

VIABILITY OF SUBSTITUTION OF ELECTRICITY WITH BIOGAS FOR  
THERMAL USES AT NEUDAMM CAMPUS OF THE UNIVERSITY OF  
NAMIBIA

A MINI THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE  
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## **ABSTRACT**

The growing demand for sustainable and affordable energy solutions in rural areas has led to increased interest in biogas technology, particularly in developing regions. This thesis presents the design and evaluation of a low-cost biogas digester for the Neudamm Campus of the University of Namibia. The study addresses the campus's energy cost and the underutilisation of livestock manure as a renewable energy resource.

A 100 L digester, constructed from locally available materials, was fed with a cow manure-water slurry and operated over a 60-day period. Key operational parameters included an estimated 30-day hydraulic retention time, with pressure monitored three times daily in the first week, twice daily from Days 8–21, and once daily thereafter..

The digester achieved an average daily biogas yield of 0.95 L, equivalent to 7.61 MJ (2.11 kWh). Based on manure availability at Neudamm (22.2 tonnes/day), the system could theoretically produce 318.76 L/day of biogas. This represents a payback period of 2.5 years and an estimated 594% return on investment over a 10-year lifespan.

The gas produced was sufficient to substitute part of the campus's electricity demand for cooking and water heating, demonstrating both economic and environmental benefits, including reduced greenhouse gas emissions and nutrient-rich slurry for fertilizer.

The study acknowledges limitations such as short monitoring duration, reliance on pressure as the sole gas measurement, and minor leakage issues.

Despite these constraints, the study demonstrates the feasibility of low-cost, small-scale digesters in Namibia and provides a replicable model for rural settings. The findings contribute to renewable energy knowledge in Southern Africa and highlight practical opportunities for integrating biogas into campus and farm operations.

Keywords: Biogas, Renewable Energy, Sustainability

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## LIST OF ACRONYMS

This section provides a list of abbreviations used throughout this paper, along with their meanings.

**CH<sub>4</sub>**: Methane – A primary component of biogas and a significant greenhouse gas.

**CO<sub>2</sub>**: Carbon Dioxide – A greenhouse gas and one of the major components of biogas.

**DIY**: Do It Yourself – Refers to the approach of constructing and maintaining the digester using readily available materials and without professional help.

**HDPE**: High-Density Polyethylene – A durable plastic material used in the construction of the digester to resist chemical reactions and mechanical wear.

**kPa**: Kilopascal – A unit of pressure used to measure the pressure build-up in the biogas digester.

**kWh**: Kilowatt-hour – A unit of energy used to quantify the energy output or consumption.

**L**: Litre – A unit of volume, used to quantify the volume of biogas produced per day.

**m<sup>3</sup>**: Cubic Meter – A unit of volume used to express the volume of biogas produced.

**MJ**: Megajoule – A unit of energy measurement, used to express the energy content of biogas.

**N\$**: Namibian Dollar – The currency used in Namibia, relevant for cost analysis in this study.

**PVC**: Polyvinyl Chloride – A type of plastic used in the construction of certain components of the digester.

**ROI**: Return on Investment – A financial metric used to evaluate the profitability of the biogas digester.

**SAV:** Single Action Valve – A type of valve used in the biogas digester system for controlling gas flow.

**SV:** Soil Vent – A type of pipe used in the construction of the digester.

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## **DEDICATION**

To my children, Dorteia, Pineas, Tomas and Brave


This thesis is dedicated to you with the hope that it serves as a source of inspiration and encouragement. May it remind you that the pursuit of knowledge is a powerful tool that can open doors to endless opportunities and pave the way for fulfilling careers. Always strive to further your studies, set high goals, and believe in your potential. The journey may be challenging, but the rewards are worth the effort. Embrace every opportunity to learn and grow, for it is through education that you will shape a bright and successful future.

With all my love and encouragement,

Pineas P Tomas

## DECLARATION

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|                 |   |              |
|-----------------|---|--------------|
| Pineas P Tomas  |  | October 2025 |
| Name of Student | Signature   | Date         |

# **1 INTRODUCTION**

This chapter provides a comprehensive overview of the research, detailing the background of the study, the research problem, objectives, significance, and limitations. It concludes with an outline of the study's scope, providing a preview of the following chapter of the thesis.

## **1.1 Background of the study**

The widespread and localized adoption of renewable energy technologies such as solar, wind, and hydro power have become well-established, particularly in developed nations. However, despite the enormous potential, the cost of energy conversion technologies remains prohibitively high for many in Africa. Biomass, another renewable energy source, is both sustainable and abundant, and can be converted into biogas, primarily composed of methane, a combustible gas (Mupambwa, Namwoonde, Liswaniso, Hausiku, & Ravindran, 2019). By constructing anaerobic biogas digesters using locally available materials, medium and large-scale farmers with substantial livestock manure can harness sustainable, low-cost clean energy and use the nitrogen-rich effluent as fertilizer for their crops. Nonetheless, in Namibia, due to limited knowledge and technological access, large amounts of biomass, such as livestock manure, are often left to decompose untreated, releasing methane, a greenhouse gas that harms the environment. This thesis explores the design of a simple, low-cost, yet effective biogas digester as a potential solution to meet farmers' clean energy needs

Biogas, which is rich in methane, is generated through the anaerobic digestion of organic materials such as food waste, animal manure, and other agricultural and organic residues . The production of bioenergy from agricultural biomass or residues is becoming increasingly attractive due to the rising cost of fossil fuels and the urgent need to reduce global warming caused by increasing greenhouse gas emissions (Okudoh, Trois, Workneh, & Schmidt, 2014). While biogas consists of methane, carbon dioxide, and other impurities, methane is the valuable component due to its high calorific value, making it an ideal biofuel for heating and electricity generation (Otieno, Kiplimo, & Mutwiwa, 2023).

In Namibia, large quantities of livestock wastes, such as cow dung and abattoir waste, are generated. Disposing of these wastes safely is particularly challenging in urban areas where space is limited (Otieno et al., 2023). Namibia raises over 351,000 cattle annually on average (Namibia Statistics Agency, 2016). However, despite the substantial livestock population and the significant amount of manure produced, which has the potential to generate considerable biogas, this agricultural residue is seldom utilized for energy production. For instance, the Neudamm campus of the University of Namibia, an agricultural campus with a cattle population of more than 700, continues to use electric stoves and geysers for cooking and water heating, incurring high costs on electricity.

Besides providing energy advantages, anaerobic waste decomposition in a digester helps the environment by preventing the release of untreated manure wastes, which emit raw methane - a gas more harmful to the climate than carbon dioxide. After the

manure is digested, farmers can use the resulting substrate as fertilizer for their crops, thereby enhancing food security (Mrosso, Mecha, & Kiplagat, 2023).

## **1.2 Statement of the Problem**

The University of Namibia is currently facing significant financial challenges, further aggravated by the high costs of conventional electricity for water heating.

Beyond financial costs, large volumes of livestock manure at the Neudamm Campus remain underutilised, releasing methane emissions when unmanaged and representing a missed opportunity for renewable energy production. Nationally, Namibia lacks widespread adoption of biogas technology despite favourable livestock resources and supportive renewable energy policies. This highlights technological, environmental, and policy gaps that a low-cost, locally adaptable digester could help address.

## **1.3 Research Question**

Can a locally constructed digester provide a technically feasible and economically viable alternative to electricity-based thermal energy at Neudamm Campus?

## **1.4 Objectives of the Study**

The aim of this project is to design a cost-effective and environmentally sustainable biogas digester system for the Neudamm Campus of the University of Namibia (UNAM), demonstrating clear, quantifiable benefits.

To achieve the said aim, the following four objectives were formulated:

- a) To design a low-cost biogas digester
- b) To determine the biogas yield per unit mass of cow manure

- c) To quantify the potential of biogas production from manure at Neudamm campus
- d) To determine the possible cost savings due to biogas production and use in comparison to conventional electricity usage

### **1.5 Significance of the Study**

The results of this research project will enhance awareness in the field of renewable energy and educate the community on converting agricultural waste into energy sources. It will encourage individuals to construct their own low-cost biogas digesters, thereby reducing electricity bills. Furthermore, the widespread adoption of biogas in Namibia will improve the national carbon footprint and contribute to the achievement of access to affordable and clean energy, in alignment with the United Nations Sustainable Development Goals 7 (SDG7), which focuses on ensuring access to affordable, reliable, sustainable, and modern energy for all.

### **1.6 Limitations of the study**

Despite the availability of sophisticated, optimized digester designs, this study employs a simple design using only materials available in local Namibian shops. Furthermore, it is recognized that livestock feed significantly impacts the energy yield from manure used for biogas generation. However, due to the ongoing drought in the country, there are limited options for selecting and categorizing manure based on different feeds. Consequently, the digester was tested using any fresh cow manure available at the time.

## **1.7 Delimitation of the study**

The agricultural waste used in this study was limited to fresh cattle manure sourced exclusively from cattle at the Neudamm Campus of the University of Namibia.

## **1.8 Outline of the Thesis**

This thesis is structured into seven chapters, each addressing a specific aspect of the study on Viability of Substitution of Electricity with Biogas Energy for Thermal Uses at Neudamm Campus of The University of Namibia.

**Chapter 1: Introduction:** This chapter provides the background, problem statement, objectives, significance, Limitation, Delimitation, Definition of terms, Outline and the Summary

**Chapter 2: Literature Review:** This chapter reviews existing literature on biogas production, focusing on anaerobic digestion processes, biogas technology applications, and relevant case studies from Africa and other developing regions. The chapter also examines the economic, environmental, and technical aspects of biogas systems.

**Chapter 3: Research Methods:** This chapter describes the materials used and the methodology adopted for the design and testing of the biogas digester. It covers the experimental setup, data collection procedures, and the analysis techniques employed to evaluate the performance of the digester.

**Chapter 4: Presentation of Results:** This chapter presents the findings from the experimental study, including data on biogas production, and the economic feasibility of the system.

**Chapter 5: Discussion:** This chapter discusses the results in the context of existing literature, highlighting the implications of the findings for the design and implementation of biogas systems at Neudamm Campus and similar settings. The discussion also addresses the potential challenges and benefits of adopting biogas technology in rural areas.

**Chapter 6: Conclusion:** This chapter concludes the thesis by summarizing the key findings and their significance.

**Chapter 7: Recommendations:** This chapter provides recommendations for future research, potential improvements to the biogas digester design, and suggestions for policy and practice to promote biogas technology in Namibia.

**References:** This chapter lists all the academic references, articles, books, and other sources cited throughout the thesis. The references are presented following a consistent citation style, providing the necessary details for locating the original sources.

**Appendices:** This chapter includes supplementary material relevant to the thesis but not included in the main body.

## **1.9 Summary**

The introduction chapter set the stage for the study on designing a low-cost biogas digester for the Neudamm Campus of the University of Namibia. It outlined the background and rationale for the research, emphasizing the need for sustainable energy

solutions in rural settings. The chapter began by discussing the global energy crisis and the potential of biogas as a renewable energy source. It highlighted the environmental and economic benefits of biogas technology, including waste management and cost savings.

The specific context of the Neudamm Campus, detailed the campus's energy needs and the challenges it faces in accessing reliable and affordable energy sources. It justified the choice of a low-cost biogas digester as addressing the need for a locally applicable and economically feasible solution.

Key objectives of the study are outlined, as well as the scope of the study, the research questions, and the overall significance of the research in contributing to sustainable energy solutions in rural Namibia.

*The next chapter is on literature review related to the study subject.*

## **2 LITERATURE REVIEW**

This chapter explores the potential of biogas as a renewable energy source within the broader context of renewable energy technologies. Biomass, abundant and sustainable, offers a promising alternative to other renewable sources such as Solar, Wind and Hydro energy. Specifically, biogas, obtained from anaerobic digestion of biomass, presents an accessible and cost-effective solution for rural and agricultural communities in Africa. Through locally constructed anaerobic digesters, farmers can convert livestock manure into clean, low-cost energy. The chapter delves into the importance of biogas in rural settings and for small scale farmers, technical aspects of biogas production, various digester designs, economic and environmental impacts, and the challenges and solutions for successful biogas project implementation.

### **2.1 Introduction to Biogas**

#### **2.1.1 Biogas as a Renewable Energy Source**

Renewable energy technologies like solar, wind, and hydro have been significantly adopted, especially in developed countries. Despite the vast potential, the cost of energy conversion technologies remains prohibitive for many in Africa (Mupambwa et al., 2019). Biomass, another renewable energy source, is abundant and sustainable, offering a viable alternative. Anaerobic digestion of biomass produces methane (CH<sub>4</sub>), with a calorific value of approximately 55.5 MJ/kg, that can burn in oxygen to produce heat. Breaking the bonds between Carbon, Hydrogen and Oxygen requires energy that can be supplied by certain microbes as they digest these biomass materials. In the absence of oxygen, Carbon and Hydrogen recombine to form CH<sub>4</sub>. Burning CH<sub>4</sub>

requires heat to be supplied to break the Carbon from the Hydrogen, and when Oxygen from the air recombines with Carbon to form Carbon dioxide, and with Hydrogen to form water (H<sub>2</sub>O), more energy is released in comparison to what was needed to break the CH<sub>4</sub>. The equation that describes the difference in these energy values indicates that the enthalpy is negative. Refer to enthalpy calculation under chapter 3

Thus, combustion of methane will give out more energy, though some of that energy still is used to break the methane into Carbon and Hydrogen. The net heat produced when Carbon combines with Oxygen to form Carbon dioxide, and Hydrogen combines with Oxygen to form Water, is more, making CH<sub>4</sub> an energy carrier. Through locally constructed anaerobic digesters, farmers can harness livestock manure to produce clean, low-cost energy.

### **2.1.2 Importance of Biogas in Rural Settings**

Biogas technology holds significant promise for rural areas, offering a range of benefits that extend beyond just energy production. In rural settings, where access to conventional energy sources like electricity is often limited or unreliable, biogas serves as a viable alternative that can greatly improve the quality of life.

**Energy Security and Environmental Sustainability:** Biogas provides a sustainable energy source by converting organic waste, such as animal manure and crop residues, into clean fuel. This not only reduces dependence on firewood and other traditional biomass fuels but also helps to mitigate deforestation, soil degradation, and greenhouse

gas emissions. By harnessing locally available materials, rural communities can achieve greater energy security and contribute to environmental conservation.

**Socio-Economic Benefits:** One of the key socio-economic benefits of biogas technology is the improvement of public health, particularly through the reduction of indoor air pollution. In many rural households, cooking with firewood or charcoal produces harmful smoke, which can lead to respiratory problems, eye irritation, and other health issues. Biogas burns more cleanly, producing fewer pollutants and thereby improving indoor air quality. This transition can significantly reduce the incidence of respiratory illnesses, particularly among women and children who are often most exposed to cooking smoke (Amigun & Von Blottnitz, 2010).

The adoption of biogas technology can empower women by reducing the time and labour associated with collecting firewood, a task that typically falls on women and girls in rural communities. With less time spent on these labour-intensive activities, women can engage in other productive activities, such as education, income-generating ventures, or community involvement. This shift not only enhances the socio-economic status of women but also contributes to gender equality and the overall development of the community.

**Economic Savings and Agricultural Productivity:** The use of biogas also offers economic advantages, as it can significantly reduce household energy costs. Families that switch to biogas for cooking and heating can save money that would otherwise be spent on purchasing firewood, charcoal, or other fuels. Additionally, the by-product of biogas production, known as digestate, is a nutrient-rich slurry that can be used as a

natural fertilizer. This not only enhances soil fertility and agricultural productivity but also reduces the need for chemical fertilizers, leading to further cost savings and promoting sustainable farming practices.

**Community Development and Sustainability:** Biogas technology fosters community development by encouraging the collective management of resources and waste. Communities can work together to establish and maintain biogas systems, sharing the benefits and responsibilities. Such collaborative approaches strengthen social ties and promote sustainable development at the local level.

Institutions with access to biomass, like the University of Namibia's agricultural campuses, can also benefit from biogas production and use, at a larger scale than household projects.

## **2.2 Technical Aspects of Biogas Production**

Biogas production is a complex process that hinges on anaerobic digestion, a natural biological process where microorganisms break down organic matter in the absence of oxygen. This process is the foundation of biogas technology, converting waste materials like animal manure, crop residues, and food waste into a mixture of gases, primarily methane and carbon dioxide, which can be used as a renewable energy source. Understanding the interconnected stages of anaerobic digestion is crucial for optimizing biogas production and ensuring the efficiency of the system.

### **2.2.1 Four Fundamental Processes Anaerobic Digestion**

Figure 2.1 highlights the four fundamental processes that occur in a biogas digester to produce methane.

**Hydrolysis:** In the hydrolysis reaction, water reacts with cellulose to produce glucose as the primary product. Along with glucose, additional products such as formic acid, levulinic acid, and hydroxymethyl furfural are formed (Okudoh et al., 2014). This reaction involves the conversion of cellulose into the final products, aided by microorganisms that help break down chemical bonds. Enzymes play a crucial role in this process, where high molecular weight enzymes are transformed into smaller molecular weight forms.

Various bacteria, including Bacteroides, Lactobacillus, Propionibacterium, Sphingomonas, Sporobacterium, Megasphaera, and Bifidobacterium, are involved in the hydrolysis reaction. Large and stable enzymes are utilized in this process, following a first-order kinetic method. Enzymes like cellulase, amylase, protease, lipase, and xylanase are responsible for catalyzing the hydrolysis reaction (Keerthana Devi et al., 2022).

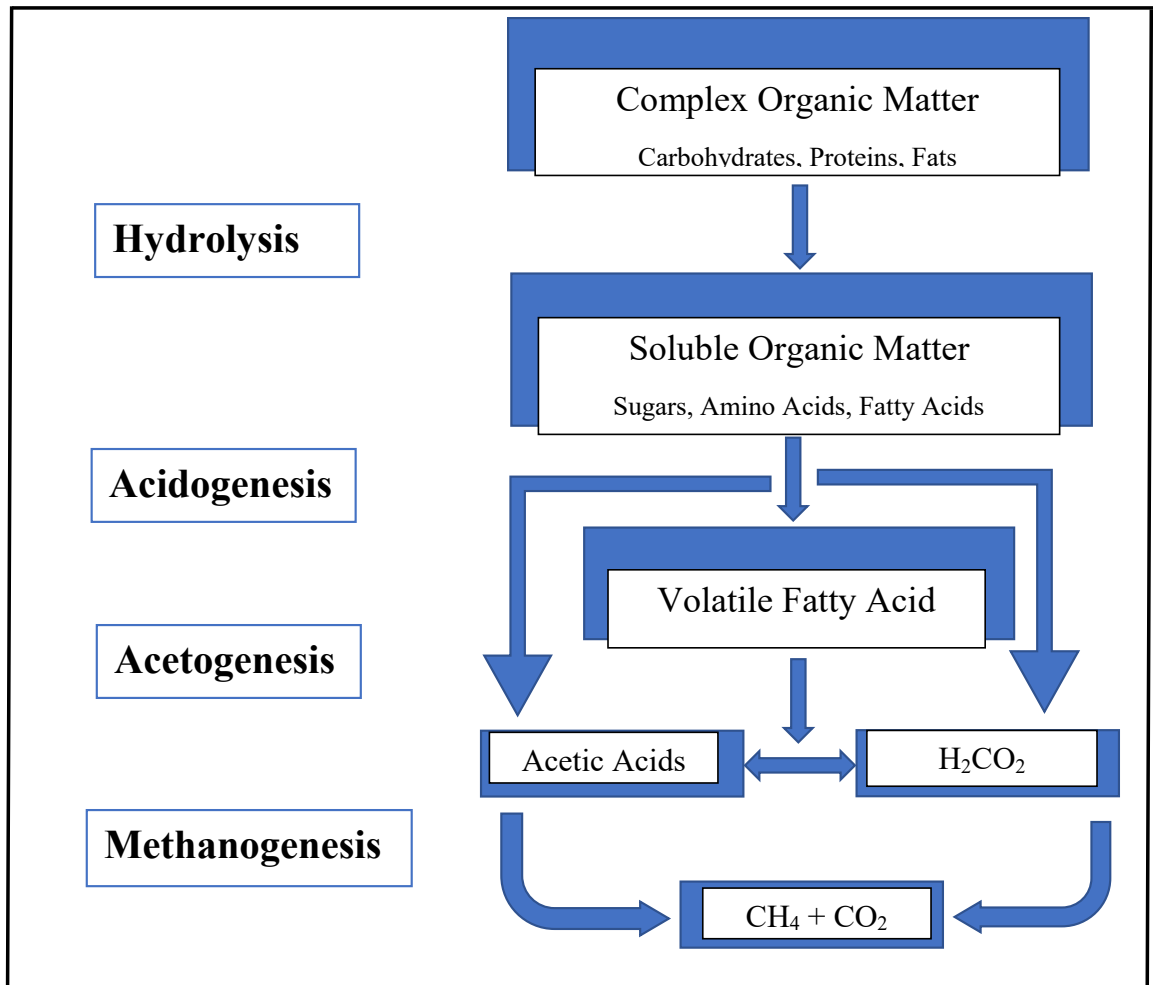
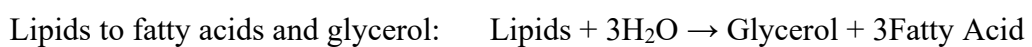
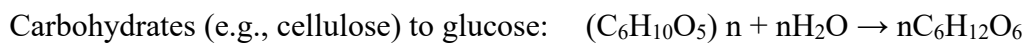


Figure 2-1: Anaerobic digestion Process Flow Chart

**Chemical reactions:** complex organic polymers such as carbohydrates, proteins, and fats are broken down into simpler monomers like sugars, amino acids, and fatty acids.

This process is facilitated by hydrolytic enzymes:



**Acidogenesis:** Further decomposition occurs as acidogenic bacteria ferment the hydrolysis products, yielding ammonia, carbon dioxide, and hydrogen (Keerthana Devi et al., 2022). Additionally, other low molecular weight organic compounds, including carbonic acids and alcohols, are generated. In the process of biogas production, several enzymes play crucial roles in catalyzing specific reactions. These enzymes include acetate kinase, acetaldehyde dehydrogenase, C-acetyl transferase, and hydrogen lyase. The overall reaction involves the conversion of glucose into ethanol and carbon dioxide. Additionally, hydrogen reacts with glucose to produce acetic acid and water. It is important to note that these reactions occur under acidic conditions and are maintained at a specific acidic pH value (Cavinato, Fatone, Bolzonella, & Pavan, 2010).

**Chemical reactions:** The products of hydrolysis are further broken down by fermentative bacteria into volatile fatty acids, alcohols, hydrogen (H<sub>2</sub>), carbon dioxide (CO<sub>2</sub>), and other by-products:

Glucose to ethanol and CO<sub>2</sub>:  $C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$

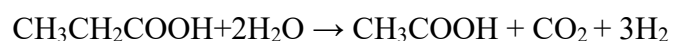
Glucose to butyrate:  $C_6H_{12}O_6 \rightarrow CH_3CH_2CH_2COOH + 2H_2 + 2CO_2$

**Acetogenesis:** Acetogenic bacteria are a group of microorganisms that convert various substrates, such as alcohols, fatty acids, aromatic acids, and amino acids, into acetic acid under acetogenic conditions. These bacteria are unique in their ability to produce acetic acid directly from glucose through the reaction with water, resulting in the production of acetic acid, carbon dioxide, and hydrogen (Keerthana Devi et al., 2022).

One of the most well-studied reactions facilitated by acetogenic bacteria is the conversion of ethanol into acetic acid. During this reaction, ethanol reacts with water to produce acetate and hydrogen, with a high liberation of hydrogen. This reaction is particularly important for the production of hydrogen-producing acetogenic bacteria, such as *Syntrophomonas* and *Syntrophobacter*, which can generate a yield of up to 70% from the reaction. The ability of acetogenic bacteria to facilitate the conversion of various substrates into acetic acid is due to the presence of specific enzymes, such as the hydrogenase enzyme and the carbon monoxide dehydrogenase enzyme. These enzymes play a crucial role in the metabolism of these bacteria and allow them to efficiently convert a wide range of substrates into acetic acid. The combination of methanogenesis and acetogenesis is an important step in the production of biogas, as it allows for the efficient conversion of organic matter into methane and carbon dioxide. Acetogenic bacteria, such as *Clostridium* and *Syntrophospora*, play a crucial role in this process by using the carbon monoxide dehydrogenase enzyme to convert carbon monoxide into acetic acid, which can then be converted into methane through methanogenesis (Keerthana Devi et al., 2022).

**Chemical reactions:** The products of acidogenesis, particularly volatile fatty acids, are converted into acetic acid, hydrogen, and carbon dioxide by acetogenic bacteria:

Propionate to acetate, CO<sub>2</sub>, and H<sub>2</sub>:



Butyrate to acetate and hydrogen:



**Methanogenesis:** The methanogenesis reaction is a process that converts acetic acid into methane, which is regulated by methanogenic bacteria. These bacteria are responsible for the conversion of acetic acid into carbon dioxide and methane, as well as the reduction of carbon dioxide and hydrogen gas into methane and water. The methanogenesis reaction involves two different types of bacteria: hydrogenophilic and acetophilic bacteria (Okudoh et al., 2014). Hydrogenophilic bacteria are responsible for the reduction of hydrogen gas and carbon dioxide into methane, while acetophilic bacteria are responsible for the conversion of acetic acid into methane. During the methanogenesis reaction, these two types of bacteria work together to convert all substrates into a final product, which is biogas (Maria et al., 2023).

**Chemical reactions:** In methanogenesis, methanogenic archaea convert the products of acetogenesis (mainly acetate, hydrogen, and carbon dioxide) into methane and water:

Acetoclastic methanogenesis (acetate  $\text{COOH} \rightarrow \text{CH}_4 + \text{CO}_2$   
to methane and  $\text{CO}_2$ ):

Hydrogenotrophic methanogenesis  $\text{CO}_2 + 4\text{H}_2 \rightarrow \text{CH}_4 + 2\text{H}_2\text{O}$   
( $\text{CO}_2$  and hydrogen to methane and  
water):

**Interconnectedness of the Process:** Each stage of anaerobic digestion is interconnected and dependent on the preceding and following stages. For instance, the effectiveness of methanogenesis hinges on the successful completion of hydrolysis, acidogenesis, and acetogenesis. If one stage is disrupted or inefficient, it can lead to

imbalances in the system, reducing the overall biogas yield and potentially causing operational issues. Understanding these interconnections is crucial for designing and managing biogas systems that maximize energy production and maintain stability within the digester.

By grasping the full scope of anaerobic digestion, from hydrolysis to methanogenesis, one can better appreciate the technical aspects of biogas production and make informed decisions to enhance the efficiency and sustainability of biogas systems.

### **2.2.2 Nitrogen Enrichment Mechanisms in Biogas Digester Effluent**

The effluent from biogas digestion becomes rich in nitrogen due to the breakdown of nitrogenous compounds during the anaerobic digestion process. In biogas digestion, nitrogen primarily originates from the feedstock, such as manure, which contains nitrogenous compounds like proteins, urea, and ammonia (Karidio Daouda Idrissa et al., 2023). During anaerobic digestion, proteins are broken down into amino acids through proteolysis, and these amino acids are further deaminated to produce ammonia ( $\text{NH}_3$ ). Ammonia can then volatilize into the biogas, but a significant portion remains in the digester fluid. The pH, temperature, and microbial activity within the digester influence the form and amount of nitrogen released.

Ammonia ( $\text{NH}_3$ ) in the digester can be converted to ammonium ions ( $\text{NH}_4^+$ ) in the presence of water, especially at lower pH levels. The ammonium ions are soluble in the digester fluid, contributing to the nitrogen content of the effluent.



The nitrogen in the effluent is primarily in the form of ammonium ions, which are highly soluble and remain in the liquid phase. The retention of these ions, along with partially degraded organic nitrogen compounds, results in effluent that is rich in nitrogen. This nitrogen-rich effluent can be beneficial as a fertilizer due to its nutrient content, promoting plant growth when applied to agricultural fields (Ali et al., 2020).

### 2.2.3 Types of Feedstocks

Various organic wastes, including food waste, animal manure, and agricultural residues, can serve as feedstock for biogas production. Each feedstock type offers different biogas yields and compositions (Singh et al., 2023), (Otieno et al., 2023), as shown in Table 1. Namibia produces significant livestock waste, which remains largely underutilized despite its potential for biogas production (Namibia Statistics Agency, 2016).

**Table 1: Methane and energy equivalent yields for various feedstocks in a Biogas Digester at 25°C**

| Feed Stock | Methane Yield (m <sup>3</sup> /t) | Mass (kg) | Retention Time in Biogas Digester, at 25°C (days) | Energy (kWh equivalent) |
|------------|-----------------------------------|-----------|---|-------------------------|
|            |                                   |           |   |                         |

|                      |     |       |    |          |
|----------------------|-----|-------|----|----------|
| Cow dung             | 700 | 469.0 | 30 | 7,269.50 |
| Poultry poops        | 550 | 368.5 | 20 | 5,712.75 |
| Horse manure         | 500 | 335.0 | 40 | 5,192.50 |
| Pig manure           | 360 | 241.2 | 20 | 3,743.40 |
| Goats & Sheep manure | 350 | 234.5 | 30 | 3,634.75 |
| Maize Grain          | 324 | 217.1 | 60 | 3,364.05 |
| Bran                 | 270 | 180.9 | 25 | 2,804.00 |
| Old Bread            | 254 | 170.2 | 25 | 2,638.10 |
| Corn                 | 106 | 71.02 | 55 | 1,100.81 |
| Potatoes Reject      | 92  | 61.64 | 40 | 957.42   |
| Animal Blood         | 83  | 55.61 | 15 | 861.95   |

### **2.3 Overview of Common Biodigester Designs**

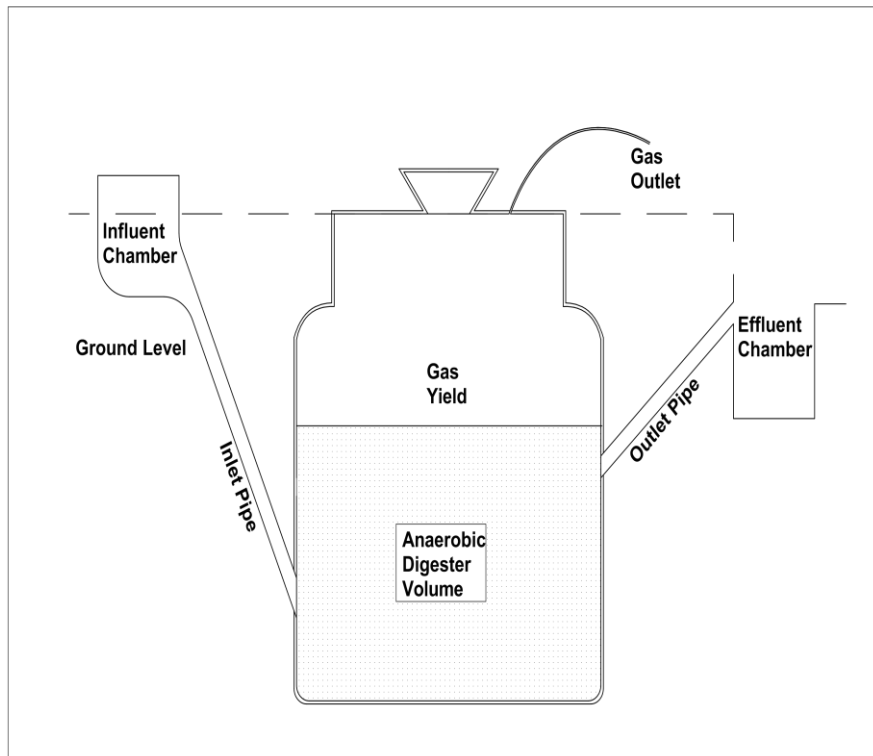
Biodigesters come in various designs, each tailored to specific needs and environmental conditions. The primary types include fixed-dome, floating drum, and tubular digesters. Each design has unique features, advantages, and challenges, making them suitable for different applications. Understanding these designs helps in selecting the most appropriate biodigester for efficient biogas production and waste management.

#### **Fixed-Dome Digester**

The conventional fixed-dome digester, crafted from either concrete or steel, is a gas-tight structure typically built underground. As depicted in Figure 2-2, it features an

inlet pipe for waste introduction into the digester, and a sizable storage volume where the slurry undergoes digestion. Positioned atop the digester is a gas storage space that houses the generated biogas. On the opposite side of the influent, there exists an effluent pipe through which digestate overflows as more waste is fed into the system.

Waste material is combined with water and introduced into the digester, where it interacts with substances already undergoing degradation. Within the digester, anaerobic digestion occurs, resulting in the generation of biogas in the slurry. The produced gas rises to the upper section of the digester, where it accumulates and creates pressure, with the gas outlet valve closed. The pressure build-up at the digester's top forces some of the digested slurry to exit through the outlet pipe. Upon the release of gas through the gas outlet, the pressure at the digester's top decreases, prompting the slurry inside to re-establish equilibrium at a new level.



***Figure 2-2: Schematic diagram of the Fixed-Dome Digester***

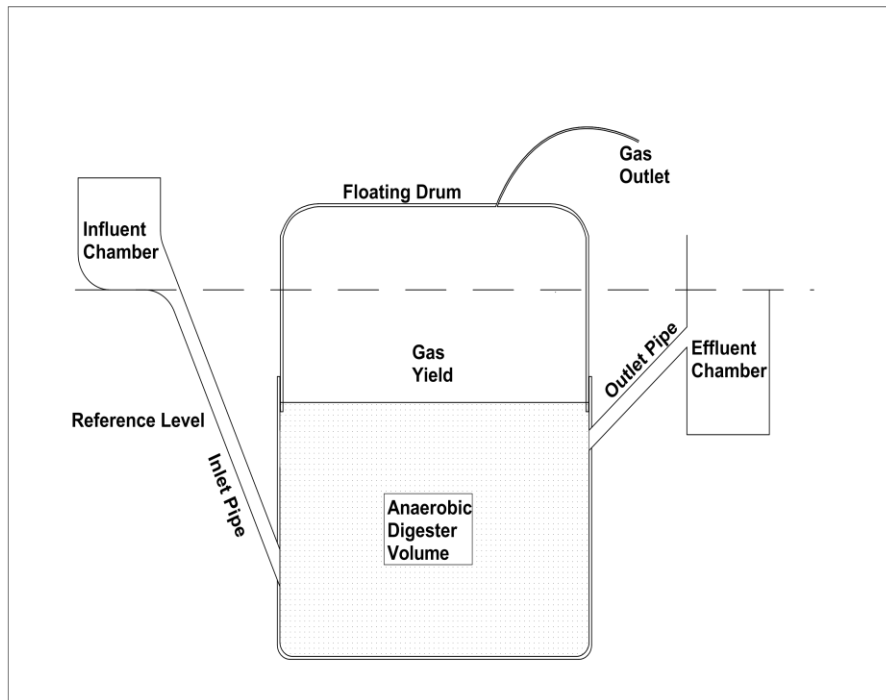
The fixed-dome digester boasts a reasonably economical construction and, if built correctly, exhibits longevity. This underground digester type offers a more consistent temperature and is space-efficient when contrasted with alternative digester varieties (Singh et al., 2023). However, achieving a gas-tight construction for a fixed-dome digester necessitates the use of specific sealants, Polyurethane Sealants, Silicone Sealants, Epoxy Sealants or Bituminous Sealants. Furthermore, it requires expertise of skilled personnel to prevent the risk of explosions and gas leakage. The underground construction of fixed-dome digesters also introduces difficulties in their maintenance.

### **Floating drum digester**

The essential elements of a floating drum digester comprise the digester tank, gas holder (floating drum), influent, effluent pipe, and gas outlet. The influent pipe serves

to introduce organic waste into the digester, while the effluent pipe enables the removal of digestate from the system. The gas outlet functions as a means to collect and utilize the biogas produced within the digester. Positioned atop the slurry inside the digester, the gas holder, often a large drum or dome-shaped structure (refer to Figure 2), floats. As gas accumulates and pressure rises within the digester, the gas holder ascends to accommodate the generated gas. Upon the release of gas through the gas outlet, the weight of the gas holder pushes it down to a new position.

The construction of a floating drum digester is cost-effective and straightforward, and it does not demand highly skilled personnel. The volume of accumulated gas can be easily gauged by measuring the displaced volume of the floating drum. Additionally, its mobility facilitates easier emptying and maintenance. The gas pressure within the floating drum stays constant. However, floating drums made from steel are costly and prone to corrosion, especially in areas with moving parts. Poor balance can cause the floating drum to become stuck and hinder its vertical movement. As the gas holder ascends with increased pressure, the gas from a floating drum maintains a low pressure. Moreover, it necessitates more frequent maintenance due to the wear and potential damage to its moving parts.

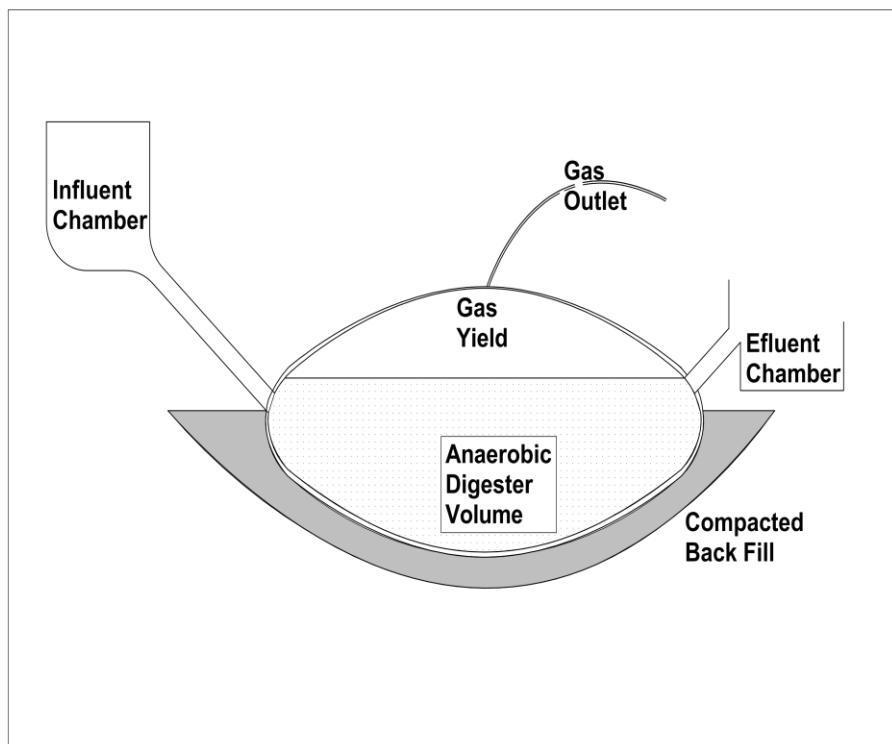


*Figure 2-3: Schematic diagram of the Floating Drum Digester*

### **Tubular Digester**

The tubular digester is typically an elongated, horizontally positioned tube crafted from flexible materials like plastic and rubber. This tube is tightly sealed to establish an oxygen-free environment, fostering the growth of microorganisms that produce methane. Both the influent and effluent are directly connected to the surface of a balloon (refer to Figure 3). In regions with warm climates, tubular digesters efficiently absorb heat due to their direct exposure to sunlight. The enclosed design assists in containing the odours associated with the anaerobic digestion process. Noteworthy advantages include a low construction cost, ease of transportation, and straightforward emptying and maintenance procedures. However, tubular digesters come with certain drawbacks, including a relatively short lifespan, limited availability of construction

materials locally, and challenges in repair, which may require specialized skills not commonly found among local craftsmen.



*Figure 2-4: Schematic diagram of the Tubular Digester*

## **2.4 Successful Biogas Projects in Africa**

### **Khangezile Primary School, South Africa**

Khangezile Primary School, located in KwaThema, east of Johannesburg, implemented a biogas project as part of the Sustainable Energy and Livelihoods project by Earthlife Africa (Links, 2020). The school uses a biogas digester cooking and heating, funded by the European Union and Oxfam, which helps feed about 400 children twice a day. This initiative not only provides clean energy for cooking but

also addresses waste management issues and improves the quality of life for students and their families by reducing waste-related health problems.

### **Africa Biogas Partnership Programme (ABPP)**

The Africa Biogas Partnership Programme (ABPP) operates in multiple countries, including Ethiopia, Kenya, Tanzania, Uganda, and Burkina Faso. The program focuses on providing access to sustainable energy through the installation of biogas digesters in partnership with local enterprises, NGOs, and governments. By June 2018, the program had installed over 50,000 biodigesters, benefiting around 320,000 people. The initiative not only provides clean energy but also promotes low-carbon employment opportunities, particularly for women and youth, and enhances agricultural productivity through the use of biogas by-products as fertilizers (Clemens, Bailis, Nyambane, & Ndung'u, 2018).

### **Kenya's Biogas Program**

The study on the adoption and sustainability of biogas technology among farmers in Nakuru Districts, Kenya highlights how biogas technology has provided a sustainable solution for energy needs in rural areas, reducing dependence on firewood and improving waste management. The project encountered socio-economic constraints, but overall, it significantly improved the quality of life for the farmers by providing a reliable and clean energy source (Mwirigi, Makenzi, & Ochola, 2009).

### **Rwanda's Biogas Program**

The Rwanda Biogas program saw the implementation of biogas digesters in households across Rwanda. Supported by the Dutch government and implemented by

SNV Netherlands Development Organisation, the program began in 2007 and successfully installed over 12,000 biogas digesters by 2021. The biogas systems provided a sustainable energy source for cooking, reduced indoor air pollution, and utilized biogas slurry as a fertilizer, enhancing agricultural productivity. (Arthur, Baidoo, & Antwi, 2011).

## **2.5 Summary**

This chapter examines the potential of biogas as a renewable energy source, highlighting its significance within the broader renewable energy landscape, which includes solar, wind, and hydro energy. Biomass, a plentiful and sustainable resource, emerges as a promising alternative, particularly through the anaerobic digestion process that converts organic waste into methane-rich biogas. The chapter underscores biogas's vital role in providing low-cost, clean energy for rural and agricultural communities in Africa, especially through locally constructed digesters that utilize livestock manure.

The literature review covers several key aspects: the importance of biogas in rural settings, technical processes involved in biogas production, various biodigester designs, and the economic and environmental impacts of biogas technology. It details the four stages of anaerobic digestion—hydrolysis, acidogenesis, acetogenesis, and methanogenesis—each contributing to efficient biogas production. The chapter also explores different biodigester designs, including fixed-dome, floating drum, and tubular digesters, each with unique advantages and challenges.

The review concludes by discussing successful biogas projects in Africa, such as the Khangezile Primary School in South Africa, the Africa Biogas Partnership Programme, Kenya's Biogas Program, and Rwanda's Biogas Program. These case studies demonstrate biogas technology's capacity to provide sustainable energy, improve waste management, and enhance agricultural productivity, particularly in rural areas.

*The next chapter focuses on Research methods*

### **3 RESEARCH METHODS**

This chapter outlines the experimental approach used to evaluate the biogas production potential of a low-cost digester designed specifically for the Neudamm Campus of the University of Namibia. It details the research design, including the construction and operation of miniature sized biogas digester using locally sourced materials. The study area, sample collection methods, and data analysis techniques are described to ensure the reliability and validity of the results. Additionally, ethical considerations are discussed to provide a comprehensive understanding of the methodology employed in achieving the research objectives.

#### **3.1 Research Design**

This study employs a quantitative experimental research design to evaluate biogas production in a low-cost, custom-designed biogas digester at the Neudamm Campus of the University of Namibia. The experimental design was chosen to empirically test the effectiveness of the digester in producing biogas from cow manure. This approach involves feeding the digester with a solution of cow manure and water, collected from the campus's drinking facility, ensuring fresh manure is used. The experimental setup allows for an easy to do with accurate measurement of biogas yield by quantifying the pressure build-up within the digester using a pressure gauge. By doing so, the study aims to achieve its objectives of designing a low-cost digester, determining biogas yield per unit mass of cow manure, quantifying the potential biogas production at the campus, and evaluating the cost savings compared to conventional electricity usage. This method provides a reliable framework for assessing the feasibility of biogas production using locally available materials and resources.

Neudamm Campus hosts extensive livestock farming activities that make it an ideal site for biogas experimentation. The farm is divided into several units, including large stock, small stock, dairy, piggery, poultry, and agronomy, which provide reliable access to fresh cow manure for use as feedstock. These facilities ensured that the digester could be tested under realistic farm conditions, supporting the aim of assessing the feasibility of a low-cost biogas system using locally available resources. Sample

The study focused on cow manure from livestock at the Neudamm Campus. At Neudamm, the cow population consists of 107 dairy cows and 619 meat cows. On average, a dairy cow produces 54 kg of manure per day, while a meat cow produces 27 kg of manure per day. This results in a total manure mass of 22.2 tons per day.

Manure was collected from a drinking facility where cattle gather, ensuring the acquisition of fresh dung. Approximately 80 litres of fresh cow manure were available daily at the drinking trough. For this study, a sample of 20 litres of manure was used, which represented the cleanest manure that could be collected dairy without contamination from sand or other debris.

### **3.2 Research Instruments/Data Collection**

The primary research instrument in this study is a pressure gauge connected to the gas hose from the top of the digester to measure the buildup of pressure, which serves as a proxy for biogas production. This pressure gauge, an existing instrument widely used in biogas research, records readings that allow for the estimation of biogas volume generated over time.

### **3.2.1 Design of the biogas digester**

The digester design in this study focused on simplicity and cost-effectiveness to make biogas production accessible and affordable for farmers and villagers. By utilizing a straightforward design and locally available materials, the digester can be easily constructed by individuals with minimal technical expertise. This approach encourages the widespread adoption of biogas technology in rural areas, promoting sustainable energy practices and reducing dependency on expensive conventional fuels.

The design of the biogas digester was adapted from both the fixed dome and floating drum designs. The fixed dome design is known for its durability and efficiency, while the floating drum design offers simplicity and ease of construction. By combining elements of both designs, the new digester maintains the robustness of the fixed dome while incorporating the user-friendly aspects of the floating drum. This hybrid approach ensures that the digester is both effective in producing biogas and easy to build using materials from local shops, such as water drums, sewer pipes, low-pressure gas pipes, tank connectors, universal seals, pressure gauges, and shut-off valves

The positioning of the inlet and outlet pipes was carefully considered to optimize the flow of materials within the digester and ensure efficient biogas production. The inlet and outlet pipes are located on opposite sides of the digester to facilitate the separation of feedstock and digestate (Pilloni & Abu Hamed, 2021); (Karidio Daouda Idrissa et al., 2023). The inlet pipe is positioned higher than the outlet pipe to allow for the natural movement of slurry as gas accumulates within the digester. This design ensures

that as biogas is produced, the pressure forces the slurry to move downwards, pushing it into the effluent pipe and out of the digester (Nkoi, Lebele-Alawa, & Odobeatu, 2018). The height difference between the inlet and outlet pipes also helps maintain a consistent flow of materials, preventing blockages and ensuring continuous biogas production.

### **3.2.2 Digester sizing**

The volume of the digester was determined based on the feedstock quantity. Using the ratio of feedstock to digester volume (50kg per 2m<sup>3</sup>) (Singh et al., 2023), the necessary digester volume was calculated.

$$\text{Digester volume (DV)} = \frac{FQ \times 2}{50} \quad (2)$$

Where:

DV is the volume of the required digester

FQ is the available feed stock

### **3.2.3 Biogas digester Construction**

**Selection of Materials:** Locally available materials were employed to minimize costs and facilitate maintenance. This included a suitable container, pipes, and seals.

**Preparation of the Digester Container:** The container was cleaned thoroughly to ensure there were no contaminants that could interfere with the anaerobic digestion process.

**Installation of Inlet and Outlet Pipes:** The inlet and outlet pipes were placed on opposite sides of the container. The inlet pipe was positioned higher than the outlet pipe to allow the slurry to flow naturally, as the biogas accumulates, pressure builds up forcing the feedstock in the digester to move downwards, and its volume increases

**Sealing of the Container:** It is crucial to ensure that all joints and connections are airtight to prevent gas leakage. The use of appropriate seals and fittings to secure the inlet and outlet pipes is essential.

**Attachment of the Gas Outlet:** A gas outlet pipe was installed at the top of the container. This pipe can be connected to a biogas storage unit or directly to the point of use.

### **3.2.4 Experimental Setup**

**Preparation of the Feedstock:** Cow manure was mixed with water and stirred to create a slurry. The mixture should be consistent to ensure efficient fermentation.

**Filling the Digester:** The prepared slurry was poured into the digester through the inlet pipe until it filled the digester volume.

**Monitoring and Maintenance:** The digester was regularly checked for any leaks or blockages. In the case of the designed digester in this project, stirring was not possible, but periodical stirring of the slurry could enhance biogas production, if the design allows. Pressure readings were taken three times daily during the first week, twice daily during days 8–21, and once daily thereafter for the 60-day experimental period. Biogas composition (CH<sub>4</sub> %) was not measured due to equipment limitations; therefore, calorific value was estimated from literature

**Operating conditions:** Retention time was approximately 30 days, consistent with mesophilic operation

**Collection and Use of Biogas:** As biogas is produced, it will accumulate at the top of the digester and flow through the gas outlet pipe to the storage or usage point. In this project, a pressure gauge was installed at the entrance of the gas outlet line, to monitor the pressure as the gas accumulated in the digester.

### **3.3 Procedure**

The experimental setup involved feeding the biogas digester with a slurry. The digester design, adapted from both fixed dome and floating drum designs, uses locally available materials such as water drums, sewer pipes, low-pressure gas pipes, and pressure gauges. This design ensures the construction is cost-effective and accessible for local farmers.

Biogas production was quantified by measuring the pressure build-up within the digester using a pressure gauge. This measurement is critical as it directly correlates with the volume of biogas produced. The pressure gauge is connected to the gas hose from the top of the digester, allowing for continuous monitoring of gas production.

The data collection process was systematic to ensure accuracy and reliability. The digester was regularly monitored, and pressure readings were recorded at consistent intervals. This data was then analysed to determine the biogas yield per unit mass of cow manure, assess the potential for biogas production at Neudamm Campus, and

evaluate the cost savings from using biogas compared to conventional electricity usage.

Although the experiment employed three digesters to improve reliability, all were tested under identical conditions. Replicates under varying environmental conditions (e.g., temperature, manure type, or feedstock loading rates) would provide more robust validation of the results.

### **3.4 Data Analysis**

Data analysis in this study involved several steps to quantify biogas yield and perform a cost-benefit analysis. The data collected from the experimental setup, including pressure readings and volume measurements, were analysed using Excel.

#### **3.4.1 Biogas Yield Calculation**

To determine the volume yield of biogas per unit mass of cow manure, the following formula was used:

$$\text{Gas Yield (Y)} = \frac{\text{Volume of biogas Produced (V)}}{\text{Mass of feed stock (M)}} \quad (3)$$

where:

V is the total volume of biogas produced, measured in litres, at 9.95 kPa.

M is the mass of the cow manure feedstock, measured in kilograms.

The volume of biogas produced was calculated based on the pressure readings obtained from the pressure gauge. The ideal gas law can be employed to convert pressure readings into volume, assuming the temperature and pressure are constant:

$$PV = nRT \quad (4)$$

where:

P is the pressure of the gas.

V is the volume of the gas.

n is the number of moles of gas.

R is the ideal gas constant.

T is the temperature in Kelvin.

In this analysis, a temperature of 35oC inside the digester was assumed as it is commonly used in agricultural and small-scale biogas digesters, similar to the one discussed here.

### **3.4.2 Potential Biogas Production**

To estimate the potential biogas production from the manure at Neudamm Campus, the following formula was used:

$$\text{Potential Biogas Production}(P) = Y \times \text{Total Mass of Available Manure } (T)$$

(5)

where:

Y is the biogas yield per unit mass of cow manure.

T is the total mass of available manure, which could be estimated based on the average manure production per cow and the number of cows at the campus.

### **3.4.3 Cost-Benefit Analysis**

The cost-benefit analysis involved comparing the costs associated with constructing and operating the biogas digester to the savings generated from using biogas instead of conventional electricity.

#### **Cost of Construction**

- **Materials:** Costs of water drums, pipes, seals, pressure gauges, and other components.
- **Labour:** Costs associated with construction and assembling the digester.
- **Maintenance:** Costs of maintaining and repairing the digester.

#### **Operational Costs**

- **Feedstock:** Collection and transportation of cow manure. The manure was obtained free of charge, and the same will be assumed for large biogas digesters at Neudamm campus, otherwise it must be factored in.
- **Water:** This cost was also neglected as the amount of water is negligible in a campus that pumps water for irrigation from boreholes.
- **Labour:** Daily operation and monitoring of the digester.

- Effluent: Collection and disposal or usage of effluent.

### **Savings**

$$\text{Energy Savings}(S) = \text{Energy Cost of Conventional Electricity}(E) - \text{Cost of Biogas Production}(B) \quad (6)$$

where:

E is the cost of using conventional electricity for heating and cooking.

B is the cost of producing biogas, including construction and operational costs.

### **3.4.4 Comparative Analysis**

The results from this study were compared with existing literature and similar studies to validate the findings and provide context. This comparison helped in understanding the effectiveness of the designed biogas digester and its potential scalability.

### **3.5 Ethical Considerations**

Ethical clearance with reference number SOS-0027 was issued by the University of Namibia School of Science Decentralised Ethics Committee (DEC). The animal manure used in this study did not undergo any chemical treatment and was left to ferment naturally. The digester's waste was safely disposed of and used as fertilizer, with no direct or indirect impact on the surrounding environment.

### **3.6 Summary**

A quantitative experimental research design is used to empirically test the effectiveness of the biogas digester in producing biogas from cow manure. The study involved feeding the digester with a cow manure and water solution and measuring biogas yield by quantifying the pressure build-up within the digester using a pressure gauge. This method aimed to determine the biogas yield per unit mass of cow manure, the potential biogas production at the campus, and the cost savings from using biogas compared to conventional electricity usage.

The digester was designed using locally available materials to ensure cost-effectiveness. The study focused on cow manure from livestock at the University of Namibia's Neudamm Campus. A sample of 20 Liters of the manure was used for the experiments. The experimental setup involved creating a slurry from cow manure and water, which was then fed into the biogas digester. Regular monitoring and systematic data collection were conducted to ensure accuracy and reliability.

The equations used for data analysis involving the quantification of biogas yield, and performance a cost-benefit analysis, were given.

*The next chapter discusses the findings of the study.*

## 4 PRESENTATION OF RESULTS

This chapter presents the findings of the study on the biogas production potential of a low-cost digester designed specifically for use with cow manure from the Neudamm Campus of the University of Namibia. The results are discussed in relation to the research objectives, which include the design and performance evaluation of the digester, biogas yield per unit mass of cow manure, potential biogas production on the campus, and cost savings compared to conventional electricity usage. The discussion integrates data analysis and interpretation, comparing the results with existing literature to provide context and validate the findings. The chapter also explores the practical implications of the results, emphasizing the feasibility and benefits of implementing such biogas systems in rural settings. Through a thorough analysis, the chapter aims to provide insights into the effectiveness of the biogas digester and its potential impact on energy sustainability and cost efficiency at the Neudamm Campus.

### 4.1 Biodigester Design

Figure 4.1 below illustrates a hybrid biogas digester system that combines elements from both floating drum and fixed dome designs. Details of the components of the digester are discussed next.

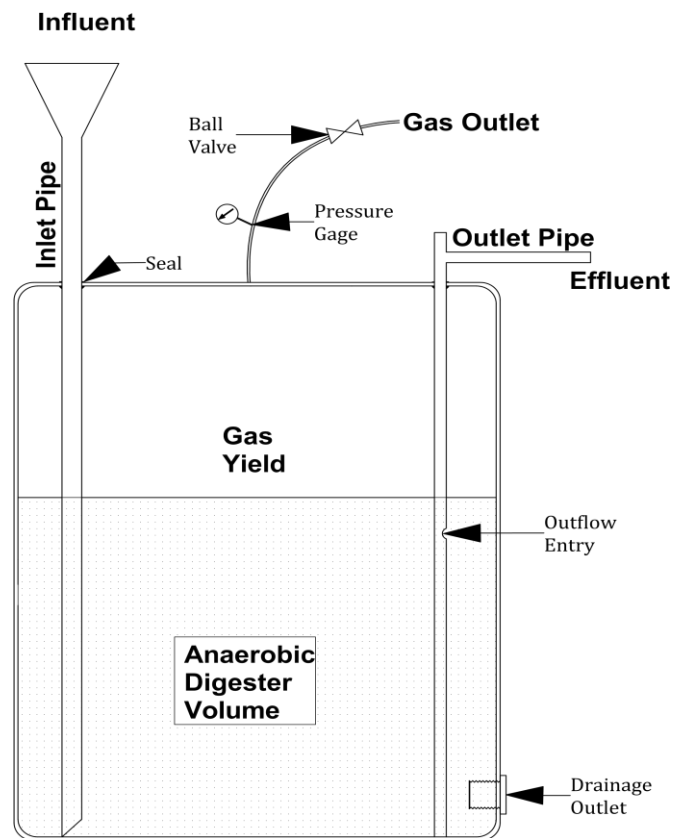
**Influent:** This is the chamber through which the slurry (organic waste, such as cow manure mixed with water) is fed into the digester.

**Digester Tank:** The digester is the main component where anaerobic digestion takes place. In this tank, bacteria break down the organic matter in the absence of oxygen, producing biogas (mainly methane). In this hybrid system, the floating drum is

integrated into a fixed-dome structure, allowing for controlled gas storage and a consistent pressure output.

**Gas Outlet:** This is the pipe through which biogas is extracted from the system for use in cooking, heating, or electricity generation. The gas outlet is typically connected to gas appliances or a storage system.

**Effluent Chamber:** After digestion, the leftover slurry (digestate) is pushed out through the slurry outlet. This slurry is rich in nutrients, such as Nitrogen, and can be used as organic fertilizer for agriculture.

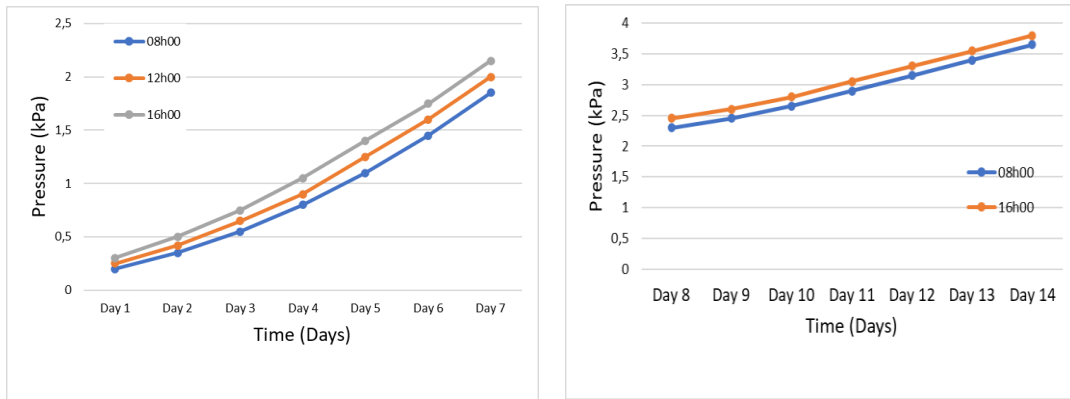


*Figure 4-1: Biogas Digester Setup*

The outflow entry in Figure 4.1 is needed so that as pressure rises inside the digester, the slurry is forced out, and the positioning of that outlet ensures that the pressure cannot build up beyond a certain value, so that if the gas is not used, some of it escapes through. Three identical digesters were constructed, placed under the same environment and fed with similar slurry. Measurements were taken around the same time, with a variation of not more than one minute in each case, which was considered insignificant.

## **4.2 Biogas Production**

The biogas digester consistently produced biogas, over a 60-day evaluation period, with variations observed mainly due to gas leakage at some fittings. The daily biogas production was recorded and averaged to determine the overall efficiency of the digester. The pressure on the digester reached a maximum of 10.05 kPa which could be maintained if the digester was fed at least once in three days. During the first week, the pressure within the digester rose slowly, starting at 0.20 kPa on Day 1, and reaching 2.15 kPa by the end of Day 7 (Fig. 4-2(a)). This gradual increase reflects the early stages of anaerobic digestion, where the microbial community is still establishing itself and beginning to break down the organic material in the cow manure. The modest pressure build-up suggests that gas production was just starting, as the bacteria adapted to the environment and initiated the decomposition process.

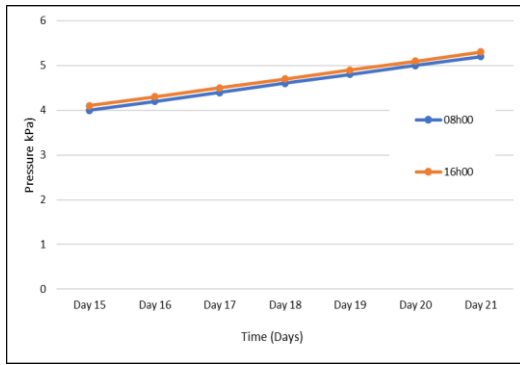


(a) (b)

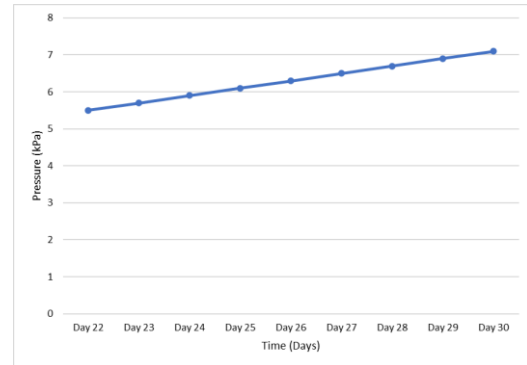
*Figure 4-2: Pressure build-up in the constructed biogas digester during (a) week 1, and (b) week 2*

The second week showed a slower increase in pressure, with readings rising from 2.30 kPa on Day 8 to 3.80 kPa by Day 14 (Fig. 4-2(b)). The bacteria are now slowly breaking down the organic matter, resulting in a low rate of biogas production. However, the increase in pressure during this period indicates that the digester was functioning properly, with a well-maintained anaerobic environment that facilitated gas yield. The consistent rise in pressure highlights the digester's ability to retain the produced gas.

By the third week, the pressure readings rose from 4.00 kPa on Day 15 to 5.30 kPa on Day 21 (Fig. 4-3(a)). This phase marks a consistent gas production, as the bacteria continue to break down the organic material. The consistent rise in pressure during this period suggests that the digester was performing as expected, with minimal gas loss and maximum retention. The pressure readings during these days indicate that the digester had reached a stable phase, where the conditions were optimal for sustained biogas production.



(a)

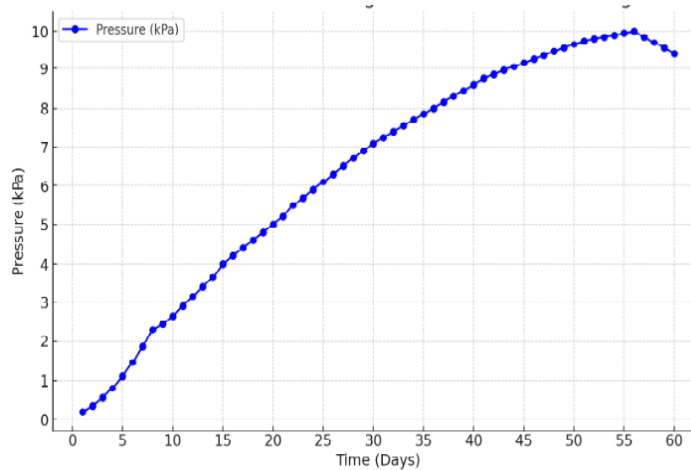


(b)

*Figure 4-3: Pressure build-up in the constructed biogas digester during (a) week 3, and (b) week 4*

In the fourth week, the pressure build-up accelerated again, with readings reaching 7.10 kPa by Day 30. This increase suggests that the rate of biogas production was rising as less digestible material was being consumed. The digester continued to produce gas at a faster rate compared to the earlier phases. The pressure readings during this period indicate that the gas production was still strong, with the digester approaching its maximum gas retention capacity.

The final phase, from Day 31 to Day 60, shows the digester reaching its maximum pressure of around 10 kPa by Day 55. Following this peak, the pressure readings began to stabilize and eventually decline, dropping to 9.40 kPa by Day 60. This phase indicates that the digestion process was winding down, with the bacteria having consumed most of the available organic material. The stabilization and subsequent decline in pressure suggest that biogas production is tapering off as the digester approaches the end of its operational cycle. The pressure readings during this period reflect the natural progression of the digestion process, where gas production decreases as the substrate becomes depleted.



*Figure 4-4: Overall Pressure Readings in the Designed Biogas Digester*

Overall, these pressure readings provide valuable insights into the performance of the biogas digester, showing how improved sealing and gas retention can lead to higher pressure build-up and more efficient biogas production. The data also highlight the different phases of the digestion process, from initial gas production to peak operational capacity and eventual decline, offering a comprehensive understanding of the digester's functionality over time.

The digester produced an average of 0.95 litres of biogas per day, demonstrating its capacity to generate a substantial amount of energy from cow manure. The peak production was observed in the 8th week of operation.

### **4.3 Biogas Yield Analysis**

Over the 60-day evaluation period, the biogas digester consistently produced biogas, with variations observed mainly due to gas leakage at the fittings. The daily biogas production was recorded and averaged to determine the overall efficiency of the

digester. The pressure on the digester reached a maximum of 10.05 kPa which could be maintained if the digester is fed at least once in three days.

The digester produced an average of 0.95 liter of biogas per day, demonstrating its capacity to generate a substantial amount of energy from cow manure. The peak production was observed 8<sup>th</sup> week of operation. Once the experiment was complete, the gas was released by opening the outlet pressure valve and burnt in a normal LPG gas burner, and it burnt with a light blue flame. Burning CH<sub>4</sub> produces Carbon dioxide and water and releases a large amount of heat. Once burnt, slurry at the inlet was seen to flow in to take up the volume left by the biogas.

#### **4.4 Potential Biogas Production**

**Biogas Potential** is calculated as the product of gas yield and the total mass of available manure.

At Neudamm, the cow population consists of 107 dairy cows and 619 meat cows. On average, a dairy cow produces 54 kg of manure per day, while a meat cow produces 27 kg of manure per day. This results in a total manure mass of 22.2 tons per day, which corresponds to an estimated biogas production of 318.76 litres per day.

#### **4.5 Energy Content**

The energy content of biogas depends on its methane (CH<sub>4</sub>) content. Pure methane has an energy content of about 39.8 megajoules per cubic meter (MJ/m<sup>3</sup>) or 10.9 kilowatt-hours per cubic meter (kWh/m<sup>3</sup>). However, biogas typically contains 50-70% methane. We assume 60% methane content in this study.

To calculate the energy content of the biogas, the formula is utilized:

*Energy Content*

$$= \text{Volume of Biogas} \times \text{Methane Content Fraction} \\ \times \text{Energy Value of Methane}$$

For 0.31876 m<sup>3</sup> of biogas daily with 60% methane:

$$\text{Energy Content} = 0.31876\text{m}^3 \times 0.60 \times 39.8 \text{ (MJ/m}^3\text{)} = 7.61 \text{ MJ}$$

The equivalent of this in kWh is  $7.61/3.6 = 2.11$  kWh

## **4.6 Analysis of Costs**

### **4.6.1 Biogas digester construction cost**

The table below lists all the material costs required to construct the 100L biogas digester used in this study. The total net cost for all materials required to construct the biogas digester summed up to N\$2,122.56, covering all necessary parts and components for the complete setup.

**Table 2: Costs of Materials for a 100L Biogas Digester**

| <b>Description</b>                 | <b>Unit price (N\$)</b> | <b>VAT (N\$)</b> | <b>Quantity</b> | <b>Net price (N\$)</b> |
|------------------------------------|-------------------------|------------------|-----------------|------------------------|
| 100L Water drum                    | 550.62                  | 82.59            | 1               | 633.21                 |
| SV pipe plain 75mm                 | 104.00                  | 15.60            | 1               | 119.60                 |
| SV pipe plain 50mm                 | 51.20                   | 7.68             | 1               | 58.88                  |
| SV single junction 87.5 plain 50mm | 8.28                    | 1.24             | 1               | 9.52                   |
| uniseal tank adaptor 75mm          | 125.23                  | 18.78            | 1               | 144.01                 |
| uniseal tank adaptor 50mm          | 122.40                  | 18.36            | 1               | 140.76                 |
| Tank adaptor 15mm                  | 12.34                   | 1.85             | 1               | 14.19                  |
| Thread Tape 19mm                   | 26.74                   | 4.01             | 1               | 30.75                  |
| Poly threaded end cap 2            | 17.29                   | 2.59             | 1               | 19.88                  |
| uPVC Solvent cement High Pressure  | 163.03                  | 24.45            | 1               | 187.48                 |
| Tank adaptor 50X40                 | 76.89                   | 11.53            | 1               | 88.42                  |
| 1/4" Pressure gauge                | 120.96                  | 18.14            | 1               | 139.10                 |
| Gas hose 8mm                       | 14.70                   | 2.21             | 2               | 33.81                  |
| 1/4" Needle valve                  | 118.50                  | 17.78            | 1               | 136.28                 |
| Pipe male run tee                  | 46.26                   | 6.94             | 1               | 53.20                  |
| Hose Clamps                        | 12.83                   | 1.92             | 6               | 88.53                  |
| Hose tail 1/4" BSP male            | 39.07                   | 5.86             | 2               | 89.86                  |
| Hose tail 1/8" BSP male            | 37.16                   | 5.57             | 1               | 42.73                  |
| Hose tail 1/2" BSP Female          | 80.28                   | 12.04            | 1               | 92.32                  |
| <b>TOTAL</b>                       |                         |                  |                 | <b>2122.56</b>         |

The labour cost for constructing this digester is 30% of the material cost, amounting to N\$636.77. Therefore, the total cost of constructing a 100L digester, including both materials and labour, is N\$2,759.33. Labour costs are considered in this analysis in

case the owner of the biogas digester is unable to assemble it themselves. However, constructing this digester is straightforward and involves simple tasks like cutting holes in the drum, cutting pipes, attaching fittings, and applying adhesives and sealants. Most farmers should be able to assemble the digester on their own.

#### **4.6.2 Maintenance and Operation Cost**

The operation and repair of the digester does not result in any additional costs. As designed in this study, the digester is simple to construct, maintain, and operate, requiring minimal manpower. If someone can build it, they should also find it easy to repair any components that fail. Users should be able to collect manure, mix it with water, and feed it into the digester without difficulty. Additionally, since the digester will be located on the farm where the cows are, there are no transportation costs for the manure. Considering the daily tasks that farmers already perform, maintaining and operating this digester should be a small additional task for them.

#### **4.7 Return on Investment (ROI)**

The estimated operational duration of a biodigester constructed from the materials listed above typically ranges between 10 to 15 years, depending on various factors such as the quality of materials used, construction methods, and maintenance practices. High-density polyethylene (HDPE) or similar materials for the drum and pipes ensure durability against chemical reactions from biogas and mechanical wear and tear. Proper assembly and regular maintenance, such as checking for leaks, repairing any minor damages promptly, and ensuring that the fittings and seals are in good condition, can significantly extend the lifespan of the digester.

By generating 2.11 kWh of energy per day over a period of 10 years, the digester will produce a total of 7 717.71 kWh. With the cost of electricity in Namibia at N\$2.48 per kWh, the biogas produced would be valued at N\$19 139.92, breaking even just after 2 years and 6 months of operation. The analysis indicates that replacing a substantial portion of the campus's electricity consumption with biogas could yield a profit of over 594% from the biogas investment. This profit could be reallocated to other essential services, helping to ease the financial burden on the university.

#### **4.8 Summary**

The results indicate that a low-cost biogas digester can effectively produce biogas using cow manure, providing a sustainable energy source while offering significant cost savings and environmental benefits. The data suggests that biogas systems have the potential to contribute significantly to rural energy needs, promoting energy independence and sustainability.

*The next chapter discusses the results in comparison to existing literature*

## **5 DISCUSSION**

This chapter provides a detailed discussion of the findings from the biogas production study of a low-cost digester designed for the Neudamm Campus of the University of Namibia. The analysis is contextualized by comparing results with existing literature and explores practical implications, including the impact of a gas leakage issue experienced during the study.

### **5.1 Biodigester Design and Performance**

The hybrid design of the biogas digester, integrating floating drum and fixed dome elements, was expected to enhance gas retention and overall performance. However, the study identified a significant issue with gas leakage at various fittings, which affected the digester's efficiency. Despite this challenge, the digester demonstrated a capacity for gradual and substantial pressure build-up, indicating that the design could be effective if the leakage issue is addressed.

Gas leakage is a common issue in biogas digesters and can significantly impact performance by altering pressure readings. Similar studies have documented gas leakage problems in both floating drum and fixed dome digesters, often attributed to poor sealing or inadequate fittings (Jelínek et al., 2021). Addressing these issues through improved sealing techniques and more robust fittings could enhance the digester's performance and reliability.

## **5.2 Biogas Yield and Potential**

The biogas yield averaged 0.95 litres per day, which is somewhat lower than expected due to the leakage issue. Gas leakage typically reduces the amount of usable biogas, leading to lower overall yield and efficiency. The peak production observed in the 8th week, despite the leakage, suggests that the digester has the potential to perform well under optimal conditions. Comparing these findings with other studies on low-cost digesters reveals that gas leakage can account for up to 20-30% loss in biogas production (Sieling et al., 2013).

The estimated biogas potential at Neudamm Campus, based on the cow population and manure output, aligns with general expectations but might have been slightly underestimated due to the leakage issue. Accurate measurements of biogas potential should account for potential losses, which could be corrected with better maintenance and sealing strategies.

## **5.3 Energy Content and Cost Savings**

The calculated energy content of the produced biogas, at 7.61 MJ (or 2.11 kWh) per day, indicates that the system can provide a consistent energy supply, suitable for various applications such as cooking and heating. This aligns with typical energy content values for biogas with a methane content of 50-70%, as reported in the literature (Brahmi, Bruno, Dhayal, Esposito, & Parziale, 2024). The biogas produced offers a viable alternative to grid electricity, particularly in areas where electricity costs are high, or supply is unreliable.

The cost analysis shows that constructing a 100L biogas digester costs N\$2,759.33, including labour. Given the potential savings from reduced electricity use, the digester would break even after approximately 2 years and 6 months, assuming continuous operation and consistent biogas production. This payback period is relatively short, compared to other renewable energy investments, making it an attractive option for rural settings where capital investment must be minimized. The analysis indicates that replacing a portion of the campus's electricity consumption with biogas could yield a profit of over 594% over the digester's operational life, demonstrating significant financial benefits.

#### **5.4 Practical Implications and Feasibility**

The study highlights the practical feasibility of implementing low-cost biogas digesters at farm settings like the Neudamm Campus. The digester's simple design and construction, coupled with minimal maintenance requirements, make it accessible to farmers and rural communities with limited technical expertise. The ability to utilize readily available materials and resources further enhances the system's viability, reducing dependency on imported equipment and parts.

Moreover, the use of cow manure, a waste product, as the primary feedstock promotes waste management and environmental sustainability, addressing two critical issues in rural areas. The digester also produces nutrient-rich effluent that can be used as fertilizer, contributing to agricultural productivity and supporting sustainable farming practices.

Addressing the leakage issue through improved design and construction practices could enhance the digester's performance and increase its attractiveness as a renewable energy solution for rural communities. Effective training for users on maintenance and repair could also contribute to better overall performance.

### **5.5 Comparison with Existing Literature**

The findings of this study are consistent with those of similar research on small-scale biogas digesters in rural settings. For instance, studies conducted in other African countries, such as Kenya and Cameroon, have reported comparable biogas yields and operational performance from digesters using cow manure (Rupf, Bahri, de Boer, & McHenry, 2017). These studies also emphasize the importance of local context in designing and implementing biogas systems, noting that factors such as climate, feedstock availability, and community involvement play crucial roles in the success of biogas projects.

The current study contributes to the growing body of evidence supporting biogas technology as a viable solution for rural energy needs. It provides a practical example of how low-cost digesters can be designed, constructed, and operated effectively, offering insights for policymakers, researchers, and practitioners interested in promoting renewable energy solutions in rural Africa.

### **5.6 Limitations and Future Research**

While the study demonstrates the potential of low-cost biogas digesters, several limitations should be noted. The digester's performance was evaluated over a relatively

short period (60 days), which may not fully capture seasonal variations in temperature and manure availability that could impact biogas production. Future research should consider longer-term monitoring to assess the digester's performance under varying environmental conditions and explore the effects of different feedstock types and combinations on biogas yield. The experiment employed three digesters to improve reliability, all were tested under identical conditions. Replicates under varying environmental conditions (e.g., temperature, manure type, or feedstock loading rates) would provide more robust validation of the results.

Additionally, while the cost analysis provides valuable insights into the financial benefits of biogas systems, it does not account for potential economic and social barriers to adoption, such as initial capital costs, access to materials, and community acceptance. Future studies could explore these factors in more detail, providing a comprehensive understanding of the challenges and opportunities associated with biogas technology in rural settings.

*The next chapter conclude the findings of the study*

## 6 CONCLUSIONS

The study aimed to design and evaluate the performance of a low-cost biogas digester with the idea of upscaling it for the Neudamm Campus of the University of Namibia. The hybrid design, integrating elements of both floating drum and fixed dome digesters, was intended to optimize gas retention and overall efficiency. Despite encountering gas leakage issues that affected the digester's performance, the system demonstrated potential for biogas production, achieving an average yield of 0.95 litres per day. The findings highlight the digester's capability to produce a consistent energy supply, with an estimated energy output of 7.61MJ (2.11 kWh) per day, proving to be a viable alternative to conventional energy sources.

The economic analysis underscored the financial viability of the system, with a payback period of approximately 2 years and 6 months, assuming consistent operation. This makes the biogas digester an attractive investment for rural settings, where capital investment is often constrained, and energy costs are high. The practical feasibility of the system was further supported by its simple design, ease of construction, and the use of readily available materials, making it accessible to rural communities with limited technical expertise.

The study also identified several challenges that need to be addressed to optimize the digester's performance. The gas leakage issue significantly impacted the digester's efficiency and biogas yield. This issue, along with the relatively short evaluation

period, suggests the need for further research to fully understand the system's long-term performance and to explore strategies for improving its reliability and efficiency.

*The next chapter presents some recommendations*

## 7 RECOMMENDATIONS

Based on the findings of this study, the following recommendations are proposed:

**Addressing Gas Leakage Issues:** The primary challenge identified in this study was the gas leakage problem, which affected the overall performance of the biogas digester. It is recommended that future designs incorporate improved sealing techniques and more robust fittings to minimize gas loss. Regular maintenance and monitoring should also be implemented to identify and rectify leaks promptly.

**Extended Monitoring and Performance Evaluation:** The current study was conducted over a relatively short period, which may not fully capture the digester's performance across different seasons and varying environmental conditions. It is recommended that future research extend the monitoring period to assess the digester's long-term performance, particularly in terms of biogas yield and system reliability.

**Exploration of Alternative Feedstocks:** While cow dung was the primary feedstock used in this study, the potential for using other locally available organic materials should be explored. This could include agricultural residues, food waste, and other animal manures. A broader evaluation of feedstock options could enhance the flexibility and efficiency of the biogas system.

**Community Engagement and Training:** For the successful implementation and sustainability of biogas technology in rural settings, it is crucial to engage the local community and provide training on the operation and maintenance of the system. This will empower users to effectively manage the digester, troubleshoot issues, and maximize its benefits.

**Policy Support and Financial Incentives:** To promote the adoption of biogas technology in rural areas, government support in the form of subsidies, grants, or low-interest loans could be instrumental. Policymakers should consider creating frameworks that encourage the adoption of renewable energy technologies, particularly in off-grid and remote communities.

**Integration with Agricultural Practices:** The nutrient-rich effluent produced by the biogas digester can serve as a valuable fertilizer, enhancing soil fertility and agricultural productivity. It is recommended that future projects explore the integration of biogas systems with agricultural practices, promoting a circular economy and sustainable farming methods.

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## APPENDIX A - ETHICAL CLEARANCE CERTIFICATE



### ETHICAL CLEARANCE CERTIFICATE

**Ethical Clearance Reference Number:** SOS-0027    **Date:** 25 October 2021

This Ethical Clearance Certificate is issued by the University of Namibia Ethics Committee (REC) in accordance with the University of Namibia's Research Ethics Policy and Guidelines. Ethical approval is given in respect of undertakings contained in the Research Project outlined below. This Certificate is issued on the recommendations of the ethical evaluation done by the ethics committee.

**Title of Project:** VIABILITY OF SUBSTITUTION OF ELECTRICITY WITH BIOGAS ENERGY FOR THERMAL USES AT OGONGO CAMPUS OF THE UNIVERSITY OF NAMIBIA

**Student:** PINEAS TOMAS

**Student Number:** 200421476

**Supervisor(s):** DR. ZIVAYI CHIGUVARE (UNIVERSITY OF NAMIBIA)

#### Centre for Research Services

Take note of the following:

1. Any significant changes in the conditions or undertakings outlined in the approved Proposal must be communicated to the ethics committee. An application to make amendments may be necessary.
2. Any breaches of ethical undertakings or practices that have an impact on ethical conduct of the research must be reported to the ethics committee
3. The Principal Researcher must report issues of ethical compliance to the ethics committee (through the Chairperson) at the end of the Project or as may be requested by the ethics committee
4. The ethics committee retains the right to:
  - i) Withdraw or amend this Ethical Clearance if any unethical practices (as outlined in the Research Ethics Policy) have been detected or suspected,
  - ii) Request for an ethical compliance report at any point during the course of the research.

The ethics committee wishes you the best in your research.

A handwritten signature in black ink, appearing to read 'Z. Chiguvare', is written over a horizontal line.

Dr. Zivayi Chiguvare (Chairperson Ethics Committee)

A handwritten signature in black ink, appearing to read 'D. Mumbengegwi', is written over a horizontal line.

Prof. Davis Mumbengegwi (Head, Multidisciplinary Research)

**APPENDIX B – PRESSURE READING RAW DATA**

| <b>Days 1 to 7</b> |              |              |              |              |              |              |              |
|--------------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|
| <b>Time</b>        | <b>Day 1</b> | <b>Day 2</b> | <b>Day 3</b> | <b>Day 4</b> | <b>Day 5</b> | <b>Day 6</b> | <b>Day 7</b> |
| 08h00              | 0.2          | 0.35         | 0.55         | 0.8          | 1.1          | 1.45         | 1.85         |
| 12h00              | 0.25         | 0.42         | 0.65         | 0.9          | 1.25         | 1.6          | 2            |
| 16h00              | 0.3          | 0.5          | 0.75         | 1.05         | 1.4          | 1.75         | 2.15         |

| <b>Days 8 to 14</b> |              |              |               |               |               |               |               |
|---------------------|--------------|--------------|---------------|---------------|---------------|---------------|---------------|
| <b>Time</b>         | <b>Day 8</b> | <b>Day 9</b> | <b>Day 10</b> | <b>Day 11</b> | <b>Day 12</b> | <b>Day 13</b> | <b>Day 14</b> |
| 08h00               | 2.3          | 2.45         | 2.65          | 2.9           | 3.15          | 3.4           | 3.65          |
| 16h00               | 2.45         | 2.6          | 2.8           | 3.05          | 3.3           | 3.55          | 3.8           |

| <b>Days 15 to 21</b> |               |               |               |               |               |               |               |
|----------------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
| <b>Time</b>          | <b>Day 15</b> | <b>Day 16</b> | <b>Day 17</b> | <b>Day 18</b> | <b>Day 19</b> | <b>Day 20</b> | <b>Day 21</b> |
| 08h00                | 4             | 4.2           | 4.4           | 4.6           | 4.8           | 5             | 5.2           |
| 16h00                | 4.1           | 4.3           | 4.5           | 4.7           | 4.9           | 5.1           | 5.3           |

| <b>Days 22 to 30</b> |               |               |               |               |               |               |               |               |               |
|----------------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
| <b>Time</b>          | <b>Day 22</b> | <b>Day 23</b> | <b>Day 24</b> | <b>Day 25</b> | <b>Day 26</b> | <b>Day 27</b> | <b>Day 28</b> | <b>Day 29</b> | <b>Day 30</b> |
| 10h00                | 5.5           | 5.7           | 5.9           | 6.1           | 6.3           | 6.5           | 6.7           | 6.9           | 7.1           |

| <b>Day</b> | <b>Pressure Reading</b> |
|------------|-------------------------|
| 31         | 7.20                    |
| 32         | 7.39                    |
| 33         | 7.54                    |
| 34         | 7.71                    |
| 35         | 7.85                    |
| 36         | 8.01                    |
| 37         | 8.15                    |
| 38         | 8.30                    |
| 39         | 8.46                    |
| 40         | 8.59                    |
| 41         | 8.75                    |
| 42         | 8.85                    |
| 43         | 8.93                    |
| 44         | 9.05                    |
| 45         | 9.16                    |
| 46         | 9.24                    |
| 47         | 9.35                    |
| 48         | 9.48                    |
| 49         | 9.56                    |

|    |       |
|----|-------|
| 50 | 9.64  |
| 51 | 9.77  |
| 52 | 9.81  |
| 53 | 9.85  |
| 54 | 9.90  |
| 55 | 9.98  |
| 56 | 10.01 |
| 57 | 9.84  |
| 58 | 9.71  |
| 59 | 9.55  |
| 60 | 9.42  |