as available resources, local conditions, and the specific requirements of household applications. Ongoing research and innovations in biogas digester designs aim to address challenges and enhance the efficiency and sustainability of these systems for widespread adoption in households worldwide.

2.6 MATERIALS AND CONSTRUCTION TECHNIQUES

The successful design and construction of household biogas digesters require careful consideration of materials and techniques to ensure durability, efficiency, and cost-effectiveness. Innovations in materials and construction techniques have played a pivotal role in enhancing the performance and accessibility of biogas digesters for households.

2.6.1 Construction Materials

1. Ferrocement:

Ferrocement, a composite material consisting of cement mortar reinforced with a mesh of metal, offers durability and strength. Studies by Gildas et al. (2015) and Xue et al. (2018) explore the application of ferrocement in biogas digester construction, highlighting its resistance to corrosion, adaptability to various shapes, and potential for reducing construction costs.

2. Polyethylene:

Polyethylene, a type of plastic, has gained attention for its versatility in constructing flexible and portable biogas digesters. Research by Derese et al. (2017) and Tippayawong and Phattharaphan (2018) demonstrates the feasibility of polyethylene materials, emphasizing their lightweight nature, ease of transportation, and affordability, particularly in regions with limited access to traditional construction materials.

3. Reinforced Concrete:

Reinforced concrete remains a conventional choice for biogas digester construction due to its strength and longevity. Studies by Song et al. (2016) and Wang et al. (2019) delve into the optimization of reinforced concrete structures, addressing factors such as thickness, reinforcement ratios, and formwork techniques to enhance structural integrity and gas-tightness.

4. Brick Masonry:

Brick masonry is employed in some traditional fixed-dome biogas digester designs. Research by Nasir et al. (2014) and Hasan et al. (2017) discusses the application of brick masonry, emphasizing the importance of mortar quality, proper curing, and skilled craftsmanship to achieve gas-tight and durable constructions.

2.6.2 Construction Techniques

1. Prefabrication:

Prefabrication involves the assembly of biogas digester components off-site before transportation to the installation location. Studies by Li et al. (2020) and Zhang et al. (2021) explore the advantages of prefabrication, such as reduced on-site construction time, improved quality control, and the ability to address specific design requirements before installation.

2. Modular Designs:

Modular biogas digester designs involve the use of standardized, interchangeable components that can be assembled and disassembled easily. Research by Li and Li (2019) and Zhou et al. (2018) investigates the benefits of modular construction, including scalability, adaptability to different feedstock volumes, and simplified maintenance and repairs.

3. Smart Construction Technologies:

Advancements in construction technologies, including Building Information Modeling (BIM) and computer-aided design, have facilitated more accurate planning and execution of biogas digester construction. Studies by Chen et al. (2019) and Wang et al. (2021) showcase the integration of smart construction technologies for precise design, material optimization, and efficient project management.

4. Biodegradable Formwork:

Innovative formwork materials that are biodegradable or reusable contribute to sustainable construction practices. Research by Karim et al. (2016) and Ruan et al. (2019) explores the use of biodegradable formwork made from materials like bamboo or recycled paper, reducing environmental impact and simplifying the removal process after concrete curing.

5. 3D Printing:

Emerging technologies, such as 3D printing, are being explored for constructing biogas digesters with intricate designs. Studies by Zhang et al. (2020) and Singh et al. (2021) investigate the feasibility of 3D printing using concrete or biopolymer materials, offering potential for rapid, customized construction and reduced material waste.

6. Quality Control Measures:

Effective construction of biogas digesters involves stringent quality control measures. Research by Shuang et al. (2017) and Kusmiyati et al. (2019) emphasizes the importance of quality control in terms of material testing, construction inspection, and adherence to design specifications to ensure the longevity and safety of the digester.

In conclusion, the choice of materials and construction techniques significantly influences the performance, durability, and accessibility of household biogas digesters. The ongoing exploration of innovative materials and construction methodologies not only improves the efficiency of biogas production but also contributes to the sustainability and affordability of these systems, making them more viable for widespread adoption in diverse household settings.

2.7 FACTORS INFLUENCING BIOGAS PRODUCTION

While the production of biogas may appear to be a straightforward process, it is, in fact, a complex undertaking. Numerous factors come into play, influencing both the quantity and quality of the biogas produced. The primary objective of research on biogas technology is to improve biogas yield and quality, thereby maximizing its energy potential and environmental benefits. To achieve this goal, various methods can be employed, all while taking into account the diverse factors that impact biogas production. Some of these critical factors and methods are outlined below:

2.7.1 Feedstock

When it comes to making biogas, the starting point is crucial, and that's where choosing the right feedstock becomes really important in anaerobic digestion systems. To produce biogas, we use various biodegradable materials like solids, slurries, and liquids in different forms – either diluted or concentrated. While pretty much any organic material can be used in anaerobic digestion, we're aiming for biogas production, and the easier it is for the material to break down (or digest), the more biogas we're likely to get.

Let’s think of it this way: agricultural wastes, leftovers from crops, animal waste, marine waste, forest leftovers, and even solid waste from our environment– they're all part of the mix that can be used (R. Khoiyangbam, 2011). So, it's not just about waste; residues from different farming practices and products can play a big role in making biogas.

Agricultural waste and leftover crop materials are good sources of biomass that can be used as feedstock for anaerobic digestion. When it comes to animal breeding, Animals also contribute a significant amount of waste. In India, for instance, cattle dung has been a go-to solid waste feedstock, with a whopping 354 million tons available annually (N. Ravindranath et al., 2005). If we shift our focus to aquatic sources, seaweeds, micro- and macroalgae, and even water hyacinths emerge as fantastic feedstock options for producing bio-energy, H.-W. Yen (2007).

The duration of anaerobic digestion is contingent upon the chemical composition of the material. Substrates abundant in easily digestible sugars undergo rapid breakdown, while those comprising intact lignocellulosic material, characterized by cellulose and hemicellulose polymers, entail a more protracted decomposition process.

Originally, anaerobic digesters were all about handling manures and sewage sludge. However, since these materials have already given up a good chunk of their energy to the animals that produced them, they are not the top contenders for anaerobic digestion. So, this leads us to co-digestion which means using two or more types of feedstocks. Imagine a farm-based digester mainly chomping on dairy waste. Now, if you throw in a secondary feedstock like grass or corn, or even some organic waste like household waste, restaurant grease, fats, and oils, you will amp up the gas production speed.

2.7.2 Retention time / Detention time

The retention time in the digester is defined as the duration during which a specified quantity of feedstock remains within the anaerobic digestion system. Essentially, it characterizes the period over which the feedstock undergoes anaerobic digestion.

Calculated as the volume of the digester divided by the daily added feedstock, retention time is expressed in days. The retention time is subject to influence based on the operating temperature conditions of the biogas digester and the nature of the feedstock employed. The gradual decomposition of organic materials in anaerobic conditions contributes to an extended digestion duration.

In some digesters, when the feedstock is diluted with an identical composition, a distinction between solid and liquid components becomes prominent, leading to the introduction of the terms "solid retention time" (SRT) and "hydraulic retention time" (HRT).

i. Solid Retention Time (SRT): SRT signifies the duration during which the volatile solid content of the feedstock remains within the digester.
ii. Hydraulic Retention Time (HRT): HRT represents the average period during which the dissolved portion of the waste spends time in the digester.

SRT stands out as a critical parameter in the design of anaerobic digesters. An SRT significantly below the design values can lead to the rate of methanogen loss in the digester effluent surpassing the rate of growth. This imbalance may result in the accumulation of volatile fatty acids (VFAs) at concentrations harmful to methanogens. Consequently, an upset or "stuck" digester becomes the ultimate outcome.

2.7.3 Moisture Content

The moisture content of a material, expressed as a percentage of its weight, signifies the mass of water it can retain. In the experiment conducted by Mrosso et al. (2023), a meticulous procedure was followed. The crucible underwent thorough cleaning, drainage, and heating at 105°C for approximately 30 minutes before being left in the oven to cool to room temperature. Subsequently, the dried crucible's weight (W1) was measured prior to usage.

For each substrate, the wet sample was introduced into the crucible, which was then placed in an oven set below 105°C for about three hours to achieve a stable weight (W2). After allowing both the crucible and the feedstock to cool to room temperature in the oven, a final measurement was taken using a mass balance (W3) (Mrosso et al., 2023).

2.7.4 Total Solids

The amount of solid remaining in the feedstock after water has evaporated or the amount of organic matter that is still in the crucible after the vaporescence process is the total solid. In the experiment carried out by (Mrosso et al., 2023), the drying procedure was carried out in a 105°C oven.

2.7.5 Total Volatile Content

The residues obtained from the TS calculation were burned for 1 hour at 550°C in a muffle furnace to produce greyish-white ash. The crucible and the ignited sample were given six hours to cool in the kiln.

2.7.6 Nutrient Composition and C: N Ratio

The attainment of high-quality biogas hinges on maintaining a balanced C/N ratio within the range of 20-30:1. The carbon-to-nitrogen (C: N) ratio delineates the proportion of carbon to nitrogen in organic matter, serving as a crucial measure of nutrient balance necessary for microbial assimilation into their cell structures. Imbalances in this ratio, exemplified by elevated C/N ratios in woody materials or diminished ratios in manure, can respectively result in sluggish decomposition and ammonia inhibition, compromising biogas quality.

The presence of essential macronutrients, including carbon (C), nitrogen (N), phosphorus (P), and sulphur (S), is vital for the success of anaerobic digestion processes. Additionally, hydrogen (H2) is considered, as it is a requisite for methane production by hydrogenotrophic methanogens.

Carbon degradation occurs 25-30 times faster than nitrogen, influencing the optimal C:N ratio, which also varies based on substrate characteristics. The recommended carbon: nitrogen: phosphorus (C: N:P) ratio for maximizing methane yield is reported as 100:3:1, while the ideal C: N:P:S ratio is approximately 100:10:1:1. According to Deublein and Steinhauser (2008), a ratio of C:N:P:S in the range of 333-167:7-4:2:1 is deemed suitable for methane formation, as supported by research findings.

2.8 EFFLUENT MANAGEMENT AND BYPRODUCT UTILIZATION

Effluent management and byproduct utilization are crucial aspects of a holistic approach to household biogas digester systems. Proper handling of the digester's effluent, known as digestate, ensures environmental sustainability, while the utilization of digestate as a valuable resource contributes to agricultural productivity and soil health. Here, we explore key considerations and advancements in effluent management and byproduct utilization in the context of household biogas digesters.

2.8.1 Effluent Management:

1. Nutrient-Rich Digestate:

The digestate produced in biogas digesters is a nutrient-rich organic slurry containing nitrogen, phosphorus, potassium, and other essential elements. Effective effluent management involves strategies to harness these nutrients while minimizing environmental impact.

2. Separation Techniques:

Studies by Zhang et al. (2018) and Li et al. (2020) have investigated various separation techniques to refine digestate into solid and liquid fractions. Separation facilitates easier nutrient application and reduces the risk of nutrient leaching into water bodies.

3. Solid-Liquid Separation:

Techniques such as sedimentation, filtration, and mechanical separation are employed to separate solid and liquid fractions. Solid fractions can be used as a nutrient-rich soil amendment, while liquid fractions are suitable for nutrient-enriched irrigation.

4. Dewatering and Composting:

Dewatering digestate solids and composting them can further stabilize the organic matter. This process reduces the volume of digestate, enhances its handling characteristics, and transforms it into a valuable, pathogen-free soil conditioner.

5. Odor Control:

Effluent management also addresses the issue of potential odors associated with digestate. Measures such as aeration, pH adjustment, and microbial treatments are explored to mitigate odors and improve the overall acceptability of digestate in agricultural applications.

2.8.2 Byproduct Utilization:

1. Agricultural Soil Amendment:

One of the primary uses of digestate is as a nutrient-rich soil amendment. Application of digestate to agricultural fields enhances soil fertility, improves water retention, and promotes plant growth. Research by Dong et al. (2018) and Sun et al. (2019) explores the agronomic benefits of digestate application on various crops.

2. Biogas Residue as Fertilizer:

The solid residue remaining after biogas production, often referred to as biogas slurry, can be utilized as a fertilizer. Research by Khanal et al. (2016) and Xie et al. (2021) demonstrates the positive impact of biogas slurry on crop yield and nutrient availability, highlighting its potential as an alternative to traditional chemical fertilizers.

3. Vermicomposting:

Combining digestate with vermicomposting processes introduces earthworms to further break down organic matter. Vermicomposting enhances nutrient availability and produces a nutrient-rich vermicompost that can be used as a potent organic fertilizer.

4. Aquaculture and Irrigation:

Liquid fractions of digestate are explored for use in aquaculture and irrigation. Studies by Krishna et al. (2017) and Zhang et al. (2019) investigate the impact of digestate on fish farming and crop irrigation, emphasizing the potential for sustainable water use in agriculture.

5. Biogas Residue in Mushroom Cultivation:

Biogas residue has been utilized in mushroom cultivation due to its favorable nutrient content. Research by Bhat et al. (2018) and Kumar et al. (2020) explores the feasibility of using biogas residue as a substrate for mushroom cultivation, demonstrating its potential in creating value-added byproducts.

6. Energy Crop Cultivation:

Certain crops, known as energy crops, can be cultivated using digestate as fertilizer. Research by Li et al. (2016) and Wang et al. (2021) explores the potential of energy crops, such as switchgrass or miscanthus, in bioenergy production, creating a closed-loop system within the biogas digester framework.

Effluent management and byproduct utilization in household biogas digesters underscore the importance of turning waste into a valuable resource. Integrating these practices not only enhances the sustainability of biogas systems but also contributes to the circular economy, promoting agricultural productivity and reducing dependence on conventional fertilizers. The continued exploration of innovative approaches to effluent management and byproduct utilization holds the key to maximizing the benefits of household biogas digesters in diverse agricultural and environmental contexts.

2.8.3 Byproducts of biogas digestion: Digestate

The residual output from biogas production within the digester is commonly referred to as digestate. Derived from the anaerobic digestion process, digestate is a nutrient-rich substance resulting from the breakdown of organic matter in the feedstock. Comprising both solid and liquid fractions, the composition of digestate is contingent upon the specific feedstock and the nuances of the digestion process. Below, the composition, treatment, and potential applications of digestate as an agricultural fertilizer are meticulously examined:

1. Composition of Digestate:

The solid fraction of digestate predominantly contains partially decomposed organic matter and residual undigested materials, often including fibrous residues from the original feedstock. It encompasses suspended and dissolved nutrients such as potassium, sulphur, ammonium, and various trace components of nitrogen and phosphorus (in both inorganic and organic forms). Typically, digestate exhibits varying pH levels, predominantly leaning towards a slightly alkaline range contingent upon the operational conditions of the digester.

2. Treatment of Digestate:

Digestate can undergo diverse treatments to render it suitable for use as fertilizer. Effective management involves the separation of solid and liquid portions, often achieved through mechanical techniques like settling tanks. Reducing moisture content through drying procedures facilitates the handling and transportation of the solid portion. Additionally, valuable nutrients, such as phosphorus, can be recovered from the liquid fraction using methods like struvite crystallization. Further stabilization of digestate can be achieved by combining it with other organic materials and subjecting it to composting, resulting in reduced odour.

3. Potential Application in Agriculture as Fertilizer:

Due to its nutrient-rich composition, digestate holds promise as an organic fertilizer and soil conditioner in agriculture. Acting as a source of essential nutrients like nitrogen, phosphate, and potassium, it has the potential to reduce reliance on synthetic fertilizers. The organic matter in digestate enhances soil structure, moisture retention, and microbial activity, ultimately improving soil fertility. Beneficial bacteria present in digestate contribute to enhanced soil biological activity. Applying digestate as fertilizer mitigates the risk of nutrient runoff into water bodies, thus preventing environmental damage. Customization of the nutritional content of digestate, through alterations in the digestion process or blending with other fertilizers, enables its adaptation to specific crop and soil requirements. The alkaline nature of digestate aids in balancing acidic soils by elevating pH levels. Application techniques, such as surface broadcasting, injection, or inclusion, should be chosen considering crop type, soil quality, and equipment accessibility.

However, challenges may arise in the utilization of digestate as fertilizer. The nutrient content may not consistently align with crop requirements, necessitating additional nutrient management. Risks of pathogens and contaminants require proper treatment and quality control measures to mitigate harmful effects. Logistical challenges in transportation and application may be posed by the high moisture content and bulkiness of digestate.

To optimize the utilization of digestate in agriculture, several recommended practices include:

i. Development of nutrition management strategies detailing the nutrient content of digestate and the specific nutrient needs of crops.

ii. Regular checks and tests for pH levels, nutritional content, and potential pollutants in digestate.

iii. Implementation of quality control procedures to efficiently incorporate digestate into agricultural practices.

iv. Adoption of crop rotation techniques to balance nutrient needs and prevent imbalances in the soil.

v. Environmental monitoring to assess the impact of digestate use, particularly in terms of nutrient runoff and groundwater contamination.

vi. Economic feasibility assessments, including cost-benefit analyses, to evaluate gains in crop production and savings on synthetic fertilizers.

2.8.4 Contribution to Climate Change Mitigation

In the context of biogas production sustainability, concerns centre around emissions of atmospheric pollutants, including carbon monoxide, formaldehyde, nitrogen oxides, sulphur dioxide, suspended particles, aromatic hydrocarbons, and odorous substances (e.g., hydrogen sulphide) (Janas M. et al., 2018; Mezzullo W.G. et al., 2013).

For instance, a study by Battini et al. (Paolini V. et al., 2018) on a dairy farm in the Pad River Valley demonstrated a 23.7% to 36.5% reduction in emissions through anaerobic fermentation, depending on digestate management. Additionally, Kaparaju et al. estimated greenhouse gas reductions of 177, 87, and 125 t CO2 equivalent per year for dairy, sows, and pig farms, respectively (Kaparaju P. et al., 2011).

1. Methane Emissions:

Despite limited data on biogas effects on biological systems, methane, a potent greenhouse gas, poses environmental concerns. With a global warming potential (GWP) 28-36 times higher than CO2 over a 100-year horizon, methane emissions during biomass storage and digestion are critical. Effective operation and processes are essential to minimize methane emissions (Klingler B., 2005; Paolini V. et al., 2018; Pipatti B. et al., 2008; Vorbrodt-Strzalka K. et al., 2013).

The annual increase in atmospheric methane is approximately 1%, with agriculture contributing significantly, particularly from animal digestion and manure (Jorgensen P.J., 2009). Anaerobic treatment of animal manure not only produces renewable energy but also mitigates CO2 emissions, offering a dual benefit by reducing demand for fossil fuels (Klingler B., 2005).

2. Carbon Dioxide Emissions:

Combusting biogas oxidizes methane to CO2, with a rate of 83.6 kg per GJ for a biogas containing 65% CH4 and 35% CO2. Overall, biogas production, considering combustion and emissions during transport and storage, is considered climate-neutral, promoting a negative CO2 balance due to effective CO2 capture (Paolini V. et al., 2018).

Studies emphasize the sustainability of biogas production from by-products over energy crops, and proper digestate management significantly contributes to emission reduction (Paolini V. et al., 2018).

3. Nitrous Oxide (N_2O) Emissions:

Nitrous oxide, a potent greenhouse gas, contributes to global warming, with 1 kg CH4 equivalent to approximately 22 kg CO2 and 1 kg N2O to approximately 310 kg CO2. Anaerobic fermentation of waste reduces N2O emissions through careful manure storage, mitigation of anaerobic conditions in the soil, increased nitrogen availability, reduced fertilizer use, and avoidance of N2O during fertilizer production (Paolini V. et al., 2018; Jorgensen P.J., 2009).

4. Ammonia Emissions:

Anaerobic digestion increases ammoniacal nitrogen concentration, leading to ammonia release during digestate storage. Preventive measures, such as covering digesters, can reduce ammonia losses (Amon T., 2010).

5. Particulate Matter Emissions:

While biogas combustion has low particulate matter emissions, secondary emissions may occur due to NOx and ammonia release from unfermented and digested substrate. Biomethane usage as an alternative to diesel can improve air quality, and the inclusion of biogas in national networks may reduce solid fuel consumption, positively impacting indoor air quality and human health (Paolini V. et al. 2018).

2.8.5 Applications and Benefits of Anaerobic Digestion

Anaerobic digestion offers a wide range of applications across various sectors, each accompanied by its unique set of benefits. Here's an overview:

1. Waste Management

Applications: Anaerobic digestion can effectively treat organic waste from various sources, including municipal solid waste, sewage sludge, food waste, agricultural residues, and industrial wastewater.

Benefits: It reduces the volume of organic waste, mitigates odour emissions, and minimizes the environmental impact of waste disposal by diverting organic matter from landfills and incinerators. Additionally, anaerobic digestion produces nutrient-rich digestate that can be used as a soil conditioner or fertilizer.

2. Biogas Production

Applications: Anaerobic digestion generates biogas, a renewable energy source primarily composed of methane (CH_4) and carbon dioxide (CO_2). Biogas can be utilized for various purposes, including electricity generation, heat production, and vehicle fuel.

Benefits: Biogas is a clean and sustainable alternative to fossil fuels, reducing greenhouse gas emissions and dependence on non-renewable energy sources. It can contribute to energy security, decentralized energy production, and promote rural development by providing income opportunities for farmers and rural communities.

3. Renewable Energy Generation

Applications: Biogas produced through anaerobic digestion can be used to generate electricity and heat in combined heat and power (CHP) systems, or it can be upgraded to biomethane for injection into natural gas grids or used as a transportation fuel.

Benefits: Anaerobic digestion contributes to the transition to a low-carbon economy by harnessing renewable energy from organic waste streams. It helps reduce greenhouse gas emissions, combat climate change, and promote sustainable development.

4. Wastewater Treatment

Applications: Anaerobic digestion is widely used in wastewater treatment for the stabilization and reduction of organic pollutants in sewage, industrial effluents, and agro-industrial wastewaters.

Benefits: It improves water quality, reduces the biochemical oxygen demand (BOD) and chemical oxygen demand (COD) of wastewater, and facilitates the removal of pathogens and contaminants.

Anaerobic digestion can be integrated into wastewater treatment plants to enhance overall treatment efficiency and reduce operational costs.

5. Resource Recovery

Applications: Anaerobic digestion enables the recovery of valuable resources from organic waste streams, including biogas for energy production and digestate for soil amendment.

Benefits: It promotes a circular economy approach by closing the loop on organic waste management and utilizing waste as a resource. Anaerobic digestion facilitates the recovery of energy, nutrients, and organic matter from waste streams, contributing to resource conservation and sustainable resource management.

2.9 TECHNOLOGICAL INNOVATIONS IN HOUSEHOLD BIOGAS DIGESTERS

As the demand for sustainable and decentralized energy solutions grows, technological innovations have played a pivotal role in advancing the design, operation, and efficiency of household biogas digesters. These innovations encompass a wide range of areas, including process monitoring, automation, safety, and integration with other smart technologies. Here, we delve into some key technological advancements shaping the landscape of household biogas digesters.

2.9.1 Process Monitoring and Control Systems:

1. Smart Sensors:

The integration of smart sensors is transforming the monitoring of anaerobic digestion processes. These sensors measure parameters such as temperature, pH, gas composition, and organic loading rates in real-time. Studies by Li et al. (2019) and Saha et al. (2020) highlight how smart sensor technologies enable precise control over the digestion process, optimizing gas production and overall system efficiency.

2. Internet of Things (IoT):

IoT technologies connect biogas digesters to the internet, allowing for remote monitoring and control. Real-time data analytics enable users to track digester performance, receive alerts for potential issues, and remotely adjust operational parameters. Research by Wang et al. (2020) and Shen et al. (2021) showcases the potential of IoT in improving system reliability and ease of management.

2.9.2 Safety Innovations:

1. Methane Detection Systems:

Safety is a paramount concern in biogas systems due to the flammable nature of methane. Methane detection systems, including gas detectors and alarms, provide an added layer of safety by promptly alerting users to potential leaks. Research by Sun et al. (2018) and Chen et al. (2020) explores the implementation of advanced methane detection technologies for enhanced safety.

2. Fail-Safe Mechanisms:

Innovations in fail-safe mechanisms ensure that in the event of a malfunction or abnormal condition, the biogas digester system can automatically shut down or initiate safety protocols. This includes pressure relief valves, emergency venting systems, and automatic gas shut-off devices, as discussed by Wu et al. (2019) and Liang et al. (2022).

2.9.3 Gas Purification and Upgrading:

1. Biogas Cleaning Technologies:

Advanced gas purification technologies remove impurities, such as hydrogen sulfide and moisture, from biogas. These technologies enhance the quality of biogas, making it suitable for direct use in appliances or injection into natural gas grids. Studies by Wu et al. (2018) and Li et al. (2021) delve into various biogas cleaning methods, including adsorption, absorption, and membrane separation.

2. Biogas Upgrading to Biomethane:

Innovations in biogas upgrading technologies allow for the conversion of biogas into biomethane, a high-purity methane that meets natural gas standards. These processes, such as pressure swing adsorption (PSA) and membrane separation, enable the injection of biomethane into existing natural gas infrastructures. Research by Zhao et al. (2017) and Liu et al. (2020) explores the feasibility and efficiency of biogas upgrading technologies.

2.9.4 Remote Control and Automation

1. Automated Digestate Management:

Automation extends beyond the digestion process to the management of digestate. Automated systems for separating, dewatering, and processing digestate contribute to efficient byproduct management. Research by Cai et al. (2019) and Yang et al. (2021) highlights how automation enhances the overall sustainability of the biogas digester system.

2. Smartphone Applications:

User-friendly smartphone applications provide a convenient interface for monitoring and controlling biogas digesters. These apps allow users to receive real-time data, set operational parameters, and receive alerts, contributing to the accessibility and user-friendliness of biogas systems.

2.9.5 Integration with Renewable Energy Systems:

1. Solar and Wind Integration:

Combining biogas digesters with solar and wind energy systems creates hybrid renewable energy solutions. This integration ensures a continuous energy supply, even when biogas production is limited. Research by Zhang et al. (2019) and Zhang et al. (2020) explores the synergies between different renewable energy sources.

2. Power Generation from Biogas:

Advanced technologies in combined heat and power (CHP) systems enable the simultaneous generation of electricity and heat from biogas. These systems maximize energy utilization and contribute to the overall efficiency of the biogas digester. Studies by Jiang et al. (2018) and Li et al. (2022) delve into the optimization of CHP systems for household biogas applications.

Technological innovations in household biogas digesters not only enhance the efficiency and safety of these systems but also pave the way for their integration into broader smart and sustainable energy ecosystems. As research and development in this field continue, the synergy between advanced technologies and biogas digesters holds great promise for meeting the growing energy demands in a sustainable and environmentally conscious manner.

2.10 DIGESTER AND FEEDSTOCK DATA

2.10.1 DIGESTER DESIGN

Digester tank is cylindrical in shape, made of stainless steel, and the top of the digester is tightly screwed with using bolts and nut and sealed at the top so that gas is unable to escape from it. The digester is an airtight cylindrical shaped vessel with an inlet through which feedstock (Biomass + Water) is fed by means of a manual hand pump from the mixing tank into the digester. The digester tank houses both the slurry and the gas produced, these two substances makes up the volume of the tank. The digester has an outlet through which digestates are removed from the digester periodically, located at this point is a one-way valve that only allows the flow of fluid in one direction. Located at the top of the digester is the gas outlet, pressure gauge.

Vessels, tanks and pipelines that receive fluid flow in to it, whether as a means of passage or for storage are known as “pressure vessels”. A container in which there is a pressure differential between the inside and outside is known as a pressure vessel (B.S. Thakkar, and S.A. Thakkar 2012). In light of this the anaerobic digester qualifies as a pressure vessel. Pressure vessels by design can either be horizontal or vertical but in this project, we are designing for a vertical pressure vessel. The ASME viii division 1 code was used in the design of the digester following the following steps, which are; selection of material, calculating the size, determining the thickness of the cylinder, determining the internal pressure on the walls of the cylinder and calculating the dimensions for legs and support (G. Shibashis 2008). Pressure vessels are classified as thin and thick shells based on the thickness of its walls. It is classified as thin shell if the ratio of the inner radius to its thickness is greater than or equal to 10 and thick-walled for anything less than (G. Shibashis 2008). The vessels used in this work will be designed in accordance with ASME Boiler and Pressure Vessel Code in 1914. If the ratio of the inner radius and the wall thickness of the pressure vessel are greater than or equal to 10, then it is called a thin shell or thin-walled pressure vessel or it will be a thick-walled one (G. Shibashis 2008). This will also be mentioned in the course of this work.

This portable digester is designed as a vertical thin shell pressure vessel; if the ratio of the inner radius and the wall thickness of the pressure vessel are greater than or equal to 10, ($\frac{ri}{t} \geq 10$).

Where ri is the inner radius. A temperature of 35^{o}c is adopted for this study.

2.10.2 Pressure vessel sizing equation

For determining the sizing of the digester

$V = \pi r^2 h$

h = Straight height, V = volume of the digester.

Volume V = Daily feed input (m^3/ days) × Retention time (days)

2.10.3 Thickness of the cylindrical shell

According to the ASME section eight two sets of equation were provided for determining the thickness of cylindrical vertical thin walled pressure vessel.

Case 1 - Circumferential Stress (Longitudinal Joints)

When the thickness does not exceed one half of the inside radius or P does not exceed $0.385SE$ the following formulas are viable.

$\sigma = (Pd) / (2t)$ (Kumar, 2023)

Case 2 - Longitudinal Stress (Circumferential Joints)

When the thickness does not exceed one-half of the inside radius, or P does not exceed 1.25SE, the following formulas shall apply; $\sigma = (P \times L) / (2 \times T \times E)$ (ASME, 2019, Equation 3.2)

T_s = Shell thickness

R = Cylinder Radius

P = Designing pressure

S = Maximum allowable stress value

P_s = maximum allowable working pressure.

E = Joint efficiency for, or the efficiency of, appropriate joint in cylindrical or spherical shells, or the efficiency of ligaments between openings, whichever is less.

Note that: E = 1.0 if radiated test is used, meanwhile E = 0.7 is used if non-radiated tests are used.

According to the American Society of mechanical Engineers the maximum allowable pressure (Pm) is the minimum between P_1 and P_2. it is worth noting that the actual working pressure of the digester should be less the maximum allowable working pressure in order for the design to be considered safe ($P_w < P_m$), where Pw is the working pressure.

The time for the production of biogas varies depending on the temperature and method adopted. In 2002 El-Wakil documented the retention time for complete combustion, in this experiment he made use of different substrates to achieve this result, the table below shows the result from the experiment.

Table 2.1: Retention time (Time for complete decomposition) for different materials (Khanal, S. K. 2008)

S/N	MATERIALS	RETENTION TIME
1	Cow and Buffalo Dung	50 days
2	Pig Dung	20 days
3	Poultry Droppings	20 days
4	Night Soil	30 days

Table 2.2: Methane production for common agricultural waste (Rai, 2004)

TYPE OF WASTE	VOLUME OF YIELD(litres)/KG	CONCENTRATION IN BIOGAS (%)
Cow Manure	180-250	60-70
Pig Manure	210-300	58-60
Poultry Manure	350-400	58-65
Human Content	160-300	60-65
Green Plant	250-450	55-62
Straw	150-180	58-60

All types of organic waste are suitable for producing biogas by the process of anaerobic digestion in a biogas plant. The organic materials sourced from human, animal and plant waste reduced to 3-6mm in size for adequate digestion. Water is needed in the bio-conversion process, as it enables quicker decomposition of waste. In this project, emphasis was placed on anaerobic digestion. According to Rai (2004), methane production varies for different agricultural waste used as substrates as shown in Table 2.

The general equation for anaerobic digestion by Rahimpour, Mohammad Reza, et al. (2020), is given as:

$$\mathbf{C_XH_YO_Z + \frac{2(X-Y)}{4-Z}H_2O \rightarrow (\frac{X}{2} - \frac{Y}{8} + \frac{Z}{2})\ CO_2 + (\frac{X}{2} + \frac{Y}{8} - \frac{Z}{4})\ CH_4}$$

In order to be able to determine the dimensions of the digester it is necessary to know the gas production rate per day for different feedstock as it applies to this project. Table 3 shows the biogas production rate for plantain peels and yam peels.

Table 2.3: Methane production from yam peels and plantain peels (Ojikutu et al., 2014)

Feedstock	Average biogas production per week (ml per 20L)	Estimated production per day (ml per liter)
Yam peels	1048.6	7.49
Plantain peels	916.3	6.546

Table 2.4: Methane production from cooked rice and Irish potato peels (Mrosso et al., 2023)

Feedstock	Average biogas production per week (ml per 1.5L)	Estimated production per day (ml per liter)
Cooked rice	705.25	67.167
Irish potato peels	210	20

CHAPTER THREE

MATERIALS AND METHODOLOGY

Our approach to the design and fabrication of a household biogas digester will follow the design flow chart shown in fig 3.1.

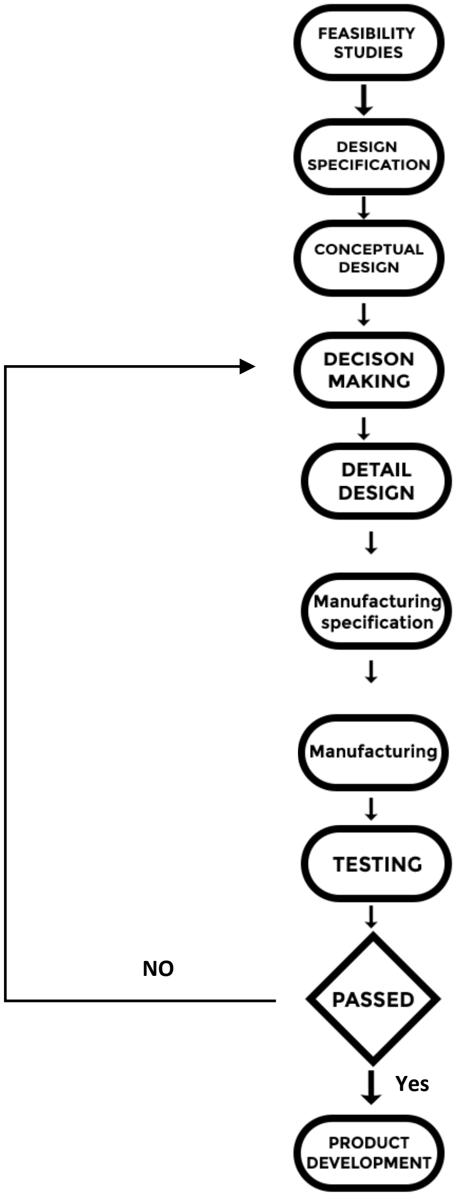


Fig 3.1 Design Flow chart

3.1 Feasibility Studies

The feasibility study evaluates the possibility of designing and manufacturing household biogas digesters for biogas (renewable energy) production and waste management. This include the assessment of technical, financial, and economic feasibility and the potential for fabricating of biogas digesters for residential use.

Household biogas digesters offer a sustainable solution for households seeking renewable energy sources and effective waste management. By converting organic waste into biogas through anaerobic digestion, biogas digesters provide clean cooking fuel, heating, and electricity while reducing greenhouse gas emissions and environmental pollution.

Targeting urban and rural households with access to organic waste sources, market demand for biogas digesters is driven by energy needs, environmental awareness, and rising fuel costs. The fabrication process involves designing and constructing durable and efficient digester systems using locally available materials and skilled labor.

Cost estimates include expenses for materials, labor, equipment, and overhead costs, while revenue projections are based on projected sales volumes and pricing strategies. The financial analysis assesses profitability, ROI, and payback period, while the economic viability considers job creation, income generation, and local economic development.

Potential risks and challenges include technical issues, market competition, regulatory compliance, and financial constraints, requiring risk mitigation strategies to address and minimize these risks.

3.2 DESIGN SPECIFICATION

Designing a household biogas digester requires careful consideration of various specifications to guide the design and manufacturing of the plant.

Key elements required in the design specifications include the following;

1. **Cost of the biogas digester:** This determines how affordable the biogas digester can be. The cost should be #300,000 ≤ cost ≤ #400,000, This price range was chosen because an average biogas digester made up of steel, that also have a capacity of 150 litres would cost #412,000.

2. **Capacity**: The digester is expected to hold 150 litres of both the slurry and the biogas.
3. **Gas Quality**: The biogas produced should contain about 50 to 60 percent methane (CH4), 30 to 40 percent carbon dioxide (CO2), and about 10 percent impurities.
4. **Temperature Control**: The system's temperature would be maintained at 35 to 40 degrees Celsius for optimum biogas production.
5. **Mixing Ratio**: The ratio of organic waste materials, such as animal manure, crop residues, or food waste, to water is 1:1.
6. **Retention Time**: The expected retention time for organic waste materials inside the digester to achieve maximum biogas yield and pathogen reduction is between 20 and 25 days.
7. **Gas Utilization**: The intended use of the biogas produced is cooking, heating and other household use.
8. **Maintenance Requirements**: Maintenance requirements, such as cleaning schedules, inspections, and repairs, to ensure the long-term reliability and efficiency of the digester.
9. **Material**: The digester is designed to use stainless steel due to its high strength, corrosion resistance, aesthetics appeals, durability, sustainability and availability.
10. **Shape**: A cylindrical shape is chosen to improve constraints and mixing efficiency.
11. **Mixing System**: Mixing the digester contents to ensure uniform distribution of organic matter and microorganisms for efficient biogas production.
12. **Inlet Design**: The inlet system would be designed to include, inlet tank, manual hand pump, one way valve to facilitate easy and efficient feeding of organic waste into the digester while preventing clogging and ensuring proper sealing.
13. **Outlet Design**: The outlet system would be designed for efficient removal of digested slurry, by including a manual valve, while minimizing the loss of biogas and preventing clogging.

14. **Gas Storage**: A gas holder which will be above the slurry in the digester vessel would be included.
15. **Safety Measures**: Safety features, such as pressure relief valves and gas detectors to prevent accidents and ensure safe operation would be installed.
16. **Monitoring System**: To monitor the pressure of the biogas produced, a pressure gauge is installed.
17. **Environmental Impact**: Environmental impact of the digester design, including emissions, odor control, and effluent management, to minimize negative effects on surrounding ecosystems and communities.

3.3 CONCEPTUAL DESIGN CONSIDERATION

The diagrams shown below are some of the conceptual designs which were initially developed, but due to factors stated above only one of the designs would fit best as would be seen.

3.3 1 Concept 1: Hexagonal digester with stirrer

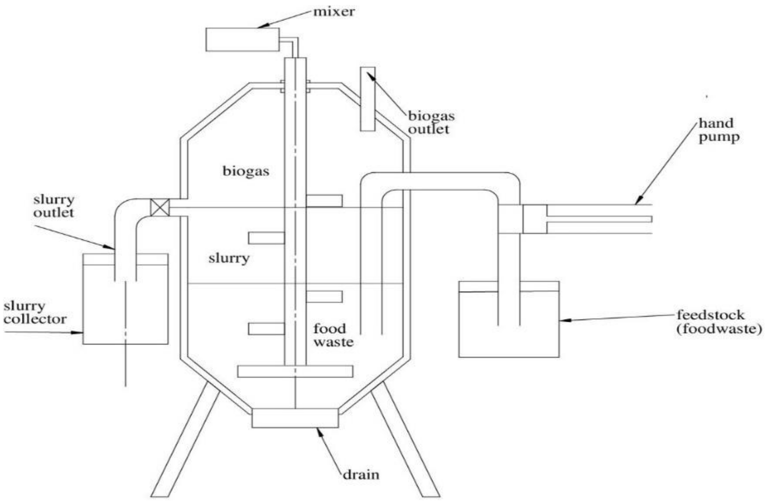


Fig. 3.2 Concept 1

a) Description of Design

The above design makes use of a horizontal hand pump located at the input unit, two separate tanks outside the digester (slurry outlet and the mixing tank), a support stand for which the digester sits on, a mixer or stirrer, it has a shape similar to that of a hexagon, having two of the sides longer than the other, this shapes helps for easy drain and also for compression of the gas formed at the top.

b) Limitation of the Design

i. It makes use of an extra material for the leg stand and pipes for the input unit making it more expensive.

ii. Increased pump work due to its positioning

iii. Due to its shape, it is more prone to corrosion attack

iv. Due to the shape of the head, it will be very difficult to machine.

v. Gases can be lost during feeding

3.3.2 Concept 2: Vertical cylindrical digester with hopper inlet

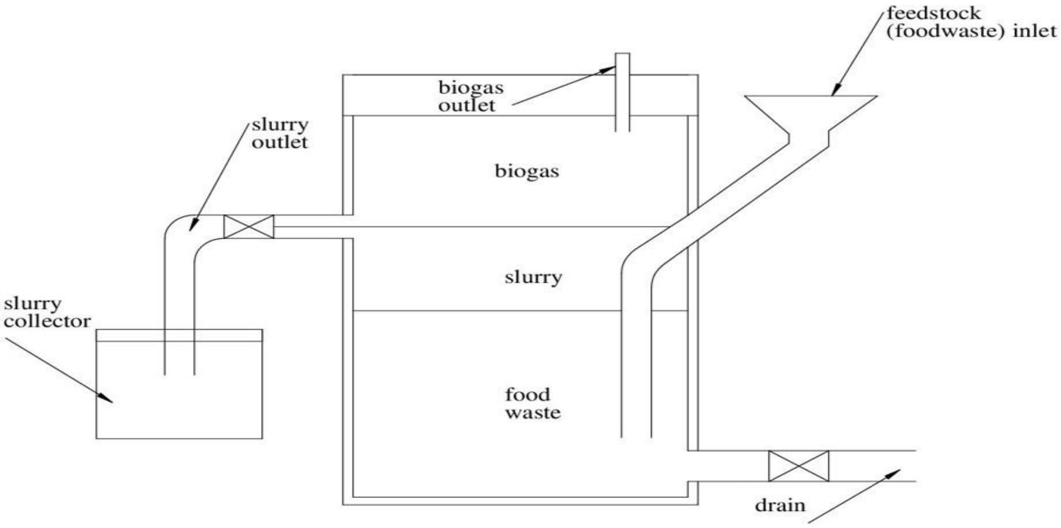


Fig. 3.3 Concept 2

a) Description of design

The above concept makes use of a slurry outlet tank, coupled with a one-directional valve, it makes use of a hopper, to which pipe is connected to it, the pipe extends down to the bottom of the digester the outlet gas pipe is located at the top (head) of the digester, it also has an outlet pipe at the bottom of digester tank.

b) Limitations of the Design:

i. The absence of a valve to regulate fluid flow at the inlet unit may result in the loss of gas from the tank through the feeding unit.
ii. Additionally, without a stirrer for proper mixing of the slurry, there's a risk of solids coagulating at the bottom part of the digester.
iii. Furthermore, the design lacks a mixing tank, making it challenging to measure the volume of input accurately. This is because the volume of slurry leaving through the slurry outlet must equal the volume of feedstock entering the digester, and the feedstock needs to be chopped and mixed in a separate container before being fed into the digester.

3.3.3 Concept 3: Dome shape digester

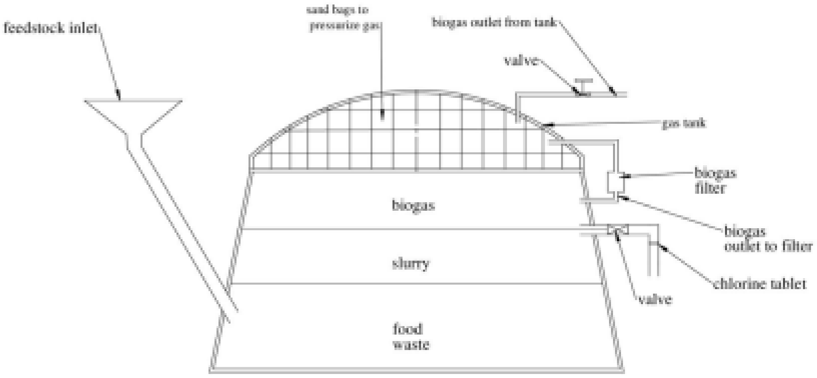


Fig. 3.4 Concept 3

a) Description of the Design

The design depicted in figure 4 is a dome-shaped digester, featuring a hopper and a hose connected to the digester tank. A slurry outlet pipe, controlled by a valve, facilitates the removal of digested slurry from the digester. A tin sheet metal serves as a separator between the gas holder tank and the digester tank. A pipe, equipped with a filter, connects the digester tank to the gas holder tank, allowing for the transfer of gas between the two components.

b) Limitations of the Design:

i. Lack of drainage system
ii. Lack of valve at the slurry inlet
iii. Challenges in machining the shape of the digester
iv. High cost due to additional materials required, including thin metal separator, secondary gas holder, sand bath for gas pressurization, gas filter, and chlorine tablet.

3.3.4 Concept 4: Cylindrical vertical digester with stirrer and pump

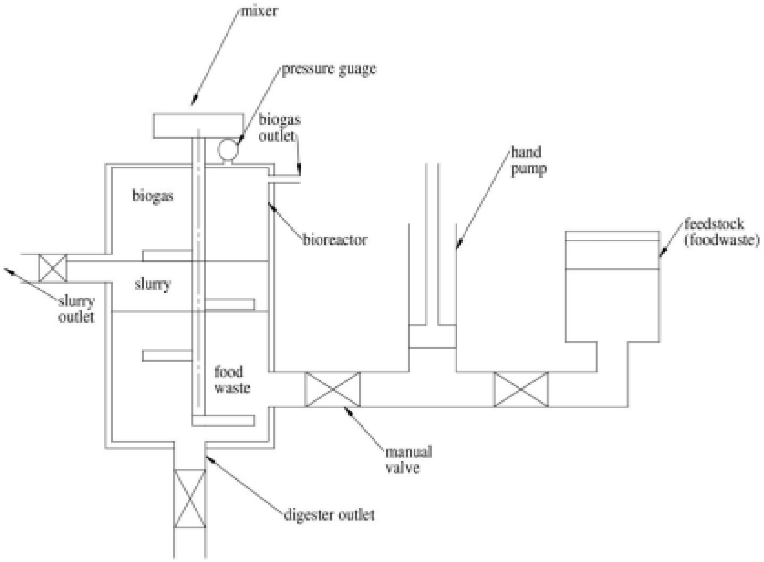


Fig. 3.5 Concept 4

a) Description of the Design

The described design incorporates a mixing tank and utilizes a hand pump to transfer slurry into the digester. The flow of slurry from the mixing tank to the digester is controlled by two non-return valves. Additionally, there is a pressure gauge situated at the top (head) and a stirrer positioned at the centre of the head, extending down to the bottom of the digester. The design features a slurry outlet located just above the input unit (inlet) and below the gas outlet, both of which are regulated by valves. Furthermore, there is a drain located at the bottom of the tank for easy removal of contents.

b) Limitations of the Design:

i. The positioning of the drain requires additional support material for the digester, resulting in increased construction costs.
ii. Utilizing two valves at the input unit alone adds to the overall expenses of the design.
iii. The reliance on a hand pump for feeding presents challenges as finding one suitable for handling slurry (biomass and water) is difficult and may require frequent maintenance.
iv. The length between the digester and the mixing tank must be sufficient to accommodate all materials used, potentially increasing costs further.

3.3.5 Concept 5: Cylindrical vertical digester with pump

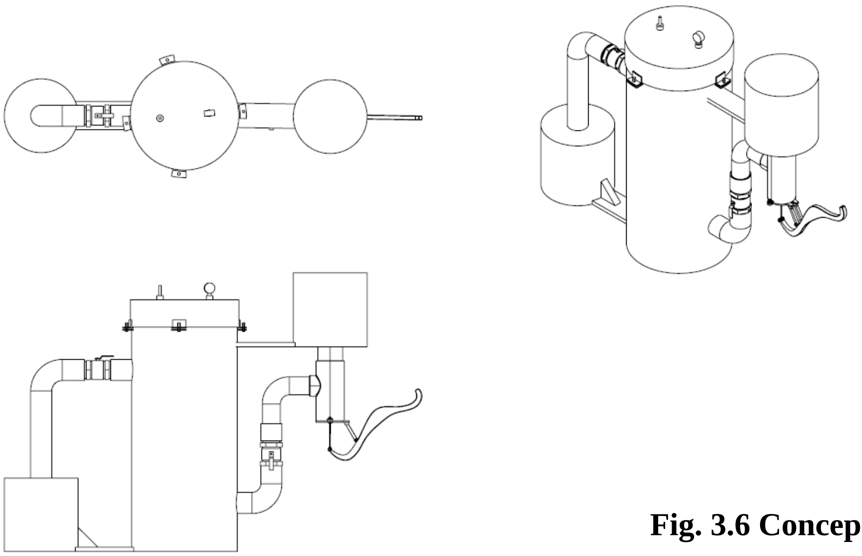


Fig. 3.6 Concept 5

a) Description of the design

The described design incorporates a mixing tank and utilizes a hand pump to transfer slurry into the digester. The flow of slurry from the mixing tank to the digester is controlled by a non-return valve, and the pressure from the pump. Additionally, there is a pressure gauge situated at the top (head). The design features a slurry outlet located just above the input unit (inlet) and below the gas outlet, both of which are regulated by valves. Furthermore, there is a drain located at the bottom of the tank for easy removal of contents.

b) Limitations of the Design:

i. The positioning of the drain requires additional support material for the digester, resulting in increased construction costs.
ii. Utilizing a valve and manual at the input unit alone adds to the overall expenses of the design.
iii. The reliance on a hand pump for feeding presents challenges as finding one suitable for handling slurry (biomass and water) is difficult and may require frequent maintenance.

The length between the digester and the mixing tank must be sufficient to accommodate all materials used, potentially increasing costs further.

3.4 SELECTION OF CONCEPT

The various concept developed were carefully analyzed with reference to the design specifications and one was selected using category weighting method as follows:

Measure of Value (MOV) scale:

1 = Very poor

2 = Poor

3 = Average

4 = Good

5 = Excellent

Weights scale was measured on a scale of 0-1

Then the MOV's will be multiplied by the weights to get the weighted Average (WA).

Table 3.5: Evaluation of the various concept for decision making

Attributes	**Weights**	**Concept 1**	**Concept 2**	**Concept 3**	**Concept 4**	**Concept 5**
		MOV(WA)	**MOV(WA)**	**MOV(WA)**	**MOV(WA)**	**MOV(WA)**
Cost	0.10	4(0.4)	3(0.3)	3(0.3)	3(0.3)	4(0.4)
Capacity	0.12	3(0.36)	3(0.36)	2(0.24)	2(0.24)	4(0.48)
Continuous biogas production	0.15	4(0.6)	2(0.3)	2(0.3)	4(0.6)	4(0.6)
Maintenance	0.08	2(0.16)	2(0.16)	3(0.24)	2(0.16)	3(0.24)
Mixing ratio	0.05	3(0.15)	3(0.15)	3(0.15)	3(0.15)	3(0.15)
Temperature control	0.10	2(0.20)	3(0.30)	2(0.20)	3(0.30)	3(0.30)
Retention time	0.08	5(0.4)	5(0.4)	5(0.4)	5(0.4)	5(0.4)
Gas utilization	0.12	4(0.48)	5(0.60)	5(0.60)	4(0.48)	5(0.60)

Gas Quality	0.10	5(0.50)	5(0.50)	5(0.50)	5(0.50)	5(0.50)
Material	0.08	3(0.24)	2(0.16)	3(0.24)	3(0.24)	4(0.32)
Shape	0.05	4(0.20)	3(0.15)	3(0.15)	3(0.15)	4(0.20)
Inlet Design	0.05	3(0.15)	3(0.15)	3(0.15)	3(0.15)	4(0.20)
Outlet Design	0.05	4(0.20)	4(0.20)	4(0.20)	4(0.20)	4(0.20)
Monitoring System	0.08	3(0.24)	3(0.24)	3(0.24)	4(0.32)	4(0.32)
TOTAL	1	49(4.28)	46(4.12)	46(3.91)	48(4.19)	56(4.91)

According to the category weighing concept 5 has the highest weighted average value, hence we would go with **Concept 5**

3.5 DETAILED DESIGN

3.5.1 COMPONENTS OF THE PLANT

<u>THE DIGESTER</u>

The digester is a cylindrical stand-alone digester with a flat head. For this system. The volume, height, and diameter of the digester can be deduced thus:

The system being solely for household use, the choice of feedstock is restricted to biodegradable waste, such as food waste, animal dung, etc.

From Table 3 and 4, the average gas produced per day for the different constituents if our feedstock is:

1. 1kg of cooked rice produces 0.067167 Litres of biogas per day
2. 1kg of plantain peels produces 0.006546 Litres of biogas per day
3. 1kg of cow Irish potato peels produces 0.02 Litres of biogas per day
4. 1kg of yam produces 0.00749 Litres of biogas per day.
5. 1kg of cow dung produces 35 Litres of biogas per day

For this project we would assume the percentage composition of all the feedstock is the same i.e. 20% each, all amounting to 100%

Cooked rice - 20% of 0.067167 = 0.0134334Litres

Plantain peels - 20% of 0.006546 = 0.0013092Litres

Irish Potato peels - 20% of 0.02 = 0.004Litres

Yam - 20% of 0.00749 = 0.001498Litres

Cow dung - 20% of 35 = 7litres

Volume of the total feedstock = 7 + 0.0134334 + 0.0013092 + 0.004 + 0.001498 = 7.02

That is approximately 7Litres per day or 0.007 cubic meters for 1kg of feedstock.

For this model, we are designing for 20litres of gas. Hence:

Design volume = 0.02 m^3 = 20Litres

Amount of feedstock needed per day to produce design volume 0.02/0.007 = 2.857 3

Slurry = Biomass + water (1:1) hence,

3parts of biomass + 3parts of water = 6litres = 0.006 meters cube day

Daily feed input = $0.006m^3$/day

Volume of the digester (V) = $\pi r^2 h$ = daily feed input × Retention time, where r = $^D/_2$,

Volume of digester = 0.006m³/day × 25 days = 0.15m^3 or 150Litres

3.5.2 Determine the dimensions of the tank:

ASME standard for pressure vessels whose internal pressure ranges from 0-250 Per Square Inch Gauge (PSIG), the length to diameter ratio is 3. (ASME BPVC Section VIII, Division 1: Rules for Construction of Pressure Vessels. American Society of Mechanical Engineers, 2023)

i.e. **H = 3D** ……………….. (3.51)

$V = \frac{\pi D^2 h}{4}$ ………………………………………………………………… (3.52)

$V = \frac{3\pi D^3}{4}$ ………….……………………………………………………... (3.53)

Diameter (D) = $\sqrt[3]{\frac{4V}{3\pi}}$, D = $\sqrt[3]{\frac{4x0.15}{3\pi}} \cong 0.4m$

Height of the tank (H) $= 3 \times 0.4 = 1.2m$

a) Determining the Volume of the Slurry and Gas holder:

In determining the volume of digester, it is common practice to make the slurry volume three quarters of that of the digester volume, hence:

Volume of Slurry (Vs) = 3/4 × 150 ≅ 113Litres

Volume of Gas holder = 150 - 113 = 37Litres.

The extra volume remaining in the gas holder can serve in times where the biogas is not immediately in use.

b) Determining the height of the Gas holder and the Slurry

The digester volume equation, $V = \frac{\pi D^2 h}{4}$

Height of slurry (H_1) = $\frac{4V}{\pi D^2}$ ……………………………………………………………. (3.54)

$H_1 = \frac{4x0.113}{\pi x\ 0.4^2} = 0.889\ \cong 0.9m$

Height of gas holder (H_2) = 1.2 – 0.9 = 0.3m

c) Design for the feedstock injection and ejection tanks

The tanks are cylindrical in nature

Amount of slurry input = 6 Litres = 0.006m^3

But, taking into consideration, the volumes that would be occupied in the pipelines, we decided to design for extra 4 litres. Hence,

Total volume of the injection and ejection tanks (V_3) = 6litres + 4litres = 10litres = 0.01 m^3

Also considering the amount of stainless-steel material left, we decided to maintained the heights of the tanks (H_3) at 12inches = 0.3048 m

Therefore,

H_3 = 0.3048 m, and

V_3 = 0.01 m^3

From $V = \frac{\pi D^2 h}{4}$,

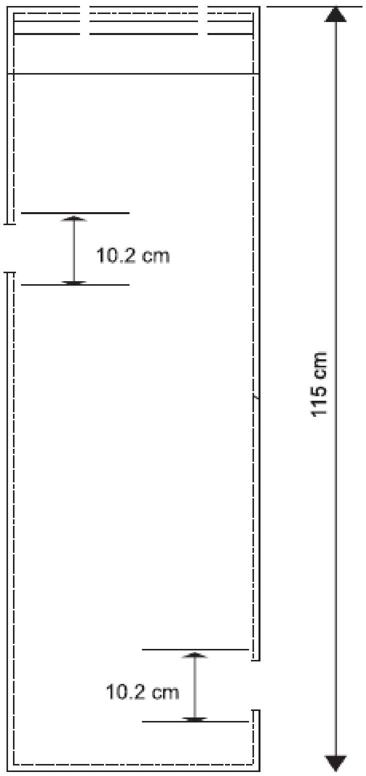
$$D = \sqrt{\frac{4V}{\pi h}} = \sqrt{\frac{4\times 0.01}{\pi\times 0.3048}} = 0.2045\text{m} \cong 8 \text{ inches}$$

Diameter of the tanks = $8inch$es + $1inch$ allowance = $9inches$

Fitted on top of the digester is its cover. Also fabricated with stainless steel, the cover is a 10mm high cylinder, covered at one end (the top). The diameter is only a fraction greater than 0.4m (approximately 0.42m). Since the digester is to be airtight, adequate measures have been taken to ensure that there are no leakages due to the installation of digester cover.

1. It is firmly fastened to the digester (as shown in the design below) using M8 hexagonal bolts and nuts.
2. A mechanical seal is used, in this case a rubber gasket, is employed to completely seal the gap between the cover and the digester

On the top the cover, we have installed a "5" bar pressure gauge and a gas regulator. The reading of the pressure gauge indicates how much gas is left in the gas holder. A high pressure reading indicates that a greater amount of gas is left in the gas holder, and vice versa. The regulator acts as a valve that shuts on, or shuts off the flow of gas when it is actuated manually. It reduces high pressure from the gas holder to a consistent regulated pressure as required by the burner it is meant to supply to.



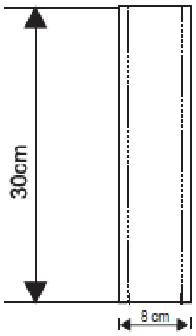


Fig. 3.8 Long steel pipe

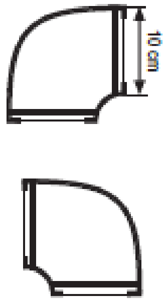


Fig. 3.9 Elbow connectors

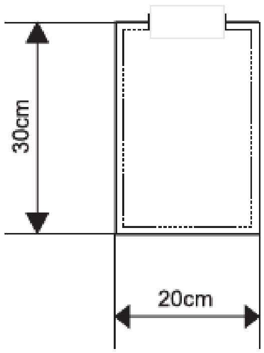


Fig. 3.10 Waste tank

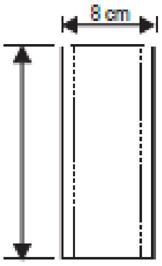


Fig. 3.11 Short steel pipe

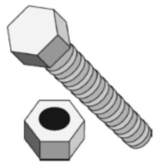


Fig. 3.12 M10 Bolt and Nut

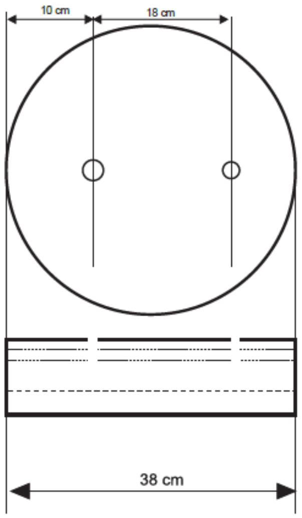


Fig. 3.13 Digester cover

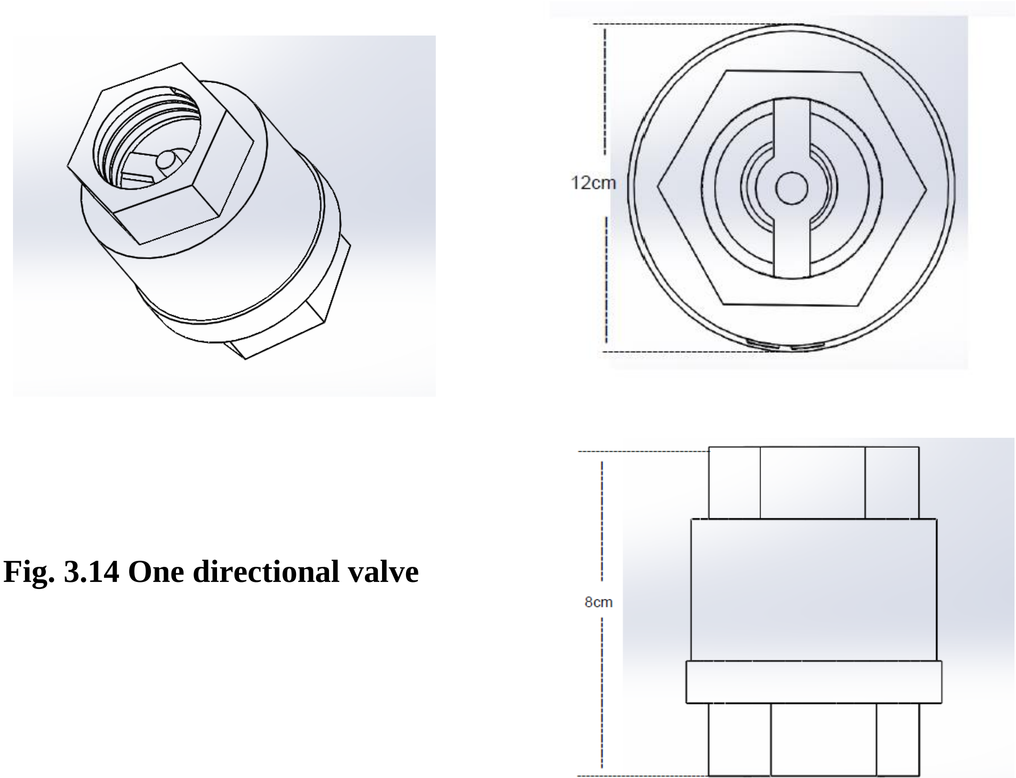


Fig. 3.14 One directional valve

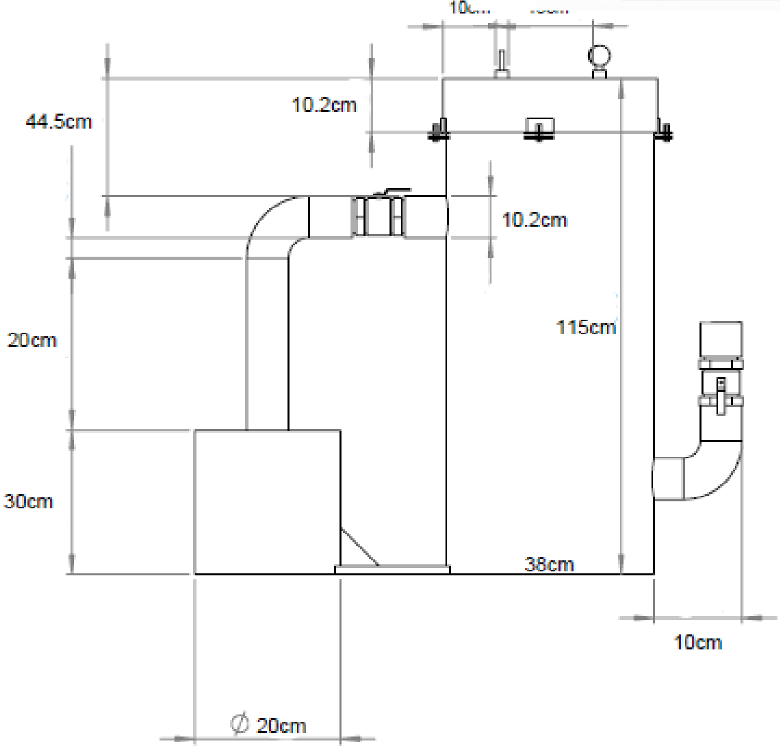


Fig. 3.15 Assembly of the digester

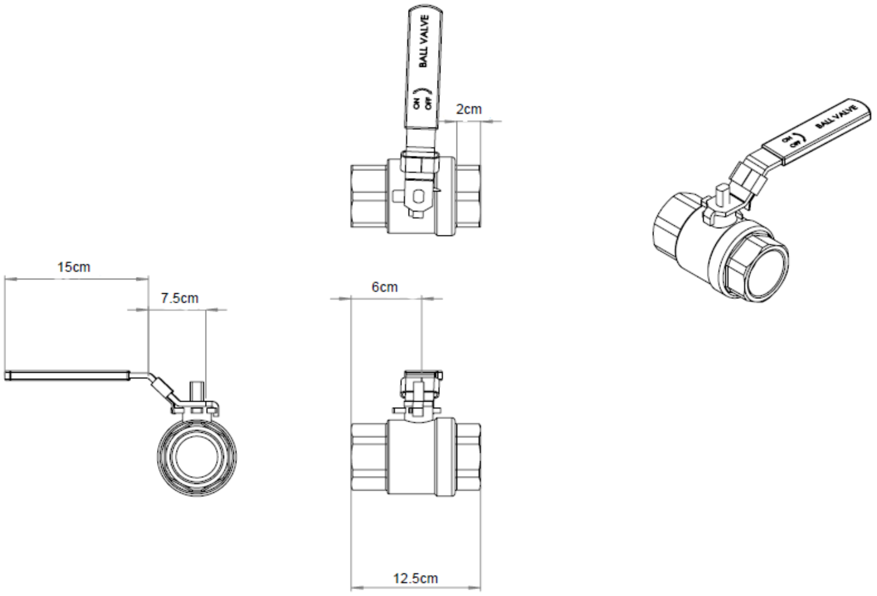


Fig. 3.16 Manual Valve

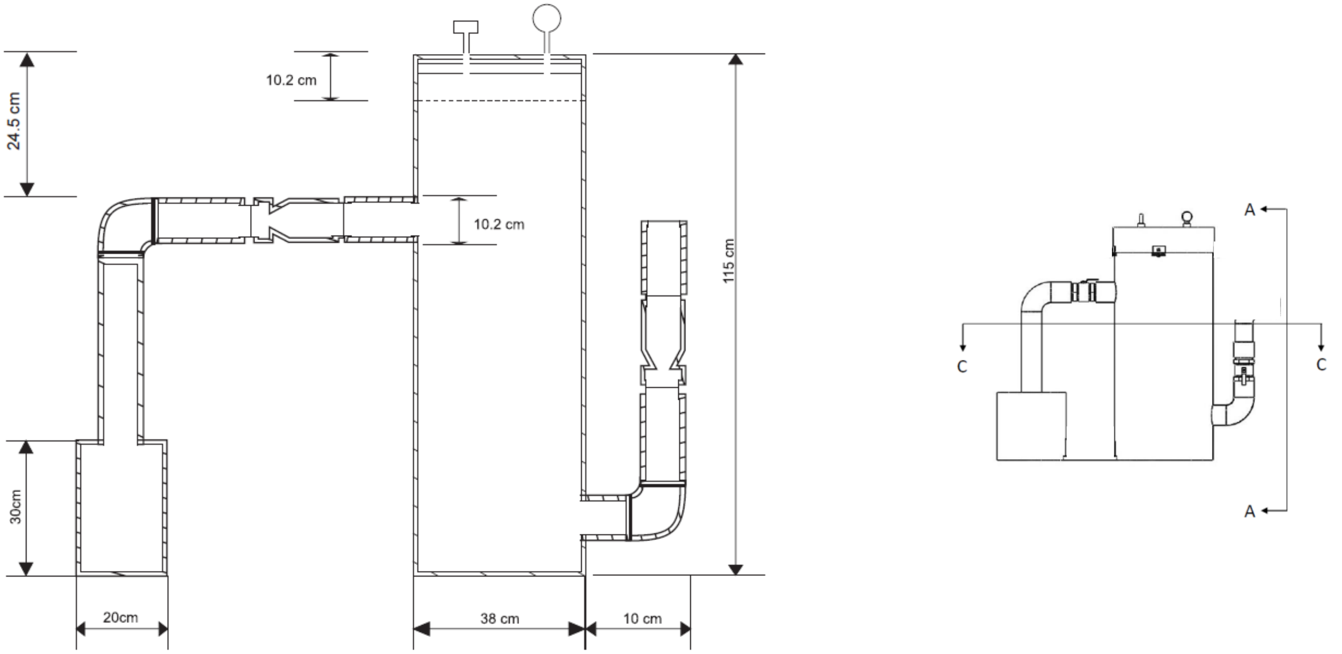


Fig. 3.17 Section A-A view of the digester

d) FEEDSTOCK INJECTION AND EJECTION SYSTEMS

The injection and ejection units consist of:

1. 4 inch stainless steel pipes
2. 4 inch high pressure brass ball valve
3. 4 inch high pressure brass non return Valve
4. A manual pump
5. 10 litres stainless steel feedstock inlet and ejection tanks.

The inlet of pipe is welded horizontally near the base of the digester. An elbow bend is used to change the direction from horizontal to vertical. The one-way valve is welded in between the inlet pipe, allowing only downward flow of feedstock. As the inlet pipe proceeds, it is welded to the outlet of the manual pump, then the suction pipe of the pump is welded to the 10litre feedstock inlet tank. The pump is placed upside down under the injection tank. This orientation aids the suction process of the pump, since the suction force will be in the same direction as the weight of the feedstock, only minimal force is needed for suction. However, during discharge, a greater force will be needed.

The outlet pipe is welded horizontally to the digester at 5 cm from its top. Another elbow bend is welded to change the pipe direction vertically downwards. The ball valve is welded in between the outlet pipe. The pipe proceeds further towards ground level, before it's fitted into the outlet tank placed on the ground.

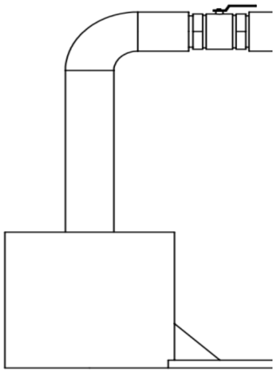


Fig. 3.18 Feedstock outlet system

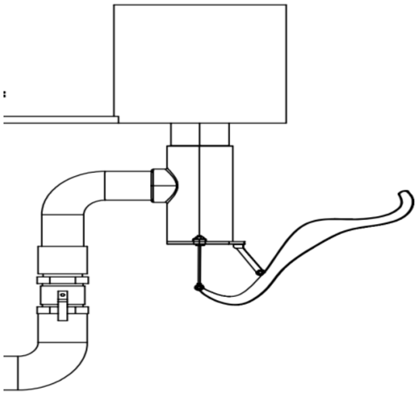


Fig. 3.19 Feedstock inlet system

e) THE MANUAL PUMP

The manual pump is the most important component of this design, as it is responsible for the continuous production of gas. It provides the pressure sufficient to drive out already used up feedstock from the top of the digester, and hence allowing the intake of new feedstock, therefore allowing continuous production. For our project, the type of pump used is the OIHYA Stainless Steel Suction Pump.

While carrying out feasibility studies for our project we encountered different kinds and designs of manual pumps. The OIHYA Stainless Steel Suction Pump has been chosen because of its characteristics outlined below.

1. Stainless steel does not contain any lead like the cast iron pitcher pumps.
2. The well hand pump has a smooth surface and anti-rust properties to ensure non contaminated feedstock.
3. It is by far the largest type of hand pump we encountered having suction and discharge end diameter
4. Also, since the rest of our fabrication was done using stainless steel, opting for a stainless-steel pipe would maintain uniformity and aesthetics.

5. Its Cost effectiveness

Fig. 3.20 the Manual Pump

3.6 DIGESTER COMPONENTS

An anaerobic household biogas digester consists of several key components that work together to facilitate the anaerobic digestion process. The main components include:

1. **Inlet or Feed System** - This component is responsible for introducing organic feedstock into the digester. It can include devices like pumps or conveyors to facilitate the controlled entry of material.
2. **Mixing System** - To ensure homogeneity and uniform microbial activity, a mixing system will be incorporated. This will be achieved through mechanical agitators, gas recirculation, or other mixing mechanisms.
3. **Digestion Vessel** - The digestion vessel is the main chamber where anaerobic digestion

takes place. It is designed to provide an oxygen-free environment, allowing anaerobic bacteria to break down organic material.

4. **Effluent Outlet** - After digestion, the remaining material, called digestate, exits the digester through an effluent outlet. The digestate can be further processed for use as fertilizer.
5. **Pressure monitoring system** - Anaerobic digestion often requires specific pressure conditions. A thermometer will be incorporated to monitor the temperature in the digester.

From literature, an all-inclusive table can be prepared for all the feedstock used in this project.

Table 3.6: Feedstock and estimated production rate

Feedstock	Estimated production per day (liter per liter of feedstock)
Yam peels	0.00749
Plantain peels	0.006546
Irish potato peels	0.020
Cooked rice	0.067167

Biogas Properties

Energy value - 21,000-23,000 kJ/Kg

Pressure - 75-250mm H_2O

Density - 1.2 kg/m^3

Design Calculations

Digester design - The digester is a cylindrical stand-alone digester with a flat head, the volume, height, and diameter of the digester are gotten as seen below.

Step 1: List of all the feedstock and the biogas production rate.

- 1kg of cow dung produces 35 Litres of biogas per day
- 1kg of cooked rice produces 0.067167 Litres of biogas per day
- 1kg of plantain peels produces 0.006546 Litres of biogas per day
- 1kg of cow Irish potato peels produces 0.02Litres of biogas per day
- 1kg of yam produces 0.00749 Litres of biogas per day.

Step 2: Determine the percentage composition of the feedstock and the total Gas production rate of the feedstock.

For this project will would assume the percentage composition of all the feedstock is the same i.e. 20% each, all amounting to 100%

Cow dung - 20% of 35 = 7litres

Cooked rice - 20% of 0.067167 = 0.0134334Litres

Plantain peels - 20% of 0.006546 = 0.0013092Litres

Irish Potato peels - 20% of 0.02 = 0.004Litres

Yam - 20% of 0.00749 = 0.001498Litres

GPR of the total feedstock = 7 + 0.0134334 + 0.0013092 + 0.004 + 0.001498 = 7.02

That is approximately 7Litres per day or 0.007 cubic meters for 1kg of feedstock.

Step 3: Determine the amount of feedstock required to produce the desired biogas produce and the volume of the digester.

Design volume = 0.02 m^3 / 20Litres

Amount of feedstock needed per day to produce design volume = ${}^{0.02}/_{0.007}$ = 2.857 ≅ 3

Slurry = Biomass + water (1:1) hence,

3parts of biomass + 3parts of water = 6litres = 0.006 meters cube day

Daily feed input = 0.006m^3/day

Volume of the digester (V) = $\pi r^2 h$ daily feed input × Retention time, where r =$D/_2$,

Volume of digester = 0.006× 25 = 0.15m^3 or 150Litres

Step 4; determine the dimensions of the digester

According to ASME standard for pressure vessels whose internal pressure ranges from 0-250 Per Square Inch Gauge (PSIG), the length to diameter ratio is 3. (**ASME BPVC Section VIII, Division 1: Rules for Construction of Pressure Vessels.** American Society of Mechanical Engineers, 2023)

I.e. **H = 3D** ……….. (3.61)

$V = \frac{\pi D^2 h}{4}$ ……………………………………………………………………… (3.62)

$V = \frac{3\pi D^3}{4}$ ……………………………………………………………………..… (3, 63)

Diameter (D) = $\sqrt[3]{\frac{4V}{3\pi}}$, D = $\sqrt[3]{\frac{4x0.15}{3\pi}} \cong 0.4m$

Height of the tank (H) $= 3 \times 0.4 = 1.2m$

Step 5: Determining the Volume of the Slurry and Gas holder.

In determining the volume of digester, it is common practice to make the slurry volume $3/_4$ that of the digester volume, hence:

Volume of Slurry (Vs) = $3/_4$× 150 ≅ 113Litres

Volume of Gas holder = 150 - 113 = 37Litres.

The extra volume remaining in the gas holder can serve in times where the biogas is not immediately in use.

Step 6: Determining the height of the Gas holder and the Slurry

$H = \frac{4V}{\pi D^2}$, Height of gas slurry (H_1) = $\frac{4x0.113}{\pi x\ 0.4^2} = 0.889 \cong 0.9m$

Height of gas holder (H_2) = 1.2 – 0.9 = 0.3m

Step 7: Design for the mixing tank

The mixing tank is cylindrical in nature

Amount of slurry input = 6Litres = $0.006m^3$

Area$= \frac{Volume}{Depth}$, assuming a depth of 0.15m

Area = $^{0.006}/_{0.15}$ = $0.04m^2$

Area = $\pi r^2 = \pi \times r^2 = 0.04$

r = 0.113m.

The components system should have the following parameters based on the calculations carried out.

Table 3.7: Manufacturing specification

S/N	COMPONENT	PARAMETERS
1	Digester capacity (V)	150 litres
2	Digester tank height	1.2 m
3	Digester cover diameter (D)	0.4 m
4	Maximum feedstock	21.5 kg
5	Operating Pressure (P)	0.15 bar
6	Inlet and outlet tank capacity	10 litres
7	Inlet and outlet tank height	0.3 m
8	Socket connector	1 inch

9	Pressure Gauge	0-15 bar
10	Elbow Connectors	4 inches
11	Hex head Bolts	M10
12	Hex Nuts	M10
13	Flat type Washer	Size 10
14	Manual valve	3 inches
15	One way valve	3 inches

3.7 COST ANALYSIS

The estimated cost of the project including the cost of materials, transportation and fabrication are as shown below.

Table 3.8: Cost of materials

S/N	Component	Quantity	Amount (N)	Remarks
1	Inlet and outlet tank (sheet material)	1	35,000	
2	One way valve	1	65,000	
3	Digester tank (Sheet material)	1	80,000	
4	Socket connector	2	2,000	
5	Pressure Gauge	1	3,500	
6	Glue	1	3,500	

7	Electrodes	30	9,000	
8	Cutting Disc	1	3,000	
9	Elbow Connectors	2	17,000	
10	Hex head Bolts	6	600	
11	Hex Nuts	6	600	
12	Flat type Washer	12	600	
13	Manual Pump	1	180,000	
14	Manual valve	1	30,000	
	Total		**429,000**	

Table 3.9: Cost of labour

S/N	Component	Operation	Unit cost (N)	Quantity	Amount (N)	Remarks
1	Digester tank	Cutting, rolling and welding	10,000	1	10,000	
2	Inlet and outlet tank	Cutting, rolling and welding	5,000	1	5,000	
3	One way valve	Application of glue and installation	2,000	1	2,000	
4	Socket	Welding and	500	2	1,000	

		installation				
5	Pressure Gauge	Application of glue and installation	1,500	1	1,500	
10	Elbow Connectors	Welding	2,500	2	5,000	
11	Manual valve	Installation	1000	1	1000	
	Total				**26,000**	

Table 3.10: Bill of Engineering Measurements and Evaluation (B.E.M.E)

S/N	**Component**	**Material**	**Dimension**	**Unit cost (N)**	**Quantity**	**Amount (N)**	**Remarks**
1	Inlet and outlet tank (sheet material)	Stainless Steel	36 x 8 x 1/8 inches	40,000	1	40,000	
2	One way valve	Brass	3 inches dia	67,000	1	67,000	
3	Digester tank (Sheet material)	Stainless steel	52.4 x 20 x 1/8 inches	90, 000	1	90,000	
4	Socket	Cast iron	1 inch Dia	1,250	2	2,500	
5	Pressure Gauge	Plastic	0-16 bar range	3,500	1	3,500	

6	Glue	Polyethane Silicon sealant	600 ml	3,500	1	3,500	
7	Electrodes	Stainless steel	-	300	30	9,000	
8	Cutting Disc	Aluminuim Oxide Abrasive grit	9 inches dia	3000	1	3,000	
9	Elbow Connectors	Cast iron	4 inches dia	11,500	2	23,000	
10	Hex head Bolts	Steel	M10 x 1.5 x 40	100	6	600	
11	Hex Nuts	Steel	M10	100	6	600	
12	Flat type Washer	Steel	M10	50	12	600	
13	Manual Pump	Stainless steel	-	180,000	1	180,000	
14	Manual valve	Cast iron	3 inches dia	30,000	1	30,000	
15	Miscellaneous					25,000	
	Total					**480,000**	

Table 3.11: Total cost

S/N	Component	Amount (N)	Remarks
1	Cost of material	429,000	
2	Cost of labour	26,000	
3	Miscellaneous	25,000	
	Total	**480,000**	

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 RESULT

The biogas digester we set out to fabricate was a continuous biogas producer consisting of an inlet system, the digester tank and outlet system. The inlet system was to consist of an inlet tank, a manual pump, a no return valve and connecting steel pipes, the tank was designed to be a 150 liters steel tank with pressure gauge and gas regulator installed, and the outlet system was to include the outlet tank, a manual valve and other connecting steel pipes.

After fabrication, most of the expected components were incorporated while others were not due to certain challenges faced. A picture of the final product of fabrication is shown below;

Fig. 4.1 the Biogas Digester

4.1.1 Digester Tank

Components: It consists of the tank, the tank cover, a pressure gauge and a pressure regulator.

Dimensions: As shown, the digester has tank of 150 liters with a height of 1.2m and diameter of 0.4m.

Fig. 4.2 Pressure Gauge

4.1.2 Inlet system

Components: It consists of a check valve and steel pipes.

Dimensions: The valve is a 3 inch diameter valve and 4 inch steel pipes.

Fig. 4.3 Check Valve

4.1.3 Outlet system

Components: It consists of a manual valve, an outlet tank and connecting pipes

Dimensions: The manual valve has a 3 inch diameter, the steel pipes are 4 inches in diameter and the outlet tank has a volume of less than 10 liters.

Fig. 4.4 Manual Valve

4.1.4 Materials Used

The digester tank, the outlet tank and the connecting pipes are all made of stainless steel. The check valve is made of brass and the manual valve is made up of cast iron.

4.2 DISCUSSION

The design used for the digester was aimed at ensuring continuous biogas production, improving efficiency and maintaining simplicity. The dimensions loosely balance with the capacity of processing household waste within manageable size and cost.

The choice of materials were selected due to their suitability for biogas production. Stainless steel prevents rusting and ensures longevity, the corrosion resistance and aesthetic appeal of brass also helps the system while the high tensile stress, wear and corrosion resistance and cost effectiveness of cast iron makes it a good choice for the manual valve.

The digester is expected to efficiently and continuously produce biogas from household waste to serve various purposes. Our calculation estimates that 7 liters of biogas can be produced per kg of feedstock.

The major challenge encountered during the fabrication was finding a suitable pump for the system, other foreseeable potential challenges could include feedstock consistency, regular maintenance and temperature control.

With certain modifications to address the challenges, the design is suitable for both urban and rural settings and is also scalable for larger or smaller households for waste management and energy production.

CHAPTER FIVE

CONCLUSION AD RECOMMENDATIONS

5.1 CONCLUSION

Pursuant to its objective, the design and fabrication of the continuous household biogas digester has provided a sustainable and cost friendly solution for household energy needs and waste management.

The continuous biogas digester has was successfully designed and manufactured.

5.2 RECOMMENDATIONS

The continuous biogas digester should be carefully loaded and tested for performance.

Based on the experience of the project, the following recommendations are advised to enhance functionality;

i. Improvements should be made on the deigns and the use of reinforced materials should be considered as opposed to stainless steel and cast iron.
ii. Insulation should be provided to the system to aid with temperature control.
iii. The manual pump procured had some shortcomings and further work should be done to improve the pump and performance of the system.
iv. Regular maintenance should be done to maintain the efficiency and durability of the system.
v. Initiatives should be taken to train the communities on how to operate and maintain such systems.
vi. Further research should be carried out to improve the functionality of the system and new technologies should also be used to make the system better and more efficient.

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