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(Research Article)

Mathematical approach of the design and fabrication of a HDPE geomembrane biodigester for the recycling of biodegradable waste into biogas and organic liquid fertilizer

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Abstract

The purpose of this work is to design a biodigester with high density polyethylene (HDPE) geomembrane material which will be effective in recycling biodegradable waste and produces both biogas and organic liquid fertilizer. A tubular trapezoidal biodigester is designed, following by the fabrication of a 300 litter's prototype biodigester with a tarpaulin. After running air and water tightness of the system, quantified biodegradable waste are introduced with and observed for a period of 60 days. Several tests are then conducted on the biodigester to ensure that the system can support the load it will be subjected under normal functioning condition. These tests included shear test, peel test, and air tightness of the system. In order to predict the quantities of elements that can be produce by the biodigester, the nonlinear differential equations of the exchange inside the biodigester are written and solved by using the differential transformed method. Results obtained from the prototype and the HDPE geomembrane biodigester shows that, this design permits the recycle of biodegradable waste from any facility. The biogas obtained was proven to be rich in methane content and the organic liquid fertilizer was also rich in N-P-K fulfilling the basic requirement for plant healthy growth. The HDPE geomembrane biodigester could produce 1,250L of biogas daily at an approximate pressure 1.8 bars which can be approximated to 5 hours minimum bu4rning with a burner of 200L/h.

Keywords: Biodigester; Biodegradable waste; Hydraulic retention time; Differential transform method

1. Introduction

Nowadays the high increasing of population in a certain area all over the world leads to the increasing the wastes, contributing to climate change and their disposal are the main issue. Wastes are partially responsible to high exposure to diseases such as malaria, water bone diseases, pest's multiplications and more greenhouse gas (GHG) emissions. This is why it is necessary to develop technics and solutions to manage them efficiently with less environmental impact [1]. Among the solutions used, one can enumerate both the energy production (biogas) and the organic liquid fertilizer. The importance of energy in national development cannot be over emphasized, energy is the hub around which the development and industrialization of any nation revolved [1]. Several studies have shown that by incorporating renewable energy resources into the overall energy mix or unit of nations, any of the negative environmental impacts of energy used could be avoided or minimized [2,3]. Biodegradable waste entails biomass wastes (agricultural crop wastes, forest residues, animal manure, and organic waste) and Municipal solid wastes. They can be used as alternative

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source of energy through anaerobic digestion technology [3]. Thus the solving of the problem of biogas technology dissemination and waste management issues is very important to develop an alternative anaerobic digester constructed using a different material and design. Anaerobic digestion of biodegradable waste leads usually to the production of biogas such as methane (CH_4) and carbon dioxide (CO_2), as well as organic liquid fertilizer which helps in solving pressing development issues like food security, clean energy capacity, climate change mitigation and adaptation, economic improvement [4,5,6] .

A biodigester (also called bioreactor or anaerobic reactor) is a structure, usually referred to as the biogas plant in which different chemical and microbiological reactions occur. Its primary function is to provide within it an anaerobic condition. Many digesters exist and diverse materials could be used in fabricating the digester chamber in different sizes and patterns.[7]. There exist the single or multi-stage digesters, low-rate digestion (floating dome, fixed dome, balloon digester), large scale, low-rate digesters (covered lagoon, plug flow, fixed film, suspended media, anaerobic sequencing batch reactor), high rate anaerobic digesters (anaerobic continuously stirred reactor, anaerobic contact reactor) second generation high-rate digesters (up flow anaerobic filter, down flow stationery fixed film, up flow anaerobic sludge blanket, fluidized bed/expanded bed), third generation high rate digesters. [8-18]. The aim of this research work is the design and fabrication of a biodigester with HDPE geomembrane material which will be effective in recycling biodegradable waste and then produces biogas and organic liquid fertilizer.

Geomembranes, or geosynthetic as barriers, are very low permeability coefficient polymeric sheets (typically $10^{-13}\ cm\ s^{-1}$1to $10^{-13}\ cm\ s^{-1}$), manufactured by the industry, delivered in rolls and installed in the site. They are often used in current landfill liners. Geomembranes can be produced with smooth faces or textured ones and with different colors [19, 20]. Geomembranes are used in many situations and in different types of construction sites and structures, such as [21]: Solid waste landfills and industrial waste; Water ponds and waste liquid ponds; Waterproof liners with tunnels; Under highways; Farm ponds; Covers and subsoils of buildings; Raised or buried water tanks; Adduction and irrigation canals; Pools and artificial beaches; Vertical walls for contaminated areas. They are exposed to different aging mechanisms, including UV degradation, extraction degradation, thermal degradation, swelling, oxidative degradation, and biological degradation, which can influence the material properties and even decrease their durability [22]. HDPE geomembranes are formulated with 96-97.5% polyethylene, 2-3% UV protection, generally carbon black, and 0.5-1.0% antioxidants and thermostabilizers [23, 24]. Investigations of both exhumed and laboratory samples can indicate different behaviors and responses concerning HDPE geomembrane durability. Accelerated HDPE geomembrane laboratory tests, simulating field boundary conditions are mainly for future use of this geosynthetic. In addition, thermal analysis has shown the importance in gaining more knowledge about the behavior of exposed geomembranes.

The paper is organized as follows: The second section is concerned with the literature review. It shall contain the theoretical aspects on biogas production, fertilizer, and geomembrane material. In section 3 dealing with the materials and methods, we shall focus on the fabrication aspects. The section 4 shall regroup the results and discussions. Finally section 5 is devoted to conclusion.

2. Literature review

2.1. Biodegradation

Biodegradable waste are materials that can be broken down into basic molecules (e.g. carbon dioxide, water) by organic processes carried out by bacteria, fungi, and other microorganisms. Two (02) types of degradation is under practice which include aerobic and anaerobic digestions [25-27]. The anaerobic digestion is described by the following steps:

2.1.1. Hydrolysis

Consisting in conversion of complex molecules (large protein macromolecules, fats, cellulose and starch) into simple sugars, long-chain fatty acids and amino acids. For instance, polymers after hydrolysis become monomers and oligomers. Hydrolysis catalyzers are enzymes excreted from bacteria. [28-30]. The main reactions and bacteria occurring in hydrolysis are:

$$lipids \xrightarrow{lipase} fatty\ acids, glycerol,$$

$$Polysaccharide \xrightarrow{cellulas, cellobiase, xylanase, amylase,} monosaccharide\ ,$$

$$Proteins \xrightarrow{protease} amino\ acids\ .$$

The hydrolysis reaction equation is expressed by

$$C_6H_{10}O_4 + 2H_2O \overset{k_1}{\rightarrow} C_6H_{12}O_6 + 2H_2 \quad \ldots\ldots\ldots\ldots\ldots (1)$$

2.1.2. Acidogenesis or fermentation

Here the hydrolysis products are converted into volatile fatty acids (VFAs; mainly lactic propionic, butyric and valeric acid), acetates, alcohols, ammonia, carbon dioxide and hydrogen sulfide. Their equations are:

$$C_6H_{12}O_6 \overset{k_2}{\rightarrow} 2CH_3CH_2OH + 2CO_2 \ldots\ldots\ldots\ldots\ldots (2)$$

$$C_6H_{12}O_6 + 2H_2 \overset{k_3}{\rightarrow} 2CH_3CH_2COOH + 2H_2O \ldots\ldots\ldots\ldots\ldots (3)$$

$$C_6H_{12}O_6 \overset{k_4}{\rightarrow} 3CH_3COOH \quad \ldots\ldots\ldots\ldots (4)$$

2.1.3. Acetogenesis

Equations 4 and 5 describe this 3rd step of anaerobic digestion and the yields are:

$$CH_3CH_2COOH + 2H_2O \overset{k_5}{\rightarrow} CH_3COOH + CO_2 + 3H_2 \ldots\ldots\ldots\ldots\ldots (5)$$

$$C_6H_{12}O_6 + 2H_2O \overset{k_6}{\rightarrow} 2CH_3COOH + 2CO_2 + 4H_2 \quad \ldots\ldots\ldots (6)$$

$$CH_3CH_2OH + H_2O \overset{k_7}{\rightarrow} CH_3COOH + H_2 \ldots\ldots\ldots\ldots (7)$$

2.1.4. Methanogenesis

Catalyzers contributing to the production of methane, Carbone dioxide and water are according to [25, 27, 30], acetrophic, hydrogenotrophic and methylotrophic bacteria. The equations of the reaction are:

$$acetic\ acid \xrightarrow{methabogenic\ bacteria} methane + carbon\ dioxide \ldots\ldots\ldots\ldots (8)$$

$$hydrogen + carbon\ dioxide \xrightarrow{methabogenic\ bacteria} methane + water \ldots\ldots\ldots\ldots (9)$$

The following equations describe methanogenesis in details with other side reactions

$$2CH_3CH_2OH + CO_2 \overset{k_8}{\rightarrow} 2CH_3COOH + CH_4 \ldots\ldots\ldots (10)$$

$$CH_3COOH \overset{k_9}{\rightarrow} CH_4 + CO_2 \ldots\ldots\ldots\ldots\ldots (11)$$

$$CO_2 + 4H_2 \overset{k_{10}}{\longrightarrow} CH_4 + 2H_2O \ldots\ldots\ldots\ldots\ldots\ldots (12)$$

2.1.5. Side reactions

$$CH_3COOH + SO_4^{2-} + 2H^+ \overset{k_{11}}{\longrightarrow} 2H_2O + 2CO_2 + H_2S \ldots\ldots\ldots\ldots (13)$$

$$CH_3COOH + 2NO^- + 2H_2O + 2H^+ \overset{k_{12}}{\longrightarrow} 2HCO_3^- + 2NH_4^+ \ldots\ldots\ldots\ldots (14)$$

The following equation is the simplification of the entire process:

$$C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4 \quad \ldots\ldots\ldots\ldots\ldots (15)$$

2.2. Factors affecting biogas production

The factors than can affect aerobic digestion for biomass are given in Table 1 [25]:

Table 1 Main parameters for evaluation and composition of different AD system performances [25]

Operational Parameter	Formula	Description	Unit
Hydraulic Retention Time (HRT)	HRT = V/Q	HRT: Hydraulic retention time V: Reactor volume Q: Flow rate	days m^3 m^3 / day
Organic Loading Rate (OLR)	$OLR = Q \times S/ V$	OLR: Organic loading rate Q: Substrate flow rate S: Substrate concentration in the inflow V: Reactor volume	kg substrate (VS)/ m^3 reactor and day m^3 / day kg VS/m^3 m^3
Gas Production Rate (GPR)	$GPR = Q_{biogas} /V$	GPR: Gas production rate Q_{biogas}: Biogas flow rate V: Reactor volume	m^3 biogas / m^3 reactor and day m^3 / day m3
Specific Gas Production (SGP)	$\frac{Q_{biogas}}{Q \times S}$ or GRP/OLR	SPG: Specific gas production Q_{biogas}: Biogas flow rate Q: Inlet flow rate S: Substrate concentration in the inflow	m^3 biogas / kg VS fed material m^3 / day m^3 / day kg VS/m^3

3. Materials and methods

This section shall present the general designs, ways, the materials which includes the experimental milieu, and the methods used in fabrication of the HDPE geomembrane biodigester. It shall also put in evidence the characteristics and quality control procedures of the said biodigester.

3.1. Model description and parameters

3.1.1. Model

The biodigester model designed here as shown in Fig.1, has two (02) main parts; the digester and the gas storage.

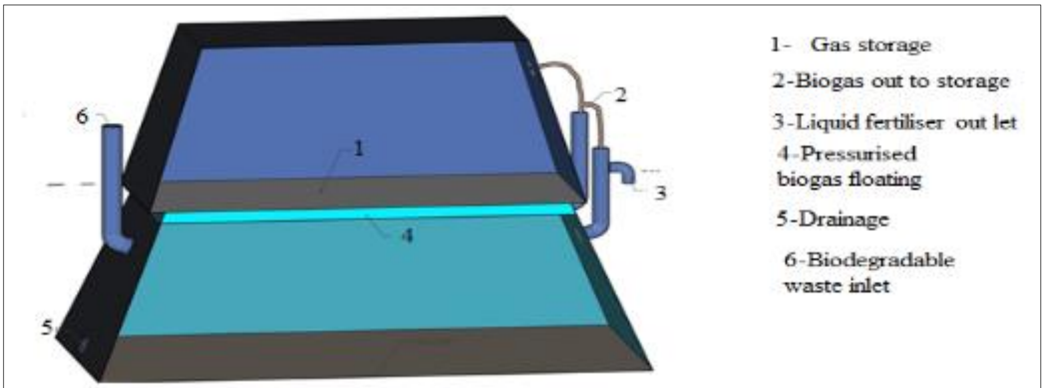

Figure 1 Biodigester model

- The Digester part

This is the section where anaerobic digestion process takes place. It consists of a longitudinal shaped heat-sealed, weather resistance plastic balloon that served as digester. It contains the mixed water and feedstock matter. It has an inlet of diameter (Ø) 100mm, well designed to permit waste into the digester and prevents biogas from escaping through it. Another part is the drain access point also at Ø 100mm, where the system can be drained either for maintenance or displacement purposes. Furthermore, the outlet of the system which provided access for digested liquid to flow out while prevents the escape of biogas into the air. Lastly, it's the gas collector pipe which gives access to trapped biogas in the digester to flow to the gas storage tank.

- The Gas storage part

In this section the biogas is stored prior to usage. It was constructed with a 1.5 mm HDPE geomembrane liner. It has just an inlet to gas flow which permits the gas to flow to and fro. The storage was also equipped with sand bags pockets which help to pressurize the system for adequate and required gas pressure for gas burners. The gas is produced in the digester and convey through tubing to the gas storage. The inlet and outlet are attached directly to the skin of the balloon. This system does neither have any stirring device nor a pump, just from its longitudinal shape, active mixing is limited and digestate flows through the system in a plug-flow manner.

3.1.2. Design Considerations/Parameters

As each situation differs in terms of gas requirement and available feeding material, a unique biodigester size could be calculated for each household. For domestic application the parameters summarized in table 2 are necessary to arrive at the practical size of the biodigester. As the aim is to develop a biodigester size range, the hydraulic retention time is applied as a minimum and maximum value

Table 2 Designed parameters. [31]

Parameter	Explanation	Values used
Waste / water ratio	Theoretically, the waste / water ratio depends on the total solids (TS) concentration of the waste, whereby optimum fermentation results are claimed at 6 to 7% TS. TS values in the 10 to 15% (cattle) and 15 to 20% (pigs) range are reported SNV.	The TS values suggest a waste / water ratio of a little under 1: 1 for cattle dung and 1: 2 for pig dung. For practical reasons. A 1 : 1 ratio has the advantage that households can easily measure the amount of required process water.
Specific gas production (SGP)	The specific gas production of dung depends on the type and quality of dung.	For cattle, typically 1 kg of dung fed to a digester produces about 40 litters of biogas per day. Values for other substrates will differ; pigs, poultry and human excreta typically have higher yields.
Minimum gas production (GPmin)	Depending on construction costs and gas demand pattern, below a certain nominal gas production the investment becomes uninteresting for the household.	One cubic meter of biogas daily will render 2.5 to 3.5 stove hours. This could, depending on family size, suffice for e.g. breakfast and lunch preparation, and would then provide a meaningful contribution.
Hydraulic Retention Time (HRT)	The HRT is the period the waste/water mix fed to the installation remains in the plant. As the fermentation process works better at higher ambient temperatures, installations in warmer climates can work with a shorter HRT and vice versa.	Typical HRTs for domestic (simple) biogas plants are 40 to 60 days for warm climates and 50 to 75 days for temperate climates.
Gas storage volume	Biogas is generated more or less continuously, but consumption in households typically takes place during 3 or 4 periods during the day. The generated gas needs to be stored in the installation.	For the gas storage volume, a fixed share of the maximum amount of daily generated gas, 60% is taken

3.2. Materials

3.2.1. Experimental phase

We proceeded in the present work to create a 300 litter's mini size of the digester with PVC black tarpaulin of 200 microns, a similar material to geomembrane. From this mini model, we carried out experiment on how the said biodigester of HDPE geomembrane would be fabricated and preceded to laboratory analysis of the gas produced from the digester and equally with the organic liquid fertilizer.

3.2.2. Materials for the fabricated biodigesters

- Descriptive list of materials

The Table3 describes the list of materials needed for the fabrication of a 3 m^3 HDPE geomembrane biodigester.

Table 3 Quantitative description of estimate for biodigester

Ref	Items	Description	Quantity
01	Pipes	PVC Ø 100 Pressure Pipe	1 Length
		PVC Ø 100 Flexible Gas Pipe 3/4''	1 Roll
02	HDPE Geomembrane	HDPE Geomembrane Black 1.5mm Liner	42 m^2
03	Elbows	PVC Ø 100 90° Pressure Type	2
		PVC Ø 100 45° Pressure Type	4
04	Glue	PVC Pipe Glue (Tube Type)	2
		HDPE Resin (Carton Type)	1
05	Gas	CAMPI Gas (Tin)	1
06	Plugs	PVC Ø 100	4
		PVC Ø 125	1
07	Reducers	PVC Ø 100 × Ø 63	1
		PVC Ø 125 × Ø 100	1
		Compressor Reducer Ø 20 mm × 16 mm	1
		Copper 3/8'' x 1/2''	1
08	Stop Valves	Compressor Type Ø 20 mm	4
09	Tees	PVC Ø 100 Tee Pressure	1
		Compressor Tee Ø 20 mm (IMF)	3
10	Sockets	Compressor Socket Ø 20 mm	3
		Compressor Nipple Ø 20 mm	2
11	Stove	Gas Stove (One Side/Single)	1
12	Reducer	Copper Reducer 3/4'' x 1/2''	2
13	Connectors	Tank Connector 1/2''	3
14	Monometer	Digital Pressure Gauge 0-10 bars	1
15	Teflon tape	50 m White tape type	1
16	Sand paper	Paper 60	1 m

The same materials were required for the 300 litter's tarpaulin prototype biodigester except for the PVC pipe and fittings which were reduced to Ø 63 mm and instead of a geomembrane liner, a black tarpaulin of 200 microns was used.

- List of Equipment used for the fabrication process

The tools and machines used for the realization of the biodigesters are summarized in Table 4

Table 4 List of equipment and their uses

Ref.	Equipment	Usage
01	Portable hot air gun	It provided the required heat needed for seaming of the HDPE geomembrane liner. Used for plastic welding.
02	Blow lamp	It provided fire for heating pipes. Used to create sockets in pipes.
03	Electric cutting edge	An electrical knife used for cutting geomembrane liners.
04	Hack saw	Used for cutting pipes
05	Measuring tape	Used for measurement
06	Pipe wrench	Used for tightening fittings
07	Adjustable plier	Used for gripping fittings
08	Scissors	Used for cutting light flexible materials
09	Computer	For programing and designs
10	Pressure roller	Work together with the hot air gun, Used to apply pressure on the heat affected zone.

3.3. Methods

This part regroups the set of procedures which permitted the fabrication of the experimented 300 litters tarpaulin prototype digester and the 3000 litters HDPE geomembrane digester.

3.3.1. Fabrication Process/Procedure

- Prototype 300 L Tarpaulin biodigester

The first process after the model design (as shown in Figure 2) is the creation of the various inlets and outlets with PVC pressure fittings of diameter 63 mm. After creating the various provisions to the system, we seam them to the body of the digester using hot air gun machine. The next step is to join the various parts of the digester together using special heating machine and specific glues to enable the complete structure to stand upright. After seaming the storage, we coupled all the parts together and came out with what is seen in Figure 3.

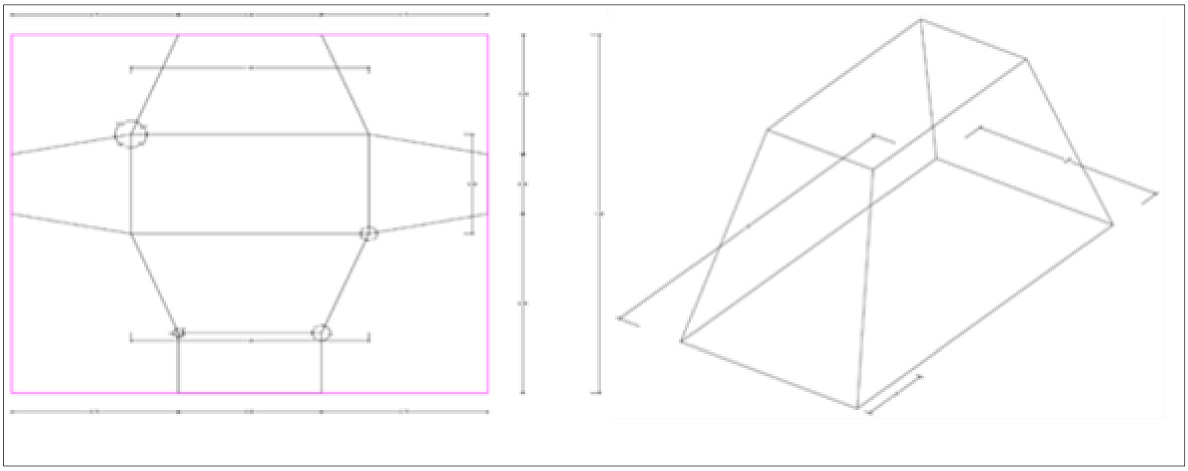

Figure 2 (Left) Geometric design of the tarp digester, (Right): Perspective view

Figure 3 Complete 300L prototype biodigester ready for feeding

- 3000 L HDPE Geomembrane biodigester

A similar thing is done with the HDPE 1.5 mm geomembrane material, except that the geomembrane varies heavy and its parts are not like those of the tarp digester, its part are larger and make it difficult for seaming. Nevertheless, we had sophisticated equipment to ensure leak free parts and joints. Due to the nature and length of the HDPE material 3m high, we had to redesign the plain view to suit the length of the material and for quick and simple joint formation. It should be noted that the jointed areas of the member are the weaknesses of the system therefore many joins should be avoided

The next design represents the HDPE gas storage unit. From the previous calculations, the gas storage was estimated to be 60% of the digester but after installing the 300 litters tarp biodigester. We realized that the 60% gas storage previewed theoretically was not practicable due to the rapid gas generation from the digester. Therefore, we increased the HDPE gas storage to 1750 litters. After cutting the required design, we proceeded to marking the various inlet and outlets to the system.

3.4. Determination of the quality of the biodigester

This section describes the type of substrate used for the formation of biogas and the liquid organic fertilizer obtained from the process. It also encompasses the various test methods used to determine the strength of the various digesters and gas reservoirs. Lastly it describes the numerical analysis of the HDPE geomembrane biodigester.

3.4.1. Prototype 300L biodigester

After the construction of the 300L prototype biodigester, we proceeded to testing it for leakages before putting biodegradable waste into it. The Figure 4 shows the various testing that were done to ensure a leak free biodigester.

Figure 4 (Left) Water Tight test on Gas Storage. (Right): Mounted system after various test

- Feeding the 300 L prototype biodigester with waste

To feed our digester, we used the following formula:

HRT = V/Q ……………… (16)

Where: HRT is the hydraulic retention time in days, V the reactor volume in m^3, and Q the flow rate in m^3/day

We used a HRT of 60 days, V=300 L, therefore Q=5m^3/day, but at initial, the system requires 300 L of waste. From the laboratory, we could determine the water to waste ratio, Figs 5 and 6 show the laboratory experiment. For a homogenous mixture of a kilogram of cattle waste, we had 4 litters of water, making it 1:4, with a density of 966k g/m^3. Therefore, for our system of 300 litters, we required 75kg of cattle waste.

Figure 5 Measuring cattle waste

Figure 6 Homogenous mixture of waste and water (1:4)

Collecting data after HRT of the digester

Figure 7 (Left): Prototype biodigester after HRT; (Right): Gas sample collection

Figure 8 Sample of the liquid fertilizer

After the retention time, we collected samples of the gas produced and the organic liquid fertilizer for laboratory examination. Figure 7 (left) shows the state of the system after its hydraulic retention days. Sample of the gas was collected using a mini balloon as seen in Fig 7 (right), while Fig 8 shows the organic liquid fertilizer collected from the system for examination.

3.4.2. HDPE Geomembrane 3000L Biodigester

- Quality of joints

The joints were professionally designed and realized with seam from hot air gun, the ***Figs 9 and 10 d***escribe the procedures used to realize the joints and followed by a vivid test to ensure the solidify of the system. In the first step, the membrane is welded in first pass using heat from hand weld hot air device and pressure with the hand. In the second step, the weld continues in the mid-portion of the overlap in a manner similar to that in step1. Finally in step 3, the weld is finalized by continuing application of heat and sealing edge with roller.

According to shear test, the elongation E is calculated by

$$E = \frac{L}{L_{\circ}} \times (100) \text{ ……………………} (17)$$

with ≥50% for all seams, where L is the elongation at break, L_0 the gage length (typ. 25mm), and $A = 625\ mm^2$. Bv some additional details for the shear testing:

- Speed 50 mm/min for HDPE and 500 mm/min for more flexible GMs
- Grip separation 50 mm plus seam width
- Gauge length is 25 mm
- Test is complete for HDPE at 50% elongation
- Regarding peel separation, also called peel “incursion”

$$S = \frac{A}{A_{\circ}}(100), \text{ …………………..} \qquad (18)$$

Where S is the separation, with (S≤25% for all seams), A is the average area of separation and A_0 the original bonded area (A and A_0 are visual approximations). Some additional details

- Speed 50 mm/min for HDPE and 500 mm/min for more flexible GMs
- Grip separation equals 50 mm
- Estimate of separation is reported to the nearest 25%
- If grip separation is reduced, it must be reported accordingly.

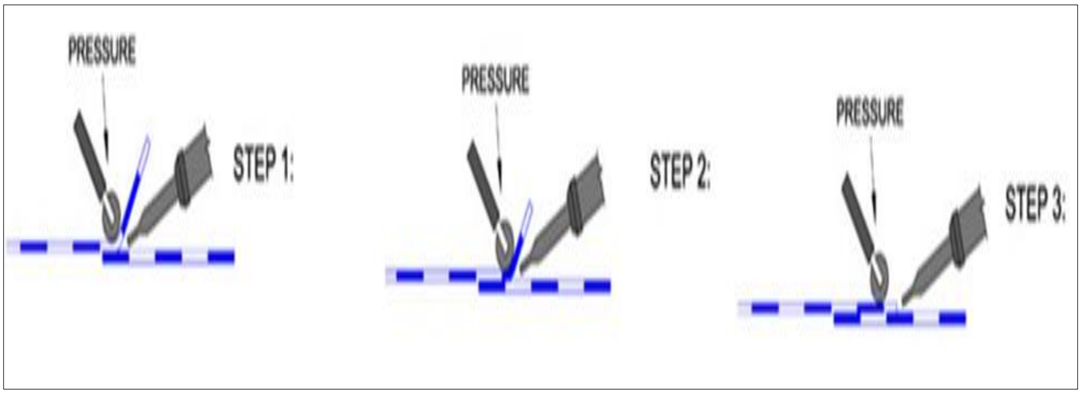

Figure 9 Seam hot air welding process

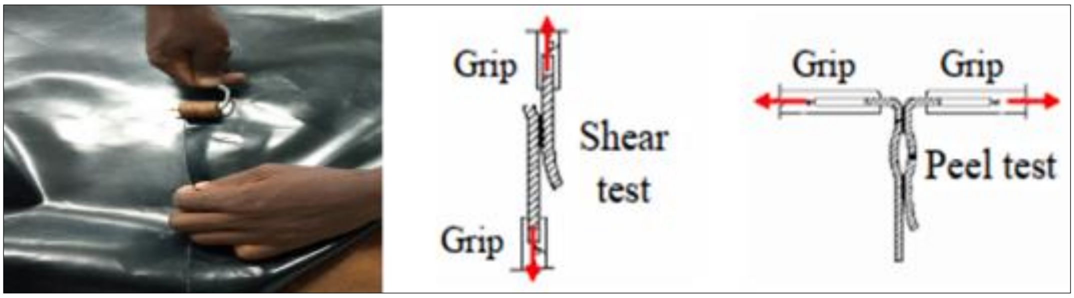

Figure 10 (left) Jointing Process, (right) Type of test carried out

- ➢ Quality of air tightness of the digester and storage unit

The digester and storage units were equally tested for leaks despite the excellent quality of the joints. For this section of testing, we used a fridge compressor to pressurize the system and with soap test, we verified all the joints.

- Digester air test make evidence the air test on the digester.
- Gas Storage Test: As with the digester, an accurate air test was done on the gas storage unit using a compressor while measuring with a pressure gauge

Numerical Analysis of the HDPE Geomembrane Biodigester

- Component of the stress F (See Figure 11)

Let A be a digestion area of the section as shown in Fig.16 , by considering the system full with waste before gas production, the pressure $P = \frac{F}{A}$, leading to $F = \int PdA$ and

$$F_x = \int_A \rho g w(z) z \, dz \text{ ……………. (19)}$$

With, the constraints: w (0) =1m, w (1) =1.5m, leading to w (z) =1+0.5z leading Eq (19) to $F_x = \int_A \rho g(1 + \frac{1}{2}z) z \, dz$.

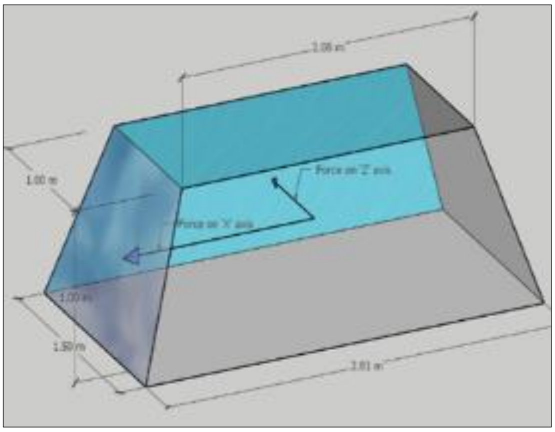

Figure 11 Digestion perspective dimensioned view

For $\rho = 966\ \mathrm{kg/m^3}$ and $g = 9.81\ \mathrm{m/s^2}$, one has $F_x = \rho g\left(\frac{h^2}{2} + \frac{h^3}{6}\right) = 6317.64\mathrm{N} \approx 6.3\mathrm{KN}$. For the z direction, one has $F_z = \int_A \rho g w_1(z) z\, dz$ With the constraints $w_1(0) = 2.06\mathrm{m}$, $w_1(1\mathrm{m}) = 2.81\mathrm{m}$, therefore $w_1(z) = 2.06 + 0.75z$, leading to $F_x = \rho g\left(\frac{2.06h^2}{2} + \frac{0.75h^3}{3}\right) = 121229.87\mathrm{N} \approx 12\mathrm{KN}$.

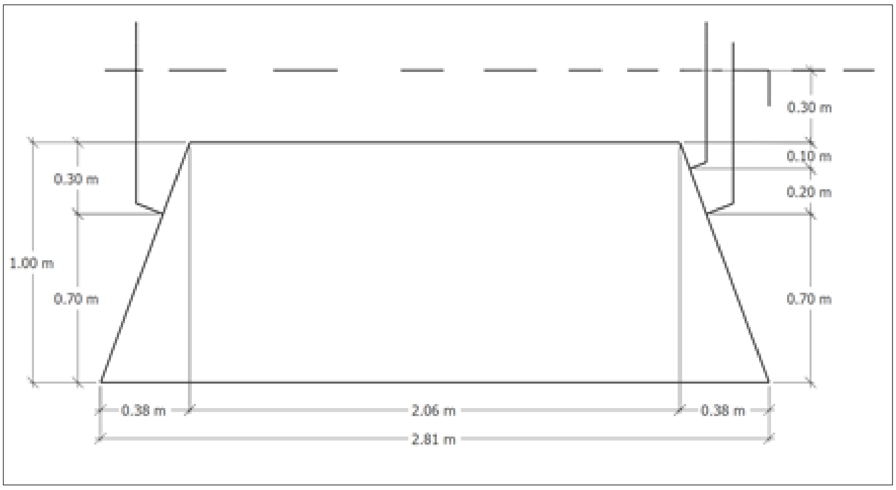

Figure 12 Digestion section

The force acting on the y axis is neglected it since the digester is supported by the ground. The main forces causing deformation on the system are the force on the x and y directions, F_x and F_z respectively as shown in Figure 13.

- Determination of the deformation ε

The Young modulus $E = \frac{\sigma}{\varepsilon}$. Solving for circumferential stress σ_z: considering the system taking a cylindrical shape, the Figure 17 shows the reaction $\sigma_z = \frac{F_z}{A}$. From the equilibrium condition, one has $\sum F_z = 0$, that is $P(2r)dz - 2\left(\frac{F}{2}\right) = 0$, leading to $F = 2Prdz$. Since $A = 2tdz$, one has

$$\sigma_z = \frac{Pr}{t} = 1593.62KPa = 1.6MPa \text{ ……………….. (20)}$$

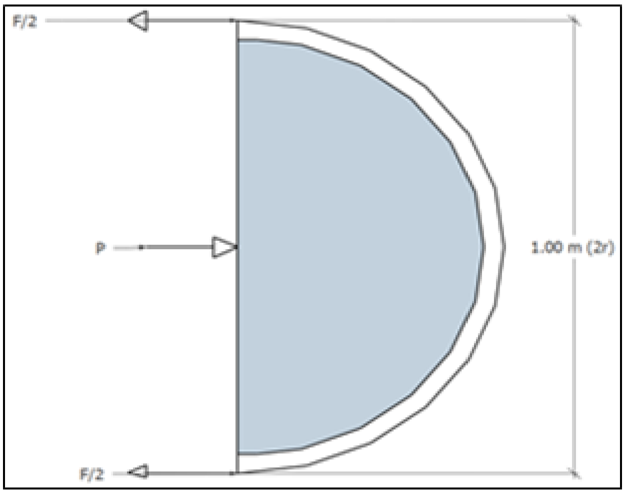

Figure 13 Hoop stress

It is then obvious that $\varepsilon = \frac{\sigma}{E}$ where the Young modulus $E = 0.8\ GPa$ for HDPE, therefore $\varepsilon_z = 0.002$

- Longitudinal or axial stress is usually half the hoop stress: $\sigma_x = \frac{Pr}{2t} = 08MPa$ and $\varepsilon_x = 0.001$
- **Solving for Pressure when biogas starts producing**
- ❖ **Pressure at the bottom of the tank**

$$P_{Bottom} = PG_{out} + 0.9\rho_{waste}g \quad \text{……….. (21)}$$

Solving for PG_{out}

$$PG_{out} = \frac{nRT}{V_{out}} + 0.3\rho_{waste}g \quad \text{………… (22)}$$

Density of biogas is 1.15 kg/m^3, $Vout = 0.17m^3$, $R = 8.31441$, $T = 29^0C + 273$, therefore

$$PG_{out} = 183317.6Pa \approx 183.32KPa \quad \text{……………. (23)}$$

Considering density of waste to be 966 kg/m^3, the pressure at the bottom, $P_{Bottom} = 183317.6 + 966 \times 9.81 \times 0.9 = 191846.41Pa \approx 192KPa$. Note: $g = 9.81\ m/s^2$. We also assume the gas to be perfect, and that atmospheric pressure is neglected.

- Solving for security pressure level PGs: The height for the gas to attain a security level state in the digester is at 0.30m (30cm) from the top of the digester. Therefore, the pressure,

$$PG_s = \frac{nRT}{V_s} + 0.6\rho_{waste}g, \text{ Where } V_s = 0.58m^3 \quad \text{……….. (24)}$$

Leading to $PG_s = 186160.54Pa \approx 186.16KPa$. This value was used to design a security valve which will prevent gas from being ejected out through the waste out let or through the waste inlet of the system.

4. Results

4.1. Mathematical prevision

In order to describe mathematically the kinetics process of the formation of the methane (CH_4), let us rewrite the set of Equations from (1) to 14 by introducing the designation indicated in the Table 5

Table 5 Designation of chemical elements appearing in Equations from 1 to 14

Elements	$C_6H_{10}O_4$	$C_6H_{12}O_6$	CH_3CH_2OH	CH_3CH_2COOH	CH_3COOH	CH_4
Designation	X_1	X_2	X_3	X_4	X_5	X_6
Elements	CO_2	H_2	NOH	H_2SO_4	$(NH_4)HCO3$	H_2S
Designation	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}

$$\begin{cases} \frac{dx_1}{dt} = -k_1x_1, \\ \frac{dx_2}{dt} = \frac{1}{5}[k_1x_1 - (k_3x_8^2 + k_2 + k_4 + k_6)x_2], \\ \frac{dx_3}{dt} = \frac{1}{3}[2k_2x_2 - k_7x_3 - 2k_8x_3^2x_7], \end{cases} \quad \ldots\ldots\ldots\ldots(25)$$

$$\begin{cases} \frac{dx_4}{dt} = k_3x_8^2x_2 - \frac{1}{2}k_5x_4, \\ \frac{dx_5}{dt} = \frac{1}{8}[(3k_4x_5 + 2k_6)x_2 + k_5x_4 + k_7x_3 + 2k_8x_3^2x_7 - (k_9 - k_{11}x_{10} - k_{12}x_9^2)x_5], \\ \frac{dx_6}{dt} = \frac{1}{3}[(k_8x_3^2 + k_{10}x_8^4)x_7 + k_9x_5], \end{cases} \ldots\ldots\ldots\ldots(26)$$

$$\begin{cases} \frac{dx_7}{dt} = \frac{1}{7}[2(k_2 + k_6)x_2 + k_5x_4 + (k_9 + k_{11}x_{10})x_5 - (k_8x_3^2 + k_{10}x_8^4)x_7], \\ \frac{dx_8}{dt} = \frac{1}{6}[2k_1x_1 + k_7x_3 + 3k_5x_4 + 4k_6x_2 - 2k_3x_2x_8^2 - 4k_{10}x_7x_8^4], \\ \frac{dx_9}{dt} = -2k_{12}x_5x_9^2, \frac{dx_{10}}{dt} = -k_{11}x_5x_{10}. \end{cases} \ldots\ldots\ldots\ldots (27)$$

x_i with $i = 1,2,\ldots,12$ are the concentrations of elements shown in Table 7, while k_i, $i = 1,2,\ldots,12$ are the rate of transformations shown in Equations from 1 to 14.

In order to solve the above set of differential equations by using the differential transform method, let us remember the procedure outlined in [32]. Then let us find

$$x_i(t) = \sum_{n=0}^{\infty} y_i(n)\,(t - t_0)^n, \; y_i(n) = \frac{1}{k!}\frac{d^n x_i(t)}{dt^n} \quad \ldots\ldots\ldots (28)$$

which is the differential transform of the quantity $x_i(t)$ leading to following recursive equations:

$$\begin{cases} y_1(n+1) = -\frac{k_1}{n+1}y_1(n), \\ y_2(n+1) = \frac{1}{5(n+1)}\left[k_1y_1(n) - (k_2 + k_4 + k_6)y_2(n) - k_3\sum_{n_2=0}^{n}\sum_{n_1=0}^{n_2} y_8(n_1)y_8(n_2 - n_1)y_2(n - n_2)\right], \\ y_3(n+1) = \frac{1}{3(n+1)}\left[2k_2y_2(n) - k_7y_3(n) - 2k_8\sum_{n_2=0}^{n}\sum_{n_1=0}^{n_2} y_3(n_1)y_3(n_2 - n_1)y_7(n - n_2)\right], \end{cases} \ldots\ldots\ldots(29)$$

$$\begin{cases} y_4(n+1) = \frac{1}{(n+1)}\left[k_3\sum_{n_2=0}^{n}\sum_{n_1=0}^{n_2} y_8(n_1)y_8(n_2 - n_1)y_2(n - n_2) - \frac{1}{2}k_5y_4(n)\right], \\ y_5(n+1) = \frac{1}{8(n+1)}\left[\sum_{n_1=0}^{n}\left(3k_4y_5(n_1)y_2(n - n_1) + k_{11}y_{10}(n_1)y_5(n - n_1)\right) + k_7y_3(n) + 2k_6y_2(n) + \right. \\ \left. 2k_8\sum_{n_2=0}^{n}\sum_{n_1=0}^{n_2} y_3(n_1)y_3(n_2 - n_1)y_7(n - n_2) + k_5y_4(n) - k_9y_5(n) + k_{12}\sum_{n_2=0}^{n}\sum_{n_1=0}^{n_2} y_9(n_1)y_9(n_2 - n_1)y_5(n - n_2)\right], \\ y_6(n+1) = \frac{1}{3(n+1)}\left[k_9y_5(n) + k_8\sum_{n_2=0}^{n}\sum_{n_1=0}^{n_2} y_3(n_1)y_3(n_2 - n_1)y_7(n - n_2) + \right. \\ \left. k_{10}\sum_{n_4=0}^{n}\sum_{n_3=0}^{n_4}\sum_{n_2=0}^{n_3}\sum_{n_1=0}^{n_2} y_8(n_1)y_8(n_2 - n_1)y_8(n_3 - n_2)y_8(n_4 - n_3)y_7(n - n_4)\right], \end{cases} \ldots\ldots\ldots(30)$$

$$\begin{cases} y_7(n+1) = \frac{1}{7(n+1)}\left[2(k_2+k_6)y_2(n) + k_5y_4(n) + k_9y_5(n) + k_{11}\sum_{n_1=0}^{0} y_{10}(n_1)y_5(n-n_1) \right. \\ \quad -k_8\sum_{n_2=0}^{n}\sum_{n_1=0}^{n_2} y_3(n_1)y_3(n_2-n_1)y_7(n-n_2) - \\ \quad \left. k_{10}\sum_{n_4=0}^{n}\sum_{n_3=0}^{n_4}\sum_{n_2=0}^{n_3}\sum_{n_1=0}^{n_2} y_8(n_1)y_8(n_2-n_1)y_8(n_3-n_2)y_8(n_4-n_3)y_7(n-n_4)\right], \\ y_8(n+1) = \frac{1}{6(n+1)}\left[2k_1y_1(n) + k_7y_3(n) + 3k_5y_4(n) + 4k_6y_2(n) - 2k_3\sum_{n_2=0}^{n}\sum_{n_1=0}^{n_2} y_8(n_1)y_8(n_2-n_1)y_2(n-n_2) \right. \\ \quad \left. -4k_{10}\sum_{n_4=0}^{n}\sum_{n_3=0}^{n_4}\sum_{n_2=0}^{n_3}\sum_{n_1=0}^{n_2} y_8(n_1)y_8(n_2-n_1)y_8(n_3-n_2)y_8(n_4-n_3)y_7(n-n_4)\right], \\ y_9(n+1) = -2\frac{k_{12}}{n+1}\sum_{n_2=0}^{n}\sum_{n_1=0}^{n_2} y_9(n_1)y_9(n_2-n_1)y_5(n-n_2)\ , y_{10}(n+1) = -\frac{k_{11}}{n+1}\sum_{n_1=0}^{n} y_{10}(n_1)y_5(n-n_1)\,. \end{cases} \quad \ldots..(31)$$

Subjected to the initial conditions: $y_i(n=0) = x_i(t=t_0)$. The first line of Eq.(29) leads to $y1(1) = -k1y1(0)$, $y_1(2) = \frac{(-k1)^2}{2}y_1(0)$, $y_1(3) = \frac{(-k1)^3}{3!}y_1(0)$, $y_1(4) = \frac{(-k1)^4}{4!}y_1(0)$, leading from the transformation (28) to

$$x_1(t) = y_1(0)\left(1 - k_1t + \frac{k_1^2}{2}t^2 - \frac{k_1^3}{3!}t^3 + \frac{k_1^4}{4!}t^4 + \cdots + \frac{(-k_1)^n}{n!}t^n\right) = x_1(0)\exp(-k_1t) \ \ldots\ldots\ldots. (32)$$

In order to simplify our investigations we set $t_0 = 0$, and $x_1(0) = A_0$, $x_9(0) = B_0$, $x_{10}(0) = C_0$, $x_i(0) = 0, i = 2,3,\ldots,8$. For our illustration let $A_0 = 0.75 mol/l$, $B_0 = 0.6 mol/l$, $B_0 = 0.6 mol/l$, $C_0 = 0.1 mol/l$, $k_1 = 3.9\times10^{-3}$, $k_2 = 5.0\times10^{-3}$, $k_3 = 2.0\times10^{-3}$, $k_4 = 1.0\times10^{-4}$, $k_5 = 1.50\times10^{-2}$, $k_6 = 1.0\times10^{-3}$, $k_7 = 5.0\times10^{-3}$, $k_8 = 2.0\times10^{-2}$, $k_9 = 5.6\times10^{-3}$, $k_{10} = 1.0\times10^{-2}$, $k_{11} = 2.0\times10^{-2}$, $k_{12} = 3.0\times10^{-2}$, leading to the coefficients summarized in the following table:

Rang n	y_1	y_2	y_3	y_4	y_5
0	0.75	0	0	0	0
1	-2.925×10^{-3}	5.85×10^{-4}	0	0	0
2	5.70375×10^{-6}	-1.4976×10^{-6}	9.75×10^{-7}	0	7.3125×10^{-8}
3	-7.414875×10^{-9}	2.091999×10^{-9}	$-2.205666667\times10^{-9}$	0	1.002625×10^{-10}
4	$7.229503125\times10^{-12}$	$-2.139571882\times10^{-12}$	$2.662360278\times10^{-12}$	$2.780578125\times10^{-13}$	$-1.909253719\times10^{-13}$
5	$-5.639012438\times10^{-15}$	$1.919462882\times10^{-15}$	$-2.31383468\times10^{-15}$	$-1.765110994\times10^{-15}$	$2.953401150\times10^{-16}$
6	$3.665358085\times10^{-18}$	$-1.884924029\times10^{-18}$	$1.709100123\times10^{-18}$	$6.014196873\times10^{-18}$	$-6.993839992\times10^{-19}$
7	$-2.042128076\times10^{-21}$	$2.347395439\times10^{-21}$	$-2.212455349\times10^{-21}$	$-1.449605483\times10^{-20}$	$1.887084489\times10^{-21}$

Rang n	y_6	y_7	y_8	y_9	y_{10}
0	0	0	0	0.6	0.1
1	0	0	9.75×10^{-4}	0	0
2	0	5.014285714×10^{-7}	-1.70625×10^{-8}	0	0
3	4.55×10^{-11}	$-8.293071429\times10^{-10}$	2.4096583×10^{-9}	-5.265×10^{-10}	-4.875×10^{-11}
4	$4.678916667\times10^{-14}$	$9.237851071\times10^{-13}$	$-2.613367702\times10^{-12}$	-5.414175×10^{-13}	-5.013125×10^{-14}
5	$-7.127880553\times10^{-17}$	$-6.558579489\times10^{-16}$	$2.904549418\times10^{-15}$	$8.247976064\times10^{-16}$	$7.637014876\times10^{-16}$

6	$9.188359133 \times 10^{-20}$	$-3.023386502 \times 10^{-20}$	$-4.805536425 \times 10^{-18}$	$-6.01220664 \times 10^{-19}$	$-8.65638925 \times 10^{-20}$
7	$4.832480762 \times 10^{-22}$	$9.804635404 \times 10^{-22}$	$9.400973198 \times 10^{-21}$	$3.108286908 \times 10^{-21}$	$2.242629841 \times 10^{-22}$

From the above table, it is obvious from (28) that:

$x_1(t) = 0.75(1 - 3.9 \times 10^{-3}t + 7.605 \times 10^{-6}t^2 - 9.8865 \times 10^{-9}t^3 + 9.6393375 \times 10^{-12}t^4 - 7.518683251 \times 10^{-15}t^5 + 4.887144113 \times 10^{-18}t^6 - 2.722837435 \times 10^{-21}t^7 + \cdots)$,

$x_2(t) = 0.75(7.8 \times 10^{-4}t - 1.9968 \times 10^{-6}t^2 + 2.7893 \times 10^{-9}t^3 - 2.852762509 \times 10^{-12}t^4 + 2.559283843 \times 10^{-15}t^5 - 2.513232038 \times 10^{-18}t^6 + 3.129860585 \times 10^{-21}t^7 + \cdots)$

$x_3(t) = 0.75(1.3 \times 10^{-6}t^2 - 2.94089 \times 10^{-9}t^3 + 3.549813704 \times 10^{-12}t^4 - 3.085112907 \times 10^{-15}t^5 + 2.278800164 \times 10^{-18}t^6 - 2.949940465 \times 10^{-21}t^7 + \cdots)$

$x_4(t) = 0.75(3.7074375 \times 10^{-12}t^4 - 2.353481325 \times 10^{-15}t^5 + 8.018929164 \times 10^{-18}t^6 - 1.93280731 \times 10^{-20}t^7 + \cdots)$ ....(33)

The solution (33) is plotted in Figure (14) showing the variations of different species as a function of time.

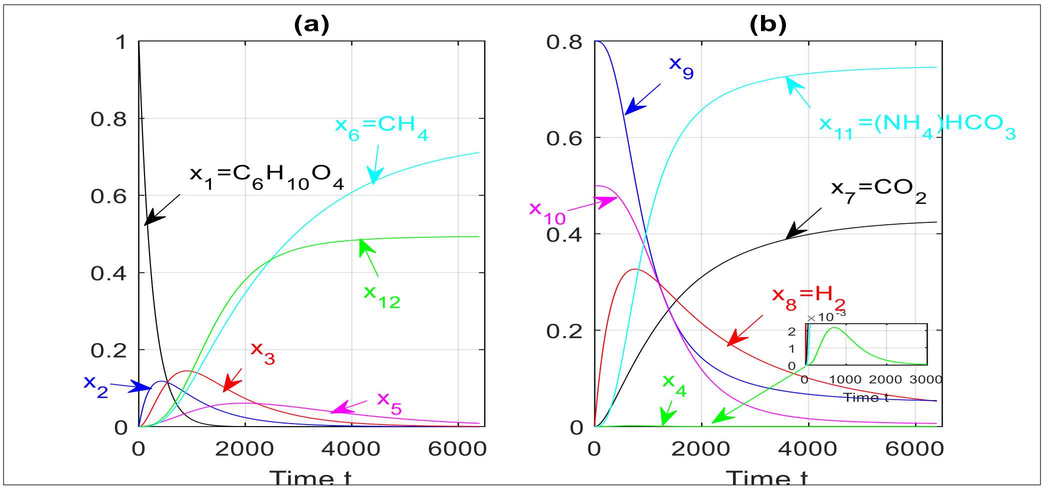

Figure 14 Evolution of the concentrations of different species as obtained in Eq.(33)

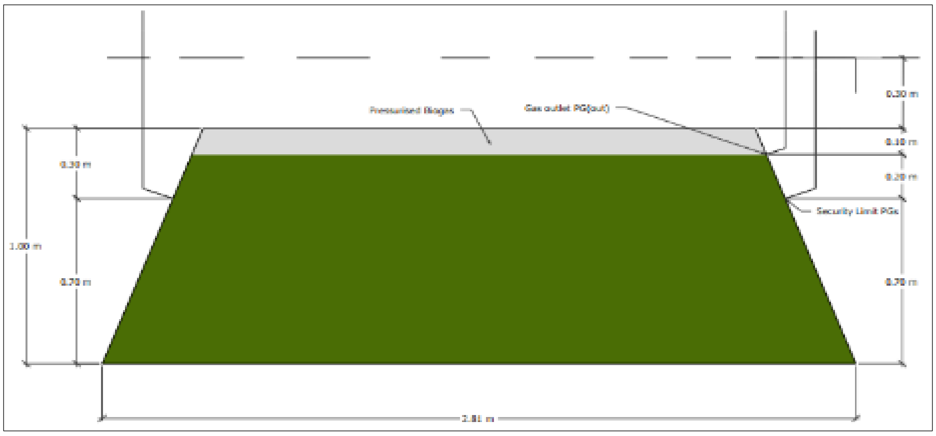

Figure 15 Digester during production stage

4.2. Fabrication protocol

In other to fabricate a hermetical HDPE geomembrane biodigester, we required a prototype which will aid us to investigate the form (design), jointing techniques, hydraulic retention time, gas production process and the quality of the liquid organic fertilizer.

Figure 16 Prototype (left): At day 1 after feeding, (right): After 60 days

This prototype has a digester capacity of 300litters with a 150 litter's gas storage. Both systems were tested for both water and air tightness and they were successful. It produces an average of 40 litters of biogas daily while receiving 5litters of waste (1kg of solid waste mixed with 4litters of fresh water) daily. From the success of the prototype, we fabricated the HDPE geomembrane biodigester.

4.3. Characteristics of the biogas obtained from the prototype

The properties of the biogas sample determined are shown in Table 6.

Table 6 Typical composition of biogas sample from waste

	Components	Symbol	Concentration (Vol-%)
Chemical properties	Methane	CH_4	55 – 70
	Carbon dioxide	CO_2	35 – 40
	Water	H_2O	2 (20 °C) – 7 (40 °C)
	Hydrogen sulphide	H_2S	20 – 30 ± (2 %)
	Nitrogen	N2	< 2
	Oxygen	O2	< 2

	Hydrogen	H2	< 1
	Ammonia	NH_3	< 0.05
physical	Colour	Colourless	
	Flame	Blue flame with little or no carbon	
	Odour	Rotten smell (like bad egg)	
	Density	1.15 kg/m^3	

Figure 17 Burning biogas from prototype digester

4.4. Organic Liquid Fertilizer

During laboratory analysis, two distinct samples were analyzed: the liquid digestate (LD) and another part of it which was dewatered called dry digestate (DP). All digestate samples were obtained using the composite sample technique: more than 5 subsamples (approx. 1.0 kg) were collected and mixed in order to obtain a composite sample. A subsample was analyzed according to the European methods for fertilizers. Dry weight and ashes were determined as weight residue at 105°C and 550°C, respectively. The pH was measured in the water extract (3:50 w/v) after 30 min of shaking at room temperature (RT). The electrical conductivity was determined in the filtered water extract (1:10 w/v) after 30 min of shaking at RT. Total organic C was determined by wet oxidation with potassium dichromate. Total N was measured, after wet acid mineralization, using a Kjeldahl distillation instrument (K355). The ammonium (NH_4^+) and nitrate (NO_3^-) N were determined after extraction with 1 M KCl (1:10 w/v) and steam distillation with magnesium oxide for NH_4^+ and reduction with Devarda alloy for (NO_3^-). Total organic N was calculated subtracting the inorganic N to total N. Total P, S, and metals were determined by microwave wet acid digestion and by inductively coupled plasma optical emission spectroscopy. Available Cu and Zn were extracted with DTPA and determined by ICP-OES.

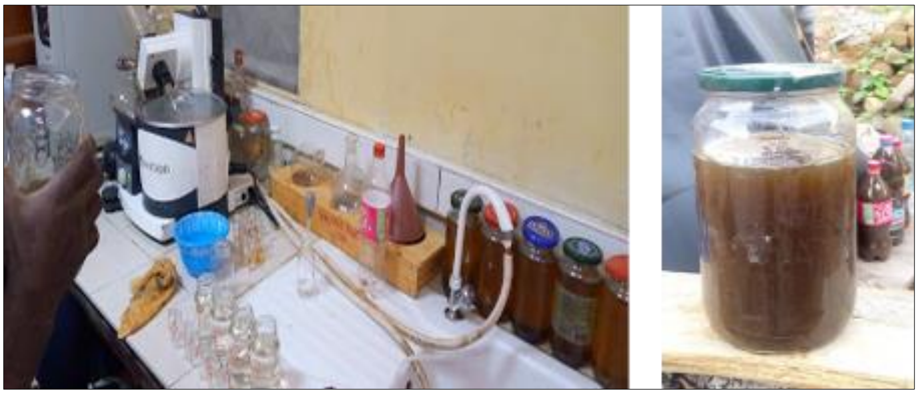

Figure 18 Liquid organic fertilizer in laboratory

Table 9 shows the main characteristics of DL and DP digestates. As expected, the total solids (or dry weight) content was lower in DL than DP. Conversely, the ashes (on DW basis) were higher in DL than DP, therefore the DP had a higher content of volatile solids (or organic matter) than DL. These results are in agreement with the productive process of digestates: the DL process concentrates the soluble salts (increases the ashes and decreases the volatile solids), while the DP process concentrates the organic matter (increases the volatile solids and decreases the ashes). The pH was alkaline in all digestates and resulted highest for the DP. The total organic C (on dry weight basis) was similar in both digestates ranging from 36 to 42% in the DL and DP, respectively; the total N was higher in DL (8.4% DW) than DP (2.0% DW), the C/N ratio resulting <5 for DL and >20 for DP. In DL half of total N was present as NH_4^+ (4.4% DW), while in DP the inorganic forms of N were negligible, and organic N was higher than 85% of total N. For all the other total macronutrients such as P, K, magnesium (Mg) and Sulphur (S), the DL showed higher content than DP.

Table 7 Main Properties of the organic fertilizer

properties	Digestates		Initial waste (Cow dong)	properties	Digestates		Initial waste (Cow dong)
	Liquid (DL)	Pellet (DP)			Liquid (DL)	Pellet (DP)	
Dry weight (% FW)	8.8	89	92.1	Total MgO (% DW)	3.6	1.4	1.1
Ash (% DW)	39	18	28.8	Total SO_3 (% DW)	3.4	1.2	1.8
pH (water)	8.77.	9.75	7.1	Total Fe (% DW)	0.25	0.29	0.46
Total Organic C (% DW)	36	42	33.9	Total Cd (mg/kg DW)	0.1	0.4	<0.1
Total N (% DW)	8.4	1.97	3.21	Total Cr (mg/kg DW)	10	16	34
NH_4^+ N (% DW)	4.4	0.04	0.44	Total Cr_{VI} (mg/kg DW)	<0.2	<0.2	<0.2
NH_4^+ N (% DW)	0.02	0.06	0.02	Total Cu (mg/kg DW)	10	59	91
Organic N (% DW)	4.0	1.87	2.75	Total Hg (mg/kg DW)	0.2	0.2	0.2
C/N ratio	4.2	22	11	Total Ni (mg/kg DW)	11	11	13
Total P_2O_5 (% DW)	4.3	2.0	2.8	Total Pb (mg/kg DW)	11	6	5
Total K_2O (% DW)	10.7	1.8	2.3	Total Mn (mg/kg DW)	360	218	402
Total Zn (mg/kg DW)	64	1.1	NA				

FW: fresh weight; DW: dry weight; cfu : colony forming unit; MPN: most probable number; NA : not analysed.

4.5. HDPE geomembrane biodigester

After the realization of the prototype biodigester, we proceeded to fabricate the HDPE geomembrane biodigester. During fabrication, we carried out some testes on the joints to ensure a water and air tight system. Figure 23 shows the complete fabricated biodigester ready to be installed.

Figure 19 Successful HDPE geomembrane biodigester ready for installation

4.5.1. Results of the joint test

The table 8 explains the results of the joint test. Seam strength and properties of thermally bonded and textured high density polyethylene (HDPE) geomembrane (S.I.unit)

Table 8 HDPE geomembrane 1.5mm Hot Seam Joint test

Geomembrane Nominal thickness		1.5 mm (60 mils)
HOT WEDGE SEAMS		
Test Type	unit	
Shear strength,	N/25 mm	525
Shear elongation at break,	%	50
Peel strength,	N/25 mm	398
Peel separation,	%	25

4.5.2. Air test result

The system was compressed with air from an air compressor at 0.5 bar and left outside under varying climatic conditions for 4 days. At the 4 th day we verified the jointing areas with water soap before decompressing the system for packaging.

4.5.3. Numerical analysis

From our calculations, the force acting by the side of the inlet and outlets was evaluated to be approximately to 6.3KN causing a longitudinal stress of 0.8MPa. As of the side of the system, we had a force approximately to 12KN causing a tangential stress of 1.6MPa. Comparing these values to the resistance test carried out, we observe that the system can support up to 21KN at the joints, making the biodigester super fit for the quantity of waste that it will be receiving.

4.5.4. Pressure Evaluation in the system

The pressure at the bottom of the digester was evaluated at approximately 192KPa equivalent to 2 bars. The gauge pressure which is the pressure required for the generated biogas to move to the storage unit was evaluated at approximately 183.32KPa. This pressure varies since the rate of gas production varies with temperature.

4.5.5. Security limit level

For the gas to attain a security level state, it means either the gas valve is closed or the gas storage is full or even a blockage in the gas network. Also, the gas in the digester must had attained a height greater than or equal to 30cm from the top downward. We evaluated the pressure to be approximately greater than 186.16KPa for such to occur. For safety reasons, we designed a security system in function with the security limit gas pressure. The functioning principle of this security valve is the same as that of a pressure reducing valve. This valve permits fluid to pass through it only at a pressure of 186KPa. This valve is linked to a piping network that leads to the roof top.

Note: These numerical values are mere theories and in reality may differ due to the many assumptions we took such as assuming that the gas is perfect, considering our calculations the number of moles to be of methane. Due to this factor, during installation of this system, numerical values should be taken from the pressure gauge after the system is subjected under pressure by closing the gas outlet. This practical value will be used to adjust the security valve or better still install a pressure relief valve.

5. Conclusion

In this work a biodigester with HDPE geomembrane material is designed and fabricated which will be effective in the recycling of biodegradable waste for the production of biogas and organic liquid fertilizer. Then a 300litters prototype with a tarpauling material is first fabricated. The system was fed with biodegradable waste and observed for a retention period of 60 days. From the success of the prototype, a 3000 litters biodigester is next fabricated. With sophisticated equipment, excellent joints were made and samples were examined and proven to withstand its contain. Numerically the system will produce an average of 1.25 m^3 of biogas daily and serve for a minimum period of 5 hours daily. Sample of the gas produced from the prototype including the rich organic fertilizer were examined and the gas physically was flammable with a rich blue flame while the effluent from the prototype biodigester was a good organic fertilizer in terms of its chemical composition such as nitrogen (N), phosphorous (P), and potassium (K), as well as the trace elements essential to plant growth, were available in the organic liquid fertilizer. The impact of the HDPE geomembrane biodigester shows that the system could actually aid in the reduction of fuel cost in homes and actually be the solution to proper waste management in our country and if implemented around the globe, maybe the perfect mechanism in Fighting against climate change.

We strongly recommend that this HDPE geomembrane biodigester design system should be used all through the all poor and developing countries.

Compliance with ethical standards

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Disclosure of conflict of interest

All of the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved the final version. Additionally, there are no conflicts of interest in connection with this paper, and the material described is not under publication or consideration for publication elsewhere.

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