African Journal of Environment and Natural Science Research
ISSN: 2689-9434
Volume 8, Issue 4, 2025 (pp. 14-47)
www.abjournals.org

DESIGN, FABRICATION AND ASSEMBLY OF A BIOGAS DIGESTER FOR SUSTAINABLE BIOENERGY AND BIO-FERTILIZER PRODUCTION FROM COW DUNG

Martin Olorunfemi Akeredolu[1], Olawale John Olukunle[2], Moses Adeyeye Awodun[3],

and Johnson Toyin Fasinmirin[4*].

[1]International Institute of Tropical Agriculture (IITA), Ibadan, Oyo State, Nigeria.

[2,4]Department of Agricultural and Environmental Engineering,
Federal University of Technology, Akure, Ondo State, Nigeria.

[3]Department of Crop, Soil and Pest Management, Federal University of Technology, Nigeria.

*Corresponding Author's Email: jtfasinmirin@futa.edu.ng

Cite this article:

M. O., Akeredolu, O. J., Olukunle, M. A., Awodun, J. T., Fasinmirin (2025), Design, Fabrication and Assembly of a Biogas Digester for Sustainable Bioenergy and Bio-Fertilizer Production from Cow Dung. African Journal of Environment and Natural Science Research 8(4), 14-47. DOI: 10.52589/AJENSR-7LHWQFML

Manuscript History

Received: 24 Oct 2025

Accepted: 25 Nov 2025

Published: 26 Dec 2025

ABSTRACT: *The demand for renewable energy is on the increase in the sub-Saharan Africa due to the escalating cost of fossil fuel and unreliable conventional power supply from national grid. The technology is gaining recognition and adoption but the process of biogas production from this waste resources is still at its experimental stage in most developing countries. This study therefore presents a comprehensive engineering design, fabrication, and assembly of a biogas digester for bioenergy and bio-fertilizer production. This system consisted of a low-cost, scalable biodigester suitable for decentralized bioenergy generation and high-quality biofertilizer production. A 1000-litre capacity Intermediate Bulk Container (IBC) was made of High density polyethylene (HDPE) designed for use in the anaerobic digestion of biological wastes. The IBC container was repurposed as the main digestion chamber due to its structural durability, chemical resistance, and availability as recycled industrial packaging. The engineering design process incorporated a range of analytical calculations, including mechanical, hydrostatic, and biochemical equations, which were applied to determine the biodigester's structural feasibility and performance potential. The IBC container was repurposed as the main digestion chamber due to its structural durability, chemical resistance, and availability as recycled industrial packaging material. The engineering design process incorporated a range of analytical calculations, including mechanical, hydrostatic, and biochemical equations, which were applied to determine the biodigester's structural feasibility and performance potential. The digester system includes polyvinyl chloride (PVC) piping as flow channels, gas collection ports, and a water-based bubbler (scrubbers, gas storage, and mixing component). This system design was guided by multidisciplinary principles and integration of concepts from fluid mechanics, material science, biochemical kinetics, and structural engineering to ensure both technical efficiency and structural stability. The biodigester system was designed as a continuous-feed type, above-ground anaerobic bioreactor. The approach incorporates mechanical stress evaluations, hydrostatic calculations, and gas pressure considerations in order to deliver a robust and efficient system suitable for decentralized, rural, or small-scale energy production. The biodigester inlet pipe area was 0.00196m^2 and average volumetric flow of cow dung slurry was 4.92×10^{-7} m^3 /s. The slurry was formed using a 1:2 mixture of cow dung and water, resulting in a dilution of approximately 8–10% Total Solids (TS). The digester was filled to a volume of 850 litre mark, with 1:2 cow dung-water slurry, while the 150 litres space was meant for gas collection. The slurry was left inside of the biodigester for a 20 days retention time. The average fluid velocity when total flow rate is spread evenly across the entire cross-sectional area of the tank was 4.1×10^{-7} m/s. The inlet pipe was inserted vertically into the tank, up to a minimum insertion depth of 70 cm to facilitate smooth flow, while the outlet pipe was installed at the bottom corner (with a valve) to facilitate efficient removal of digestate.*

KEYWORDS: Anaerobic Digestion; Biodigester; Biogas; IBC Tank; Digestate.

Article DOI: 10.52589/AJENSR-7LHWQFML
DOI URL: https://doi.org/10.52589/AJENSR-7LHWQFML

INTRODUCTION

Rising energy demands, farm-land degradation, and the persistent challenge of sustainable waste management continue to impact rural and semi-urban communities across developing nations (Robinson, 2024; Lackner and Besharati, 2025). In addition, Voumik and Sultana (2022) documented rapid urbanization, industrialization, and the unsustainable exploitation of fossil fuels as reasons for significant environmental degradation and increased greenhouse gas emissions. As a result of these multiple challenges, biogas technology, particularly through the anaerobic digestion (AD) process in an oxygen-free environment called a biodigester, offers a practical, multi-purpose solution (Achinas *et al.*, 2017). This environmentally friendly technology converts organic waste into renewable energy in the form of methane-rich biogas while simultaneously producing a nutrient-rich digestate that could serve as high-quality organic fertilizer useful for land remediation (Wang, *et al.*, 2023). The technology presents a sustainable and reliable solution for rural and semi-urban communities due to its affordability, accessibility, and circular nature.

Mapantsela *et* al. (2024) reported that among the many biodigester designs for the anaerobic digestion process that have been explored globally, plastic digesters and high-density polyethylene (HDPE) containers have gained attention due to their affordability, accessibility, and ease of use. Traditional biogas systems, such as dome-type digesters constructed from bricks or steel, often require significant financial investment and skilled labour, making them less feasible for low-income households or smallholder farmers (Ni, 2024). As a result, low-cost innovative options that are durable and replicable are urgently needed. One such alternative, currently gaining traction, is the use of Intermediate Bulk Containers (IBCs) as biodigesters. This container was originally designed for industrial storage and transport of liquids and chemicals. The 1000-litre HDPE IBC tanks are enclosed in galvanized steel cages that offer both mechanical strength and protection from external damage. Their chemical resistance, structural durability, and wide availability, particularly as recycled units, make IBCs a compelling option to be considered for use in biodigester construction, especially in resource-constrained environments.

Due to their modular shape and manageable size, IBC tanks can be easily modified with basic tools and minimal technical expertise. This makes them particularly well-suited for decentralized, small-scale energy systems in rural settings. With proper retrofitting, including the integration of inlet, outlet, gas capture, and safety valves, IBC tanks can be converted into effective anaerobic digesters capable of supporting daily energy needs for cooking and lighting in households and small farms. While prior studies have examined the performance of HDPE and fiberglass digesters (Kenmogne, *et al.*, 2023: Issahaku, *et al.*, 2024), there remains a scarcity of comprehensive research on the structural and biochemical evaluation of IBC tanks specifically used as biogas biodigesters (Budiman, 2021). Many existing studies focus either on operational outcomes or on cost comparisons (Alvarez, *et al.*, 2025; Makamure *et al.*, 2021) but few address the integrated mechanical performance, hydrostatic behaviour, and long-term efficiency of IBC-based digesters.

In the context of Nigeria, where access to grid electricity and clean cooking fuel remains inconsistent in rural areas, coupled with the challenges of unaffordable cost of chemical fertilizer for farmers, this type of solution is particularly relevant as a system designed for household and small community use; providing both methane-rich biogas for cooking, decentralized electricity generation, and nutrient-rich digestate as a biofertilizer (Mapantsela *et al*., 2024; Meegoda, *el al*., 2025). This cost-effective, user-friendly, and scalable biodigester design has the potential to empower households, reduce deforestation caused by firewood collection, mitigate greenhouse gas emissions, and promote food security (Prasad *et al*., 2025). The adoption of recycled IBC tanks for biodigester construction represents an innovative step toward achieving the United Nations Sustainable Development Goals (SDGs), particularly those related to affordable clean energy (SDG 7), responsible consumption and production (SDG 12), and climate action (SDG 13).

Therefore, the objective of the study was to design, assemble and test a locally fabricated biodigester for bioenergy and bio-fertilizer production

METHODOLOGY

Design Objectives.

The primary aim of this biodigester design was to develop a cost-effective, structurally safe, and high-performance anaerobic biodigester, using a 1000-liter Intermediate Bulk Container (IBC) for small to medium-scale bioenergy production and nutrient-rich biofertilizer generation.

The design objectives are to:

i. ensure mechanical stability and integrity of the IBC tank structure.
ii. withstand internal gas and fluid pressures
iii. prevent leakage or rupture
iv. incorporate standard fittings for gas and slurry handling.
v. maintain anaerobic conditions to support microbial activity
vi. optimize biogas yield from cow dung slurry.
vii. maintain cost-effectiveness, replicability. And ease of operation

System Description and Configuration of Biodigester

The System comprises the following primary components all assembled for effective digestion of raw material:

The components include the followings:

i. A 1000 L HDPE IBC container with a galvanised steel frame cage.
ii. A Cuboid shape (standard IBC geometry)
iii. A working volume of 850 L.
iv. PVC plumbing pipes and fittings as feedstock inlet, slurry outlet pipe, and overflow outlet pipe.

Article DOI: 10.52589/AJENSR-7LHWQFML
DOI URL: https://doi.org/10.52589/AJENSR-7LHWQFML

v. A gas outlet port with flexible tubing and gas storage

vi. A top cover with a seal.

vii. A manual paddle agitator (removed)

viii. Glass thermometer and pH probe(4 in 1 instrument) for monitoring

Technical Design of Biodigester System

This section presents the technical design considerations used for the built biodigester using a 1000-litre Intermediate Bulk Container (IBC). The approach incorporates mechanical, hydrostatic, and biochemical considerations, with relevant equations essential for optimizing the biodigester's anaerobic digestion (AD) performance.

The technical design of the biogas biodigester system is fundamental to ensuring efficient operation, structural durability, and user safety. This system design was guided by multidisciplinary principles and integration of concepts from fluid mechanics, material science, biochemical kinetics, and structural engineering to ensure both technical efficiency and structural stability (Okwu *et al.,* 2020). In this section, detailed design framework for the biodigester system were outlined and constructed using a 1000-litre Intermediate Bulk Container (IBC) with an HDPE liner and an external galvanized steel cage. The biodigester system was designed as a continuous-feed type, above-ground anaerobic bioreactor as described in de Souza Guimarães and da Silva Maia (2023). The approach incorporates mechanical stress evaluations, hydrostatic calculations, gas pressure considerations, and anaerobic digestion (AD) optimization strategies. The aim was to deliver a robust and efficient biodigester suitable for decentralized, rural, or small-scale energy production. Important design parameters and their specifications is presented in Table 1.

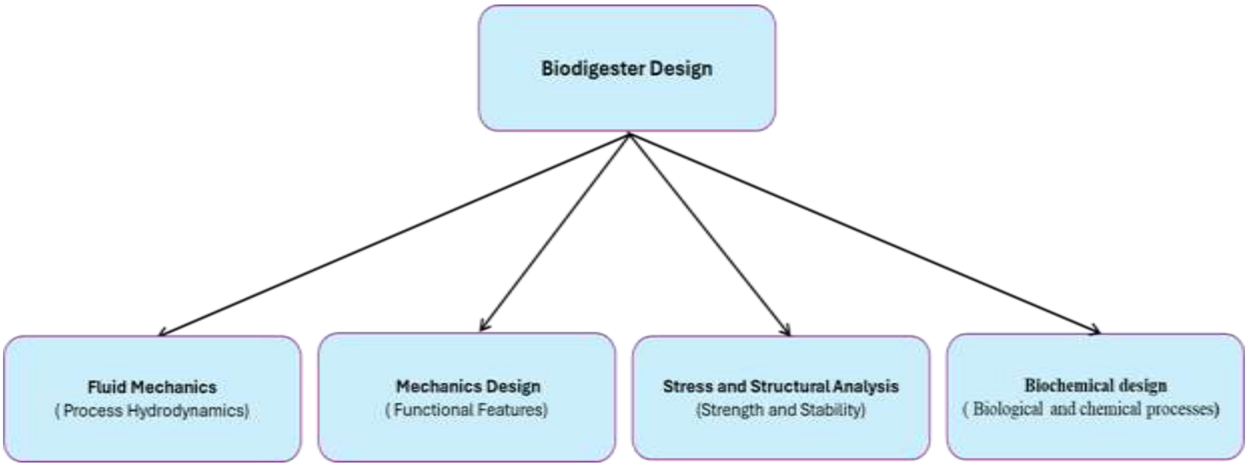
Table 1: IBC Tank Specifications and Design Assumptions

S/N	Parameter	Value
i	Volume	1000 litres
ii	Dimensions	1.0 m × 1.0 m × 1.2 m
iii	Material	HDPE (High-Density Polyethylene)
iv	Wall Thickness (t)	6 mm (HDPE)
v	Fillet radius	0.05 m
vi	Cage Material	Galvanized steel
vii	Weight (empty)	55 kg
viii	Gravity (g):	9.81 m/s^2

Design assumptions followed FAO (1996) and typical biogas engineering guidelines (Kinyua, 2025)). For simplicity, the hierarchical view of Biodigester engineering considerations adopted is summarized in Figure 1.

Article DOI: 10.52589/AJENSR-7LHWQFML
DOI URL: https://doi.org/10.52589/AJENSR-7LHWQFML

Figure 1: The Hierarchical View of Biodigester Engineering design Considerations



Fluid Mechanics Considerations.

These are considerations of the movement and behaviour of slurry and gas inside the biodigester (hydrodynamic condition). The flow, mixing, velocity profiles, and mass transfer of slurry inside the tank were considered. The flow of slurry inside the biodigester was designed following the method described in Singh *et* al. (2021), and Kariyama and Wu (2018) in order to maintain near-homogeneous mixing, prevent or minimize sedimentation, and optimize contact between microorganisms and substrates. Hydraulic Retention Time (HRT) and slurry velocity were selected to avoid dead zones and short-circuiting (Deng *et al*., 2021). The inlet and outlet positioning were designed to ensure laminar inflow and gradual outflow of digestate.

The fluid-mechanics design supports the following operational goals:

i. facilitate uniform mixing of feedstock and microbes.

ii. Prevention / minimizes sedimentation at the bottom and floating scum at the top.

iii. Optimize biogas collection by creating favourable flow paths for bubbles and releasing gas efficiently.

Furthermore, the determination of Hydraulic Retention Time (HRT) was linked with biodigester volume, flow rate, and digestion efficiency as described in Parajuli *et al*. (2022). Feedstock slurry design under fluid mechanics means tailoring solids concentration, viscosity, velocity, and particle size such that the slurry can be pumped and distributed evenly in the digester without settling or clogging, while still maintaining a high energy density for biogas production (Jeppu *et al*. (2021). In biodigesters, feedstock slurry must be formulated with attention to flow behavior. The slurry is not just “waste + water.” Its flow behaviour determines the followings:

- How easily it can flow or be pumped into the digester.
- Whether its solids settle or stay suspended.
- How mixing and digestion occur inside the tank.

The followings were design considerations for Feedstock Slurry:

i. **Rheology (flow behaviour)**

- Digesters typically handle non-Newtonian slurries (thicker than water).
- To remain pumpable, total solids (TS) is usually kept between 8–12%.
- Too much dilution results in less biogas per volume, while too much thickness result in too viscous to flow.

ii. **Viscosity & density**

- High viscosity resists flow, corresponding to low Reynolds number (laminar regime).
- Density differences between liquid and solids influence settling velocity.

iii. **Superficial velocity (u = Q/A)**

- It must be enough to carry solids and prevent sedimentation.
- If it is too low, solids will settle at the bottom.
- If it is too high, beneficial stratification will be disturbed, and efficiency will be reduced.

iv. **Reynolds number (R_e)**

$$R_e = \frac{\rho \ x \ v \ x \ D}{\mu} \qquad 1$$

Most biodigester flows are laminar (R_e < 2000), so mixing relies more on gas bubbles or mechanical means, not turbulence (Singh *et al.*, 2021).

v. **Particle size distribution**

- Large fibrous or coarse particles increases friction, clog inlets/pipes, and raise viscosity.
- Feedstock pretreatment involves, milling, chopping, or screening, to improve flow.

Hydraulic Retention Time (HRT)

The Hydraulic Retention Time, (HRT) is the average time the substrate (slurry) remains in the biodigester, ensuring sufficient microbial contact with substrates before being displaced by new inflow (Aboudi *et al.*, 2023).

Hydraulic Retention Time, HRT = V_e/Q 2

Where the choosing IBC tank biodigester design parameters:

V_e = biodigester working/effective slurry volume = 850 L = 0.850 m^3

Q = Daily slurry volumetric input/ Daily influent flow rate = 42.5 L/day

Article DOI: 10.52589/AJENSR-7LHWQFML
DOI URL: https://doi.org/10.52589/AJENSR-7LHWQFML

HRT = Hydraulic retention time = V_e / Q = 850 L / 42.5L/day = 20 days

This is to ensure sufficient microbial digestion time.

Slurry Velocity & Mixing

Slurry velocity is the average linear velocity of slurry through the biodigester cross-section. To prevent sedimentation of heavy particles (e.g., cow dung Fibers**),** slurry velocity must exceed the minimum suspension velocity (Muller *et al.,* 2007).

To ensure flow continuity, the general velocity equation, referred to as continuity equation was used:

$$v = \frac{Q}{A} \qquad 3$$

where:

v = Average slurry velocity (m/s)

A = effective cross-sectional area of (flow path) the biodigester (m^2)

Q = volumetric flow rate (m^3/s)

IBC Biodigester Inlet Pipe Area

For the selected inlet pipe diameter = 0.05 m (2-inch pipe),

$$\text{Pipe Area, } A_{pipe} = \frac{\pi d^2}{4} = \frac{3.14\ x\ (.05)^2}{4} = 0.00196\text{m}^2$$

Average volumetric flow (based on daily feed) per second

Flow rate (average daily inflow) = Daily feed, Q_{ave} = 42.5 L/day

Converting flow to m^3/s

Conversion to cubic meters:

Q_{ave} = 42.5 L/day = 0.0425 m^3/day

Conversion to seconds:

$$\boldsymbol{Q_{ave}} = \frac{0.0425}{day} = \frac{0.0425}{60\ x\ 60\ x\ 24} = \frac{0.0425}{86400}\ m^3/s \quad (\text{ if spread over full day})$$

$$\boldsymbol{Q_{ave}} = 4.92\times10^{-7}\ \text{m}^3\ /\text{s}$$

which is Q_{ave} = 0.0004919 L/s (very small).

Article DOI: 10.52589/AJENSR-7LHWQFML
DOI URL: https://doi.org/10.52589/AJENSR-7LHWQFML

IBC Biodigester cross-sectional (footprint) Area

$A_{tank} = 1.20\times1.00 = 1.20\ m^2$

Average tank (superficial) velocity

$V_{tankave}$ is the average fluid velocity when total flow rate is spread evenly across the entire cross-sectional area of the tank.

$$V_{tankave} = \frac{Q_{ave.}}{A_{tank}} = \frac{4.92\times 10^{-7}}{\mathbf{1.20}}\ m^3/s \quad (\text{if spread over full day})$$

$V_{tankave} = 4.1\times10^{-7}$ m/s

That is about 4.1×10^{-7} m/s = 0.0354 m/day (extremely slow).

Instantaneous pulse flow during for an estimated 15-minute feeding duration

Biodigester estimated feeding (pouring in of feedstock) duration is 15 minutes (i.e. 900 s), not 24 h:

Therefore,

$$Q_{pulse} = \frac{0.0425}{15 minutes} = \frac{0.0425}{60\ x\ 15} = \frac{0.0425}{900} = 4.722\ \text{x}\ 10^{-5}\ m^3\ /s$$

which equals 0.04722 L/s or 2.833 L/min while pouring.

Instantaneous inlet velocity in a 50 mm pipe during feeding (when pouring in feedstock)

This is the actual velocity of fluid entering the system (tank or biodigester) at a given moment in time. If the inlet flow fluctuates (e.g., pump pulsations or hand feeding), this velocity varies with time, hence it is *instantaneous*.

Applying the inlet pipe area and the Average volumetric flow (based on daily feed) per second as determine above,

Pipe cross-sectional area:

$$A_{inst} = \frac{\pi\ \text{x}\ D^2}{4} = \frac{\pi\ \text{x}\ (0.05)^2}{4} = 1.96\ \text{x}\ 10^{-3}\ m^3$$

$$v_{inst} = \frac{Q_{inst}}{A_{pipe}} = \frac{4.72\ x\ 10^{-5}}{1.96\ x\ 10^{-3}} = \mathbf{0.024\ m/s}$$

So, the inlet jet (i.e. the velocity of slurry as it comes out of the inlet pipe) during the 15-minute pour is = 0.024 m/s.

Article DOI: 10.52589/AJENSR-7LHWQFML
DOI URL: https://doi.org/10.52589/AJENSR-7LHWQFML

Mechanical Design Considerations

The mechanical design of the Intermediate Bulk Container (IBC)-based biodigester is crucial to ensuring its structural stability, safety, and operational efficiency (Nkoi *et al*., 2018; Mungwe *et al*., 2021). Unlike conventional underground concrete digesters, the IBC biodigester is a surface-mounted, repurposed high-density polyethylene (HDPE) tank encased within a steel cage (Onuoha *et al*., 2019). Mechanical design considerations revolve around fluid pressure, material strength, stress distribution, thermal effects, and biogas headspace management. Discussion in this section is on the key parameters that influence the IBC-based biodigester's design.

Hydrostatic Pressure.

This is the static (i.e., at rest) pressure of the slurry inside the IBC tank. The focus is on how the slurry's column height imposes pressure and stress on the tank walls and base. Hydrostatic pressure develops as slurry height increases inside the tank. The pressure acts laterally on the tank walls and vertically on the bottom plate (Mateescu, 2016). It follows a linear distribution with a maximum value at the base. Mateescu (2016) reported that the importance of the evaluation of pressure from slurry was to ensure that the tank and outlet fittings withstand internal pressure from the slurry without creep, deformation, or rupture:

The IBC tank is rated for 1000 Liters and has dimensions approximately 1.2 m (L) × 1.0 m (W) × 1.0 m (H). The tank is seated in a galvanized steel cage on a pallet (footprint ≈ 1.20 m × 1.00 m).

For an effective slurry volume $V_e = 0.85\ m^3$, and estimated slurry density $\rho_s = 1050\ kg/m^3$

Height of Slurry (h_s)

The Slurry height (h_s) inside the Biodigester was determined using equation 4:

$$h_s = Ve/A \qquad 4$$

where,

$V_e = 0.85\ m^3$ (effective Biodigester Slurry Volume)

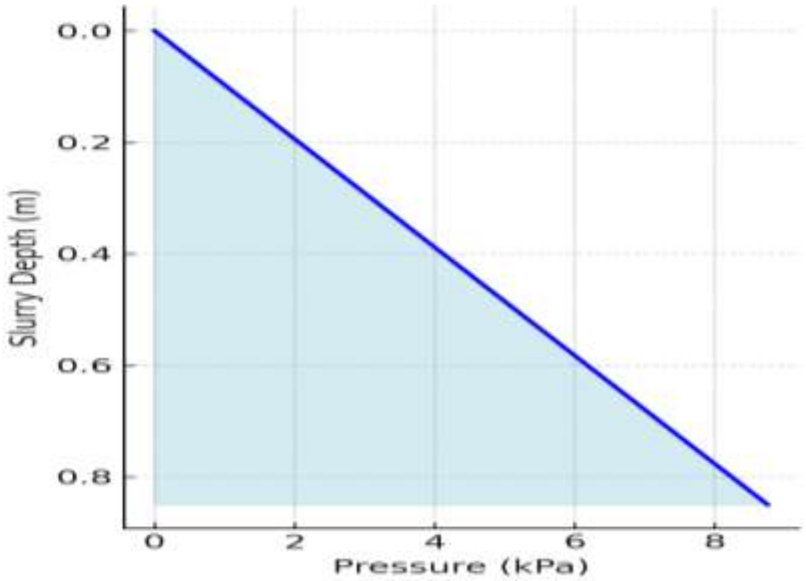
$A = 1.20 \times 1.00 = 1.20\ m^2$, (IBC biodigester floor plan Area)

Slurry height, $h_s = Ve/A = 0.85/1.20 = 0.708\ m$

Hydrostatic Pressure Distribution Diagram – showing the triangular pressure profile against the digester wall (increasing with slurry depth.)

Article DOI: 10.52589/AJENSR-7LHWQFML
DOI URL: https://doi.org/10.52589/AJENSR-7LHWQFML

Figure 2: Hydrostatic pressure distribution in slurry at height h (it increases with slurry depth).



The pressure on the biodigester wall,

The maximum hydrostatic pressure exerted on the biodigester walls at any depth was calculated using equation 5 (Vogeli *et al*., 2014):

$P_h = \rho_s \times g \times h_s$ 5

Pressure at the Bottom

The maximum hydrostatic pressure exerted at the Bottom,

At maximum depth, $P_h = \rho_s \times g \times h_s$

where:

$h_s =$ 0.708 m (calculated height of slurry column)

$\rho_s = 1050\ kg/m^3$ (density of slurry)

The Pressure at the Bottom of the IBC biodigester, $P_h = 1050 \times 9.81 \times 0.708 \approx 7.3$ kPa,

Force on Tank Walls

Total horizontal force exerted by a liquid on a vertical wall (like the side wall of an IBC biodigester) is given in equation 6 (Nkoi *et al*., 2018):

$F = \frac{1}{2} \rho g h^2 b$ 6

where:
ρ = slurry density (1050 kg/m³ assumed)

g = gravitational acceleration (9.81 m/s²)

h = slurry height (0.708 m)

b = width of the wall considered (1.0 m)

Substituting, into $F = \frac{1}{2} \rho g h^2 b$

$F = 0.5 \times 1050 \times 9.81 \times (0.708)^2 \times 1 = 2{,}582$ N (2.58 kN).

This is the total horizontal thrust pushing outward on one wall of the tank. It indicates the lateral force the tank walls must resist without failing. This is equivalent to 263 kgf acting laterally on each side, justifying the use of metal cage reinforcement.

Bottom Plate Loading – Slurry Weight

The bottom plate supports the entire slurry weight. Load distribution must be uniform to prevent deformation or cracking. The total load is given by the slurry volume multiplied by density and gravity (equation 7).

$$W = \rho \times g \times V \qquad 7$$

where:

W = Total load (N)

ρ = Slurry density (kg/m^3) ~ 1050

g = Gravitational acceleration (9.81 m/s^2)

V = Effective volume (m^3) = 0.85 m^3

Slurry weight, $W = 1050 \times 9.81 \times 0.85 = 8755.42$ N (~8750 N).

Thermal Expansion of HDPE Tank

The HDPE material expands and contracts with temperature changes. Thermal stress is especially critical at joints and connections. Expansion can be estimated using the coefficient of linear expansion (equation 3.13) (Baglari *et al*., 2011).

$$\Delta L = \alpha \times L \times \Delta T \qquad 8$$

where:

ΔL = Change in length (m)

α = Thermal expansion coefficient for HDPE (2×10^{-4} /°C)

L = Original length (m) = 1.0 m

ΔT = Temperature change (°C) = 10 (daily swing)

Therefore, $\Delta L = 2 \times 10^{-4} \times 1.0 \times 10 = 0.0020$ m (~2 mm).

HDPE tolerates this flex without cracking or fatigue.

Gas Pressure Estimation with Thermal Expansion.

Assuming a worst-case gas buildup (sealed tank, 5% expansion):

$V_g = 0.05 \text{ X } 1 = 0.05 \text{ m}^3$

Using the ideal gas law

$$P = \frac{nRT}{V} \qquad 9$$

where $n = \frac{m}{M}$

P = Pressure of the gas (in pascals, Pa)

V = Volume occupied by the gas (in cubic meters, m^3)

n = Amount of substance of gas (in moles, mol)

m = Mass of the gas (in kilograms or grams, depending on unit consistency)

M = Molar mass of the gas (in kg/mol or g/mol)

R = Universal gas constant, R=8.314 J/mol

T = Absolute temperature (in kelvins, K)

Approximate pressure rise (ΔP): 1.2–1.5 psi

This is below the HDPE burst pressure of (3.2–3.6 MPa)

Headspace Biogas Pressure and Water- Bubbler Backpressure Effects

Biogas accumulates in the headspace, with a volume of about 0.150 cubic metres above the slurry, exerting pressure on the tank roof and walls. Safe operation requires a pressure relief mechanism (vent to storage) to prevent over-pressurization and tank rupture (Meegoda *et al.*, 2025).

The water height in the water-bubbler was used as a Headspace pressure limiter.

With water-bubbler water height h = 4cm,

$$P = \rho \times g \times h \qquad 10$$

$= 1000 \times 9.81 \times 0.04 = 392.4$ (0. 392 kPa)

= 0.39 kPa (3.92 mbar, 4 cm H_2O).

Headspace Biogas pressure limit on the roof = 0.39 kPa

It should be noted that the IBC is not a pressure vessel; safe working pressure is very low (typically <2–3 kPa) at higher backpressure, the tank roof may bulge, crack, or rupture.

Article DOI: 10.52589/AJENSR-7LHWQFML
DOI URL: https://doi.org/10.52589/AJENSR-7LHWQFML

Forces on the Headspace Roof and IBC Inlet Lid Cover due to Biogas Pressure Loading.

The biodigester's roof and top cover experience upward forces resulting from internal biogas pressure buildup calculated above. These forces can be expressed using the relationship:

$$F = P \times A \qquad 11$$

where:

F = Force due to biogas pressure (N)

P = Gas pressure (Pa) ~ 392.4 Pa

A = projected Area.

For headspace roof, $A = A_{roof}$ = Roof area (m^2) = $1.2 \times 1.0 = 1.2\ m^2$

Force on headspace roof, $F_{roof} = P \times A_{roof} = 392.4 \times 1.20 = 470.88$ N

IBC inlet lid cover Area, $A_{lid} = \pi r^2$. with a cover radius = 0.15 m.

IBC inlet lid cover Area, $A_{lid} = \pi \times (0.15)^2 = 0.0707\ m^2$

Force on Inlet lid $F_{lid} = P \times A_{lid} = 392.4 \times 0.0707 = 27.74$ N.

The galvanized cage upper guide restrains the IBC tank from bulging up due to the force exerted by the biogas pressure, while the lid cover and its sealing system are designed to withstand this force due to biogas pressure without deformation or leakage

IBC Biodigester Inlet and outlet pipe placement

The Key objectives include the followings:

- Avoiding short-circuiting i.e. fresh feed exiting immediately.
- Minimising dead zones where solids settle and biodegradation stalls.
- Allowing controlled residence time (HRT) by encouraging bulk flow through the tank.
- Preventing clogging and enable easy maintenance.
- Protecting gas system integrity (no gas leaks, no siphoning of gas).

General layout principles.

The separation between inlet and outlet is maximised by putting them on opposite sides or as far apart as geometry allows so flow traverses the full tank volume.

- The full dimension of available vertical separation height (inlet high, outlet low) is used as the hydraulic path to maximise effective flow length and HRT.
- Avoid coaxial alignment that points the inlet directly at the outlet (this creates a jet that promotes short-circuiting)

Article DOI: 10.52589/AJENSR-7LHWQFML
DOI URL: https://doi.org/10.52589/AJENSR-7LHWQFML

Inlet Pipe Positioning

Inlet determines where new slurry enters. The purpose of correct inlet positioning are:

- Good distribution of the incoming slurry,
- Minimal disturbance to the stratified layers,
- Avoidance of solids accumulation at the base,
- And efficient flow-through toward the outlet

Location:

- The inlet pipe enters from the top of the IBC tank. Positioned at the top corner or upper side of the IBC tank, usually near one end (either top-left or top-right corner).
- Then the pipe extends downwards into the digester so that its outlet opening is about 15–20 cm above the bottom of the tank.
- The inlet pipe end inside the biodigester, could be turned parallel to the tank wall with 90° elbow or angled slightly downward at 10–20° to allow the feed slurry to spread along the wall rather than shooting directly across the tank.

Effect:

- The feed enters below the liquid surface, above the sludge layer, and disperses gradually.
- It avoids direct discharge at the bottom, preventing resuspension of settled solids.
- It still allows incoming flow to push older material toward the outlet.

Outlet Pipe Positioning

To enhance process optimization, a new approach of hybrid outlet configurations, with a combined bottom and top-side outlets configuration was adopted for the IBC biodigester design.

In a standard single-outlet design (top-side outlet only**),** liquid digestate (supernatant) exits easily, but heavier well digested slurry settled at the bottom.

A combined outlet configuration introduces a bottom outlet in addition to the normal top-side outlet, giving the opportunity for more flexibility in managing both:

- Supernatant discharge, and
- Removal of heavier fully digested substrates or slurry concentrate that resides at the lower parts around the bottom.

Top-Side Digestate Outlet

- This is located on the biodigester side wall opposite to the inlet position to create a longer flow path across the tank, and at about 10 – 15 cm near the top side.

Article DOI: 10.52589/AJENSR-7LHWQFML
DOI URL: https://doi.org/10.52589/AJENSR-7LHWQFML

- The outlet end inside the biodigester is orientated downward with an elbow and extended to a depth of about 10–15 cm below the liquid surface, to allow clearer, digested slurry to overflow out while retaining the heavier biomass.
- It provides hydraulic flow-through and maintains constant biodigester volume.
- Outside the biodigester, the top digestate outlet should be connected to a gate or plug valve for controlled discharge.

Bottom Digestate Outlet:

- It was positioned low, but not at the base; typically, about 6–12 cm above the tank bottom.
- It is for removal of heavier fully digested substrates or slurry concentrate that resides at the lower parts around the bottom.
- Outside the biodigester, the bottom outlet was connected to a gate or plug valve for controlled discharge, and then to a riser with a 90-degree elbow. The riser extends to the same level with the topside Digestate Outlet.

Combined Flow Behavior

- The inlet (top) introduces fresh feed that sinks and displaces older material downward.
- The topside Digestate Outlet serves as Overflow Outlet, preventing overfilling, and removes clarified liquor.
- The Bottom Outlet (opposite side) allows mature digestate to leave slowly.
- This creates a plug-flow–like pattern with minimal mixing and uniform retention.
- Proper spacing and elevation prevent short-circuiting (i.e., feed exiting too soon).
- Hybrid outlet Configuration Improve process control and enhances flexibility in operation.

MATERIAL SELECTION CONSIDERATIONS

Material Composition and Structure

Most IBC tanks are made from high-density polyethylene (HDPE), encased within a galvanized steel or stainless-steel cage.

HDPE Core (Liner):

The HDPE liner consist of thermoplastic polymer composed primarily of ethylene monomers, characterized by:

- High molecular weight and crystalline structure (60–80% crystalline).
- Excellent resistance to organic acids, alkalis, and anaerobic digestion effluents.
- Non-reactivity with microbial media and methane gas.

Figure 3: The HDPE Tank

Figure 4: Steel Reinforcement Cage

The steel reinforcement cage provides mechanical support against bulging and deformation due to hydrostatic and gas pressures, prevents creep (slow deformation) of the polymer wall over time, and enhances impact resistance during transport and installation.

Table 2: Critical design parameters and IBC tank's Material Science role

Aspect	Material Science Role	Benefit
Structural Strength	HDPE + steel cage	Supports hydrostatic & gas pressure
Chemical Resistance	HDPE, EPDM seals	Withstands acids, bases, biogas
Thermal Stability	Low conductivity	Retains digestion temperature
UV Resistance	Stabilized polymer	Prolongs outdoor durability
Creep Resistance	Reinforced frame	Prevents long-term deformation
Gas Tightness	Multi-layer HDPE	Minimizes methane leakage

Article DOI: 10.52589/AJENSR-7LHWQFML
DOI URL: https://doi.org/10.52589/AJENSR-7LHWQFML

Black Paint Surface Treatment Coating for IBC Biodigester

Outdoor exposure subjects IBC containers to ultraviolet (UV) radiation, thermal cycling, and biological fouling, all of which accelerate material degradation. Surface treatment of IBC biodigester tanks, particularly those made from high-density polyethylene (HDPE) intermediate bulk containers (IBCs), is a critical material protection and performance enhancement strategy.

The use of black paint coating on the IBC biodigester integrates principles from polymer science, heat transfer, and microbial ecology to enhance digester performance and longevity. Therefore, applying black paint to the IBC tank exterior has clear material science and operational benefits. It is a simple yet highly effective method for UV stabilization, algal inhibition, and temperature regulation, thereby extending the functional lifespan and operational stability of the biodigester. By minimizing UV degradation, maintaining anaerobic stability, and moderating thermal response, black surface treatment provides a low-cost, high-impact intervention suitable for decentralized biodigester applications in tropical environments.

Figure 5: Biodigester Liner Coated with Black Paint

$$R_d = k \, x \, I_{uv} \, (1 - \propto) \qquad 12$$

where:

- R_d = degradation rate (mm/year)
- k = empirical degradation constant (material- and environment-dependent)
- I_{uv} = incident UV radiation intensity (W/m²)
- $\propto$ = shielding coefficient of the coating (typically 0.90–0.95 for black paint)

Thus, black-coated surfaces can reduce degradation rate by up to 90–95%.

Article DOI: 10.52589/AJENSR-7LHWQFML
DOI URL: https://doi.org/10.52589/AJENSR-7LHWQFML

For a typical unpainted HDPE wall losing 0.3 mm/year, a black-painted surface (α = 0.93) yields:

For unpainted HDPE, $\propto = 0$

$$R_d^{uncoated} = k \, x \, I_{uv} \, (1 - 0) = kI_{uv} \tag{13}$$

For painted HDPE, $\propto = 0.93$

Therefore $$R_d^{uncoated} = k \, x \, I_{uv} \, (1 - 0.93) = kI_{uv}(1 - 0.93) \tag{14}$$

When taking the ratio (Comparing uncoated with coated), kI_{uv} cancels out:

$$\frac{R_d^{uncoated}}{R_d^{coated}} = \frac{kI_{uv}}{kI_{uv}\,(1-\alpha)} \tag{15}$$

$$\frac{R_d^{uncoated}}{R_d^{coated}} = \frac{1}{(1-\alpha)} \tag{16}$$

For , $\propto = 0.93$

$$\frac{R_d^{uncoated}}{R_d^{coated}} = \frac{1}{(1-\alpha)} = \frac{1}{(1-0.3)} = \frac{1}{0.07} = 14.3$$

Hence, the Black coating applied to the IBC reduces UV-induced degradation by approximately 14 times, potentially extending the IBC service life beyond 10 years under tropical exposure.

Thermal Regulation (with caution). The colour black exhibits high solar absorptivity (α = 0.95), leading to significant heat gain under direct sunlight:

Absorbed heat can be estimated as,

$$Q_{abs} = \alpha_s I_{solar} \, A \tag{17}$$

where:

- Qabs = absorbed heat flux (W
- α_s = surface absorptivity (~0.95 for black paint)
- I_{solar} = average solar flux (≈800 W/m² midday)
- A = surface area (≈2.5 m² for IBC top)

Thus, the biodigester may absorb up to 1900 W of solar energy, slightly elevating slurry temperature. This thermal benefit is useful in cooler climates for maintaining mesophilic digestion range (25–35°C), but in tropical regions, excessive heat can be mitigated by placing the digester under a ventilated shed or using reflective shading. Light penetration through translucent IBC walls promotes algal growth inside the digester's liquid phase, introducing oxygen that disrupts anaerobic microbial communities.

A black coating serves as an optical barrier, maintaining dark, anaerobic conditions optimal for methanogenesis. This also minimizes scum formation, enhances slurry homogeneity, and improves gas yield consistency. Furthermore, the coating prevents direct contact between the HDPE and any acidic or alkaline condensate that may form around outlet fittings, thus minimizing long-term chemical attack.

Stress and Structural Engineering Considerations

The structural integrity of the IBC biodigester is critical for safe and reliable operation. Stress and structural analysis were therefore carried out to evaluate how the system responds to internal loads and environmental factors over time.

The main stressors considered include:

i. Internal hydrostatic pressure from the slurry,

ii. Biogas pressure acting on the roof and fittings, and

iii. Long-term thermal and material effects on the polymer tank.

Key structural components under assessment were the IBC tank walls, filleted corners and edges, the neck and cap cover, as well as inlet and outlet PVC pipe fittings. Each of these elements was evaluated for its ability to withstand fluid loads, internal gas pressure, and long-term exposure to outdoor conditions. To improve stability, the IBC was mounted within galvanized iron support frames. These frames were designed to resist buckling, minimize wall deflection, and prevent deformation under both static and operational loads. Their performance was assessed using simplified beam theory, considering both dead weight and dynamic stresses during feeding and gas accumulation.

Safety factors were introduced across all design calculations to account for variations in feedstock composition, operational pressure fluctuations, and cumulative material fatigue. This ensures that the system not only functions under ideal conditions but remains durable and safe under realistic, variable operating environments.

Safety factors adhered to ASME Section VIII guidelines for low-pressure vessels.

Outlet Cover Cap stress

The IBC biodigester cover cap experiences direct pressure from biogas accumulation. Assuming the cap acts like a flat circular plate clamped around its edges, the maximum bending stress (Roark's Formulas for Stress and Strain by Warren and Budynas) is:

$$\sigma_{max} = \frac{3 \, x \, P \, x \, a^2}{4 \, x \, t^2} \qquad 18$$

where

a = radius of the plate (m),

t = thickness of plate (m),

P = internal pressure (biogas pressure) Pa

If a = 0.075 m, t = 0.006 m, and P = 25,000 Pa

σ_{max}= (3 x 25,000 x 0.075^2) / (4 x 0.006^2) = 421.875 / 0.000144 ≈ 2.93 MPa

Stress at inlet neck:

At the tank cylindrical region (inlet neck), hoop stress (σ) due to internal pressure can be calculated by:

$$\sigma_n = \frac{(P \times D)}{2t} \qquad 19$$

where:

P = internal pressure biogas pressure (Pa)

D = inner diameter of cylindrical section. (m)

t = wall thickness (~6 mm)

For a neck with D = 0.15 m, t=0.006 m, and P=25,000 Pa,

σ_n =25,000 x 0.152 / 0.006 =312,500 Pa (0.312 MPa)

This is well below HDPE yield strength (25 MPa), indicating structural safety.

Filleting Approximations for Edge and Rounded Corners – Stress Reduction

In any pressure-holding vessel like a biodigester, stress concentrations typically occur at corners, joints, and inlet/outlet nozzles. To minimize these concentrations in IBC biodigesters, fillets (curved transitions) are often employed at geometric discontinuities. This helps distribute stress more uniformly and improves the structural performance under internal pressure and thermal cycling.

A conservative design approach uses a fillet radius r equal to 10% of the wall height h:

$$r = 0.1h$$

For an IBC with a typical wall height h = 1000 mm =1.0 m

r = 0.1×1.0 = 0.1 m (or 100 mm)

This smooth transition ensures a gradual load path, reducing localized stresses at the tank’s corners and junctions.

Stress Reduction Factor with Fillets

Fillets are effective at lowering Stress Concentration Factors (Kt). For example:

- At sharp corners: Kt is approximately 2.5 – 3.5
- With rounded fillets: Kt is approximately 1.1 – 1.5

This reduction significantly improves fatigue resistance and the long-term structural integrity of the biodigester, especially under repetitive biogas pressure and temperature fluctuations.

Rounded corners help reduce stress concentration. In typical IBCs, the radius of curvature r_f at corners is between:

$r_f = 0.02$ m to 0.04 m

The Stress Concentration Factor (SCF) i.e. stress reduction for a corner with filleting can be determined by:

$$SCF = 1 + 2x\left(\frac{t}{r_f}\right) \tag{20}$$

where:

r_f = fillet radius.

t = wall thickness

Using t = 0.006 m, $r_f = 0.03$ m,

$$SCF = 1 + 2x\left(\frac{0.0060}{0.03}\right) = 1 + 0.4 = 1.4.$$

Thus, for the IBC neck, the expected maximum localized stress becomes:

$\sigma_{max} = SCF \times \sigma_n = 1.4 \times 0.312$ MPa = 0.437 MPa

This stress is safely within HDPE material yield strength limits of **25 MPa**, validating the safety and reliability of the design.

Stress at the Sides Flat Wall Segment

IBC walls are partially restrained by galvanized cages, approximating clamped edges. To evaluate structural integrity, the walls are modelled as flat plates under hydrostatic pressure. therefore, maximum Stress for Clamped Edges applies, and was estimated using equation 17.

Given that:

a = 0.5 m (i.e. half-width of wall supported),

t = .006,

P = Hydrostatic pressure at the bottom (i.e, maximum P):

Calculating, P= ρ g h = 1050 × 9.81 × 0.708 ≈ 7,293 Pa

P = 7,293 Pa

$$\sigma_{max.} = \frac{(3 \times 7{,}293 \times (0.5)^2}{4 \times (0.006)^2} = 10{,}416{,}666.6\text{Pa} = 10.4 \text{ MPa} = 37{,}984{,}375 = 37.98\text{MPa}$$

This is the maximum stress on the wall from the slurry inside the biodigester. This is very high, but the galvanized cage supports the biodigester.

Flat Wall Deformation and Deflection.

The wall stress and deflection of the IBC biodigester were determined on the premise of the assumptions and parameters in the Table 3.

Table 3: Assumptions and parameters of wall deformation and deflection

Parameter	Value	Description
Container	1000L	HDPE IBC, with flat vertical walls
IBC Wall Dimension	1.2 m × 1 m	flat vertical walls panel
A	0.5 m	Half of 1 m side
T	0.006 m (6 mm)	Wall thickness
E	1 GPa (1 × 10^9 Pa)	HDPE modulus of elasticity
N	0.45	Poisson's ratio for HDPE

Maximum deflection: $\delta_{\max} = \frac{(q \times a^4)}{(64 \times D)}$ 21

where,

Flexural Rigidity D, $D = \frac{(E \times t^3)}{[12 \times (1 - \nu^2)]}$ 22

D = Flexural Rigidity.

E = Young's modulus of elasticity (850 MPa)

v = Poisson's ratio (~0.42)

q =P (*Hydrostatic pressure)*

a = span length

Example,

Given: E = 1 × 10^9 Pa (HDPE modulus of elasticity); t = 0.006 ν = 0.45 (Poisson's ratio for HDPE)

Flexural Rigidity, $D = \left(\frac{1 \times 10^9 \times (0.006)^3}{12 \times (1 - 0.45^2)}\right)$ = 22.57 Nm

Now, given *Hydrostatic pressure, P* = pressure = P= ρ g h = 1050 × 9.81 × 0.708 = 7,293 Pa

Therefore, the expected maximum Deflection $\delta_{\max}$ $\delta_{\max}$ from equation 21

Becomes,

$\delta_{\max} = (7{,}293 \times (0.5)^4)/(64 \times 13.06)$ = 0.55m = 55 cm

Summary and Interpretation of the above analysis for the given parameters are as follows.

i. The Calculated maximum wall Stress is 37.98MPa, too high! The HDPE yield design limit is 25MPa; however, the galvanized cage enclosure provide needed support. The stress should be monitored for safety factors.

ii. The Calculated maximum wall deflection of 0.55m (55cm) due to internal pressure is very large, indicating wall bulging under biogas pressure. Reinforcement with the galvanized cage is also vital.

iii. The external cage and internal ribs minimize the expected deformation and deflection for an IBC biodigester wall.

Stress at the Bottom Due to Slurry Weight

When an IBC tank is reconstructed as a biogas digester, one of the most critical stress points is at the **bottom surface** due to the **hydrostatic pressure exerted by the slurry**. To ensure structural integrity under daily operation, this stress is carefully analyzed as outlined below:

Hydrostatic Pressure Equation

The hydrostatic pressure P at a given depth h in the slurry was calculated using equation 10.

$P = \rho \times g \times h$

where:

P = hydrostatic pressure (Pa or N/m²)

ρ = density of slurry (approx. 1050 kg/m³ for cow dung slurry)

g = acceleration due to gravity (9.81 m/s²)

h = height of slurry (m)

Stress on the Bottom Plate

To find the **total force (F)** acting on the bottom plate of the IBC tank:

$$F = P \times A = \rho \times g \times h \times A \qquad 23$$

where:

A = base area of the tank (m²)

For a typical IBC, $A = 1.0\text{ m} \times 1.2\text{ m}$

with:

$\rho = 1050\text{ kg/m}^3$

$h = 0.708\text{ m}$

$P = 1050 \times 9.81 \times 0.708 = 7292.754\text{ Pa}$

Article DOI: 10.52589/AJENSR-7LHWQFML
DOI URL: https://doi.org/10.52589/AJENSR-7LHWQFML

F= 7292.754 x 1 x 1.2= 8751.3 N = 8.6kN

So, the bottom of the IBC biodigester must withstand approximately 8.6 kN of downward force from the slurry alone.

Stress Considerations

The bottom panel of the IBC (Intermediate Bulk Container) tank was constructed from high-density polyethylene (HDPE), with a tensile yield ''σ_{yield}'' strength in the range of 20–30 MPa. A safety factor (also called design factor) of 2 to 3 is commonly applied for safe design.

Using the lower bound of the yield strength (20 MPa) and a safety factor of 3, the allowable design stress becomes:

$\sigma_{allowable} = \sigma_{yield}$ / Safety Factor $= 20 \times 10^6 / 3 = 6.67 \times 10^6$ Pa

The actual stress σ_{actual} calculated for the tank under normal slurry height is:

$\sigma_{actual} = 7292.754$ Pa

It shows that 'σ_{actual} '' was well below the allowable ''$\sigma_{allowable}$'' limit of 6.67×10^6 Pa, indicating that the IBC tank is structurally safe under normal operating conditions, with a uniform load distribution and adequate foundation support.

Hoop Stress at Pipe Interfaces

The inlet and outlet pipes in the IBC biodigester are subject to internal biogas pressure that induces hoop stress in the pipe walls. To ensure the structural integrity of these pipes, and to prevent deformation or failure, the hoop stress must be maintained within safe limits.

The hoop stress (σ_h) in a cylindrical pipe is calculated using the formula:

Hoop stress, $\sigma_h = \frac{(P \times d)}{2t}$ 24

where:

d = pipe diameter Where:

P = Internal pressure (Pa)

d = Inner diameter of the pipe (m)

t = Wall thickness of the pipe (m)

For example, if we assume:

- **P** = 25,000 Pa (equivalent to 0.25 bar)
- **d** = 0.05 m (50 mm pipe)
- **t** = 0.003 m (3 mm wall thickness)

Then:

Article DOI: 10.52589/AJENSR-7LHWQFML
DOI URL: https://doi.org/10.52589/AJENSR-7LHWQFML

$\sigma h = \frac{25{,}000 \times 0.05}{2 \times 0.003}$ == 208,333 Pa (or 0.208 MPa)

This value of approximately 0.208 MPa is well below the yield strength of common pipe materials such as HDPE (25 MPa), indicating that the pipe interfaces in the IBC biodigester design are structurally safe under the given conditions.

Thermal Stress Analysis

Thermal stress occurs due to environmental temperature fluctuations, particularly since the IBC biodigester is to be located in an open place, subject to daily and seasonal variations. The thermal stress (σ_T) in the material is calculated using the formula:

$$\sigma_T = E \times \alpha \times \Delta T \qquad 25$$

where:
- α = Thermal expansion coefficient of HDPE ≈ 1.2×10^{-4} /°C

- ΔT = Anticipated temperature change ≈ 25°C

- E = Modulus of elasticity of HDPE ≈ 0.8 GPa = 800 MPa

Substituting these values:

$$\sigma_T = 800 \times (1.2 \times 10^{-4}) \times 25 = 2.4 \text{ MPa}$$

This thermal stress value is well below the yield strength of HDPE (25 MPa), indicating that the material can safely accommodate the expected thermal expansion and contraction.

Mounting Frame Structural Analysis

The mounting galvanized iron frame supporting the biogas biodigester was analyzed using simplified beam theory. Simplified beam theory assumes that beams deform primarily through bending, and internal stresses follow linear elastic behavior based on Euler–Bernoulli assumptions (Türker, 2020). The frame was assumed to behave like a supported beam under a uniformly distributed load (UDL), representing the combined weight of the biodigester and slurry.

Figure 6: Beam model of the galvanized iron mounting frame under uniformly distributed load.

Assumptions:
- Beam Length (L): 1.5 m

- Total Load (W): 600 kg

- Load per unit length (w): 400 kg/m

- Converted to Newtons: $400 \times 9.81 = 3924$ N/m

- Section Modulus (Z): 8×10^{-6} m³ (assumed for galvanized iron)

Key Calculations:

1. Maximum Bending Moment (M_{max}) for UDL:

$$M_{max} = \frac{W\ x\ L^2}{8} = \frac{3924\ x\ 1.5^2}{8} = 1104.75\ Nm$$

1. Bending Stress (σ):

$$\sigma = \frac{M}{Z} = \frac{1104.75}{(8 \times 10^{-6})} = 138.1\ MPa$$

The calculated bending stress is within the allowable range for galvanized iron (150–250 MPa), confirming structural safety under expected loads.

Safety Factor (SF) or Factor of Safety (FoS)

The safety factor (SF) defined as the ratio of the material's yield strength σ_{yield} to the actual applied (or expected) stress $\sigma_{applied}$ was estimated from the relationship in equation 26 (Arta *et al*., 2022):

i.e., SF = Material Yield Strength / Applied Stress $= \frac{\sigma_{yield}}{\sigma_{applied}}$ 26

For HDPE, $FoS = \frac{\sigma_{yield}}{\sigma_{max}}$ 27

where:

σ_{yield} = 25 MPa (HDPE)

σ_{max} = maximum expected stress or applied stress

Desired FoS > 2

For example, using the neck cover calculated stress,

FoS = 25 MPa / 2.93 MPa ≈ 8.53

A safety factor (FoS) greater than 2 is generally considered acceptable for static structures, indicating that the IBC tank design remains structurally strong under typical loading conditions (Hazizi and Ghaleeh, 2023).

Fabrication and Assembly of Biodigester

Biodigester Fabrication, Installation, and Startup

This section describes the practical step-by-step implementation and installation of the IBC-tank based biodigester system. It includes IBC tank specifications and preparation, material selection, construction works, fitting of components, sealing techniques, leakage test,

Article DOI: 10.52589/AJENSR-7LHWQFML
DOI URL: https://doi.org/10.52589/AJENSR-7LHWQFML

commissioning procedures, and safety measures. Visual illustrations and on-site photos accompany the construction process

Material Specifications

IBC retrofitting Primary Materials include the procured materials/components, with specifications as detailed in the Table 4.

Table 4: Components of the Biodigester and Specifications

Component	Specification/Detail
IBC Tank	1000-liter HDPE container with steel cage
Inlet Pipe	Ø50 mm PVC pipe (slurry inlet)
Digestate Outlet	Ø50 mm PVC pipe (bottom exit with internal bend)
Gas Outlet Pipe	Ø 12.7 mm PVC pipe with ball valve
Fittings	elbows, T-joints (PVC), 2 inches backnut, and 1-inch backnut
Gas Scrubber	DIY water bubbler (a repurposed water filter cartridge plastic housing)
Silicon Sealant	Waterproof grade for bonding and sealing
Teflon Tape	Sealing thread joints for Leak prevention
Valves	0.5-inch and 1-inch ball valves (PVC/HDPE) for flow regulation
Gas Nipple	For biodigester biogas outlet
Flexible Gas hose	Transparent tubing for gas flow to the bubbler and burner
Hose Clamps	For securing a flexible gas pipe to a bubbler

Tools and Accessories

i. Electric Drill with hole saws
ii. Pipe Cutter
iii. Thermometer Probe (Digital)
iv. Gas Volume Meter (water displacement)
v. Biogas Analyser (for composition analysis)
vi. Weighing Scale (for feedstock mass)
vii. pH and Temperature Meters (for process monitoring)
viii. Platform- Cement blocks and bricks (to elevate biodigester)

Article DOI: 10.52589/AJENSR-7LHWQFML
DOI URL: https://doi.org/10.52589/AJENSR-7LHWQFML

IBC tanks Specifications

The selected IBC tank had the following specifications as presented in Table 5.

Table 5: The Selected IBC Tank and its Specification

Parameter	Value
Material	High-Density Polyethylene (HDPE)
Capacity	1000 liters
Dimensions	1.0 m x 1.0 m x 1.2 m
Wall Thickness	6 mm
Cage	Galvanized steel

Material Selection and Justification

The type of materials selected for the project and the justification for their selected in presented in Table 3.20

Table 6: Material Selection and Justification

Component	Material	Reason
Digester Body	HDPE	Non-reactive, strong, UV-resistant
Piping	PVC / HDPE	Lightweight, cost-effective, 2-inch PVC (0.0508 m diameter)
Valves and fittings	Ball valves	Precise flow control
Sealants	Silicon-based	Anaerobic, gas-tight

IBC Tank Set up Steps:

The following steps were taken to reconstruct and retrofit the IBC tank into a biodigester. These include

Step 1: Preparation of the IBC tank to a biodigester.

The 1000-litre IBC tank was obtained from a Plumbing Material shop, washed and flushed with mild detergent and properly rinsed to remove residual chemicals. It was thereafter drained and sun-dried. All its galvanized iron frames were retained intact to provide rigidity and protection

Step 2: Drilling of Ports.

A Hole-cutter was used to cut some round holes in the IBC tank. These include the:

- Feed Inlet: with a 50 mm hole cut at the top side of the IBC tank
- Digestate Outlet: with a 50 mm hole drilled at the bottom front panel near the bottom side, about 10 cm above the base, with an internal bend to prevent clogging.

- Overflow outlet: with a 50 mm hole, drilled on the upper side wall, at about 60% tank height, slightly below the feed port for the overflow pipe.
- Gas outlet: with a 12.7 mm hole cut into the IBC top centre cap or lid with a gasket. For the gas outlet, A PVC elbow or gas nozzle was fixed on the hole and then connected to a flexible hose.

Figure 7: Drilling Process of the 1000 Litres Capcity IBC Tank
Safety Note: Drilling was performed slowly to prevent melting or cracking the HDPE walls.

Figure 8: Pipe Assembly into the cut holes

PVC bulkheads were used to attach pipe ends. Joints were reinforced with PTFE tape and sealed externally using epoxy for leak prevention. Ball valves were connected for gas and digestate flow control.

Valves, Safety Features, and Mini Gas Scrubber Installation

i. Ball valves were installed at the gas outlet and digestate outlet points for gas and digestate flow control.
ii. Joints were checked for Leaks with gas soap test.

Article DOI: 10.52589/AJENSR-7LHWQFML
DOI URL: https://doi.org/10.52589/AJENSR-7LHWQFML

iii. External black painting coats was made on the biodigester for UV protection.

iv. Easy access was provided for sludge removal every 3–6 months.

v. The gas outlet was connected to a simple bubbler system made from a water filter cartridge, acting as:

- ✓ A visual gas indicator
- ✓ A water seal to prevent backflow and air intrusion
- ✓ A minor gas cleaning

vi. A secondary gas hose was connected to an inner-tube balloon for gas storage.

Base Platform Construction

i. The IBC tank was raised using four cement blocks approximately 15 cm tall.

ii. This elevation supports gravity-assisted discharge of digestate.

iii. The platform was levelled using a spirit level to ensure structural balance.

iv. A slight backward tilt at approximately 2° was introduced to direct settling solids toward the outlet zone, ensuring all outlets are angled slightly downward for gravitational flow.

Leak and Pressure Testing

Leak Testing Procedure:

i. All inlets and outlets were sealed temporarily.

ii. The tank was filled with water.

iii. Mild air pressure was introduced via a manual pump.

iv. All seams and joints were sprayed with soapy solution.

v. Bubbling at any joint was noted and resealed.

Table 7: Final Assembly and Status Checks

S/N	Task	Status Check
1	Pipe sealant cured	No leakage at joints
2	Valves installed correctly	Functional and air-tight
3	Tank pressurized	No air/gas leakage
4	Surrounding area	Clear, stable, and secure

Result: The system passed with no observable leaks after the third round of testing.

***Gas Collection Setup*:**

i. The gas outlet is connected through a water bubbler to a secondary gas hose, which was connected to an inner-tube balloon for gas storage.

Article DOI: 10.52589/AJENSR-7LHWQFML
DOI URL: https://doi.org/10.52589/AJENSR-7LHWQFML

ii. The water bubbler acts as a safety trap and a visual gas flow indicator

System Setup

The set-up, testing procedures and evaluation processes are shown in Figure 9.

Figure 9: Biofertilizer effluent from Bottom outlet and Biogas collection in Tyre tubes

Filling, Startup Procedure, and Commissioning.

i. The Slurry Initial Filling process involves mixing 250 L of fresh cow dung with 500 L of water to create a slurry at a 1:2 ratio.

ii. 350 L of slurry from an existing biodigester was added as an inoculant to expedite the process.

iii. The slurry was manually homogenized and was poured into the tank through the inlet funnel.

iv. The IBC biodigester was filled with so an effective volume of 850 L.

v. The gas valve was left open for 24 hours. This allows oxygen and initial carbon dioxide to be expelled and promotes an anaerobic condition

vi. The valve was then closed once biogas (burnable) began to bubble through the bubbler, and the gas outlet was connected to a balloon inner tube gas holder.

vii. Regular feeding commenced immediately after the detection of burnable gas; this continues daily with 42.5 L of fresh slurry for 20 days.

Article DOI: 10.52589/AJENSR-7LHWQFML
DOI URL: https://doi.org/10.52589/AJENSR-7LHWQFML

CONCLUSION

This study successfully designed, constructed, and evaluated a small-scale biogas digester using a repurposed 1000-litre IBC tank for the sustainable production of bioenergy and biofertilizer. The project was guided by a clear set of objectives, including detailed mechanical, biochemical, and structural design, system fabrication, and assembly. The structural and stress analysis confirms that the IBC tank and its modified components can safely operate under the expected biogas pressures, slurry loads, and environmental conditions. The generous safety margins ensure long-term operational reliability and minimal risk of mechanical failure, The use of an IBC tank provided significant advantages in terms of cost, transportability, ease of installation, and replicability

REFERENCES

Aboudi, K.; Greses, S.; González-Fernández, C. Hydraulic Retention Time as an Operational Tool for the Production of ShortChain Carboxylates via Anaerobic Fermentation of Carbohydrate-Rich Waste. Molecules 2023, 28, 6635. https://doi.org/10.3390/

Achinas S., Achinas, V., and Euverink, G.J.W. A Technological Overview of Biogas Production from Biowaste, Engineering (2023) 299-307.

Alvarez, Y.C., Borges, R.J., Vidal, C.D.P., Leon, F.M.C., Buendia, J.S.P., Nolasco, J.A.S. (2025). Design Improvements and Best Practices in Small-Scale Biodigesters for Sustainable Biogas Production: A Case Study in the Chillon Valley, Peru. Energies 2025, 18, 338. https://

Arta W.I., Abdullah, K., Sumardiono, W., Gafur, A., Restu W.E. and Aris M.Z. (2022). The Analysis of Tensile Strength of High-Density Polyethylene for Shipbuilding. DOI: 10.5220/0011769900003575 In Proceedings of the 5th *International Conference on Applied Science and Technology on Engineering Science (iCAST-ES 2022)*, pages 334-336

Baglari, S., Kole, M., Dey, T.K. (2011). Effective thermal conductivity and coefficient of linear thermal expansion of high-density polyethylene-fly ash composites, *Indian J. Phys*., 85(4): 559-573.

Budiman, I. (2023). The complexity of barriers to biogas digester dissemination in Indonesia: challenges for agriculture waste management, Journal of Material Cycles and Waste Management, https://doi.org/10.1007/s10163-021-01263-y

de Souza Guimarães, C.; da Silva Maia, D.R. (2023). Development of Anaerobic Biodigester for the Production of Biogas Used in Semi-Continuous System Bioprocesses: An Efficient Alternative for Co-Digestion of Low Biodegradability Biomass. Biomass 2023, 3, 18–30. https://doi.org/10.3390/biomass3010002

Deng, Q., Su, C.., Chen, Z., Going, T., Lu, X., Chen, Z., Lin, X. (2021). Effect of hydraulic retention time on the denitrification performance and metabolic mechanism of a multi-chambered bio-electrochemical system, Journal of Environmental Management, Volume 299, 1 December 2021, 113575.doi.org/10.3390/en18020338 DOI:10.1080/15397734.2020.1738246

Hazizi, K.; Ghaleeh, M. (2023). Design and Analysis of a Typical Vertical Pressure Vessel Using ASME Code and FEA Technique. *Designs* 2023, 7, 78. https://doi.org/10.3390/designs7030078

Issahaku, M., Sarfo, N., Derkyi, A., Kemausuor, F. (2024). A systematic review of the design considerations for the operation and maintenance of small-scale biogas digesters, Heliyon, 10 (2024) e34019.

Jeppu, G.P., Janardhan., J., Kaup., S., Janardhanan, A., Mohammed, S., Acharya, S. (2021). Effect of feed slurry dilution and total solids on specific biogas production by anaerobic digestion in batch and semi-batch reactors, Journal of Material Cycles and Waste Management. https://doi.org/10.1007/s10163-021-01298-1

Kariyama, I.D. and Wu, X.D. (2018). Influence of mixing on anaerobic digestion efficiency in stirred tank digesters: A review, Water Research, 143, 2021, 503 – 517.

Kenmogne, F., Abanda, A., Arnold, M.M., Donda1, W.A., Ulrich Nota Yemetio, U.N., Yamb, E. (2023). Review, Design and artisanal fabrication of anaerobic bio-digester for biodegradable waste, KFokam Journal of Applied Science & Technology, 3: 1 – 32

Kinyua, M.N. (2025). "Energy Production and Effluent Quality in Tubular Digesters Treating Livestock Waste in Rural Costa Rica" (2015). Graduate Theses and Dissertations. https://scholarcommons.usf.edu/etd/5716

Lackner, M.; Besharati, M. (2025. AgriculturalWaste: Challenges and Solutions, a Review. Waste 2025, 3, 18. https://doi.org/10.3390/waste3020018.

Makamure, F., Mukumba, P., & Makaka., G. (2021). An analysis of bio-digester substrate heating methods: A review, Renewable and Sustainable Energy Reviews, 17, 2021, 110432.

Mapantsela, Y.; Mukumba, P.; Obileke, K.; Lethole, N. Portable Biogas Digester: A Review. Gases 2024, 4, 205–223. https://doi.org/ 10.3390/gases4030012

Mapantsela, Y.; Mukumba,P.; Obileke, K.; Lethole, N. (2024). Portable Biogas Digester: A Review, Gases 2024, 4, 205–223. https://doi.org/10.3390/gases4030012

Mateescu, C. (2016). Influence of the hydrostatic pressure on biogas production in anaerobic digesters, *Romanian Biotechnological Letters*, 21(5): 11941-11948.

Meegoda, J.N., Chande, C., Bakshi, I. (2025). Biodigesters for Sustainable Food Waste Management. Int. J. Environ. Res. Public Health 2025, 22, 382. https://doi.org/10.3390/ijerph22030382

Møller, H.B., Hansen, J. D., Sørensen, C. A. G. (2007). Nutrient Recovery by Solid-liquid Separation and Methane Productivity of Solids, Transactions of the ASABE, 50(1): 193−200.

Mungwe, J.N., Asoh, D.A. and Mbinkar, E. (2021) Design Considerations of a Flexible Biogas Digester System for Use in Rural Communities of Developing Countries. Journal of Sustainable Bioenergy Systems, 11, 260-271. https://doi.org/10.4236/jsbs.2021.114016.

Ni, Ji-Qin (2024). A review of household and industrial anaerobic digestion in Asia: Biogas development and safety incidents, Renewable and Sustainable Energy Reviews, 197 (2024) 114371.

Nkoi, B., Labele-Alawa, B.T., Odobeatu, B. (2018). Design and Fabrication of a Modified Portable Biogas Digester for Renewable Cooking-Gas Production, *EJERS, European Journal of Engineering Research and Science*, 3(3): 21-29.

Okwu, M.O., Samuel, O.D., Otanocha, O.B., Balogun, P.P., Tega, O.J. and Ojo, E. (2020), "Design and development of a bio-digester for production of biogas from dual waste", World Journal of Engineering, Vol. 17 No. 2, pp. 247-260. https://doi.org/10.1108/WJE-07-2018-0249

Parajuli, A., Khadka, A., Sapkota, L., Ghimire, A. (2022). Effect of Hydraulic Retention Time and Organic-Loading Rate on Two-Staged, Semi-Continuous Mesophilic

Anaerobic Digestion of Food Waste during Start-Up. Fermentation 2022, 8, 620. https://doi.org/10.3390/fermentation8110620

Prasad, R.D. Dbouk, W., Yiadom, E.B., Vassiliades, C. (2025). Biogas digester innovations as solution to clean cooking energy challenge in the Pacific Islands: A policy perspective, Energy Reports 13 (2025), 2417-2432.

Robinson, G.M. (2024). Global sustainable agriculture and land management systems, Geography and Sustainability, 5. (2024) 637-646.

Singh, B.; Kovács, K.L.; Bagi, Z.; Nyári, J.; Szepesi, G.L.; Petrik, M.; Siménfalvi, Z.; Szamosi, Z. (2021). Enhancing Efficiency of Anaerobic Digestion by Optimization of Mixing Regimes Using Helical Ribbon Impeller. Fermentation 2021, 7, 251. https://doi.org/10.3390/

Singh, B.; Singh, N.; Cˇonka, Z.; Kolcun, M.; Siménfalvi, Z.; Péter, Z.; Szamosi, Z. (2021). Critical Analysis of Methods Adopted for Evaluation of Mixing Efficiency in an Anaerobic Digester. Sustainability 2021, 13, 6668. https://doi.org/10.3390/su13126668

Türker, H.T. (2020): A modified beam theory for bending of eccentrically supported beams, Mechanics Based Design of Structures and Machines, Taylor and Francis

Vögeli Y., Lohri C. R., Gallardo A., Diener S., Zurbrügg C. (2014). Anaerobic Digestion of Biowaste in Developing Countries: Practical Information and Case Studies. Swiss Federal Institute of Aquatic Science and Technology (Eawag), Dübendorf, Switzerland

Voumik, L.C. and Sultana, T. (2022). Impact of urbanization, industrialization, electrification and renewable energy on the environment in BRICS: fresh evidence from novel CS-ARDL model, Heliyon 8 (2022) e11457.

Wang, Z., Hu, Y., Wang, S., Wu, G., Zhan, X. (2023). A critical review on dry anaerobic digestion of organic waste: Characteristics, operational conditions, and improvement strategies, Renewable and Sustainable Energy Reviews, 176 (2023) 113208.