

**ASSESSING THE USE OF ACTIVATED CARBON TO INCREASE BIOGAS PRODUCTION**

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**S20B32/206**

**A FINAL YEAR RESEARCH AND DESIGN PROJECT REPORT SUBMITTED TO THE  
FACULTY OF ENGINEERING, DESIGN AND TECHNOLOGY, IN PARTIAL FULFILLMENT OF  
THE REQUIREMENTS FOR THE AWARD OF A DEGREE OF BACHELOR OF SCIENCE IN  
CIVIL AND ENVIRONMENTAL ENGINEERING OF UGANDA CHRISTIAN UNIVERSITY**

**April, 2024**



**UGANDA CHRISTIAN  
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## **ABSTRACT**

The enhancement of biogas production, specifically methane enrichment is critical for improving the efficiency and viability of biogas as a renewable energy source. This report examines the role of activated carbon in increasing methane yield and the quantity of biogas produced in a digester at NALIRRI by the Direct interspecies electron transfer Process (DIET). Activated carbon known for its high surface area, electrical conductivity and porosity provides a conducive environment for the adsorption of inhibitory compounds and the DIET process. Furthermore, it facilitates a more stable and enhanced microbial activity leading to increased biodegradation and methane production. Experimental setups incorporating various concentrations of activated carbon were monitored and analyzed. Parameters like pH, temperature and organic loading rate were monitored alongside the addition of activated carbon to maximize methane output. The results indicate a significant increase in methane production with the addition of activated carbon and it can contribute to the development of a cost-effective and sustainable method to increase the quantity of biogas produced in a bio-digester hence a promising approach to enhance biogas production with implications for renewable energy and waste management practices. This report concludes with recommendations for further research and application of biogas on systems.

**DECLARATION**

I ANGEANGO FAITH WANADI, hereby declare that this is my original work, is not plagiarized and has not been submitted to any other institution for any award.

ANGEANGO FAITH WANADI

Signature:..... Date:

.....

**APPROVAL**

This research project has been submitted for examination with my approval as the University supervisor.

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Signature: .....

Date: .....

## **ACKNOWLEDGEMENT**

Great thanks and appreciation goes to the Lord Almighty who has granted me life and helped me throughout this project. I extend my deepest gratitude to my supervisor, Eng. Lubaale Solomon Azarius whose expertise, understanding, and patience, added considerably to my experience. Whose guidance supported me throughout my research and writing of this paper. I am thankful to the department of Engineering and Environment staff for their valuable insights and for providing necessary resources for the completion of this project.

I extend my profound Gratitude to my parents Mr. and Mrs. Wanadi and my siblings for their continuous moral support, encouragement and financial contribution to this project. Also, I extend my sincere appreciation to my project partner Namulumba Sandra, friends and classmates for their support and encouragement. This accomplishment would not have been able without them. Thank you and God Bless you all.

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## LIST OF ACRONYMS AND ABBREVIATIONS

AD - Anaerobic digestion

BMP - Bio-methane potential

C/N - Carbon-Nitrogen Ratio

CH<sub>4</sub> - Methane

COD - Chemical Oxygen demand

DIET - Direct Inter-Species Electron Transfer

EC - Electrical conductivity

FOS - Fermentable Organic Substrate

FTIR- Fourier Transform Infrared

GHG - Greenhouse gases

HRT - hydraulic Retention Time

NALIRRI- National Agricultural Livestock Resources Research Institute

OLR- Organic loading rate

pH - potential of hydrogen

PPM - parts per million

TAC - Total Alkalinity Consumable

TS - Total Solids

VS - Volatile Solids

## CHAPTER ONE: INTRODUCTION

### 1.1 BACKGROUND

There has been a significant increase in the world population during the last decade and a lot of problems have risen including deforestation, increased energy requirements, environmental pollution and global warming. Developing economies are faced with challenges like securing cleaner affordable energy supplies and ensuring as sustainable economic development hence reducing environmental pollution (Kizito, et al., 2022). Fossil fuels contribute about 82% of the total primary energy consumption globally they include: natural gas, oil and coal. These are the main causes of environmental pollution and increased greenhouse gas emissions in the atmosphere which further results in changes in climate ecosystems (Rapier, 2023). The use of renewable energy is proving to be a way of combating the issue of pollution. For example, the use of biogas, solar, wind and hydro as forms of renewable energy.

Biogas is a form of renewable energy produced by anaerobic digestion of organic matter like agricultural waste, manure, municipal waste, plant material and sewage by microorganisms. It has a composition of methane (50-75%), carbon-dioxide (25-50%), hydrogen (0-10%), hydrogen sulphide (0-3%), oxygen (0-1%), nitrogen (0-10%) and trace amounts of ammonia (IEA, 2020). It is formed through four main stages, each characterized by specific biochemical reactions facilitated by different groups of microorganisms: hydrolysis, acidogenesis, acetogenesis and methanogenesis.

Hydrolysis refers to the breakdown of complex organic materials like proteins, carbohydrates and lipids into simpler soluble compounds by the help of the extra

cellular enzymes secreted by the microorganisms (Domingues, et al., 2022). Acidogenesis refers to the breakdown of the products from the hydrolysis stage into volatile fatty acids, hydrogen, carbon dioxide, alcohols and ammonia. Acetogenesis refers to the formation of acetate from the products of acidogenesis by the acetogenic bacteria, this process is essential for substrate formation (acetic acid, hydrogen and carbon dioxide). Methanogenesis refers to the production of methane, carbon-dioxide from the products of acetogenesis by methanogenic bacteria. It is sensitive to factors like pH, temperature and substrate availability (Domingues, et al., 2022). Biogas is produced from a bio-digester because it provides an anaerobic environment for the microorganisms to act on the substrates. Biogas is used for many activities like cooking, lighting homes, which leads reduction of costs by the community (Wilkie, 2023).

One of the significant challenges in biogas production is the rate and total volume of methane generation, which are often limited by the rate of organic material breakdown and microbial inefficiencies. Addressing these limitations could substantially enhance the viability and effectiveness of biogas as a renewable resource.

This report investigates how activated carbon can enhance biogas production, specifically by increasing methane output. Activated carbon is recognized for its extensive surface area, porosity, and electrical conductivity, qualities that can help overcome some of the key obstacles in biogas production.

Incorporating activated carbon in biogas digesters promotes Direct Interspecies Electron Transfer (DIET), enabling microorganisms to exchange electrons directly. This

process not only quickens the breakdown of organic materials but also stabilizes microbial populations, leading to more consistent and elevated levels of methane production. Additionally, activated carbon helps remove inhibitory substances that could otherwise impede microbial efficiency, thereby optimizing the digestion process.

By harnessing the distinct properties of activated carbon, this research intends to create a cost-effective, sustainable method to enhance the output of biogas production facilities, thereby improving energy security and reducing environmental impacts. The insights and recommendations provided here will offer valuable guidance for ongoing research and the wider implementation of improved biogas systems.

## **1.2 PROBLEM STATEMENT**

Despite there being favorable digester conditions in the NALIRRI bio- digester, the biogas produced is still low, with methane content averaging only 48-51%. This is attributed to slow feedstock digestion within the digester thus lowering the use of this biogas on commercial level (Yun & Fang, 2018).

This study aims to assess the potential of activated carbon to improve the productivity of the digester thereby increasing the biogas output without affecting the quality of slurry which is used for other uses.

## **1.3 OBJECTIVES**

### **1.3.1 MAIN OBJECTIVE**

To assess the use of activated carbon to increase biogas production at National Livestock Resources Research Institute.

### **1.3.2 SPECIFIC OBJECTIVES**

1. To determine the methane potential of the substrate.
2. To determine the properties of the activated carbon to be used.
3. To assess the quality of the biogas produced in the bio-digester after adding the activated carbon.
4. To determine the optimum concentration of the activated carbon in the bio-digesters.

## **1.4 RESEARCH QUESTIONS**

1. What is the methane potential of the substrate?
2. What are the properties of the activated carbon to be used?
3. What is the volume of biogas produced in the bio digester after adding the activated carbon?
4. What is the optimum concentration of the activated carbon?

## **1.6 JUSTIFICATION**

Despite the conditions (temperature, pH, constant mixing) in a biodigester being favorable, there is slow digestibility of feedstock (Liu, et al., 2021). It is reported that

the average methane yield is only 10% of its theoretical value hence making it difficult to be used on a commercial level (Liu, et al., 2021). The use of activated carbon leads to a high productivity of biogas through the direct interspecies electron transfer (DIET) process in the bio- digester considering the same amount of feedstock used. The DIET process refers to the transfer of electrons between syntrophic partners (methanogenic and fermentative bacteria) without the need for an intermediate electron carrier like hydrogen or formate (Thiangchanta, et al., 2022). DIET enables more efficient conversion of complex organic substrates into methane as the direct electron bypasses the need for hydrogen or formate as intermediate carriers, it also enables the direct interaction between syntrophic partners and hence enhancing metabolic activity of methanogens, it helps alleviate the accumulation of hydrogen that can inhibit microbial activity particularly methanogenesis (Thiangchanta, et al., 2022) therefore, reducing hydrogen buildup and enhancing overall digester performance and increasing the commercial application of the biogas since more biogas is produced within a shorter period of time and also minimal costs are involved (Thiangchanta, et al., 2022).

### **1.5 SIGNIFICANCE OF STUDY**

Addition of activated carbon to the feedstock in a biodigester, it improves methane gas production by decreasing the inter-bacterial distance between fermentative and methanogenic bacteria. This leads to a faster external electron transfer due to the electrically conductive nature of the microorganisms and because there is no need for a mediator to transfer the electrons between the micro-organisms. The carbon dioxide that would otherwise be produced is reduced and more methane is produced hence an increase in burnable gas (biogas) using the same amount of feedstock and keeping all

factors constant.

## **1.6 SCOPE OF STUDY**

National Livestock Resources Research Institute in Namulonge. The farm has two bio digesters each having a capacity of 80 m<sup>3</sup> which use cow dung as the feedstock.

## CHAPTER TWO: LITERATURE REVIEW

This chapter provides relevant literature that guided the research. It is about the preparation and use of activated carbon and the effect it has in biogas production.

### 2.1 THEORETICAL LITERATURE REVIEW

This theoretical review explores the scientific rationale behind the use of activated carbon as an additive in biogas production. It examines the interaction between activated carbon and micro-organisms, the chemical and biological mechanism used to facilitate increased biogas yield.

#### 2.1.1 Activated carbon

Activated carbon can be used as an additive to enhance biogas production. It is a rough imperfectly structured form of graphite (Ganjoo, et al., 2023). It is a carbonaceous (carbon rich) material that is typically made from wood, coconut husk, peat, corn cob and other dense carbon sources (Cavallo, 2021). Its pore structure can be seen with an electron microscope. Activated carbon is made by carbonization then activation (Cavallo, 2021). It is manufactured to create small pores with low volumes which greatly increase its surface area. The pores range in size from obvious visible cracks and fissures to molecular dimensions (Ganjoo, et al., 2023). Before activation, the specific surface area of charcoal is 2.0 to 5.0  $\text{m}^2\text{g}^{-1}$  which rises to 1000  $\text{m}^2\text{g}^{-1}$  once it has been activated. Gas adsorption analysis reveals that a single gram of AC has over 3000  $\text{m}^2$  of surface area due to its high microporosity making it highly effective for practical use (Ganjoo, et al., 2023).

Activated carbon is a carbon based additive and it enhances the direct inter-species electron transfer hence increasing the amount methane produced. It also reduces on the

greenhouse gas emissions like carbon-dioxide. There are two ways that are a driving force between the bacteria (fermentative and methanogenic) that ensures that energy is used during anaerobic digestion. These include: indirect interspecies electron transfer (IIET) and direct electron transfer (DIET). The indirect interspecies electron transfer use electron carriers in form of hydrogen and formate from the fermentative bacteria to the methanogen to form methane and carbon dioxide. Direct interspecies electron transfer (DIET) is a pathway where free electrons flow between fermentative bacteria and the methanogen during anaerobic digestion process. For methane production in anaerobic digestion, direct electron transfer is preferred compared to the indirect interspecies electron transfer because of the following reasons:

1. It requires lower energy consumption.
2. For electron exchange it needs no redox mediators.
3. In case of any stagnation, it allows no accumulation of toxic volatile fatty acids.

#### **Types of the DIET mechanisms.**

- I. DIET via conductive pili - this involves electrons being released during oxidation by the fermentative bacteria and are conducted to the methanogen for further degradation.
- II. DIET via membrane bound electron transport proteins (Rosen, et al., 2020).
- III. DIET via abiotic conductive materials: this involves a cell-to-cell electron transfer who stimulates the methanogenic process hence an increasing methane production (Rosen, et al., 2020).

Activated carbon has a high electrical conductivity, a porous structure and is an

excellent chemical stability. Electrical conductivity facilitates DIET between fermentative and methanogenic bacteria by decreasing the inter-bacterial distance between the bacteria and methanogens causing further interaction leading to an increase in methane production. They also comprise buffer pH in the hydrogen production phase and increase the macro and micro-nutrients like potassium and calcium which can increase the pH medium hence improve the biogas yield. It is noted that some carbon-based materials like activated carbon have no effect on the syntrophic acetate oxidation but only favors the hydrogen trophic methanogen pathway. The carbon dioxide reduction pathway is as follows:



## 2.2 STRUCTURE OF ACTIVATED CARBON

The ability of activated carbon to adsorb substances is significantly impacted on by its structure. Pure graphite and activated carbon have very similar and fundamental chemical structures. Weak van der Waals Forces keep the layers of fused hexagons that make the graphite crystal unified. The activated carbon structure differs from that of graphite by the distance between the layers. AC has an interlayer spacing of 0.34 nm to 0.35 nm. Carbon to carbon bonds hold the layers together. The ultimate features of activated carbon include its pore structure and is largely influenced by manufacturing process and raw material used to make it. The composition of the raw material significantly influences the porous structure and beneficial characteristics of carbonaceous adsorbents. Therefore, the selection of an appropriate material holds equal importance to choosing suitable production techniques and determining optimal processing conditions. Consequently, endeavors have been undertaken

to identify innovative raw resources suitable for producing carbonaceous adsorbents. Specifically, biomass waste from sources such as wood, food, agricultural residues, and other sources has garnered attention in this regard.

The production of activated carbons derived from biomass waste holds potential to enhance economic returns and reduce pollution. This is particularly significant considering the substantial supply potential of raw materials from industries such as wood processing, carpentry, and related sectors.

## **2.3 HOW TO MAKE ACTIVATED CARBON**

Activated carbon is made by sourcing a material, carbonizing it and then activation.

### **2.3.1 CARBONIZATION**

This is the process of converting a material rich in carbon into pure carbon by heating. The heating process is known as pyrolysis. A very dense carbonaceous material is used for this process and an extra porous result is obtained.

Pyrolysis process involves the thermal decomposition of this material which occurs above 400 °C with little or no oxygen. During the pyrolysis process, biomass is transformed into gases, liquids and solid residues containing carbon and ash. It occurs in two distinct steps i.e., removal of moisture and condensation of volatiles into liquid fraction. These steps are controlled by parameters like feed properties, rate of transfer of heat to the feeds and the residence time and reaction temperature. The residues of pyrolysis are usually 20 to 30% of the beginning weight and consist mostly of carbon. The porous form of carbon once produced has to undergo oxidization and this is known as activation.

### 2.3.2 ACTIVATION

Activation occurs in two ways.

- Physical activation
- Chemical activation

The activation of carbon can be achieved directly by subjecting carbon to heat within a chamber while simultaneously introducing gas. This process exposes the carbon to oxygen, facilitating oxidation. Upon oxidation, the activated carbon develops favorable adsorption characteristics, making it suitable for capturing contaminants in both liquid and gaseous applications (Heidarinejad, et al., 2020).

For physical gas treatment, carbonization or pyrolysis occurs in an inert environment at temperatures ranging from 600 to 900 degrees Celsius. Subsequently, oxygenated gas is introduced and heated to temperatures between 900 and 1200 degrees Celsius, causing oxygen to bond to the surface of the carbon. In contrast, chemical treatment involves a slightly different approach compared to gas activation (Cavallo, 2021).

Carbonization and chemical activation occur concurrently in this process. The material is immersed in a solution containing acids, bases, or other chemicals, and heated to temperatures ranging from 450 to 900 degrees Celsius. This simultaneous carbonization and activation process occurs at a faster rate compared to gas activation. However, certain heating methods may result in the adsorption of trace elements from the solution onto the carbon, potentially leading to impurities or reduced effectiveness (Heidarinejad, et al., 2020).

Activated carbon is characterized by a high surface area, porosity and adsorption capacity. These properties play a major role in digesters and make it possible for

activated carbon to adsorb inhibitory compounds. It can adsorb inhibitory compounds like ammonia, hydrogen sulfide as these is known to inhibit microbial activity. Adsorption by activated carbon reduces toxic stress on microbial communities and thereby facilitating a more efficient digestion (Ganjoo, et al., 2023).

The regeneration of activated carbon involves restoring its adsorptive capacity using various methods. Thermal reactivation, the most common technique, involves drying the soiled carbon, heating it in an inert atmosphere, and subjecting it to gas treatment. Thermal regeneration typically results in a weight loss of 5-15% of the original carbon, making it an energy-intensive process. Additionally, alternative regeneration methods aim to minimize both yield loss and energy consumption, including microwave regeneration, thermal swing adsorption, pressure swing adsorption, chemical regeneration, microbial regeneration, electrochemical regeneration, wet air oxidation, ultrasonic regeneration, microbial regeneration among others.

Following oxidation, activated carbon can be processed for various applications based on its unique properties (Cavallo, 2021).

Granular activated carbon (GAC) consists of larger grains compared to powdered activated carbon (PAC), each suitable for different applications. Other forms include impregnated carbon, which incorporates elements such as silver and iodine, and polymer-coated carbons. The subsequent section provides a brief overview of the different types of activated carbon and their respective characteristics.

Activated carbon, also known as activated charcoal, finds applications beyond filtration, including industrial, chemical, medical, environmental, and agricultural uses. It is employed to remove contaminants from plating solutions, purify and extract precious

metals, measure specific levels of compounds in solutions, treat poisoning and overdoses, cleanse blood of toxic substances through hemoperfusion, remove air and water pollutants, measure radon concentration in air, trap mercury emissions, serve as a pesticide, animal feed additive, processing aid, disinfectant, and fertilizer in agricultural environments (Heidarinejad, et al., 2020).

In conclusion, this theoretical review supports the potential of activated carbon to enhance biogas production in digesters through the direct interspecies electron transfer (DIET) and adsorption of inhibitory compounds. It shows that activated carbon therefore presents a theoretically promising avenue for biogas production enhancement.

## **2.4 EMPIRICAL REVIEW**

### **2.4.1 MATERIALS**

In this study, the carbon materials from waste biomass resources are woodchips. They are prepared by pyrolysis to form biochar that is then used as an additive in the bio digester. Studies reviewed predominantly employ a comparative experimental design, where digesters with activated carbon are compared against control set ups without activated carbon. Key variables analyzed include the quality and quantity of biogas produced, changes in inhibitory compounds concentration and variations in microbial community composition.

Research has consistently shown that incorporating activated carbon into biogas production processes yields positive outcomes. Specifically, the introduction of activated carbon leads to heightened levels of overall biogas and methane output in digestion units. A study by (Abbas, et al., 2021) highlights that biogas production in systems using carbon

materials experiences two significant increases: one due to the breakdown of carbohydrates and other organic molecules, and a second spike attributed to the transformation of complex molecules like crude protein and lignocellulose into biogas. The study found that of the different carbon materials tested for biochar production, mesoporous carbon was the most effective, yielding the highest biogas production on the first and twelfth days, at 19.5 mL/g TS and 37.4 mg/g TS, respectively. This indicates that mesoporous carbon enhances microbial action, leading to faster breakdown of substrates initially and speeding up the methanogenesis process at the start of digestion. In systems treated with bio-based carbon materials, two peaks in daily biogas production were observed, suggesting that these materials contribute to more consistent biogas output. This was supported by thermal TG/DTG/DSC analysis. Anaerobic digestion (AD) systems typically undergo three phases: a high solids hydrolysis phase, an acidification phase leading to volatile fatty acid (VFA) production and a subsequent drop in pH, and a wet methane production stage. The presence of VFAs, indicated by a pH decrease, causes a temporary reduction in biogas production around the fourth day. However, as VFAs are consumed by methanogenic bacteria, methane is produced, and pH levels stabilize.

(Abbas, et al., 2021) also noted that among the bio-based carbon materials tested—corn cob, walnut shell, waste carton, and sawdust—the highest biogas yields were observed to vary across different materials, demonstrating significant potential in enhancing biogas production.

pH levels play a major role in the AD environment, significantly influencing microbial growth rates. The study found initial pH levels to be low due to the acidic nature of the substrates used, such as cattle manure and sludge. However, the introduction of carbon

materials appeared to stabilize pH levels into a range favorable for methanogenic bacteria (6.6-7.8), indicating a positive effect on the digestion environment.

Finally, the research emphasized the benefits of using bio-based carbon materials, derived from waste biomass via pyrolysis, which possess a uniform particle size and pore volume distribution. These materials not only facilitate direct interspecies electron transfer between fermenting bacteria and methanogens, enhancing methanogenesis, but also significantly increase the overall biogas yield by 30% to 70% and the COD degradation rate by 74-129%. This suggests a promising application of bio-based carbon materials in anaerobic digestion processes.

Activated carbon, derived from various carbon-rich sources such as wood, coconut husk, peat, and corn cob, undergoes a transformation process involving carbonization and activation to attain its highly porous structure, characterized by a significantly increased surface area. This increased surface area enables activated carbon to exhibit exceptional adsorption properties, making it invaluable in various applications, including methane production enhancement in anaerobic digestion systems.

The utilization of activated carbon in anaerobic digestion systems offers multiple benefits, particularly through its facilitation of direct interspecies electron transfer (DIET) between fermentative bacteria and methanogens. DIET serves as a preferred pathway for methane production due to its lower energy consumption, absence of redox mediators, and prevention of toxic volatile fatty acid accumulation. Activated carbon's porous structure, high electrical conductivity, and excellent chemical stability further contribute to its efficacy in enhancing methane production by promoting DIET and buffering pH levels.

Furthermore, the incorporation of bio-based carbon materials, derived from waste biomass

resources, into anaerobic digestion systems demonstrates significant improvements in biogas yield and chemical oxygen demand (COD) degradation rates. These carbon materials, prepared via pyrolysis, exhibit well-distributed particle sizes and uniform pore volume distributions, enhancing methanogenesis by facilitating direct interspecies electron transfer. The utilization of bio-based carbon materials presents a promising avenue for enhancing the efficiency and sustainability of anaerobic digestion processes, offering substantial potential for application in renewable energy production and waste management initiatives. Activated carbon and bio-based carbon materials represent valuable tools for improving the performance of anaerobic digestion systems, offering opportunities for enhancing biogas production, reducing greenhouse gas emissions, and promoting sustainable waste management practices. Continued research and development efforts in this field hold the potential to further optimize the utilization of carbon-based additives in anaerobic digestion processes, contributing to the advancement of renewable energy technologies and environmental conservation efforts (Ganjoo, et al., 2023).

In conclusion, the empirical literature reviewed indicates that activated carbon has the potential to significantly enhance biogas production in digesters. The variability in outcomes however suggests that the effectiveness of activated carbon is influenced by factors like the nature of the feedstock, digester configuration and characteristics of the activated carbon used. Activated carbon there is a promising additive for enhancing biogas production with the potential to contribute significantly to the efficiency and stability of anaerobic digestion processes.

## CHAPTER THREE: METHODOLOGY

In order to achieve the objectives of this study, a series of activities were carried out. These include experimental tests to come up with workable solutions to achieve the set objectives.

### 3.0 RESEARCH DESIGN

The research design consisted of increasing methane gas produced by using activated carbon with objective of producing gas from an experimental biogas setup that mimics the BMP tests carried out on the substrate in the laboratory.

#### **From objectives and research questions:**

The experimental design involved:

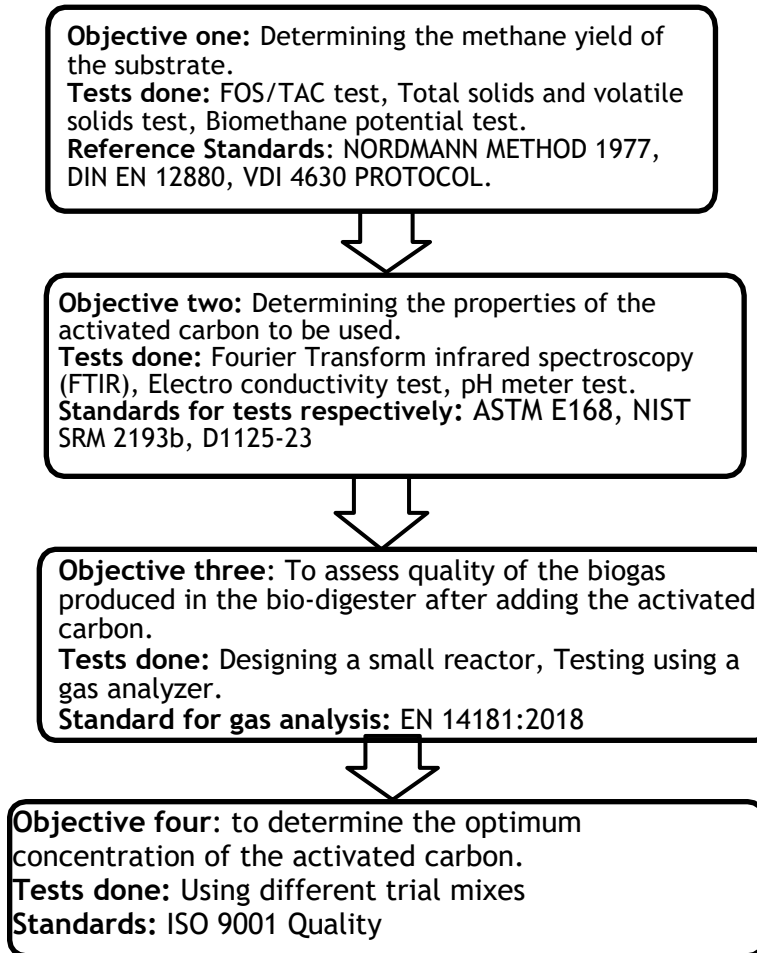
- Carrying out a FOS/TAC ratio test, TS, VS and BMP test on the cow dung and inoculum.
- The properties of the activated carbon were tested using an FTIR analysis test, pH test and Electrical conductivity test.
- Experimental set up designs for digesters were made and set up and activated carbon was added to them.
- The quality of the gas produced from the control digester and the three others with varying amounts of activated carbon was tested.
- The digester with activated carbon that produced the highest methane percentage increase is then selected.
- Optimization of the activated carbon to use is done.

### 3.1 CASE STUDY APPROACH

Using an experimental set up design for digesters that mimic the BMP tests carried out in

the laboratory and the geographical scope of study (NALIRRI).

### 3.2 METHODOLOGY STEPS



*Figure 1: Methodology steps*

### 3.3 FOS/TAC RATIO TEST

(Reference standard: Nordmann 1977)

This test is a preliminary test that is commonly used as an indicator for assessing the fermentation process within biogas reactors.

FOS is a measure of the volatile organic acids measured in mg  $\text{CH}_3\text{COOH}/\text{L}$  and TAC is a measure of the total inorganic carbon measured in mg  $\text{CaCO}_3/\text{L}$ . This ratio looks at acid

vs Alkaline in the system which helps to assess the risk of acidification in the biogas reactor. It is important as monitoring the ratio regularly allows responsiveness to the system and keeps the reactor running efficiently (Brudenell, 2019).

The Nordmann method 1977 was used in this test and the TAC value was determined by using 20 ml of centrifuged sample and titrated to a pH of 5.0 with sulfuric acid (0.1 N/0.05 mol/L) and the FOS value was determined by using the same sample and titrating to a pH of 4.4. Both amounts of titrated acid allowed calculation of the ratio value using the equation;

$$\frac{FOS}{TAC} = \frac{(ml\ of\ H_2SO_4\ added\ from\ pH\ 5.0\ to\ pH\ 4.4 \times 1.66 - 0.15) \times 500}{(ml\ of\ H_2SO_4\ added\ from\ the\ start\ to\ pH\ 5 \times 250)}$$

FOS stands for Volatile Organic acids and TAC stands for total Inorganic Carbonate measured in mg/L (SI Analytics, 2018).

In practice a FOS/TAC ratio of 0.3 to 0.4 is normal and indicates stable operation of the biogas plant (Brudenell, 2019). The deduction was made based on the rule of thumb for assessment of FOS/TAC ratios:

*Table 1: Rules of thumb for assessment of FOS/TAC ratios (Ulrich Lossie, et al., 2021)*

FOS/TAC ratios	Background	Measure	Color code
>0.6	Highly excessive biomass input	Stop adding biomass	
0.5-0.6	Excessive biomass input	Add less biomass	
0.4-0.5	Plant is heavily loaded	Monitor the plant more closely	
0.3-0.4	Biogas production at a maximum	Keep biomass input constant	
0.2 - 0.3	Biomass input is far too low	Slowly increase the biomass input	
<0.2	Biomass input is far too low	Rapidly increase the biomass input	

### 3.3.1 PROCEDURE

- A representative sample of the fermentation substrate was taken.
- Coarse components were removed from the sample.
- 20ml substrate was weighed and filled up with distilled water.
- The sample was stirred to make it homogeneous.
- It was titrated with 0.1 N H<sub>2</sub>SO<sub>4</sub> to pH 5 and the volume (ml) of acid added is noted.
- It was titrated with 0.1 N H<sub>2</sub>SO<sub>4</sub> to pH 4.4, the volume of acid added was noted.

- FOS/TAC was calculated using the formula.

#### Calculation formula

- Quantity of substrate: 20ml
- Sulphuric acid added: 0.1N (0.05mol/L)

$$\frac{FOS}{TAC} = \frac{(ml \text{ of } H_2SO_4 \text{ added from pH 5.0 to pH 4.4} \times 1.66 - 0.15) \times 500}{(ml \text{ of } H_2SO_4 \text{ added from the start to pH 5} \times 250)} \quad (2)$$



*Figure 2: Titration of sulphuric acid during FOS/TAC test*

### 3.4 TOTAL SOLIDS AND VOLATILE SOLIDS TESTS

(Reference standards: DIN EN 12880, VDI 4630 PROTOCOL)

For digestion to occur, biogas production requires consistent substrate inputted into the digester. The total solid and volatile solid content of substrate is important as it influences the design process of the system (Ejiroghene Kelly Orhorhoro, 2017).

Total solids describe dry matter of a substrate and it is expressed as a percentage of the total weight in grams per kilogram. To know the TS of organic matters, the amount of substrate is weighed and dried at 105 °C until its water content is zero (Ejiroghene Kelly

Orhorhoro, 2017).

The concentration of volatile solids is described as the organic part of total solids, measured in grams per kilogram. The pre-fried material is burnt in a muffle furnace at 600°C to separate the inorganic from the organic part of the total solids. What remains after burning is the inorganic fraction. To calculate the concentration of volatile solids, the weight of the inorganic fraction was subtracted from the weight of the dried material, and then divided by the weight of the dried material (Ejiroghene Kelly Orhorhoro, 2017).

### **TOTAL SOLIDS TEST (TS)**

This test was done by drying the sample in a lab oven at a temperature of 105°C for 24 hours.

### **PROCEDURE**

- i. Crucibles were properly washed and dried in the laboratory oven at a temperature of 105°C for one hour. The crucibles were then stored and cooled in a desiccator until needed.
- ii. The crucibles were weighed before use and recorded ( $W_2$ )
- iii. The Oven was switched on and allowed to reach a temperature of 105°C
- iv. The collected substrate samples were added to the crucible.
- v. The weight of the wet samples plus crucible was measured and recorded ( $W_3$ ) and placed in the oven at the temperature of 105°C.
- vi. The substrate was dried for 24 hours and then removed.
- vii. The crucible plus their residue were allowed to cool and weighed and recorded as ( $W_1$ )
- viii. The equation below was used to calculate the percentage total solids.

$$\%TS = \frac{W_1 - W_2}{W_3 - W_2} \times 100 \quad (3)$$

Where:

%TS = percentage total solid

$W_1$  = weight of crucible + dried residue

$W_2$  = weight of crucible

$W_3$  = Weight of wet sample + crucible

### **VOLATILE SOLIDS TEST(VS)**

The volatile solid refers to the solid remaining after evaporation and combustion at 600°C.

#### **Procedure**

- i. The residue obtained from total solids determination was combusted at 600°C for a duration of 30 minutes using a muffle furnace.
- ii. The crucible and black mass carbon were allowed to cool partially in air before it was transferred to the desiccator for complete cooling.
- iii. The sample was weighed once temperature balance was reached.
- iv. The percentage of volatile solids was calculated using the equation below.

$$\%VS = \frac{W_1 - W_4}{W_1 - W_2} \times 100 \quad (4)$$

Where:

%VS = percentage volatile solid

$W_4$  = weight of crucible + weight of residue after combustion

### **3.5 BIOMETHANE POTENTIAL TEST**

**(Reference standard: DIN EN 12880, VDI 4630 PROTOCOL)**

A BMP test is a technique used to determine the maximum amount of biogas produced from per gram of volatile solids (VS) or per gram of COD contained in the feedstock (Yilmaz, 2017). This test was used to determine the methane potential from the feedstock.

#### **Apparatus used.**

- I. 500ml reactor bottles
- II. 2 Water bath
- III. Thermometer
- IV. Sodium hydroxide
- V. Flexible tubes
- VI. silicone
- VII. Measuring cylinders
- VIII. Titration stands

#### **PROCEDURE**

In this experiment there were two kinds samples involved: control samples and substrate samples.

- Control samples

This involved inoculum only from the digester from the scope and the methane production from these samples was subtracted from the methane production from the substrate.

- Substrate samples

Basing on the TS and VS values, the volume of inoculum and cow dung required to be used

was obtained. The homogenous mixture was placed in the reactor which increased the surface area for the micro-organisms to act on the cow dung.

- Sodium hydroxide solution

A concentration of 0.6 moles per liter of sodium hydroxide solution was prepared using distilled water. This solution was used to remove carbon dioxide from the biogas produced as it passed through.

- All the reactor bottles were connected using a series of flexible tubes and if any leakages were noticed they were sealed off with silicone to ensure an air tight environment.
- The control and substrate samples were placed in the first water bath filled water that is prepared at constant temperatures of 35°C to 38°C.
- Flexible tubes carrying gas from the sodium hydroxide were placed below the clamped inverted measuring cylinders with water in them. The total volume of biogas in reactors was measured using water displacement method. As biogas is being produced the water was displaced downwards in the second water bath and the volume of biogas was determined in reference to the displaced water.

### **3.6 PREPARATION OF ACTIVATED CARBON**

Activated carbon was used and it was prepared through pyrolysis and then activation of wood chips. The wood chips were fed into the furnace and then heated at very high temperatures without oxygen i.e., 300 - 400°C. The carbon black is removed from the plant and allowed to cool.

#### **A) preparation of wood chips**

The woodchips were cleaned to make them free from any contaminants. They were then

broken into smaller pieces to ensure uniformity during pyrolysis.

## **B) Pyrolysis**

### **Procedure**

- The prepared woodchips were placed in a furnace
- They were then heated in the absence of oxygen to temperatures ranging from 400 to 900 degrees Celsius
- Then held at the desired temperature to promote the decomposition of organic matter into volatile gases and carbonaceous residues.
- The system was allowed to cool once pyrolysis process was completed.

## **C) Activation with potassium hydroxide**

- A solution of potassium hydroxide (KOH) was prepared.
- The pyrolyzed woodchips were impregnated with the potassium hydroxide solution. This was done by soaking the woodchips in the solution.
- The impregnated woodchips were dried to remove excess moisture.
- They were heated in a controlled environment, typically in the range of 600 to 900 degrees Celsius, under a limited oxygen atmosphere.
- They were then held at the activation temperature for a specified duration to promote the development of porosity and surface area.
- After activation, the activated carbon was allowed to cool and washed thoroughly with water to remove any residual potassium hydroxide.

## **3.7 pH**

**(Reference standard: NIST SRM 2193b)**

pH stands for potential of hydrogen. It represents the acidity or alkalinity of a solution. It

is measured on a scale from 0 to 14, where 7 indicates neutrality. Values above 7 are alkaline, while those below 7 are acidic. The pH of biogas is significant as it impacts the activity of microorganisms involved in decomposing organic material. Maintaining an optimal pH range is vital for maximizing biogas production efficiency. (Raswant, 2021).

In biogas production, pH influences the stability and efficiency of anaerobic digestion process directly (Raswant, 2021). pH not only influences microbial activity but other factors too like, substrate degradation rate and production of hydrogen sulfide. Substrate degradation is more efficient at an optimal pH range leading to increased biogas production.

The pH of additives influences the efficiency of the DIET process and therefore biogas production. The pH level of a biogas reactor plays a crucial role in determining the efficiency and stability of the biogas production process (Raswant, 2021). From the results above, the pH range of the activated carbon is slightly alkaline and hence within the allowable range for alkalinity. It influences the biogas production in the following ways.

- **Microbial activity-** Microorganisms require an optimal pH range between 6.5 to 7.5 to efficiently convert organic matter into biogas. A deviation from this range may cause inhibition of the microbial process leading to a decrease in biogas production. The pH of the additives can alter the general pH of the system by either promoting or inhibiting the anaerobic digestion process. By adjusting the pH through additives, it is possible to electively enhance the growth and metabolic activity of certain microbes that are more efficient in electron transfer.

- **Buffering capacity-** pH buffering systems help maintain the desired pH range by preventing drastic fluctuations and providing a stable environment for microbial activity.
- **Electron transfer efficiency** - Activated carbon acts as an electron carrier hence facilitating the DIET process. pH determines the ability of the additive to accept or donate electrons.
- **Biofilm formation-** A more conductive biofilm facilitates better electron transfer from the microbial cells to the anode.

### **Materials needed**

- Activated carbon sample
- Distilled water
- Ph Meter
- Beaker
- Stirrer

### **PROCEDURE**

- The pH meter was calibrated using standard buffer solutions (pH 4.0, 7 and 10) to ensure effective measurement.
- 10g of activated carbon was measured using a weighing scale.
- The activated carbon was then added to 100ml of distilled water (ratio of 10:100 of activated carbon to distilled water)
- The mixture was then stirred for 15 minutes to ensure uniformity and allowed to settle.
- The pH was then measured using a pH meter.

- The measurements taken were then recorded.
- The test was repeated 3 times and the average pH was got.

### **3.8 FOURIER TRANSFORM INFRARED SPECTROSCOPY**

**(Reference standard: ASTM E168)**

This refers to a technique used to obtain an infrared spectrum of emission, absorption and photoconductivity of solid, liquid and gas. It is used to detect various functional groups in materials. It uses the mathematical process (Fourier transform) to translate the raw data (interferogram) into actual spectrum (Saleh, 2022). It is a non-destructive analytical technique that measures the absorption of infrared radiation by a sample, it provides details of the chemical composition and molecular structure of a wide range of materials. This was done using an FTIR machine. Activated carbon contains distinct functional groups which means that there are reactive sites in the molecule that play a crucial role in its reactivity for example; oxygen and nitrogen containing groups. These groups create reactive sites on the surface of the activated carbon allowing it to interact with various molecules.

Identifying reactive sites in activated carbon amounts to identifying areas with low or high electron density.

The functional groups present on the activated carbon i.e., alkenes and alkynes indicate that the region is an area of high electron density. These electrons act as electron donors and therefore, facilitating the DIET process that uses electrons to act as mediators between fermentative and methanogenic bacteria.

Therefore, the functional groups identified in the activated carbon facilitate the DIET process and hence indicating an increase in overall quantity of biogas produced in the

digester.

### **3.8 DESIGNING OF SMALL BIO-DIGESTERS.**

**(Reference standard: Biogas Purification Technology: A practical Guide by U.S Department of Energy. ASME B31.3)**

A bio-digester is a system that is used for anaerobic digestion of organic matter to produce biogas was designed using AUTO CAD. A bio-digester requires to meet some factors like no leakages, high corrosion resistance, easy maintenance, controlled temperatures and low cost. A prototype/ experimental design was made using AUTO CAD software.

### **3.9 GAS ANALYSIS USING A GAS ANALYZER**

**(Reference standard: EN 14181:2014)**

The purpose of this test was to ascertain the gas composition of the biogas produced. The model of the gas analyzer used was A multitec 540. Gas analysis is a crucial factor in assessing the concentration levels of gases produced by a digester. The primary objective of gas analysis is to measure the concentrations of the gases present in a digester.

Biogas was collected in gas bags from the bio digester and the composition of the gas was determined using the gas analyzer. The gas analyzer provided the percentage of volume gases produced when the agitator and additive have been used. This will be indicator if there is an increment in the amount of methane produced by the bio-digester. A gas analyzer is designed to measure gas simultaneously like methane, carbon dioxide, hydrogen sulphide and nitrogen oxide.

## PROCEDURE

- The gas to be tested was collected in floaters.
- The gas analyzer was calibrated using fresh air until all the values on its screen turn to zero.
- Using tubing fitted on the gas analyzer probe and at the outlet of the floater, the gas analyzer uses the principle of suction to get the gas out and test it.
- After connection, the biogas components are displayed on the screen of the analyzer.

## CHAPTER FOUR: RESULTS AND DISCUSSIONS

This chapter is majorly a discussion of the results obtained from the preliminary test that was done and their significance to the aim of the research being carried out. Using protocols as guidelines, the preliminary test was carried out and results obtained.

### 4.1 THE FOS/TAC RATIO TEST.

The test was determined by titration using 0.05mol per liter of dilute sulphuric acid. The initial pH of the sample was recorded and then the pH dropped to 5 and the sulphuric acid used at this point is measured and recorded as V1. Then the Ph was further dropped to 4.4 and the sulphuric acid used is measured and recorded as V2. The initial pH values of the triplicate samples were measured using a pH meter and recorded. It was deduced that the initial pH, of all three samples was between 7.37 and 7.70 hence alkaline. Below is a table of results obtained:

*Table 2: Initial pH and temperature values*

SAMPLE	NO.	PH	temperature
A	1	7.42	25.0
	2	7.37	25.1
	3	7.43	24.8
<b>AVERAGE</b>		<b>7.41</b>	<b>74.9</b>
B	1	7.44	25.5
	2	7.57	25.4
	3	7.53	25.7
<b>AVERAGE</b>		<b>7.51</b>	<b>25.5</b>

C	1	7.59	25.0
	2	7.62	25.0
	3	7.70	25.3
<b>AVERAGE</b>		<b>7.64</b>	<b>25.1</b>

Three samples were titrated with Sulfuric acid and the FOS/TAC values obtained include:

*Table 3: H2SO4 and FOS/TAC values*

SAMPLE	V	PH	H2SO4 (ml)	FOS/TAC ratio
A	V1	5	4.6	0.328
	V2	4.4	5.1	
B	V1	5	5	0.3926
	V2	4.4	5.65	
C	V1	5	6.2	0.33
	V2	4.4	6.9	
<b>Average</b>				<b>0.3502</b>

After analysis of the raw data obtained during the test, the results obtained are further represented through a series of graphs. The graph below shows the triplicate values of the FOS/TAC tests obtained after a series of calculations.

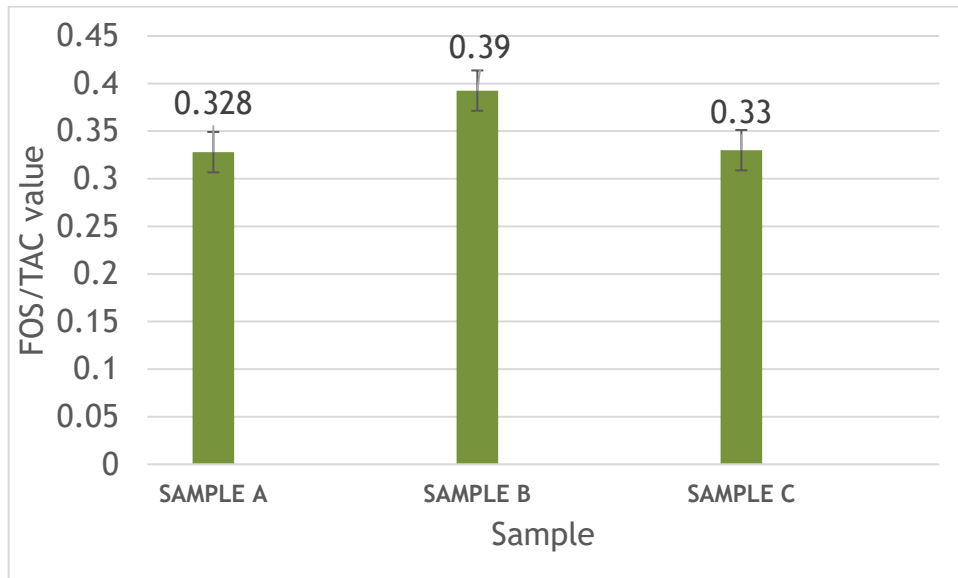


Figure 3: FOS/TAC values

## DEDUCTION

Based on the results obtained, the ratio of FOS/TAC lies between 0.3 to 0.4. This range indicates a stable and efficient anaerobic digestion process. This stable process is characterized by optimal conditions for microbial activity, which is crucial for the production of biogas. The range of the ratio indicates that the process is balanced with neither excess of volatile acids that could lead to acidification and potential system failure nor a low substrate level that would otherwise indicate underperformance in terms of substrate degradation and biogas production. Therefore, all parameters for normal biogas production are constant and the digester system is working properly.

## 4.2 TOTAL SOLIDS (TS) AND VOLATILE SOLIDS (VS) TEST

### REFERENCE STANDARDS: DIN EN 12880, VIN 4630 protocol

These tests were done in order to determine the amount of solid present in the sample after the loss of moisture present.

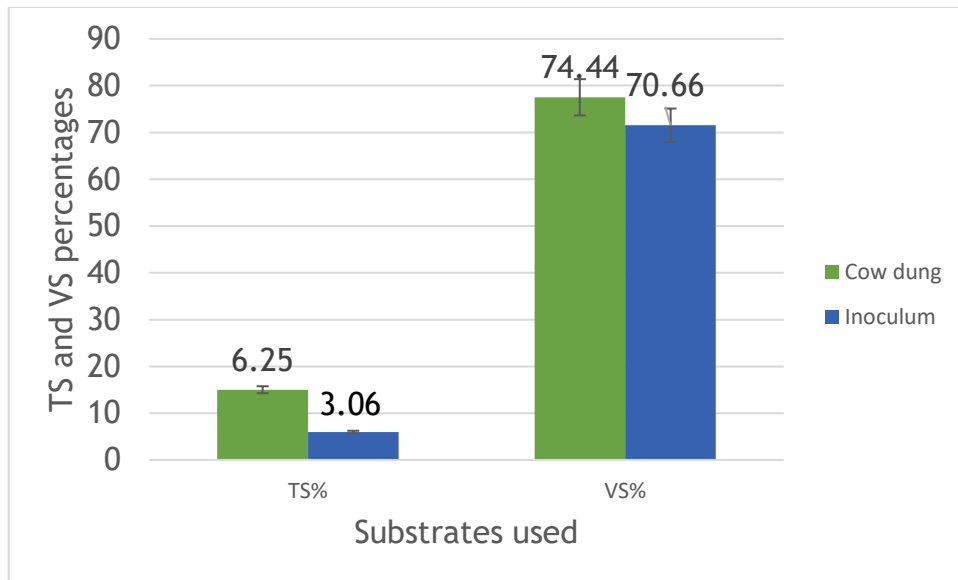
#### 4.2.1 TOTAL SOLIDS TEST

Total solids refer to the total amount of organic and inorganic matter present in a given sample. It is the quantity of material residue left in the crucible after evaporation of the moisture and its subsequent drying in a laboratory oven at 105°C for 24 hours.

*Table 4: Results of VS and TS obtained*

	Identity	Weight of Crucible + wet sample (W <sub>3</sub> )	Weight of crucible (W <sub>2</sub> )	Weight of crucible + dry material (W <sub>1</sub> )	Weight of crucible + ash (W <sub>4</sub> )	TS%	VS%
INOCULUM	B1	58.23	27.228	28.192	27.51	3.10948	70.7469
	B2	52.565	26.504	27.295	26.737	3.03519	70.5436
	B3	52.977	27.482	28.26	27.71	3.05158	70.6941
	Average					<b>3.06541</b>	<b>70.6615</b>
Cow dung	C1	55.92	27.98	29.826	28.459	6.60702	74.052
	C2	51.908	28.005	29.456	28.382	6.07037	74.0179
	C3	59.399	27.066	29.039	27.554	6.10212	75.2661
	Average					<b>6.25984</b>	<b>74.4453</b>

The out-come of the results obtained from the experiment show that the amount of biogas produced is as a result of the TS% and VS % concentration as shown in table 4. The test was done in triplicates and the results obtained are represented in the graph below.



*Figure 4: Average TS and VS values*

Figure 1 shows the average TS and VS values of inoculum and cow dung.

Inoculum with a VS content indicates that it has organic matter that has not been fully digested and can therefore support the anaerobic digestion process. The inoculum VS content can vary depending on the specific source of material and the amount of inorganic material present. Inoculum is an important component of biogas production as it contains microorganisms necessary for anaerobic digestion, it is needed in a biogas reactor to initiate and maintain the anaerobic digestion process.

Therefore, The VS value implies that the value obtained is the how much of the substrate can be converted to biogas and in the above case, over 70% of the substrate in both the inoculum and substrate can be converted to biogas, hence a high potential for biogas production is constant conditions are maintained.

The B and C samples which represent inoculum and cow dung respectively have a VS content of 70.66% and 74.445% hence indicating that the cow dung is rich in organic

material and have potential to produce significant amount of biogas. This deduction was made in accordance to the VDI 4630 protocol. Cow dung is the major source of organic material for anaerobic digestion to produce biogas.

*Table 5: Standards for VS and TS test values*

	<b>Cow dung</b>	<b>Inoculum</b>
<b>TS for liquid substrates.</b>	-	<5%
<b>TS for solid substrates.</b>	5% - 40%	-
<b>VS for substrates</b>	>50%	>50%

The Total solid and volatile content of the substrate used is within the desired range of the organic matter required for biogas production. The TS and VS test done signifies that the substrate contains the suitable organic content to support biogas production under anaerobic conditions.

The TS and VS values were also used to calculate the quantities of substrate and inoculum to be used in the bio methane potential test.

#### **4.3 BIOMETHANE POTENTIAL TEST RESULTS**

The TS and VS values obtained above were then used to determine the quantities of substrate and inoculum to be used in the bio methane potential test to determine the potential of the different substrates.

The inoculum: Substrate ratio (I:S) was made equal to 3, according to the VDI 4630 protocol:

$$\frac{\text{Inoculum}}{\text{Substrate}} = \frac{I}{S} = \frac{\text{Volume of inoculum} \times \text{VS of inoculum}}{\text{Volume of Substrate} \times \text{VS of substrate}} = 3 \quad (5)$$

Using the formula 5 above, the protocol guides that a head space of 25% for gas volume be considered and hence a substrate volume of 75% of the capacity of the reactor bottles which is 500ml. The reactor bottles containing the substrate cow dung and inoculum had the following volumes.

*Table 6: Substrate volumes to be used for BMP test*

Substrate	Volume (ml)
Inoculum (B)	253.22
Cow dung (C)	80.115



*Figure 5: BMP test set up*

The graph below shows the results that were obtained for BMP test over a period of 26 days:

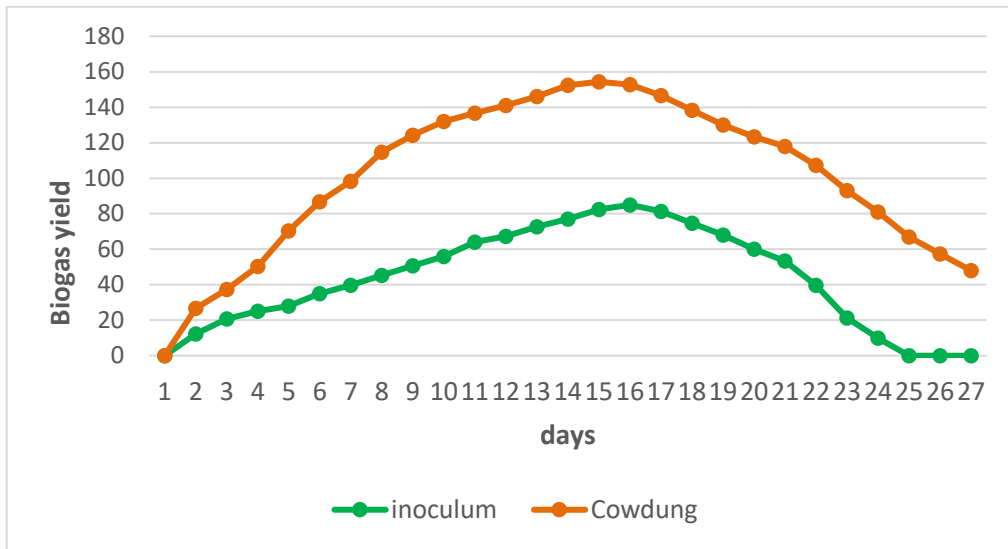


Figure 6: Graph of daily biogas yield

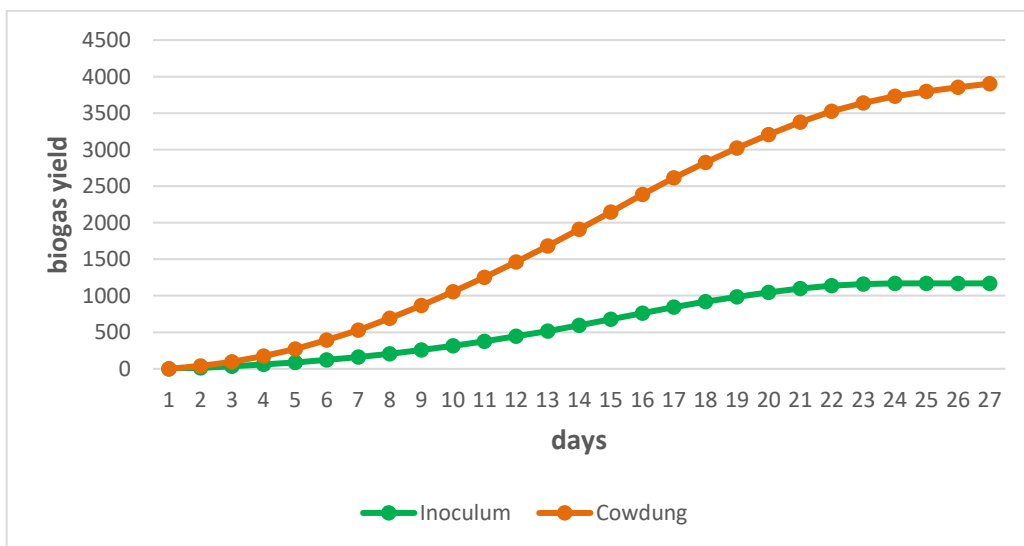


Figure 3: Graph of Cumulative biogas yield

The biogas production in all the samples started from zero on the first day and gradually increased overtime. From one to four days, there was a low biogas produced because of the slow hydrolysis stage. The biogas yields increased until it reached its peak production and started decreasing. It reached its peak production indicating that the microorganisms were most active on the 15<sup>th</sup> day and therefore efficiently broken down the organic matter

into biogas. Also, the peak indicates that optimal conditions for microbial activity like pH, temperature were present. Therefore, it means that the substrate being used has been fully broken down by the microorganisms under favorable conditions for anaerobic digestion.

The downward trend suggests that the rate of biogas production reduced due to substrate depletion as the microbes fed on all the substrate present. Therefore, it shows that anaerobic digestion of the substrate was nearing completion as most of the organic matter was converted into biogas. Therefore, there was need to re-feed the reactor bottles to allow for new substrate to be broken down by the microbes for more biogas to be produced. The production volume of the inoculum curve is relatively low throughout the experiment hence indicating that the inoculum itself is not an adequate source of biogas.

#### 4.4 PH

pH stands for potential of hydrogen and is the measure of acidity or alkalinity of a solution. It has a scale that ranges from 0 to 14, with 7 being neutral. pH values above 7 are considered alkaline and those below 7 are acidic.

*Table 7: pH values of additive*

Sample	pH
1	8.68
2	8.65
3	8.75
<b>Average</b>	<b>8.69</b>

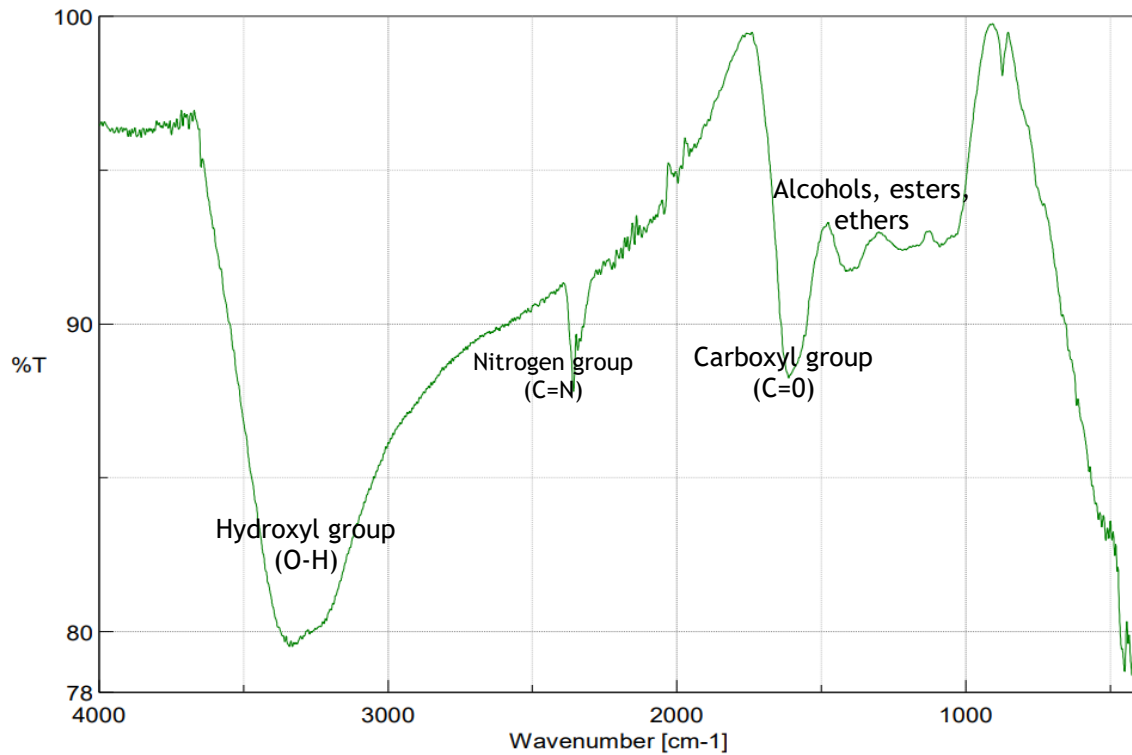
The results obtained above are within the acceptable pH range for Biogas production. 8.69 is within the range of alkalinity and therefore indicating that the additive can stimulate

the growth of microbes and ensure stability of the digester. The activated carbon will be able to accept/ donate electrons hence promoting the DIET process. Therefore, more biogas is generated since an optimal environment for biogas production is created and hence microbes will act and degrade the substrate to produce biogas.

#### 4.5 FOURIER TRANSFORM INFRARED SPECTROSCOPY(FTIR)

Fourier Transform Infrared spectroscopy of activated carbon was done and the graph that was produced showed the presence of the following functional groups:

- Hydroxyl functional group (O-H)
- Carboxyl/ Carbonyl Functional group
- Nitrogen compounds



*Figure 7: FTIR graph of activated carbon*

The above functional groups influence the adsorption of molecules on the activated carbon surface. The nature and density of functional groups enables the adsorption of inhibitory compounds and other gases like ammonia, hydrogen sulphide hence improving the quality of gas being produced and allowing for more methane to be produced in the anaerobic digestion process.

**The results obtained show that:**

The FTIR spectra for the activated carbon indicated a strong absorbance between 3300-3450  $\text{cm}^{-1}$  and this could be attributed to the O-H stretching of the hydroxyl group that includes carbohydrates and proteins that can be further decomposed by bacteria in the anaerobic digestion process (Rainer Janu, 2023).

The spectra at 1600  $\text{cm}^{-1}$  indicates the presence of a Carboxyl (C-C) or carbonyl (C=O) functional group.

At 2360  $\text{cm}^{-1}$  has a weak peak hence there is a presence of nitrogen compounds (C=N) on the surface of the activated carbon. The nitrogen is in low quantities due to its weak bond and therefore showing that the activated carbon has a low composition of nitrogen therefore a high affinity for nitrogen containing compounds in the digester and hence adsorbing them therefore more methane gas is produced.

At 1000 -1200  $\text{cm}^{-1}$  functional groups like alcohols, ethers or esters exist.

The above properties show that the use of activated carbon enhanced biogas production by enhancing the DIET (Direct interspecies electron transfer) which was influenced by the microbial population and rapid degradation of volatile fatty acids which support the role of activated carbon in support of DIET (Xia He, 2022).

#### 4.6 ELECTRICAL CONDUCTIVITY

Electrical conductivity in biogas digesters relate to the presence of ions in the fermentation medium. Manure undergoes microbial degradation releasing various ions like sodium, calcium, magnesium and volatile fatty acids and these contribute to the overall conductivity of the feedstock within the digester.

*Table 8:Electrical conductivity results of activated carbon*

Sample	Activated carbon ( $\mu\text{S}/\text{cm}$ )
1	640
2	632
3	667

The results above show that the activated carbon has sufficient ions and nutrients for microbial activity. Due to this, activated carbon acted as a conduit for electron transfer between syntrophic microorganisms involved in the DIET process whereby they directly exchanged electrons with each other to metabolize complex organic compounds into methane and carbon dioxide. By promoting electron transfer, activated carbon accelerates the metabolic reactions involved in anaerobic digestion leading to faster conversion of organic matter into biogas.

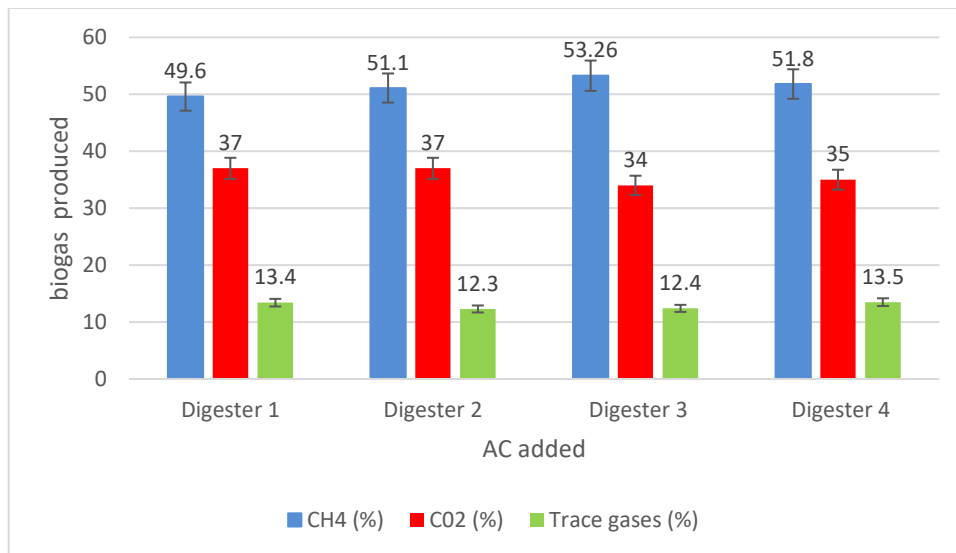
#### 4.7 GAS ANALYZING RESULTS

Gas from different digesters was collected using the floaters and was measured using the multitec 540 gas analyzer. One digester was a control digester and the three digesters had different amounts of activated charcoal which include 10g/l, 13g/l and 20g/l. These values

were obtained through reading different literature where different additives were used and what amounts were used in the digesters. This was done in triplicates for each bag we measured. In the first one week the methane production was low and there was a great number of other gases because the digester had just begun functioning.

*Table 11: Average values for biogas production before adding activated carbon*

BIOGAS ANALYSIS BEFORE ADDING ACTIVATED CARBON			
MULTITEC GAS ANALYZER 540			
Digesters	CH <sub>4</sub> (%)	CO <sub>2</sub> (%)	Trace gases (%)
Digester 1	49.6	37	13.4
Digester 2	51.10	37	12.3
Digester 3	53.26	34	12.4
Digester 4	51.8	35	13.5



*Figure 8: Biogas production before adding activated carbon*

The figure above shows the percentages of the average gas composition of biogas obtained from the digesters before adding activated carbon. The results show that the methane

value of gas being produced is relatively low in digester one compared to the other three digesters. The raw gas composition obtained from the cow dung is shown as in the figure 6 above. The composition of the biogas from cow dung varies due to various factors like type and quality of substrate used, operation conditions for the digester plant like temperature and pH. Digester 3 produced the most methane gas, the least carbon dioxide compared to other digesters. This therefore indicated that the micro-organisms in digester three adapted very quickly to the conditions and therefore produced biogas in comparison to the other three digesters.

The average amount of methane gas in biogas is about 50% to 70%. It is the main component of gas and the primary energy carrier. The results above show the average methane value being between 48.2 to 53.9% of methane hence indicating that the digester is producing methane gas normally. Carbon dioxide production in the digester is between 33% to 38% hence indicating that the digesters are producing carbon-dioxide normally. These trace gases were produced in low quantities. This shows that the digesters were working within normal range.

#### **AFTER ADDING ADDITIVES**

After adding the activated carbon in varying quantities, digester 1 is the control, 10g/L was added to digester 2, 13g/L was added to digester 3 and lastly 20g/L was added to digester 4. The following results were obtained.

Table 12: Average values for Biogas production after adding additives

BIOGAS ANALYSIS AFTER ADDING ADDTIVES			
MULTITEC GAS ANALYZER 540			
Digesters	CH <sub>4</sub> (%)	CO <sub>2</sub> (%)	Trace gases (%)
Control	52.67	34.5	12.83
2(10g)	59.83	27.83	12.33
3(13g)	61.43	27	11.4
4(20g)	60.93	27.5	11.57

The figure below shows the percentages of biogas produced after adding additives.

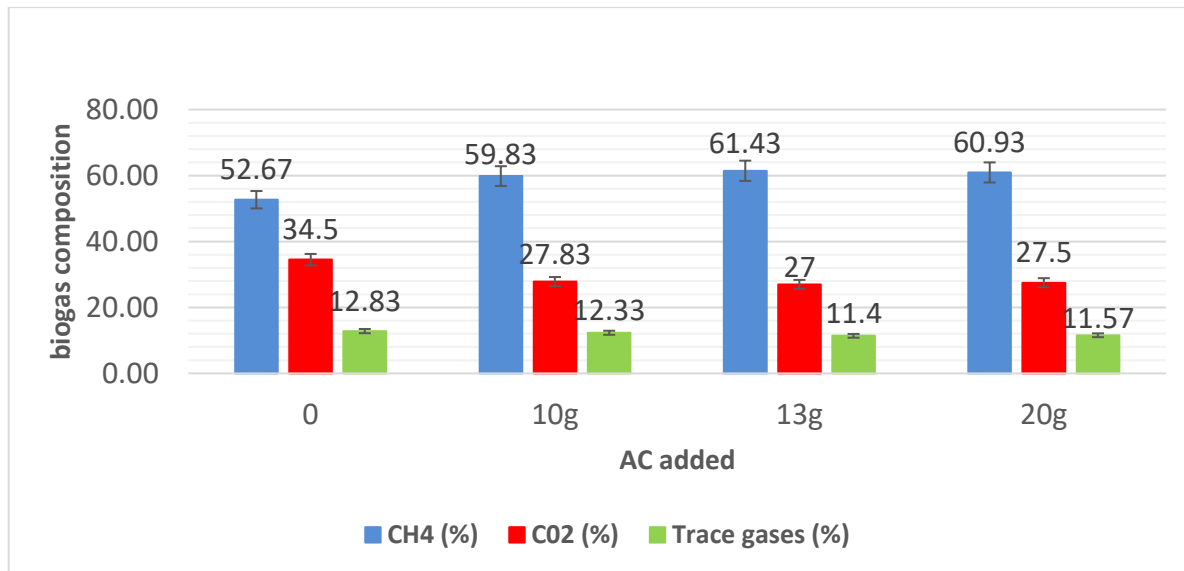


Figure 9: Biogas production after adding additives

Methane increased after adding activated carbon. Carbon dioxide reduced in the three digesters that had activated carbon. Methane gas is maximum in the digester that had 13g of activated carbon. It increased by 8.8% after 3 weeks of being added to the digester.

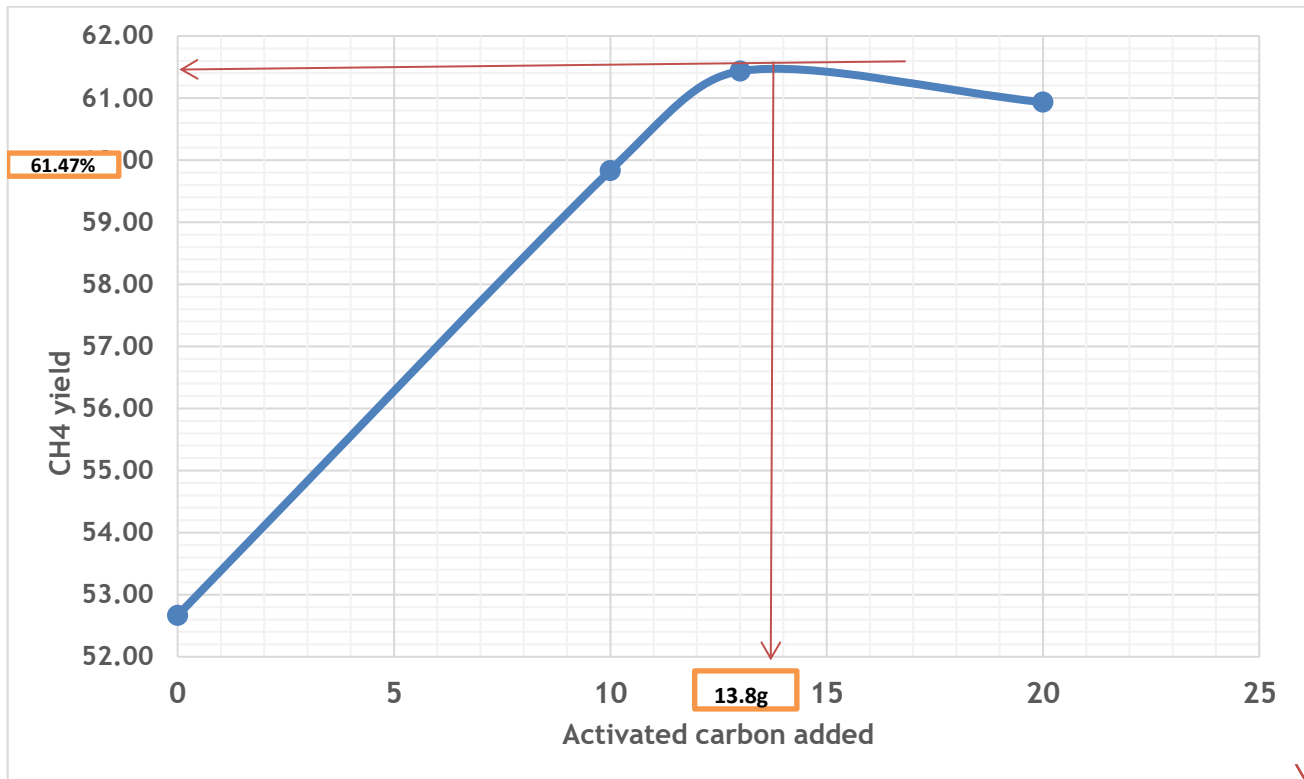
## 4.8 OPTIMIZATION

The amount of activated carbon to be used in the digester was optimized. After adding various amounts of activated carbon (10g, 13g, 20g) in the digesters, the value of activated carbon that gave the highest methane yield was taken as the optimal value.

*Table 9:Percentage increase in the digesters*

DIGESTER	% increase
1 (control)	0
2 (10g)	7.16
3 (13g)	8.76
4 (20g)	8.26

The results show the percentage increase in the digesters after adding activated carbon. Digester three with 13g gives the highest percentage increase among all three digesters. A graph of methane yield against activated carbon percentage is then plotted and the highest points are extrapolated to give the optimized value.



*Figure 10: Graph of optimization of activated carbon*

The graph above shows that 13.8g gives 61.47% of methane gas produced. This therefore is the optimized value.

#### 4.9 DESIGNING AN EXPERIMENTAL SETUP

This involved using AUTOCAD to design a prototype of the bio-digesters basing on the bio-digester information and construction manual.

The digesters were made using the following equipment.

- Four old paint buckets
- 3 / 8inch gas pipes
- Floaters to collect the gas
- 2inch PVC pipe
- Silicon

- 2-inch PVC bends



*Figure 11: cutting of Pipe for Digester inlet*

4.9.1 DESIGN FOR BIO-DIGESTER

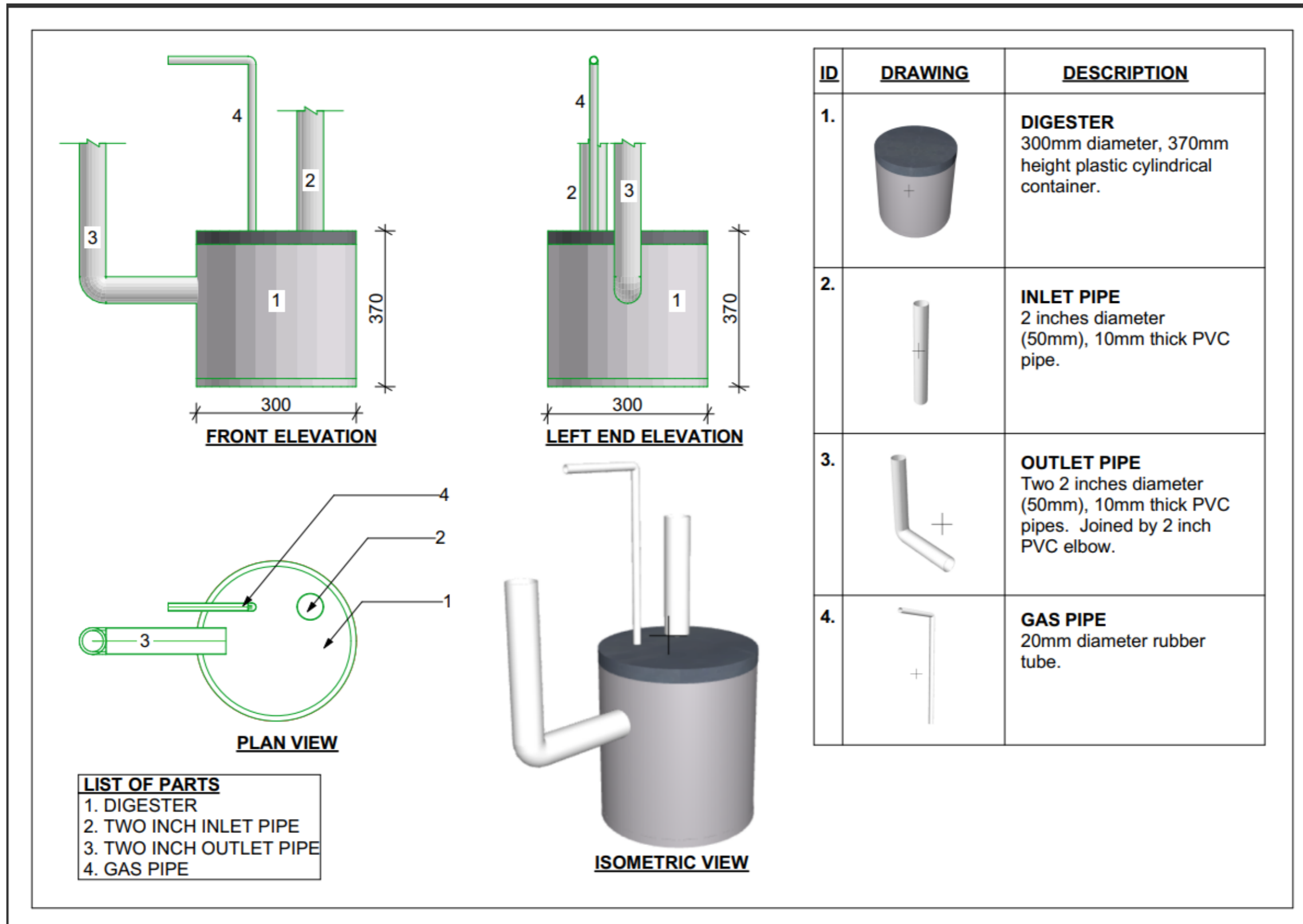


Figure 12 showing a design for experimental setup of bio-digesters

For anaerobic digestion to occur, there are conditions that necessitate anaerobic digestion to occur and these include:

### Temperature

Temperature plays a primary role in an anaerobic digestion, since it regulates the stability performance of anaerobic digestion process (Erqi Nie, 2021). Microbes responsible for anaerobic digestion are active at two temperature stages that is: 30 to 35 centigrade (mesophilic range) and 50 to 60 degrees centigrade (thermophilic range). Temperatures outside these are not conducive for methane production (bmcc.edu, 2019)

### 4.10 FEEDING DIGESTERS

The amount of feedstock to feed into the digesters was obtained by using the total solids and the volatile solids results. This was done in this way:

Total solids percentage = 6.26%

$$75\% \times 20L = 15L \text{ (feedstock volume)}$$

$$25\% \times 20L = 5L \text{ (gas)}$$

$$15L = \text{volume of inoculum}(VI) + \text{volume of substrate}(VS)$$

$$\text{therefore, volume of substrate} = 15 - \text{volume of inoculum}$$

$$\frac{\text{Inoculum}}{\text{Substrate}} = \frac{I}{S} = \frac{\text{Volume of inoculum} \times \text{VS of inoculum}}{\text{volume of substrate} \times \text{VS of substrate}} = 3 \quad (6)$$

$$\frac{VI \times 71.53}{VS \times 77.53} = 3$$

$$\frac{VI \times 71.53}{(15 - VI) \times 77.53} = 3$$

$$VI(\text{volume of inoculum}) = 11.472L$$

$$\text{volume of substrate (VS)} = 3.528L$$

Feedstock = 15L

Volume of substrate = 3.528L

Volume of inoculum = 11.472L



*Figure 13: feeding of digesters*

#### **4.10.1 ORGANIC LOADING RATE**

This refers to the amount of the organic matter fed into the digester per unit volume per unit time. A high loading rate can lead organic over load and acidification in the digester which leads to low methane production while low organic loading rate results into low biogas yield and sometimes the microorganisms can die due to lack of sufficient substrate. The organic loading rate was calculated and this is how much organic dry matter can be fed into a digester per unit volume.

$$OLR = \text{mass of substrate fed per time unit} \times \frac{\text{concentration of organic matter}}{\text{digester volume}} \quad (7)$$

$$OLR = 0.002 \times \frac{23.2426}{0.21168} = 0.2196kgVS/m^3$$

The organic loading rate of our digesters is  $0.2196kgVS/m^3$  which is within the range for unstirred digesters ( $< 2$ ).  $0.2196kgVS/m^3$  means that every cubic meter of the digester volume, 0.2196kg of volatile solids are being added to the digester within given period of time. This helps control the amount of substrate being fed into the digester and ensures efficient biogas production while maintaining the process stability.

#### **4.11 COST BENEFIT ANALYSIS**

Size of digesters at NALIRRI =  $80m^3$

Optimum value of activated carbon = 13.8g/L

Percentage increase of methane at 13.8g/L = 8.8%

500L of feedstock is fed into the NALIRRI digester daily.

#### **ASSUMPTIONS MADE**

- The woodchips/wood waste for making activated carbon is already present at NALIRRI so there's no money spent on it.
- Assuming NALIRRI has a furnace, there's no money spent on carbonizing the woodchips in preparation of activated carbon.
- Assuming the conditions are replicated and are constant in the experimental setup and the NALIRRI digester.
- Assuming NALIRRI is spending 30 million Ugandan shillings on electricity per year.

#### 4.11.1 TEST WITH CASE STUDY

20L capacity

75% of 20L = 15L

#### BIG DIGESTERS

80m<sup>3</sup> capacity

75% of 80 m<sup>3</sup> = 60m<sup>3</sup> = 60,000L

15L = 13.8g

1L =  $\frac{13.8}{15}$

60,000l =  $\frac{13.8}{15} \times 60,000 = 55,200g = 55.2kg$

Assuming the conditions are replicated and are constant at both the experimental setup and NALIRRI digester i.e., 13.8g/l gives an 8.8% increment and 55.2kg is in 60,000L then the increase is also 8.8% in the digester for a period of 3 weeks.

Therefore, at NALIRRI, methane gas production is at an average of 50% and therefore:

50% + 8.8% = 58.8%

#### 4.11.2 COSTING

1L of concentrated HCL OF 1.18mol/L = 18,000 shs

1 L of hydraulic acid was used to produce 1kg of Activated carbon (using a ratio of 1:1)

1000g = 1L

1g = 1/1000L

13.8g = 0.0138L of HCL used for the experimental setup.

#### AT NALIRRI

1000g = 1L

1g = 1/1000

55,200g = 55.2L of HCL

1L of HCL = 18,000 shs

55.2L of HCL = 18,000 x 55.2 = 993,600 shs.

In 3 weeks, 8.8% increment was realized in methane gas.

3weeks = 8.8%

1 week= 8.8 / 3

52 weeks (1 year) = 152.7% increment.

#### **COST OF USING ADDITIVE IN A YEAR**

3weeks = 993,600 shs

1week = 993,600 / 3

52weeks = (993,600/3) x 52 = 17,222,400 shs.

Therefore, the cost of adding an additive in a year is 17,222,400 shs.

#### **SAVINGS:**

30,000,000 million -17,222,400 shs = 12,777,600 shs saved on electricity per year.

Using biogas offers numerous benefits over, relying solely on electricity. Not only does it provide cost saving, but it also contributes to environmental sustainability by reducing green house gas emissions and offers an efficient solution for organic waste management. This proves to be a financially prudent and environmentally responsible choice. Adopting the use of activated carbon alongside electricity or fully switching to electricity provides savings of 12, 777,600 shs per year. NALIRRI will be able to save on electricity usage.

## CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

### 5.1 CONCLUSIONS

From the research conducted, the following can be concluded:

1. The Fermentable organic solids to total alkalinity carbon ratio (FOS/TAC) was done to check the stability of the digester for anaerobic digestion. It was seen that the digester was stable given a value of 0.3502 was obtained and this lies in the range of 0.3 to 0.4 of the standards. Therefore, indicating that biomass input was being kept constant and therefore, biogas production was kept at maximum and hence the digester was stable. Indicating an optimal production of methane gas at maximum as all factors necessary for anaerobic digestion were kept constant in the NALIRRI digester and therefore, the need for an additive (activated carbon) to increase biogas production since they were producing less biogas (48 -50%) than would be required at optimal conditions.
2. Determining the VS and TS of the cow dung and inoculum aided in understanding the nature of the feedstock used and its potential to produce biogas. This is majorly by knowing the organic matter present in the substrate and the viability of the cow dung and inoculum to be used in anaerobic digestion to produce biogas. Both the cow dung and inoculum had Volatile solid contents above 50% which is the standard and therefore implying that they were fit to be used as substrates in anaerobic digestion process.
3. The volumes for carrying out the biomethane potential test were determined from the Volatile and Total solids tests done. The biomethane potential test was done to determine the potential and capability of the substrate to produce biogas under

ideal anaerobic conditions. The biomethane potential test was also used as a control test to mimic the digesters that we set up for the experimental stages during the third and fourth objectives. It was seen that cow dung gave us a greater biogas volume produced than inoculum. This can also be attributed to the fact that the cow dung had a greater volatile solids composition compared to inoculum. Thus, the cow dung had a high potential to produce biogas and could be used for anaerobic digestion.

4. The potential of hydrogen of activated carbon was determined and the results obtained were within the acceptable pH range for Biogas production. 8.69 therefore indicated that the additive could stimulate the growth of microbes and ensure stability of the digester.

The activated carbon would be able to accept/ donate electrons hence promoting the DIET process. Therefore, more biogas was generated since an optimal environment for biogas production was created and hence microbes would act and degrade the substrate to produce biogas.

An FTIR analysis was done to determine the functional groups present in the activated carbon. This would help in knowing the reactive sites present for the DIET process to take place by facilitating the movement of electrons from fermentative bacteria to methanogenic bacteria within a shorter time without the need for a mediator. This therefore, boosted the production of methane gas being produced. The functional groups (hydroxyl group, nitrogen group, alcohols, esters and carboxyl groups) influenced the adsorption of molecules on the activated carbon surface. The nature and density of the functional groups enabled the adsorption of inhibitory

compounds and other gases like ammonia, hydrogen sulphide hence improving the quality of gas being produced. The quality and quantity of gas that was produced was improved.

The electrical conductivity of the activated carbon within the acceptable range for biogas production. Therefore, the activated carbon would provide sufficient ions and nutrients for microbial activity. The values were high and therefore correlated with increased microbial activity leading to enhanced biogas production rates.

5. Four digesters were made and one was the control and different amounts of activated carbon were added. Digester 1 was the control, digester two had 10g of activated carbon, digester 3 had 13g of activated carbon and digester four had 20g of activated carbon. Digester one had a 0% increment in methane gas, digester two had a 7.16% increment, digester 3 had an 8.76% increment and digester 4 had 8.26% increment in methane gas production. 13.8g gave the highest percentage increment in methane gas production and therefore, it is the best amount of activated carbon to be added to 15L of substrate in a bio-digester to produce the highest amount of methane gas under favorable conditions.
6. While optimizing it was concluded that 13.8g gave the highest methane value after plotting on a graph of methane gas produced against activated carbon added. It therefore means that the use of 13.8g of activated carbon gives the highest methane gas production. Therefore, activated carbon can be used to increase methane gas production in the NALIRRI digester.
7. NALIRRI is currently spending 30million on hydro-electric power per year to power the whole plant. Producing their own biogas for a year is less costly (17,222,400

shs). This is because they experience an increment of 153% in methane gas production for per year if they use the optimum concentration of additives advised. Therefore, considering the option of activated carbon to boost biogas production proves to be n environmentally and financially prudent choice.

## **5.2 LIMITATIONS AND RECOMMENDATIONS**

### **5.2.1 LIMITATTION**

This study presented the findings of the effect of using activated carbon as an additive to increase biogas produced in a digester. For better assessment in the use of this material, the limitations and recommendations are stated below:

The main limitation of the project was the time factor.

### **5.2.2 RECOMMENDATIONS**

1. Future research should be done for longer durations to see the impact of activated carbon methane gas production over a longer period of time.
2. Further study should be conducted on the use of other sources of biomass for activated carbon to be made from in order to compare the effectiveness of their use.
3. The use of activated carbon other types of feed stock for anaerobic digestion should be done.
4. An assessment of the different temperatures for pyrolysis as activated carbon is being made should be done.

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**APPENDIX A**



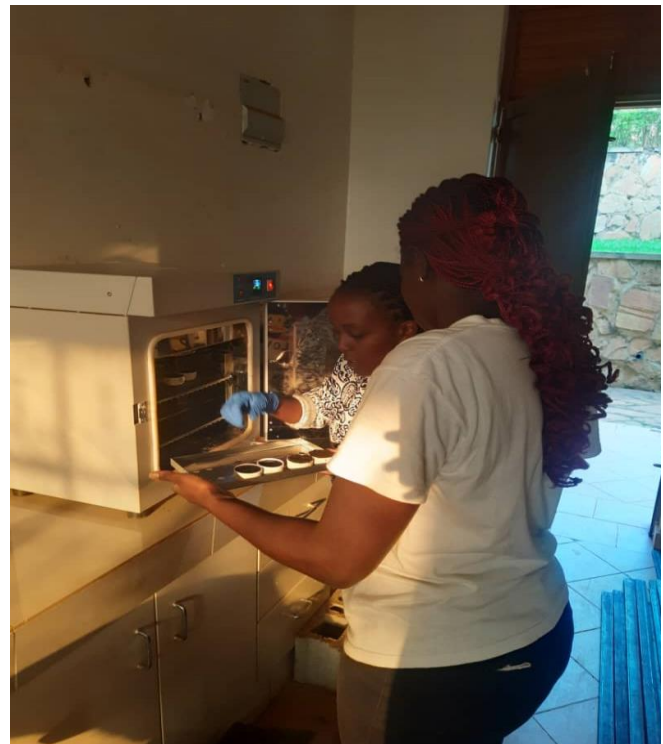
*Appendix 1: Showing FOS/TAC titration*



*Appendix 2: Showing BMP test set up*



*Appendix 3: Showing collection of BMP results*



*Appendix 4: Showing putting of TS, VS samples in oven.*



*Appendix 5: Showing testing for EC*



*Appendix 6: Showing feeding of digesters.*



*Appendix 7: Showing digesters.*



*Appendix 8: Showing cutting pipe for experimental setup*



*Appendix 9: Showing making of experimental setup.*



*Appendix 10: Showing floaters inflated with biogas before testing*

## APPENDIX B



**UGANDA INDUSTRIAL RESEARCH INSTITUTE**  
"A Lead Agency in Industrialisation of Uganda"



TO WHOM IT MAY CONCERN

15<sup>th</sup> January 2024.

**SUBJECT: CONFIRMATION OF PYROLYSIS EXPERIMENT CONDUCTED BY Ms. FAITH ANGEANGO WANADI AND Ms. SANDRA NAMULUMBA AT UGANDA INDUSTRIAL RESEARCH INSTITUTE.**

This is to confirm that the above-mentioned students conducted a pyrolysis experiment on 11<sup>th</sup> January 2024 at our laboratory facilities. The purpose of this experiment was to get biochar out of the raw materials (corn cob and wood shavings).

### KEY DETAILS OF THE EXPERIMENT

**Experiment Title:** Pyrolysis of Corncob and Wood shavings.

**Date of experiment:** 11<sup>th</sup> January 2024.

**Materials used:** Wood shavings and dry corn cob.

Safety protocols and standard operating procedures were followed throughout the experiment.

Yours in Service

Wilber Waibale

0773 379437

Scientist- Chemistry Dept



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Appendix 11 showing pyrolysis test results



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**FACULTY OF ENGINEERING AND TECHNOLOGY**  
**DEPARTMENT OF POLYMER, TEXTILE AND INDUSTRIAL ENGINEERING**  
**MATERIALS AND METALLURGY LABORATORY**

31<sup>st</sup> January 2023.

**SUBJECT: CONFIRMATION OF FTIR EXPERIMENTS CONDUCTED BY Ms. FAITH ANGEANGO WANADI AND Ms. SANDRA NAMULUMBA AT THE LABORATORY.**

This is to confirm that the above-named students conducted an FTIR experiment on 31<sup>st</sup> January 2024 at the above mentioned laboratory.

**KEY DETAILS OF THE EQUIPMENT;**

**Equipment model:** JASCO 6600 FTIR

**Serial no.** A027761790, Made in Japan

**Date of experiment:** 31<sup>st</sup> January 2024.

**Materials used:** Biochar and activated carbon

**Results obtained:** The results are sent in a raw data form that is excel, and the students are supposed to analyse, plot and get useful information required.

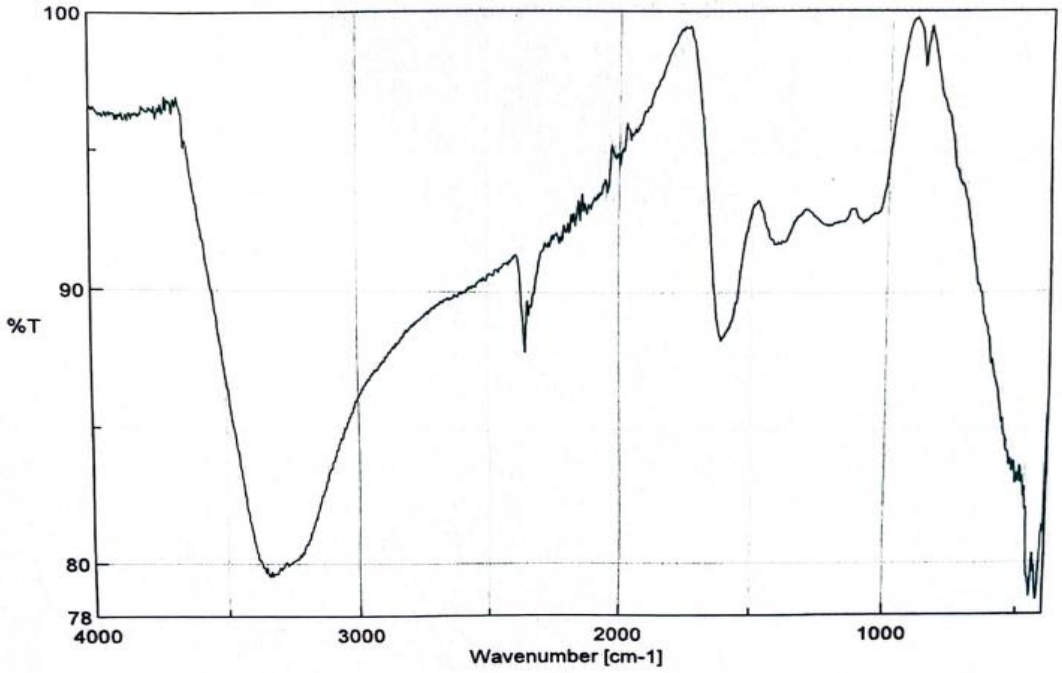
Safety protocols and standard operating procedures were followed throughout the experiment. The experiment was conducted in accordance with ethical guidelines and regulations governing research and experimentation in our laboratory.

I confirm that the two samples were analysed at our laboratory.

  
Tunusime Godias

Senior Technician

Contact; 0785005982



[Comments]  
 Sample name  
 Comment  
 User  
 Division  
 Company            Busitema University

— Spectrum1

[Measurement Information]  
 Model Name        FT/IR-6600typeA  
 Serial Number    A027761790  
 Accessory         ATR PRO ONE  
 Accessory S/N    C152861809  
 Incident angle    45 deg  
 Measurement Date 31/01/2024 10:01  
 Light Source      Standard  
 Detector          TGS  
 Accumulation     32  
 Resolution        4 cm-1  
 Zero Filling       On  
 Apodization       Cosine  
 Gain                Auto (8)  
 Aperture          Auto (7.1 mm)  
 Scanning Speed   Auto (2 mm/sec)  
 Filter                Auto (10000 Hz)

[Detailed Information]  
 Creation date     31/01/2024 10:01  
 Data array type   Linear data array  
 Horizontal axis   Wavenumber [cm-1]  
 Vertical axis      %T  
 Start               398.193 cm-1  
 End                 4000.6 cm-1  
 Data interval     0.964233 cm-1  
 Data points       3736

Appendix 13 showing FTIR analysis test results



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**FACULTY OF ENGINEERING, DESIGN, AND TECHNOLOGY**  
Department of Engineering and Environment

**LABORATORY TEST REPORT**



<b>Certificate Number: A005</b>		
<b>Client Name: NAMULUMBA SANDRA &amp; ANGEANGO WANADI FAITH</b>	<b>Sample Receipt Date:</b> 20/01/2024	<b>Analysis Start Date:</b> 20/01/2024
<b>Client Address and Contact:</b> UCU P.O Box 4, Mukono 0752087287		
<b>Lab Sample ID: A005/2024</b>	<b>Date of analysis completion</b>	<b>Date of issue of the certificate</b>
<b>Client Sample ID:</b> Substrate and Inoculum from NARO Farm	05/02/2024	05/02/2024
<b>Sample type and Location:</b> Substrate and Inoculum from NARO Farm		
<b>State of the sample on delivery:</b>  Semi-solid and liquid material in plastic bottles	<b>Testing Conditions:</b>  Water-bath Temperature: 38°C	
	<b>Testing Methods: VDI 4630</b>	

**FOSTAC TITRATION RESULTS**

SAMPLE	NO.	PH	Temperature
A	1	7.42	25
	2	7.37	25.1
	3	7.43	24.8
<b>AVERAGE</b>		<b>7.41</b>	<b>74.9</b>
B	1	7.44	25.5
	2	7.57	25.4
	3	7.53	25.7
<b>AVERAGE</b>		<b>7.51</b>	<b>25.5</b>
C	1	7.59	25
	2	7.62	25
	3	7.7	25.3
<b>AVERAGE</b>		<b>7.64</b>	<b>25.1</b>

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## FACULTY OF ENGINEERING, DESIGN, AND TECHNOLOGY Department of Engineering and Environment

SAMPLE	V	PH	H2SO4	FOS/TAC
A	V1	5	4.6	0.328
	V2	4.4	5.1	
B	V1	5	5	0.393
	V2	4.4	5.65	
C	V1	5	6.2	0.33
	V2	4.4	6.9	
Average				0.3502

### TOTAL SOLIDS AND VOLATILE SOLIDS TEST

Identity	Weight of Crucible + wet sample	Weight of crucible	Weight of crucible + dry material	Weight of crucible + ash	TS%	VS%
B1	58.23	27.23	28.19	27.51	3.11	70.75
B2	52.57	26.50	27.29	26.74	3.03	70.54
B3	52.98	27.48	28.26	27.71	3.05	70.69
Average					3.07	70.66
C1	55.92	27.98	29.83	28.46	6.61	74.05
C2	51.91	28.01	29.46	28.38	6.07	74.02
C3	59.40	27.07	29.04	27.55	6.10	75.27
Average					6.26	74.45

Appendix 15 showing FOS/TAC, VS and TS test results



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Department of Engineering and Environment

**LABORATORY TEST REPORT**

<b>Certificate Number: A005</b>		
<b>Client Name:</b> NAMULUMBA SANDRA & ANGEANGO WANADI FAITH	<b>Sample Receipt Date:</b> 20/01/2024	<b>Analysis Start Date:</b> 20/01/2024
<b>Client Address and Contact:</b> UCU P.O Box 4, Mukono 0752087287		
<b>Lab Sample ID:</b> A005/2024, A006/2024	<b>Date of analysis completion</b> 18/03/2024	<b>Date of issue of the certificate</b> 18/03/2024
<b>Client Sample ID:</b> Substrate and Inoculum from NARO Farm		
<b>Sample type and Location:</b> Substrate and Inoculum from NARO Farm, Biogas from Fabricated Portable Digesters		
<b>State of the sample on delivery:</b>  Semi-solid and liquid material in plastic jerrycans, Gas in floaters.	<b>Testing Conditions:</b>  Water-bath Temperature: 38°C	
	<b>Testing Methods:</b> VDI 4630	

**BIO-METHANE POTENTIAL TEST RESULTS**

TIME (DAYS)	SUBSTRATE VOLUMES (ML)					
	INNOCULUM			COW DUNG		
	BOTTLE 1	BOTTLE 2	BOTTLE 3	BOTTLE 1	BOTTLE 2	BOTTLE 3
0	0	0	0	0	0	0
1	11	14	12	25	28	27
2	18	21	23	36	37	39
3	21	26	28	47	46	58
4	27	28	29	65	69	77
5	35	34	36	82	87	91
6	40	38	41	97	91	107

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Appendix 16 showing Biomethane potential test results



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7	43	45	48	115	113	116
8	51	48	53	124	122	127
9	56	54	58	129	133	134
10	62	66	64	134	139	137
11	65	68	69	140	142	141
12	73	71	74	144	148	146
13	78	76	77	153	151	153
14	82	80	85	154	154	155
15	85	83	87	151	155	152
16	83	79	82	143	150	147
17	75	72	77	138	146	131
18	70	63	71	127	135	128
20	64	51	65	124	126	120
21	55	48	57	119	121	114
22	49	32	38	101	112	109
23	27	15	22	81	105	93
24	19	0	11	73	88	82
25	0	0	0	61	69	71
26	0	0	0	56	52	64
27	0	0	0	44	47	53

CUMMULATIVE BIOGAS YIELD (ML)						
TIME (DAYS)	INNOCULUM			COW DUNG		
	BOTTLE 1	BOTTLE 2	BOTTLE 3	BOTTLE 1	BOTTLE 2	BOTTLE 3
0	0	0	0	0	0	0
1	11	14	12	25	28	27
2	29	35	35	61	65	66
3	50	61	63	108	111	124
4	77	89	92	173	180	201
5	112	123	128	255	267	292
6	152	161	169	352	358	399
7	195	206	217	467	471	515
8	246	254	270	591	593	642
9	302	308	328	720	726	776
10	364	374	392	854	865	913
11	429	442	461	994	1007	1054

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Appendix 17 showing biomethane potential test results



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12	502	513	535	1138	1155	1200
13	580	589	612	1291	1306	1353
14	662	669	697	1445	1460	1508
15	747	752	784	1596	1615	1660
16	830	831	866	1739	1765	1807
17	905	903	943	1877	1911	1938
18	975	966	1014	2004	2046	2066
19	1039	1017	1079	2128	2172	2186
20	1094	1065	1136	2247	2293	2300
21	1143	1097	1174	2348	2405	2409
22	1170	1112	1196	2429	2510	2502
23	1189	1112	1207	2502	2598	2584
24	1189	1112	1207	2563	2667	2655
25	1189	1112	1207	2619	2719	2719
26	1189	1112	1207	2663	2766	2772

PH TEST	
Sample	pH
1	8.63
2	8.65
3	8.68
<b>Average</b>	<b>8.65</b>

### ELECTRICAL CONDUCTIVITY

Sample	Activated carbon
1	640
2	632
3	667

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Appendix 18 showing Electrical conductivity, ph and biomethane potential test results



**BIOGAS ANALYSIS RESULTS**

<b>BEFORE ADDING ADDITIVES</b>				
Digesters	days	CH <sub>4</sub> (%)	CO <sub>2</sub> (%)	trace gases (%)
1	1	48.2	38	13.8
	2	49.2	37	13.26
	3	51.4	37	13.15
<b>Average</b>		<b>49.6</b>	<b>37.3</b>	<b>13.43</b>
2(10g)	1	50.20	37	12.57
	2	51.2	36	12.32
	3	51.9	37	12
<b>average</b>		<b>51.1</b>	<b>36.67</b>	<b>12.33</b>
3(13g)	1	52.7	34	13.3
	2	53.2	34	12.84
	3	53.9	35	11.09
<b>average</b>		<b>53.26</b>	<b>34.3</b>	<b>12.41</b>
4 (20g)	1	50.3	36	13.66
	2	52.2	34	13.78
	3	52.9	35	13.06
<b>average</b>		<b>51.8</b>	<b>34.6</b>	<b>13.5</b>



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BIOGAS ANALYSIS AFTER ADDING ADDITIVES					
Multitec Gas Analyzer 540					
Digesters	Test	CH <sub>4</sub> (%)	CO <sub>2</sub> (%)	Trace gases (%)	
Control	1	52.4	34	13.6	
	2	51.7	35	13.3	
	3	52.5	35	12.5	
	4	52.4	35	12.6	
	5	53.3	34	12.7	
	6	53.7	34	12.3	
<b>Average</b>		<b>52.67</b>	<b>34.5</b>	<b>12.83</b>	
2 (10g)	1	56.3	31	12.7	
	2	58.8	29	12.2	
	3	59.9	28	12.1	
	4	60.7	27	12.3	
	5	61.5	26	12.5	
	6	61.8	26	12.2	
<b>Average</b>		<b>59.83</b>	<b>27.83</b>	<b>12.33</b>	
3 (13g)	1	58.9	30	11.1	
	2	60.3	28	11.7	
	3	61.6	27	11.4	
	4	61.3	27	11.7	
	5	62.8	26	11.2	
	6	63.7	25	11.3	
<b>Average</b>		<b>61.43</b>	<b>27</b>	<b>11.4</b>	
4 (20g)	1	57.5	30	12.5	
	2	59.8	29	11.2	
	3	61.2	27	11.8	
	4	61.8	27	11.2	
	5	62.4	26	11.6	
	6	62.9	26	11.1	
<b>Average</b>		<b>60.93</b>	<b>27.5</b>	<b>11.57</b>	

Laboratory Technician

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MUGISHA ARNOLD



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Appendix 20 showing biogas analysis results after adding additives