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# Biogasification of Horse Dung Using a Cylindrical Surface Batch Biodigester

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Additional information is available at the end of the chapter

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## Abstract

Anaerobic digestion of animal dung offers several benefits such as reduction of odors, pathogens, and production of renewable energy biogas. In this study, a 1 m<sup>3</sup>-surface batch biogas digester was designed, constructed, and insulated with sawdust to minimize temperature fluctuations within the digester. The horse dung was collected from the University of Fort Hare Honey dale farm and fed into the batch biogas digester. The horse dung was analyzed for total solids (TS), volatile solids (VS), total alkalinity (TA), calorific value (CV), pH, chemical oxygen demand (COD), and ammonium-nitrogen (NH<sub>4</sub>-N). The optimum total alkalinity, ammonium-nitrogen, and chemical oxygen demand were 6235, 901, and 24230 mg/L, respectively. The study found that horse dung produced biogas yield with an average methane yield of 51% without codigesting it with other wastes. Therefore, horse dung is a good substrate for biogas production, and its use in biogas digesters can reduce greenhouse gas emissions into the atmosphere leading to climate change.

**Keywords:** biogasification, digester, horse dung, biogas, methane

## 1. Introduction

South Africa like any developing country is overdependent on conventional energy sources such as coal and firewood. Coal is a fossil fuel and is the main source of electricity in the country. Fossil fuels have many negative impacts on the environment, which include environmental degradation, climate change, and human health problems [1]. Biogas production would benefit

mainly the rural population by providing a clean fuel from renewable substrates and help to end energy poverty.

After the ratification of the United Nations Framework Convention on Climate Change (UNFCCC) and Kyoto Protocol in August 1997 and July 2002, respectively, the South African government embarked on numerous projects related to climate change, including projects that have been intended as measures to reduce greenhouse gases. Furthermore, the high volatility in oil prices in the recent past resulting in turbulence in energy markets has also compelled the country to look for alternative sources of energy such as from biogasification. As a result, the South Africa Integrated Resource Plan (SAIRP) approved by the parliament in 2010 sets a target of 40% renewable energy contribution by the year 2030 [2].

Biogasification is a method by which biogas is produced from organic material through the action of microbes. It is therefore a biological process in which organic materials break down in an environment that is sufficiently warm and oxygen-free. The end product of biogasification is biogas, mainly methane, carbon dioxide, and digestion sludge. The sludge can be used as a fertilizer. Biogas is a combustible gas, which is generally used as a source for cogeneration, for producing electricity and heat by means of gas or dual fuel engines [3].

Biogas from anaerobic digestion (AD) can be viewed as one of the vehicles to reduce rural poverty and could lead to rural development. The process produces less greenhouse gases than waste treatment processes such as composting [4] and land filling [5]. It can substitute fossil fuels and can decrease environmental pollution including acid rains and global warming [6]. Therefore, AD has wide flexibility and can be modified to fulfill the precise requirements in management of agricultural farms [7]. When compared to other renewable energy sources, such as solar and wind power, the methane component of biogas can be easily stored in bio-bags. Furthermore, the biogas digesters are not prone to theft unlike solar panels and wind turbines. In addition, biogas production would benefit mainly the rural population by providing a clean fuel and reduce energy poverty.

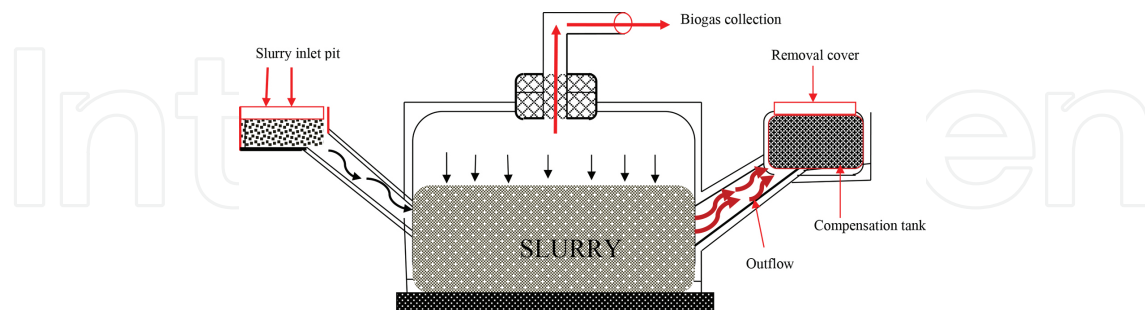
According to Ref. [8], biogas is an overlooked source of fuel in spite of the excitement surrounding the use of biofuels as an alternative source of energy. The use of biogas digesters can improve the lives of the people in rural areas in many ways; it reduces deforestation, reduces greenhouse emissions, and controls unpleasant odors from human or animal wastes and reduction of workload and marginalization of women who collect firewood.

The most common types of biogas digesters are fixed dome digester, balloon-type digester, and floating drum digester. The two most familiar types in developing countries are fixed dome and floating drum digesters. The three main digesters are discussed and their advantages and disadvantages are also given.

The fixed dome digester is the most popular digester; its archetype was developed in China as early as 1936. The fixed dome digester is shown in **Figure 1**.

It is a closed dome shape digester with an immovable, rigid gas-holder and a displacement pit (compensating tank). The biogas produced by methanogenic bacteria in the biogas digester is captured in the gas holder and the slurry is displaced in the compensating tank. When gas is

consumed, slurry enters back into the digester from the overflow tank. As a result of these movements, a certain degree of mixing is obtained. The more the gas is produced, the higher the level at the slurry outlet [10].

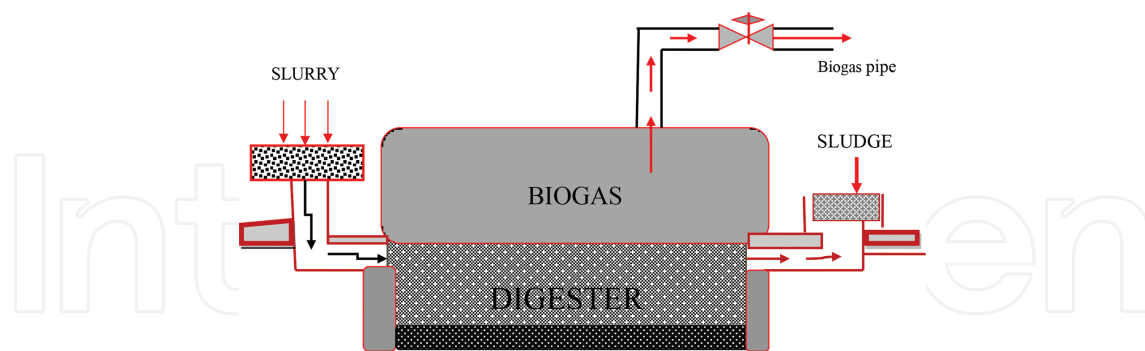


**Figure 1.** Chinese fixed dome digester, adapted with permission from [9].

The fixed dome digester has some advantages that include: relatively cheap and durable, no moving parts, and well insulated [11]. However, the fixed dome digester has disadvantages that include: high technical skills are required for a gas tight construction, special sealant is required for the gasholder, difficult to construct in high water table areas, requires more excavation work, and enormous structural strength is required for construction [11, 12].

A balloon digester (bag digester) is a plastic or rubber bag combining the gas holder and digester. This is a plug-flow-type reactor. This design was developed in the 1960s in Taiwan. Gas is collected in the upper part and manure in the lower part. The inlet and outlet are attached to the skin of the bag. The pressure of the biogas is adjustable by laying stones on the bag [13].

**Figure 2** shows a balloon digester. The biogas is collected in the balloon.



**Figure 2.** Balloon digester, adapted with permission from [10].

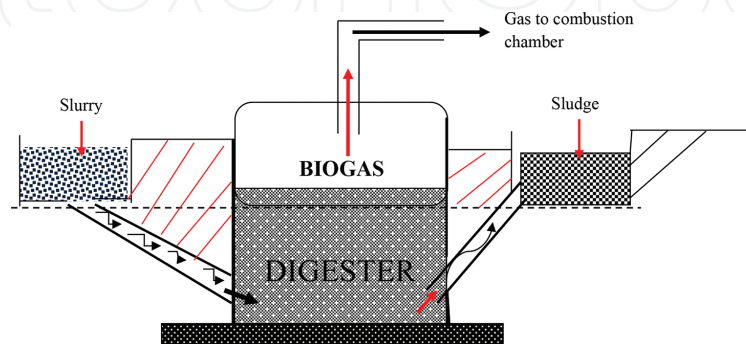
The advantages of the bag digesters include: low cost, simple technology, and easy to clean. However, the disadvantages include: short lifespan, susceptible to physical damage, hard to repair, need high quality plastic, and difficult to insulate [14].

Floating drum digesters are common in India. The digesters have a moving floating gas-holder, or drum. The gas holder floats either directly in the fermenting slurry or in a separate water jacket. The drum in which the biogas collects has an internal or external guide frame that



provides stability and keeps the drum upright. When the biogas is produced the drum moves up, and when the gas is consumed, the gas holder sinks back.

The floating drum digesters have advantages which include: the operation of the plant is easy to understand, the gas drum is air tight, and there is constant gas pressure as a result of the weight of the drum [15]. However, it does also have disadvantages which are: steel drum is relatively expensive and needs regular maintenance (priming, painting, and coating) and the effect of low temperature during winter is high [11]. A floating drum digester is shown in **Figure 3**.



**Figure 3.** Indian-type digester, adapted with permission from [9].

The main aim of the project was to measure methane content in horse dung using a designed and constructed 1 m<sup>3</sup> cylindrical batch biogas digester.

## 2. Objectives

The research was carried out with the following objectives in mind:

- (i) To design and construct a 1 m<sup>3</sup> batch biogas digester.
- (ii) To determine the impact of substrate properties on methane production.
- (iii) To determine the effect of insulation of the digester on biogas yield.
- (iv) To measure the methane and carbon dioxide in horse dung.

## 3. Methodology

### 3.1. Design of the digester

Biogas digester design plays a crucial role in digester performance and a number of considerations are taken into account. The following aspects were considered during the design process: durability, air tightness, availability of local materials and easy operation. The design parameters included:

### 3.1.1. Total solid (TS) contents of organic materials

The total solid (TS) contained in a substrate is usually used as the material unit to indicate the biogas production rate of the materials. The most favorable TS value is 8% for better biogas production [16].

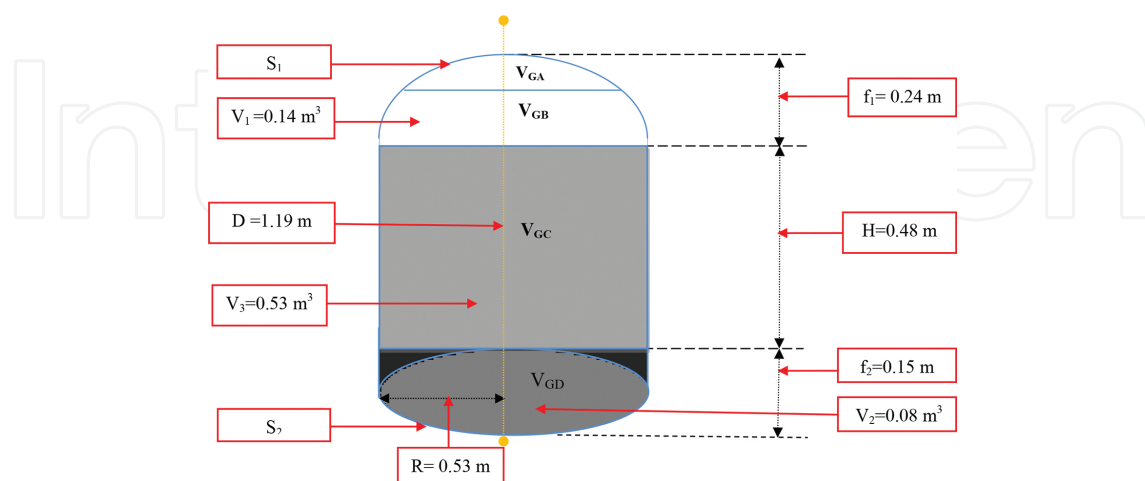
### 3.1.2. Favorable temperature, pH value, and carbon/nitrogen ratio for good fermentation

The mesophilic temperature between 25 and 35°C was chosen in the design. The digester was insulated to keep the temperature within the latter mesophilic range to optimize mesophilic bacterial activity. The pH value selected ranged from 6.8 to 7.8 because the methanogens prefer a neutral atmosphere with pH between 6.8 and 7.5.

The carbon/nitrogen ratio considered ranged from 20:1 to 30:1. Carbon and nitrogen are the main nutrients required by microorganisms. Therefore, a C/N ratio of 20–30:1 was considered for optimum anaerobic digestion, based on biodegradable organic carbon [17, 18]. Hence, codigestion experiments were done to maintain the carbon/nitrogen ratio within the desired range.

### 3.1.3. Hydraulic retention time (HRT)

For mesophilic digestion where temperature varies from 25 to 35°C, the HRT was greater than 20 days. In the thermophilic environment, HRT is usually less than 10 days [19]. Shortening retention time can lead to increase in the volatile fatty acids (VFA) [20], and this is why mesophilic digestion was considered. A surface cylindrical biogas digester was chosen because it was easy to feed, insulate, clean, and easy to construct and remove slurry after every hydraulic retention period. In addition, the batch digester was easy to agitate. **Figure 4** shows the cylindrical batch digester body with all the calculated values indicated and **Table 1** shows calculated volume and geometrical dimensions of the batch biogas digester.

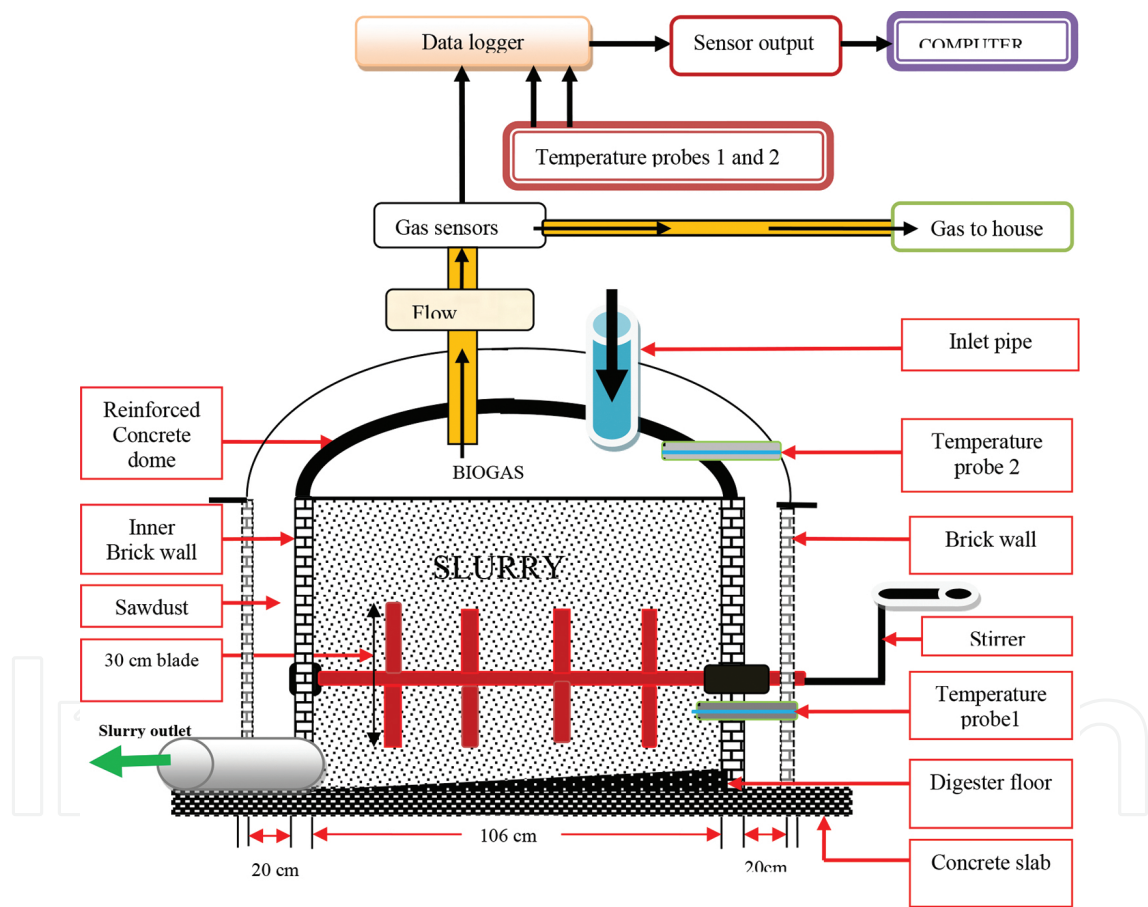


**Figure 4.** Geometrical dimensions of the cylindrical shaped biogas digester body. KEY: Volume of gas collecting chamber =  $V_{GA}$ ; Volume of gas storage chamber =  $V_{GB}$ ; Volume of fermentation chamber =  $V_{GC}$ ; Volume of the sludge layer =  $V_{GD}$ ; Total volume of the digester,  $V = V_{GA} + V_{GB} + V_{GC} + V_{GD}$ .

Assumptions: For volume	For geometrical dimensions
$V_{GD} = 5\%V$	$D = 1.3078 \times V^{1/3}$
$V_{GB} + V_{GC} = 80\%V$	$V_1 = 0.0827 D^3$
$V_{GD} = 15\%V$	$V_2 = 0.05011 D^3$
$V_{GB} = 0.5 [V_{GB} + V_{GC} + V_{GD}] k$	$V_3 = 0.3142 D^3$
$k = 0.4 \text{ m}^3/\text{day}$	$R_1 = 0.725 D; R_2 = 1.0625 D$
	$f_1 = D/5; f_2 = D/8$
	$S_1 = 0.911 D_2; S_2 = 0.8345 D^2$

**Table 1.** Assumptions for volume and geometrical dimensions [21].

**Figure 5** shows a more detailed diagram of the batch biogas digester with the monitoring sensors' positions.



**Figure 5.** Detailed diagram of the designed batch biogas digester with various sensors positions.

### 3.2. Construction of the biogas digester

A number of issues were considered during the construction of the biogas digester to ensure nonleakages and minimization of influence of ambient temperatures on the substrate temperature. The construction of the digester was done in the following stages:

- Selection of construction material
- Site selection and layout
- Excavation
- Inserting the mechanical stirrer
- Inserting the curved top of the digester
- Second wall construction of the biogas digester
- Insulation of the biogas digester

The main building materials for the biogas digester included clinker bricks, sand, concrete stones, and Portland cement. The concrete stones were free of soil and organic material. Furthermore, the sand used was clean in order to increase the strength of the digester.

The clinker bricks were first soaked in clean water for 5 minutes in order to remove dust and to prevent the bricks from sucking moisture from the mortar thus allowing a strong bonding. Clinker bricks were used in the construction because they offered the following advantages;

- Acid proof
- Wear proof
- Anticorrosive
- High compressive strength
- Low thermal conductivity of  $0.67 \text{ W/(m.K)}$
- Relatively cheaper than other types of bricks

Portland cement was used because it has a low thermal conductivity of  $0.29 \text{ W/(m.K)}$  compared to masonry cement with a thermal conductivity of  $0.5 \text{ W/(m.K)}$  and epoxy was used for painting the inside of the batch biogas digester because it has a high water proofing and low thermal conductivity of  $0.30 \text{ W/(m.K)}$ . Sawdust was selected for insulation because of its availability in the area and low thermal conductivity of  $0.08 \text{ W/(m.K)}$  compared to dry sand, which has a thermal conductivity of  $0.15\text{--}0.25 \text{ W/(m.K)}$ . Therefore, the heat transfer in materials with low thermal conductivity, for example, sawdust, is very low.

The biogas digester was constructed and reinforced concrete dome was placed on top of the plastered biogas digester with mortar smeared on its top surface to ascertain tight air seal as shown in **Figure 6**.





**Figure 6.** Biogas digester with a reinforced concrete dome.

**3.3. Second wall construction of the biogas digester and insulation of the biogas digester**

An outer wall of 1 inch (115 mm) was constructed with bricks to make the biogas digester two walled as shown in **Figure 7**. The separation gap for the two walls was 200 mm. Sawdust, an insulating material, was then put after the plastering of the outer wall.

Sawdust was selected for insulation because of its availability in the area and low thermal conductivity of 0.08 W/(m.K) compared to dry sand which has a thermal conductivity of 0.15–0.25 W/(m.K).



**Figure 7.** Constructed second wall of the biogas digester.

### 3.4. Source of substrate and mixing proportions

Fresh horse dung was collected from University of Fort Hare Honey dale farm. The horse dung, before fed into the 1 m<sup>3</sup> biogas digester, was chopped with a compost chopper to accelerate biogasification.

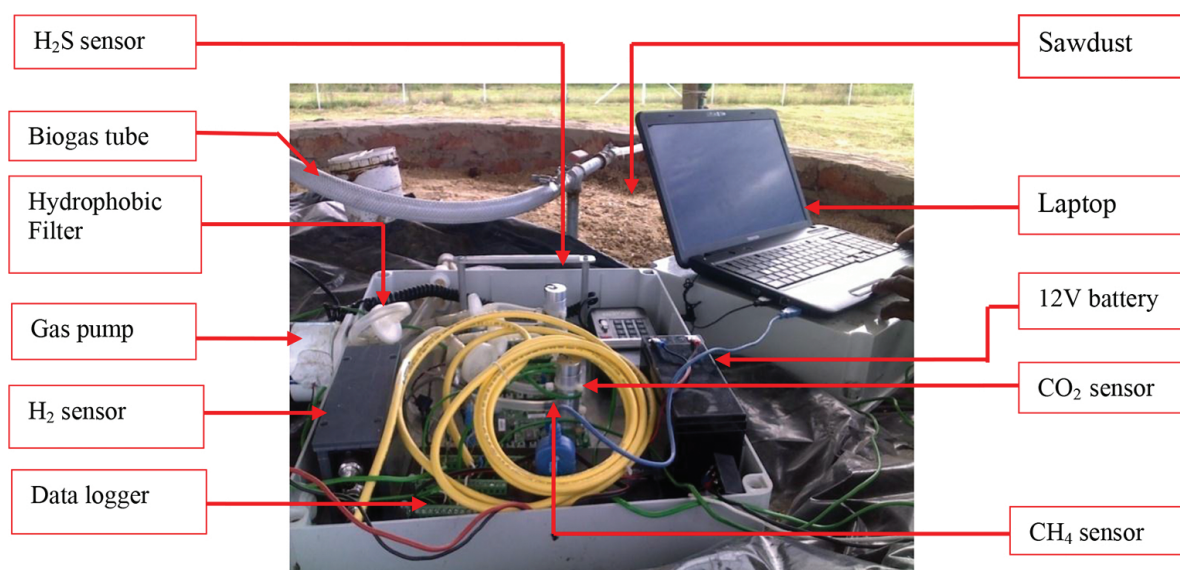
### 3.5. Substrate parameters

The following parameters in horse dung were determined: pH, total solids (TS), volatile solids (VS), ammonium-nitrogen (NH<sub>4</sub>-N), total alkalinity (TA), temperature (T), and caloric value (CV). All the analytical determinations were performed according to the standard methods for examination of water and wastewater [22].

### 3.6. Biogas analysis

The biogas composition was analyzed using the biogas analyzer consisting of nondispersive infrared (NDIR) sensor for sensing methane and carbon dioxide and palladium/nickel (Pd/Ni) sensor for sensing hydrogen and hydrogen sulfide. The data for biogas composition was recorded by a CR1000 data logger at a time interval of 2 minutes. The biogas analyzer and the CR1000 data logger were powered by a 12V DC battery that was connected to a 20 W photovoltaic module. The slurry and ambient temperatures were measured using type K thermocouples connected to the same CR1000 data logger as the biogas sensors. The data logger was interfaced to a computer.

The data acquisition system which consisted of a palladium-nickel and nondispersive infrared sensors is shown in **Figure 8**.



**Figure 8.** The data acquisition system.



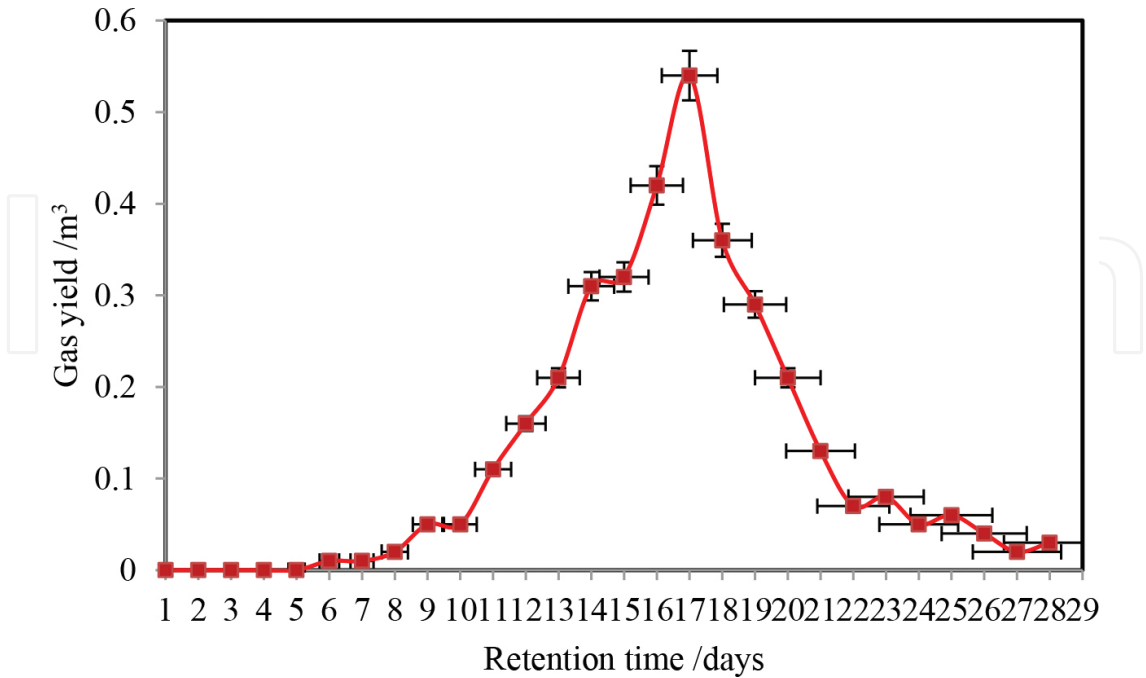
4. Results and discussion

The substrate characteristics of the horse dung is shown in **Table 2**, namely, total solids (TS), volatile solids (VS), total alkalinity (TA), pH, caloric value (CV) and ammonium-nitrogen (NH<sub>4</sub>-N).

Parameter	Horse dung
Total solids (mg/L)	269,515.67
Volatile solids (mg/L)	172,934.47
Total alkalinity (mg/L)	6234–6256
pH [average]	7.34–7.36
Calorific value (MJ/g)	26.40
Ammonium-nitrogen (mg/L)	1101–1289

**Table 2.** Substrate characteristics of horse dung.

The average slurry temperature of the batch biogas digester after the insulation was 30°C. Therefore, it can be concluded that the insulation of the batch biogas digester was advantageous because the desired temperature for optimum biogas production was achieved. **Figure 9** shows the biogas yield from horse dung. The biogas production increased until it reached the peak and then began to decline.



**Figure 9.** Biogas yield for horse dung.

The horse dung had a peak biogas yield of 0.51 m<sup>3</sup> on day 18. The linear biogas production of horse dung from day 12 (0.11 m<sup>3</sup>) to day 17 (0.54 m<sup>3</sup>) can be approximated by the equation:

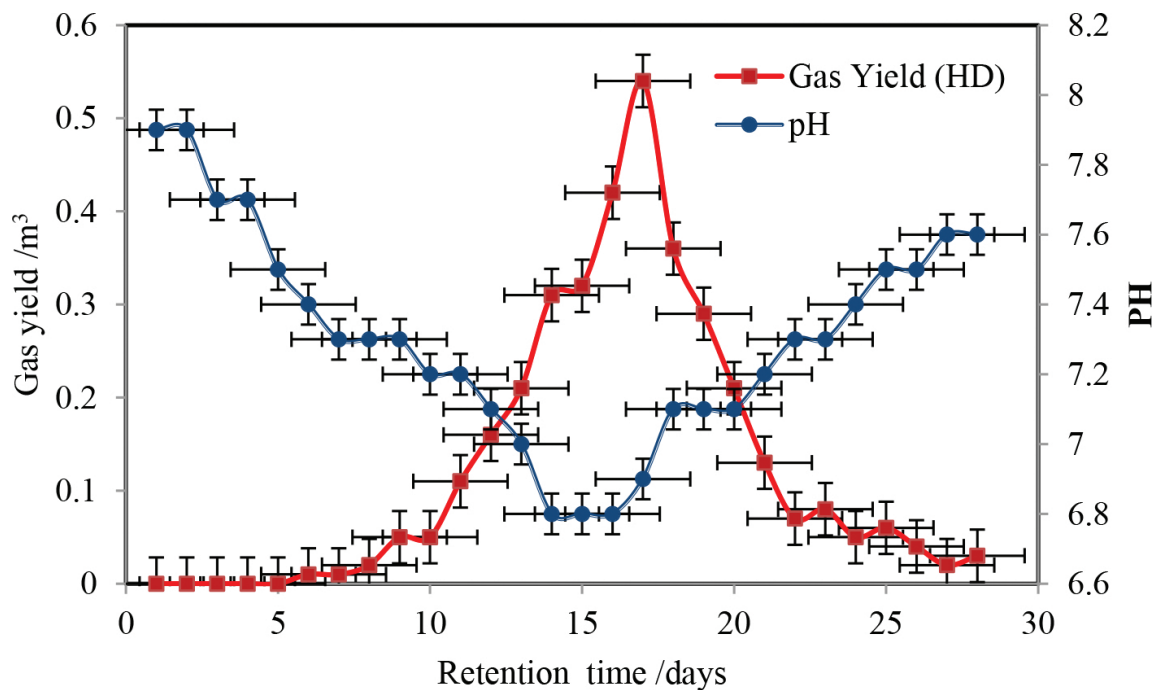
$$Y = 0.0686t - 0.6643 \quad \text{for } 12 \leq t \leq 17 \quad (1)$$

The decay of biogas production for horse dung from the peak (day 17) to day 22 is represented by:

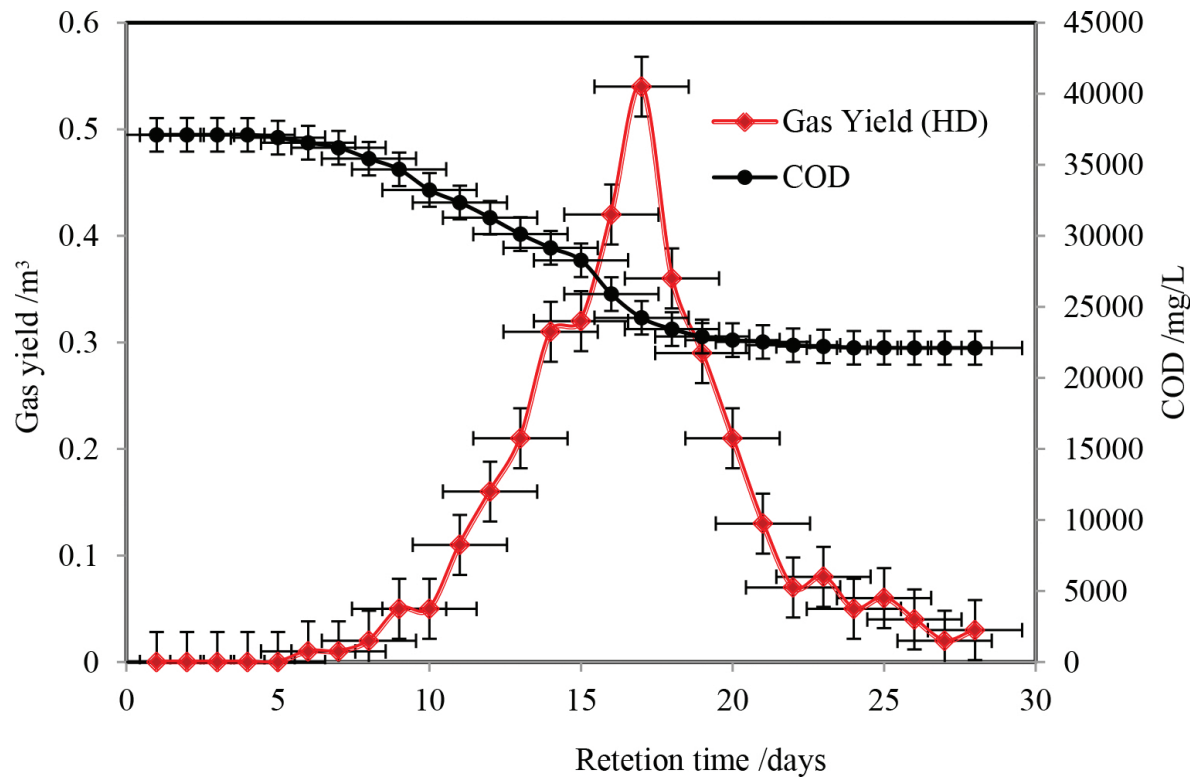
$$Y = -0.977t - 2.188 \quad \text{for } 17 \leq t \leq 22 \quad (2)$$

The relationship between biogas yield and pH in horse dung is shown in **Figure 10**. The maximum biogas yield of 0.54 m<sup>3</sup> was produced at pH 6.9. The initial pH of was 7.9 and the pH was observed to decline with time, attaining a minimum value of 6.9 where an optimum biogas production of 0.54 m<sup>3</sup> was achieved. The decline is due to the conversion of the substrate to acids during acidogenesis and acetogenesis stages of methane production. As from day 17, the pH was seen to increase as the acids produced were converted to methane by the methanogens.

Relationship between biogas yield and chemical oxygen demand (COD) in horse dung is shown in **Figure 11**. The highest biogas yield of 0.54 m<sup>3</sup> was produced on day 17 where the COD value was 24,230 mg/L as shown in **Figure 11**.



**Figure 10.** Relationship between biogas yield and pH in horse dung.



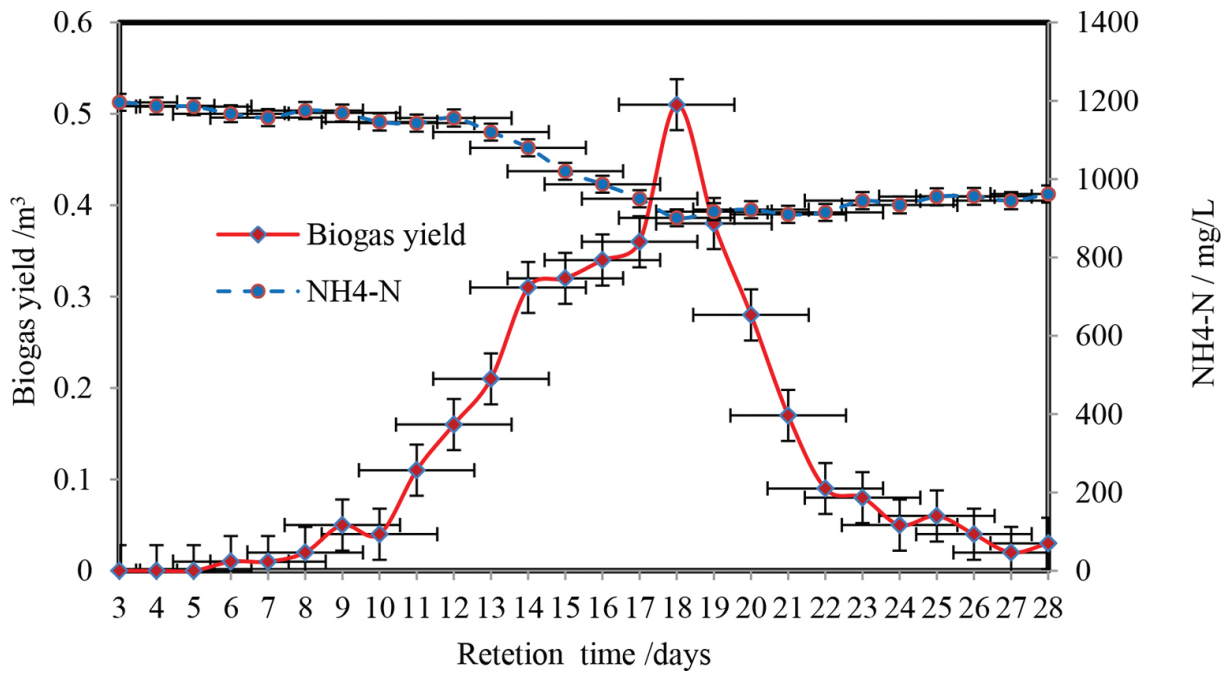
**Figure 11.** Relationship between biogas yield and COD in horse dung.

The initial COD for horse dung was 37,110 mg/L and the final COD was 22,110 mg/L. The highest COD destruction was between days 15 and 19. The concentration of COD destroyed from day 22 to day 28 was very low indicating a low biogas yield and a higher COD destruction means a high biogas yield.

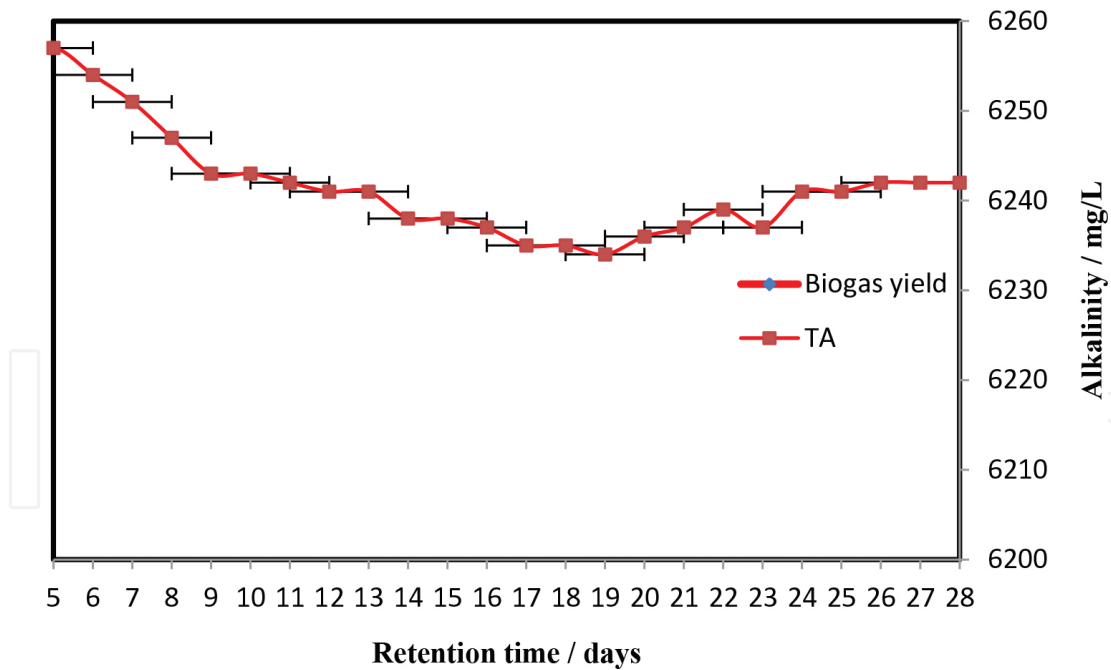
The relationship between biogas yield and  $\text{NH}_4\text{-N}$  in horse dung is shown **Figure 12**. The highest biogas yield of 0.54  $\text{m}^3$  was produced at  $\text{NH}_4\text{-N}$  concentrations of 901 mg/L. The initial  $\text{NH}_4\text{-N}$  concentration was 1196 mg/L and the final  $\text{NH}_4\text{-N}$  concentration was 962 mg/L. It was observed that the concentrations  $\text{NH}_4\text{-N}$  for horse dung were between 850 and 1196 mg/L. However, there was no inhibitory effect of the ammonium ion because the  $\text{NH}_4\text{-N}$  concentrations were below 1500 mg/L. In the experiment, it was observed that higher  $\text{NH}_4\text{-N}$  values corresponded with lower biogas production

The inhibiting concentrations of  $\text{NH}_4\text{-N}$  are reported to be above 1500 mg/L [23–25]. The stability of  $\text{NH}_4\text{-N}$  levels in the substrate improved biogasification. Relationship between biogas yield and total alkalinity is shown in **Figure 13**.

From the graph it was observed that the total alkalinity for horse dung was between 6190 and 6256 mg/L. The higher the alkalinity, the greater the buffering capacity in the anaerobic digestion process which in turn promoted a stable pH value (**Figure 10**) and this resulted in an increase in the biogas yield. It was observed that total alkalinity changes were directly proportional to changes in the pH.



**Figure 12.** Relationship between biogas yield and  $\text{NH}_4\text{-N}$  in horse dung.



**Figure 13.** Relationship between biogas yield and total alkalinity.

The composition of biogas in horse dung is shown in **Table 3**. The methane content horse dung was 51% and the carbon dioxide content was 43%. Theoretically, horse dung produces more biogas than cow dung because of its carbon/nitrogen ratio of 25:1 [10].

Gases	% yield
Methane (CH <sub>4</sub> )%	51
Carbon dioxide (CO <sub>2</sub> )%	43
Carbon monoxide (CO)	0
Hydrogen (H <sub>2</sub> )% and other gases	6

**Table 3.** Composition of biogas in horse dung.

The biogas from horse dung with methane content of above 50% can be used by rural communities for electricity production and as fuel for stoves, refrigerators, and generators, thereby replacing liquid petroleum gas (LPG) as fuel. In addition, the total lifecycle environmental impacts of the produced biogas are decreased via anaerobic digestion, since methane from biogas can be used as fuel for diesel or petrol engines. However, for biogas from horse dung to be used as fuel for vehicles, it should follow processes such as purification, upgrading, compression, and storage. The digestate of horse dung from the biogas digester is subsequently collected and used mainly to replace mineral fertilizers. Any overflow of the effluent from the storage tanks is discharged directly into the aquatic environment, as nutrient for vegetable crops. From **Table 3**, biogas from horse dung has a hydrogen content of 6%. The hydrogen from anaerobic digestion of horse dung can be used as fuel in hydrogen fuel cells. Hydrogen fuel cells have the following benefits: have a higher efficiency than diesel or gas engines, operate silently compared to internal combustion engines, fuel cells have no “memory effect” when they are getting refueled, and finally, the maintenance of fuel cells is simple since there are few moving parts in the system.

## 5. Conclusion

The 1 m<sup>3</sup> batch biogas digester was successfully designed, constructed, and insulated with sawdust and fed with horse dung. The batch biogas digester designed, constructed, and insulated with sawdust was easy to feed and clean as compared to underground fixed dome digesters which are not easy to clean and stir to agitate biogas production. Therefore, the designed biogas digester could ease energy problems if installed in rural communities of South Africa that have energy crisis. The results of the batch anaerobic digestion experiment show that horse dung is a good substrate for biogas production. The total methane potential of the horse dung was 51%, while the carbon dioxide content was 43%. In the experiment, it was observed that the methane yield from the horse dung increased exponentially with time and ceased after certain days. Furthermore, the study found that the optimum total alkalinity, ammonium-nitrogen, and chemical oxygen demand for horse dung are 6235, 901, and 24,230 mg/L, respectively.

It can also be concluded that anaerobic digestion of horse dung and other biogas digester substrates in the country would improve the country's service delivery and serve as a local solution to the world energy crisis caused by deletion of fossil fuels. From the research findings, no previous experiments to measure methane content in horse dung were done using field

scale digesters. The current study would be the first study to operate with a large digester insulated with sawdust in an outdoor setting operating at an average temperature of 30°C.

## 6. Acknowledgements

The authors would like to thank ESKOM for funding this project and University of Fort Hare for providing facilities for this project.

## 7. Author contributions

Patrick Mukumba designed, constructed, and fed the biogas digester with horse dung. Golden Makaka and Sampson Mamphweli supervised the research project. All the authors contributed to preparing and approving the final manuscript.

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