wjert, 2025, Vol. 11 Issue 7, 56-82 Original Article ISSN 2454-695X

World Journal of Engineering Research and Technology
WJERT
www.wjert.org
SJIF Impact Factor: 7.029

DEVELOPMENT OF AN AUTOMATED ORGANIC MATTER SLURRY MIXING SYSTEM FOR ENHANCED BIODIGESTER EFFICIENCY

Omonigho B. Otanocha*[1] and Benson O. Oduh[2]

[1,2]Department of Mechanical Engineering, Federal University of Petroleum Resources Effurun, Delta State, Nigeria.

Article Received on 06//05/2025 Article Revised on 26/05/2025 Article Accepted on 18/06/2025

***Corresponding Author**
Omonigho B. Otanocha
Department of Mechanical Engineering, Federal University of Petroleum Resources Effurun, Delta State, Nigeria.

ABSTRACT

Biodigesters are crucial for optimizing biogas production from organic waste, contributing to the generation of clean, low-cost renewable energy. This study focuses on the design, fabrication, and testing of an automated slurry mixer equipped with an electronically controlled stirring system, tailored for small-scale biogas production. Locally sourced materials were used to construct the mixer, with cow dung from an abattoir along Effurun-Sapele road serving as the feedstock. The mixer was engineered to achieve a homogeneous mixture by blending a calculated amount of cow dung through anaerobic digestion. The system is composed of four primary components: a conical sewage tank, stirrer, hopper, and electric motor. The tank, with a capacity of approximately 250 liters, was fabricated from Mild Steel (ASTM A36) and measures 830mm in height and 600mm in diameter. The galvanized steel (ASTM A653) stirrer extends to the full height of the tank, while the hopper and 2Hp (approximately 2800rpm) electric motor measure 220mm in height. Experimental tests revealed a direct proportional relationship between critical parameters, including operation time, feed content mass rate, mixing volume, and output slurry. The results demonstrated that mixing 50 kg of cow dung with 50 liters of water produced 74 liters of slurry, while increasing the input to 150 kg of organic matter with 150 liters of water yielded 221 liters of slurry. The total cost for designing and fabricating the automated mixer was estimated at NGN281,000. Additionally, the mixer was found to be environmentally sustainable. To enhance the design's quality and performance, future

iterations could incorporate features such as a flushing system, wheels for mobility, and a mechanical pump for transferring the slurry to the biodigester.

KEYWORDS: Biogas Production, Anaerobic Digestion, Automated Slurry Mixer, Renewable Energy, Organic Waste Management.

1. INTRODUCTION

Biogas technology is a critical component of renewable energy solutions, utilizing biodegradable waste materials such as human waste, agricultural residues, animal manure, and food waste (Mbachu et al. 2022). The process relies on microorganisms to decompose or ferment organic matter, producing biogas through a series of biological reactions (Omoregbe et al. 2022). In developing countries, particularly in remote areas, the use of biogas generated by residential plants offers a viable solution to the growing concern of energy depletion. By converting conventional biomass—such as livestock manure and agricultural by-products—into biogas, communities can achieve energy self-sufficiency (Bond & Templeton, 2011).

Biogas serves as a versatile energy resource, providing clean fuel for domestic cooking, heating, lighting, and even electricity generation, all while minimizing environmental pollution (Otanocha et al., 2021). Whether produced on a small scale or through industrial processes, biogas represents a sustainable and renewable source of energy that can significantly contribute to energy security and environmental sustainability.

Anaerobic digestion (AD) is a microbiological process that breaks down organic matter in the absence of oxygen, a phenomenon commonly observed in natural environments and extensively utilized today in the production of biogas within sealed reactor tanks, known as digesters (Omoregbe 2022). This anaerobic process relies on a diverse community of microorganisms to produce two main by-products: biogas and digestate. Biogas is a combustible mixture primarily composed of methane and carbon dioxide, along with trace amounts of other gases. Digestate, on the other hand, is a nutrient-rich substance, making it a valuable organic fertilizer for plants. The anaerobic digester, often referred to as a biodigester or bioreactor, is designed to harness these processes (Omoregbe 2022).

Domestic biogas plants, or residential digesters, are relatively small anaerobic systems with a volume typically not exceeding 10 cubic meters. These digesters are often installed near individual households in remote areas to produce biogas for domestic use, while the resulting digestate is applied as organic fertilizer on farms (Mbachu et al., 2021). However, most conventional household biogas plants lack mechanical mixers, leading to suboptimal efficiency despite their suitability for rural applications (Okonkwo et al., 2024). In these setups, feedstock mixing is typically done manually using hand tools like shovels, often on open concrete surfaces. This manual method is not only labour-intensive and hazardous but also results in low productivity and efficiency. To address these challenges, various mechanical mixing solutions have been developed over the years. A wide array of mixers is available, each suited to different phases of feedstock—whether solid, liquid, or gaseous (Kougias & Angelidaki, 2018).

The primary problem addressed in this study is the inefficiency and labor-intensive nature of mixing organic feedstock in conventional household biogas plants, which typically lack mechanical mixers. This manual mixing process is not only time-consuming and hazardous but also leads to inconsistent slurry mixtures, thereby reducing the overall efficiency of biogas production (Alengebawy et al., 2024). Consequently, there is a need for an automated mixing solution that can improve the homogeneity of the feedstock, enhance biogas output, and reduce the physical labor required in small-scale biodigester operations. The significance of addressing the problem lies in the potential to greatly enhance the efficiency and sustainability of small-scale biogas production (Nwabunwanne et al., 2020). By automating the mixing process in household biodigesters, the proposed solution can lead to more consistent and homogeneous slurry mixtures, which in turn can significantly increase biogas yield. This improvement is crucial for rural and remote communities that rely on biogas as a primary energy source, as it can provide a more reliable, clean, and cost-effective alternative to traditional energy sources. Additionally, reducing the labor intensity and safety risks associated with manual mixing not only improves the overall feasibility of biogas technology for widespread use but also contributes to the broader goals of energy security and environmental sustainability by decreasing dependence on fossil fuels and lowering greenhouse gas emission. The aim of this study is to design, fabricate, and evaluate an automated organic matter slurry mixer to enhance the efficiency and sustainability of biogas production in small-scale biodigesters. The specific objectives are to design and fabricate an automated slurry mixer that optimizes the homogenization of organic matter, specifically cow dung, for use in biodigesters; enhance the efficiency and reduce the time required for batch mixing and filtering of biomass compared to traditional manual methods, thereby improving the overall productivity of the biogas production process; assess the performance and operational efficiency of the designed and fabricated automated mixer by comparing it with manual mixing methods in terms of slurry uniformity, biogas yield, and energy consumption; conduct a cost analysis of the designed equipment, evaluating the economic feasibility and potential return on investment for small-scale users in rural and remote areas; and finally to demonstrate the environmental sustainability of the automated mixing process, highlighting its contributions to reducing greenhouse gas emissions, improving waste management, and promoting the use of renewable energy sources.

2. REVIEW OF LITERATURE

2.1. Biodigester and Its Significance

A biodigester is a system designed to break down organic materials, such as manure and organic waste, through anaerobic digestion, resulting in the production of methane-rich biogas. Biodigesters with high structural crystallinity improve the efficiency of waste-to-biogas conversion by facilitating microbial access to the substrate. In contrast, the presence of larger solid particles can obstruct the movement of energy and matter, decreasing process efficiency. Optimal hydraulic performance is essential to support microbial activity, ensuring that substrates are evenly distributed and microbial communities are well-mixed. Proper mixing prevents issues such as crust formation and facilitates sustained microbial interactions, both of which are necessary for efficient fermentation and methane yield. Insufficient mixing can lead to lower methane output and higher operational costs, while excessive mixing may disrupt microbial aggregates and key syntrophic relationships, thereby reducing biogas production efficiency (Kaparaju et al., 2008).

2.2. Role of Biodigesters in Renewable Energy and Waste Management

Biodigesters play a critical role in waste management and renewable energy, as they convert organic waste into biogas, a sustainable fuel alternative. Recent studies emphasize that optimizing biogas production through enhanced biodigester efficiency can lead to increased energy output and better waste utilization (Kougias et al., 2018). To achieve optimal efficiency, factors such as temperature, pH, substrate composition, and mixing are crucial (Nwabunwanne et al., 2020). Anaerobic digestion offers a sustainable approach to waste management and renewable energy production, addressing critical environmental and societal issues. With the global waste crisis intensifying and a strong shift toward sustainable energy, there is a pressing need to advance anaerobic digestion technologies for greater efficiency and environmental benefits. This process not only reduces waste accumulation but also strengthens energy security and lowers greenhouse gas emissions, fitting well within the framework of a circular bioeconomy. Alengebawy et al. (2024) presented a review focused on the fundamentals of anaerobic digestion and biogas production, they exposed agricultural waste and biogas applications in both rural and industrial contexts. The environmental benefits and regulatory frameworks were evaluated, with detailed examples from China and Europe well explained. Findings indicate that strategic adoption of anaerobic digestion can significantly enhance energy production and sustainability outcomes, they equally showcased how targeted policies, and technological improvements can optimize biogas use. The review further highlights environmental impacts, with insights from China and Europe offering key perspectives.

2.3. Potential Feedstocks for Biodigesters

Selecting appropriate feedstock is essential to the success and efficiency of anaerobic digestion systems, as the rate and yield of biogas production depend largely on the digestibility of the input materials. Highly digestible, or putrescible, materials are known to produce greater volumes of biogas, supporting a more efficient energy output. Several types of organic materials have proven suitable for biogas production, including:

Crop Residues: Plant materials such as sugarcane trash, corn stubble, and straw are common feedstocks for biodigesters. However, their high fiber content and relatively large particle size can impede the digestion process, requiring longer retention times to fully break down the cellulose and hemicellulose structures within these materials.

Animal Manure: Various types of manure, including waste from food processing, animal dung, and other agricultural by-products, are widely used as feedstock due to their balanced carbon-to-nitrogen ratio, which is essential for efficient microbial digestion. The specific composition and effectiveness of manure as a feedstock can vary depending on the animal source, diet, and handling practices, influencing both gas yield and digestion time.

Human Waste: Human excreta, including both feces and urine, are viable for biogas production and are effectively processed through anaerobic digestion. This approach provides a hygienic method of waste disposal while reducing waste volume and environmental impact. It also lowers greenhouse gas emissions compared to traditional waste disposal methods such as landfilling and incineration.

Agricultural and Industrial By-Products, and Aquatic Biomass: By-products from agricultural industries, such as oil cakes, bagasse, and rice bran, as well as aquatic biomass like algae, represent additional sources of digestible organic matter for biogas production. These materials offer high biodegradability and nutrient content, contributing to efficient gas production when included in biodigester feedstock mixes.

By leveraging locally available organic materials, anaerobic digestion systems can reduce the need for transporting waste over long distances, which in turn minimizes carbon emissions associated with transport. Additionally, the energy loss from electricity distribution is lowered when biogas is used near the production site. Overall, the use of biodigesters captures methane that would otherwise be released into the atmosphere from landfills, thereby reducing greenhouse gas emissions and addressing environmental challenges linked to waste disposal and energy production.

2.4 Anaerobic Digestion

Anaerobic digestion (AD) is a natural biological process that decomposes organic materials in an oxygen-free environment, resulting in the production of biogas and a nutrient-rich byproduct known as digestate. This method is widely employed for managing organic waste and generating renewable energy, providing a sustainable solution that addresses both environmental and energy needs. Biogas, the main output of this process, primarily consists of methane (CH_4) and carbon dioxide (CO_2), with small amounts of other gases such as hydrogen sulfide (H_2S), ammonia (NH_3), and trace volatile compounds that can influence its quality and usability (Omoregbe et al., 2022). By capturing methane—a potent greenhouse gas that would otherwise be released into the atmosphere—anaerobic digestion contributes to reduced emissions and supports a circular economy by recycling organic waste into valuable energy and soil enhancers.

2.5. Influence of Operational Parameters on the Anaerobic Digestion Process

The efficiency of the anaerobic digestion (AD) process and resulting biogas production is affected by various operational parameters, including feedstock characteristics, organic loading rate (OLR), pH, temperature, hydraulic retention time (HRT), carbon-to-nitrogen (C/N) ratio, solid retention time (SRT), type of microbial inoculum, and reactor design. These factors play a critical role in determining reactor performance and optimizing biogas output. Here, each parameter is analyzed in detail to provide a comprehensive understanding of their effects on biogas production.

2.6. Feedstock Characteristics

The properties and composition of the feedstock are pivotal in shaping the AD process for efficient biogas generation. Feedstock characteristics influence both process stability and the potential for selecting co-substrates that can improve productivity used biodegradable feedstocks include food waste, animal manure, sewage sludge, and crop residues (Rocamora et al., 2020). Feedstocks for AD are generally classified as: (1) highly biodegradable, containing significant organic matter content that can be effectively decomposed under anaerobic conditions, and (2) nutritionally balanced, with adequate macro- and micronutrients that support anaerobic microbial growth (Wang et al., 2023).

The properties to monitor include total solids, particle size, moisture content, and volatile solids. Research by Agyeman and Tao (2024) in which dairy manure was co-digested with food waste demonstrated that the size of particles ranging from (2.5 to 8) mm could enhance biogas production by twenty nine percent. Total solids represent the feedstock's dry matter, encompassing both organic and inorganic components, and are determined by drying the sample to a level of (103–105) °C until it reaches a constant weight (Meegoda et al., 2018). Smaller particle sizes increase the surface area available for microbial action, improve handling, and thus contribute to higher biogas yields (Yadav et al., 2022).

2.7. pH and Alkalinity in Anaerobic Digestion

Maintaining an optimal pH range is essential for supporting microbial activity within the anaerobic digestion (AD) process. Generally, an effective pH range for AD is nearly neutral, between 6.8 and 7.2, though the exact range may vary depending on the substrate, organic loading rate (OLR), and digester type (Náthia-Neves et al., 2018). Different microorganisms thrive at specific pH levels: hydrolytic and acidogenic bacteria operate effectively between pH 4 and 8.5, while methanogens, which are crucial for methane production, require a narrower range of 6.5 to 7.2.

A deviation in pH can disrupt the process. High pH levels can lead to free ammonia toxicity, while low pH can produce non-ionized sulphide that form hydrogen sulphide gas, potentially harming microbial populations. Latif et al. (2017) found that maintaining pH around 7 maximized methane production in municipal sludge digestion, with methane yield dropping by 88% when pH decreased to 5.5. Consistent pH stability in the reactor effluent suggests effective buffering capacity, which is crucial for system stability. Additionally, pH levels influence the dissolution and hydrolysis of organic materials, impacting overall efficiency throughout the various stages of AD (Panigrahi and Dubey, 2019).

2.8. Temperature and C/N Ratio

Anaerobic digestion (AD) can be categorized based on temperature ranges: psychrophilic, mesophilic, and thermophilic. These ranges typically span from {10–20)°C for psychrophilic, (20–45) °C where 35 °C is usually considered as the standard, and (50–65) °C for thermophilic digestion, the standard is usually set at 55 °C (Panigrahi and Dubey, 2019). Temperature is a critical factor in AD as it influences substrate breakdown, microbial activity, the physicochemical properties of compounds, reaction kinetics, and overall process stability, all of which directly impact biogas yield. Any temperature fluctuations within the digester can negatively affect the efficiency and stability of the AD process (Meegoda et al., 2018).

The C/N ratio represents the balance between carbon and nitrogen levels in the feedstock, indicating their relative quantities. This ratio is crucial in the anaerobic digestion (AD) process and depends on the feedstock's specific characteristics and composition. In this context, carbon provides the primary energy source for microbial activity, while nitrogen supports the growth and multiplication of the microbial population (Kothari et al., 2014).

A high C/N ratio can destabilize the anaerobic digestion (AD) process by promoting acidification and reducing methanogenesis, which impacts methane production (Chatterjee and Mazumder, 2019). Excessive carbon levels may also lower the system's pH due to increased carbon dioxide production, requiring careful management and control to maintain stability (Matheri et al., 2018). To achieve an optimal C/N ratio, substrates with contrasting C/N levels one low and the other high—can be co-digested to balance the ratio as needed (Kumar and Samadder, 2020).

2.9. Reactor Design

In anaerobic digestion (AD), the digester plays a key role in determining biogas yield, as it provides an environment where anaerobic microorganisms can thrive and perform essential functions in the breakdown process. The effectiveness of the digester relies heavily on maintaining optimal temperature and pH levels (Van et al., 2020). An ideal digester design should support low hydraulic retention time (HRT), continuous organic loading rate (OLR), and high biogas production capacity.

Digesters are generally classified based on the separation of digestion phases into single-stage, two-stage, or multi-stage systems, which can be operated in batch or continuous flow modes. In a batch system, feedstock is added at the start and the product is harvested only after the process is complete, whereas in a continuous system, feedstock input and product output occur simultaneously (Kothari et al. 2014). The simplest AD setup is a single-stage (SS) system, where all four digestion stages occur within one reactor. Depending on the total solids (TS) content, these systems can be categorized as single-stage high solids (SSHS) or "dry" systems, and single-stage low solids (SSLS) or "wet" systems (Shefali, 2002). Multi-stage reactors, on the other hand, separate the different AD stages across multiple chambers, providing greater flexibility and allowing for optimization of each stage independently to enhance overall digestion efficiency.

Others are organic loading rate and hydraulic and solid retention time etc.

Table 1: Properties of Biogas (Srinivas 2015).

S No	Property	Value
1	Energy Content	6-6.5 kWh/m^3 20 MJ/m^3
2	Fuel Equivalent	0.6-0.65 l oil (0.57 LPG)/ m^3 biogas
3	Explosion Limits	6-12 % biogas in air
4	Ignition Temperature	650-750 C
5	Critical Pressure	75-89 bar
6	Critical temperature	-82.5 C
7	Normal Density	1.2 kg/ m^3
8	Smell	Odorless at low H_2S
9	Combustion efficiency	60 % in stoves
10	Effective molecular weight	20.1 to 25.9

2.1. Biodigester Mixer System

Mixing, also known as blending, is a process used to create a homogeneous mixture from two or more distinct components by dispersing one into the other. This mechanical operation aims to enhance the uniformity of a heterogeneous system, making it more consistent. Mixing is a crucial component in various industries such as food processing, pharmaceuticals, mining, and powder metallurgy, as well as in processes involving physical and chemical transformations. In industrial operations, mixing is an essential step. The larger component is referred to as the continuous phase, while the smaller component is the dispersed phase (Berk, 2008). This process takes place within a contained equipment chamber where the mixer is situated.

2. PREVIOUS WORKS ON MIXER SYSTEMS

Recent studies have explored various mixer designs and configurations to enhance biogas production. Lebranchu (2017) found that a serpentine ribbon impeller generated 50% more biogas compared to a Rushton turbine when mixing cattle dung. Karim et al. (2005) tested different mixing methods—biogas flow, propeller mixing, and slurry recirculating—and found that these methods increased biogas production by 15% to 29% compared to a non-mixed digester. Meroney and Colorado (2009) emphasized the impact of tank design and fluid density on mixing efficiency. Battista et al. (2016) showed that various impellers, particularly the marine and Rushton impellers, improved mixing and methane production in high-viscosity fluids. Patel et al. (2012) highlighted that anchor impellers were effective for high-viscosity liquids, and Trad et al. (2017) demonstrated that combining different impeller types improved flow patterns and mixing. Wu (2010) used simulations to find that axial pumping in draft tubes was more efficient for mixing than external circulation. Finally, Hopfner Sixt et al. (2007) found that paddle mixers and egg-shaped digesters were effective for uniform mixing and reduced energy consumption. These findings are crucial for designing efficient, cost-effective mixers for biogas production, particularly in the Nigerian context.

3. MATERIALS AND METHOD

This section is focused on comprehensive methodologies employed in the development of the automated organic matter slurry mixing system designed to enhance the efficiency of a developed biodigester. The focus of the research is to optimize the mixing of organic substrates, a critical factor in the anaerobic digestion process that significantly influences biogas yield and overall operational efficiency. To achieve this objective, appropriate feedstock was systematically selected, mixer was engineered specifically suited to the needs of bio digestion, and rigorous analytical methods was applied to evaluate performance metrics. The approach implemented integrates both theoretical calculations and practical design considerations to ensure the mixer operates effectively under various conditions.

The methodologies are categorized into several key components: feedstock selection, design calculations, fabrication processes, and evaluation techniques. This structured framework not only elucidates the steps taken during the research but also highlights the rationale behind each choice, providing a clear connection between our methodology and the anticipated improvements in biodigester performance.

3.1. Feedstock Selection

The selected feedstock for this research was cow dung, obtained from an abattoir located along Effurun-Sapele Road in Warri, Delta State, Nigeria. Cow dung was chosen due to its abundant availability, which streamlined both the design and fabrication processes. A total of 150 kg of cow dung was used in this study to ensure adequate volume for testing and assessment.

3.2. Design Calculations

Detailed design calculations were conducted to determine the optimal dimensions and specifications for material selection, machine design, and construction. These calculations covered essential parameters, mathematical equations, and evaluations of key structural components, as laid out in the subsequent design analysis. Each parameter was evaluated to support the mixer's effective functionality and durability during operation.

Stirrer Motor/Agitation - The Stirring Force was calculated

Table 2: Steel Properties for Shaft Design.

Shaft Property	Value
Density	$7.86e^{-6}kg/mm^3$
Ultimate tensile strength	$485N/mm^2$
Yield strength	$17N/mm^2$
Shear Strength	$0.966N/mm^2$

It was assumed that other stresses (bending and shear) acting on the shaft are negligible in comparison to the torsional stress as represented in Table 2. Therefore, since the shaft is connected to the Agitator, the torque of the motor is equivalent to the torque of the shaft;

Torque of motor (Tm) = Torque of shaft (Ts) = 5120Nmm

Table 3: Summary of Design Analysis.

Design Parameter	Value
Stirring power; (Ps)	1500w
Stirring torque; (Ts)	5120Nmm
Torque of motor (Tm)	5120Nmm
Shaft diameter (ds)	29.85mm
Fs = Stirring Force	686N
Mass of biomass (Mc)	70kg
Design Analysis Parameters Capacity of tank	230L
Acceleration due to gravity (a)	9.8 m/s
Speed of Motor, Nm	2800RPM

Motor Power, Pm	1500w (2Hp)
Capacity of tank	230-250L
Ps = Motor Power = 1500w Nm = Motor Speed = 2800rpm	
Ps = 2 x π x N x T/60	
Shaft torque; Ts = 5120Nmm	
Shaft Diameter, Ds	29.85mm
Shaft Shear Strength, T	0.966N/mm2
Steel Properties for Shaft Design	
Density	7.86e-6kg/mm3
Ultimate tensile strength	485N/mm2
Yield strength	17N/mm2
Shear Strength	0.966N/mm2

Summary of Design Analysis

Design Parameter	Value
Stirring power; (Ps)	1500w
Stirring torque; (Ts)	5120Nmm
Torque of motor (Tm)	5120Nmm
Shaft diameter (ds)	29.85mm

3.3 Design Analysis

Incorporating mathematical equations is essential in the initial stages of any equipment design process. Solving these equations provides critical dimensions needed to ensure optimal functionality. Preliminary dimensions are often estimated and refined through iterative calculations to achieve desired performance efficiency. Below is a list of the primary equipment involved in this study, along with their relevant dimensions and mathematical formulations used in the design process.

Tank: The mixer compartment utilized a 250-liter capacity mild steel trailer diesel tank, measuring 830 mm in height and 600 mm in diameter, as shown in Figure 3.6. The tank was customized to meet the specific requirements of this project and was coated with red oxide to prevent rusting.

Stirrer: The stirrer was constructed from galvanized steel rod (ASTM A653, Grade 33), with a length of 830 mm and a diameter of 30 mm, as depicted in Figure 3.4. This material was chosen for its durability and compatibility with the operating environment.

Hopper: Serving as the inlet for the biomass feed (cow dung), the hopper was crafted from mild steel, with dimensions of 220 mm in height and 230 mm in diameter. Its design, shown in Figure 3.6, facilitates efficient loading of biomass into the mixer.

Electric Motor (Actuator): To ensure rapid and uniform mixing essential for biogas production, a 3-phase, 2 HP motor with a speed of 2800 rpm was incorporated. This motor supports the process by providing the necessary torque and speed for effective mixing, enhancing overall system efficiency.

3.4 Computer Aided Design and Simulation

With the established design equations, the automated mixer design was systematically executed to create a visual model prior to fabrication and to assess performance through stress and strain simulations. SolidWorks 2022, a comprehensive mechanical design and simulation software, was utilized for this purpose. This software, known for its user-friendly Microsoft® Windows-based interface, enabled efficient development of parts, assemblies, and detailed drawings, supporting both the design process and simulation evaluations of the mixer's structural performance.

CAD Design of the Automatic Mixer - The detailed CAD designs of the automated mixer are presented in Fig 1-6. Furthermore, the design of this shaft was fabricated using galvanized steel material having the following mechanical properties in Table 3 .3. The incorporation of mathematical equations usually for any equipment is the foremost for any design procedure. Solutions to this design equations that preludes to obtaining of the necessary dimensions. The dimensions nonetheless can be guessed prior and used before it is revised for the efficiency. Hence the major equipment's that incorporates this study and their dimensions and mathematical relations required is underlisted below:

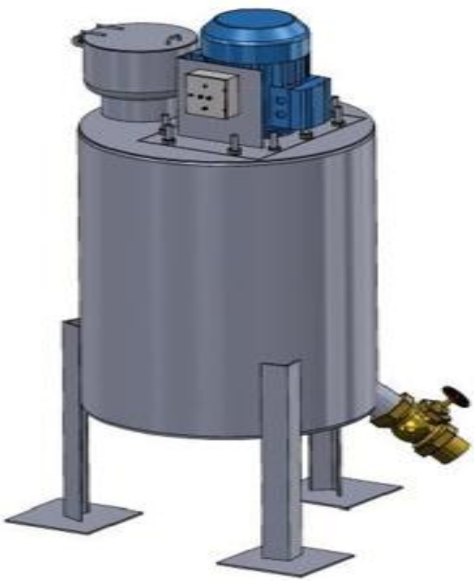

Figure 1: Automatic Biodigester Mixer.

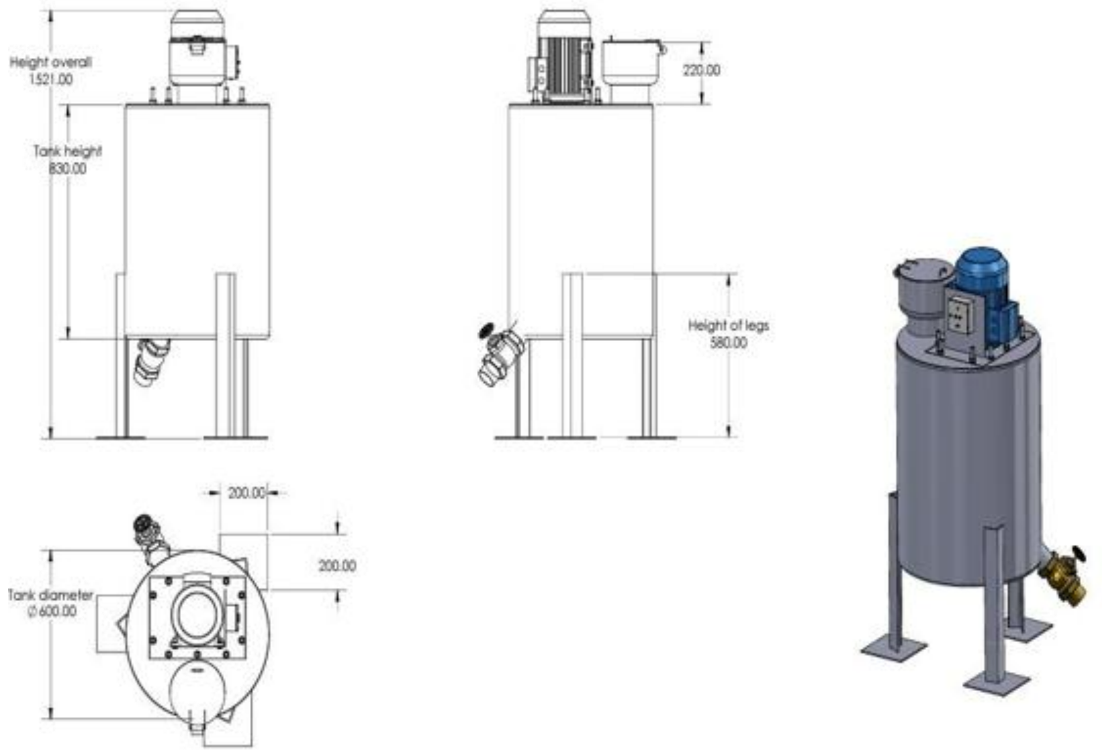

Figure 2: Schematic View of the Entire Biodigester.

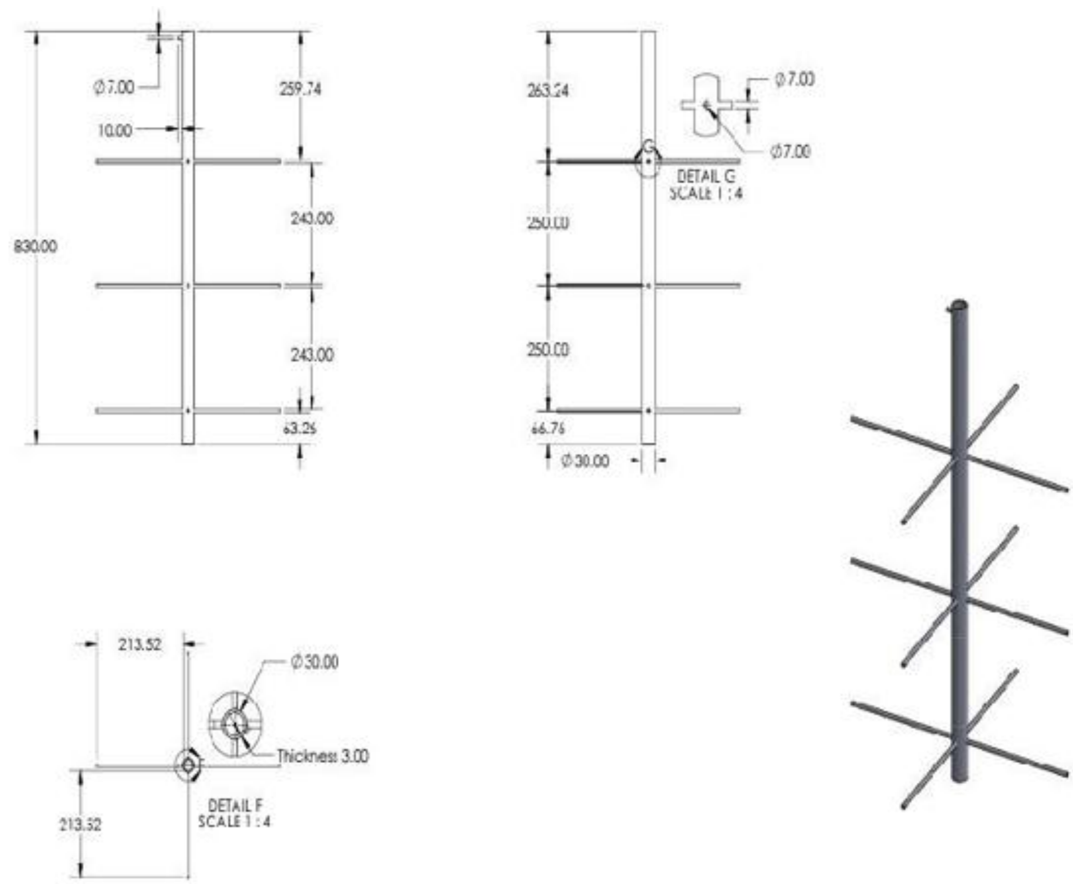

Figure 3: Stirrer Details.

1) Stress-Strain Analysis of the Biodigester Mixer

Finite element analysis (FEA) to determine the effect of the forces acting on the biomass mixing machine was conducted emphasising on the mixing Tank and Stirrer. The stress and strain value was the key concern in the analysis. Below are the details and result of the simulation:

Table 4: Mesh Information.

Mesh type	Solid Mesh
Mesher Used:	Blended curvature-based mesh
Jacobian points for High quality mesh	16 Points
Maximum element size	61.3292 mm
Minimum element size	3.06646 mm
Mesh Quality	High

Total Nodes	66134
Total Elements	31422
Maximum Aspect Ratio	150.17
% of elements with Aspect Ratio < 3	13.1
Percentage of elements with Aspect Ratio >10	37
Percentage of distorted elements	0
Time to complete mesh(hh;mm;ss):	00:00:22

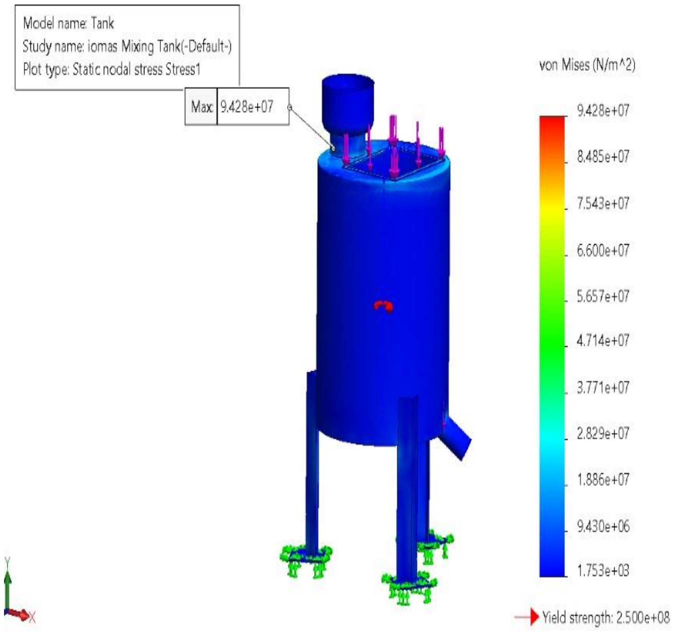

Figure 3.9: Von Mises Stress Distribution on the Tank.

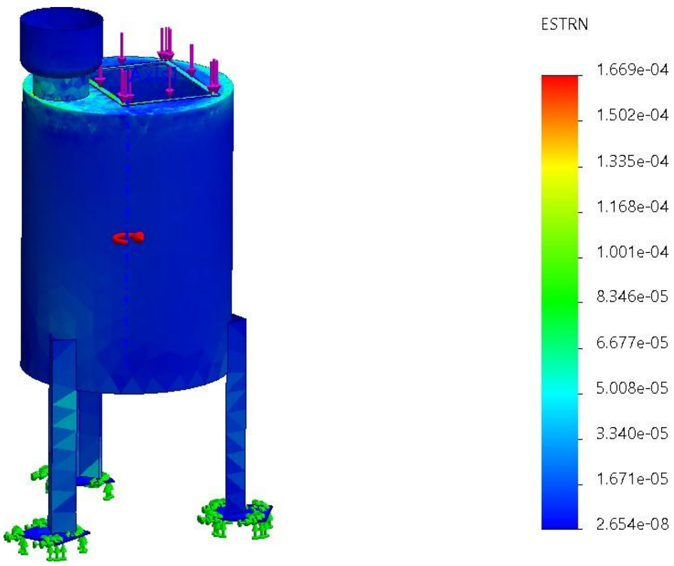

Figure 4: Strain Distribution on the Tank.

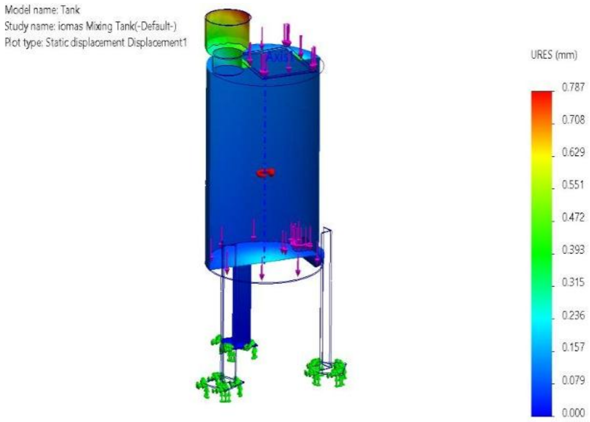

Figure 5: Displacement Distribution.

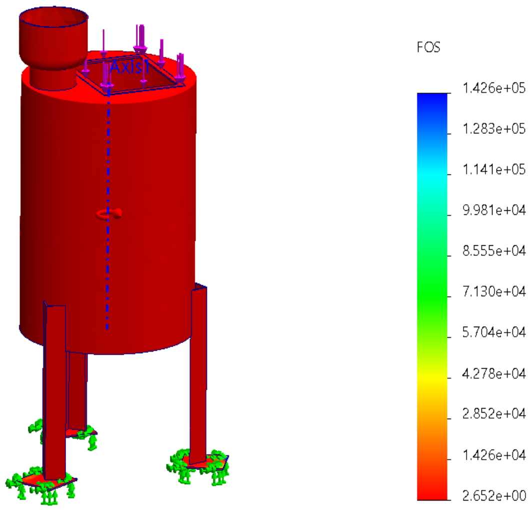

Figure 6: Factor of Safety (FOS).

From Fig 7, the maximum stress observed on the tank on it full working capacity is less than the yield strength of the material selected (see table 5 for material properties details) hence theoperating condition for the biomass mixing machine is considered safe for the design. The maximum deformation fig 7 observed is 0.787mm (negligible) too.

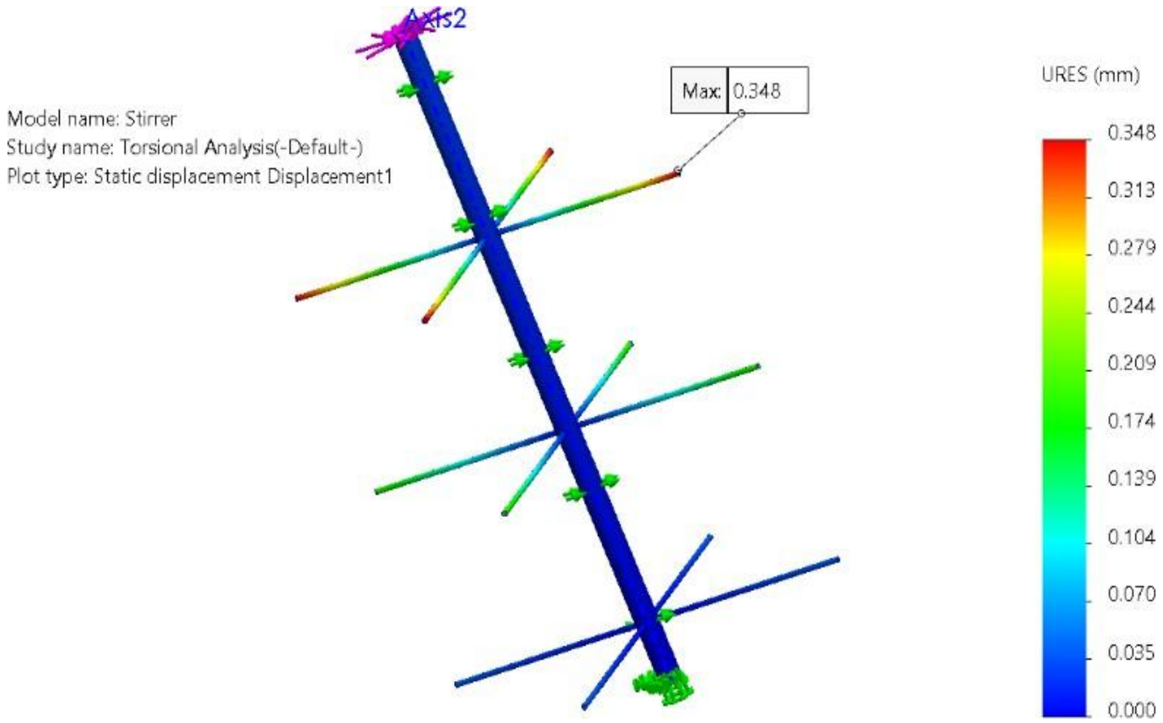

Figure 7: Displacement Distribution on the Stirrer.

Fig 7 shows the Von mises stress distribution on the stirrer, it can be observed that the maximum stress observed on the stirrer on it full working capacity is less than the yield strength of the material selected (see table 3.4 for material properties details). The maximum deformation observed is 0.348mm (negligible). Fig 3.17 shows the shear stress distribution with a maximum value of 3.542MPa.

3.5. Materials Selection

The selection of materials was specifically aimed at minimize cost, ease of availability and specific properties that will enhance the overall aim in achieving the goal of the mixer to be machined afterdesign. The materials selected for the different parts of this work and reasons for the selection aregiven in Table 3.1 below:

Table 5: List of materials selected and their mechanical properties.

Material components	Material Selection	Material Properties	Reasons for selection
Tank	ASTM A36 Mild Steel	Elastic Modulus200GPa Poisson's Ratio 0.260 Shear Modulus 79.3GPa Mass Density 7850 kg/m^{3}Tensile Strength 400 – 550MPa Yield Strength 250MPa	Welding with any sort of welding technology is simple, and the resulting welds but also joints are all of great calibre.
Stirrer and Stirrer blade	ASTM Galvanized Steel	Yield Strength, 170MPa Tensile Strength, 485MPa Mass Density, 8027kg/m^3 Elastic Modulus, 200000N/mm^2 Shear Modulus, 82000N/mm^2	Corrosion resistant, Durable, Economical,

(Kurt Gustafson (2007), Evaluation of Existing Structures, Steel wise, American Institute of SteelConstruction, February 2007).

3.6. Mixing Operation Overview

Having set up the entire machine at the workshop, homogenization began. Firstly, a 100kg metal weighing scale spring balance with hanging hook was utilized in weighing the available bags of organic matter (cow dung) retrospectively. A mass of 50kg of cow dung was then poured into the mixer with a corresponding 50litres of water to obtain the desired slurry matter. The Processing time/rate was calculated and the volume of slurry matter obtained was recollected after mixing into measuring cylinders. This experiment was repeated four more times for 70kg, 90kg, 120kg and 150kg of cow dung including their corresponding volume (in litres) of water for mixing. After all experiments setups were undertaken and experimental results obtained, the mixer was properly washed and the slurry matter discharged from the workshop.

Instrument used for batch mixing include

Spring Balance to weigh the organic matter in batches (50 – 150kg) before pouring into the mixer tank for mixing.

Digital Stop clock to record the processing time taken to effectively mix each batch of organic matter in the mixer tank

Measuring Cylinders for the measurement of volume of slurry matter formed per batch of organic matter mixed.

2) Equipment Employed for Batch Mixing

- Surgical Face mask
- Disposable latex hand gloves
- Industrial Engineering workwear
- 3phase, 2hp Electric motor attached with a fabricated galvanized steel shaft of 29.85mm in diameter.

3) Health and Safety Measures

During the mixing operations the following health protocols were observed:

- Wearing of Surgical Nose mask due to the unhealthy smell from the organic matter (cow dung)
- Wearing of Rubber latex Hand gloves to protect delicate parts of the fingers and hands.
- Wearing of Industrial Mechanical Engineering work wear OR a complete change of clothingbefore beginning experimentation to avoid the unhealthy smell permeate through your clothes.

3.7. Cost Analysis

With the establishment of the design and execution of the automated mixer process, it is essentialin estimating the process equipment's cost to disclose the monetary worth of in terms of capital cost of setting up the process. In that regard, the cost of individual process equipment's required for the design and fabrication of the automated mixer is given below in the Bill of Engineering Materials and Equipment:

Table 6: Bill of Engineering Materials and Equipment.

S/N	Items Purchased	No. Of Items	Cost
1	2.0 Hp, 3 Phase, Electric Motor	1	₦55,000
2	250L Mild Steel Tank	1	₦25,000
3	Galvanized Steel Shaft	1	₦ 6,000
4	Electrical cables & parts		₦25,000
5	Miscellaneous		₦170,000
Total Amount Expended			₦281,000

3.8. Cost Analysis Discussion

Table 3.6 above relates the cost of individual components that is employed in the fabrication of the automated mixer. It is shown that the cost for the electric motor component was the highest at ₦55,000. The reason is because of the function in which it occupies since it is the major constituent that enables the mixing process. Also, the cost of the tank and the electrical cables and parts were observed to be ₦25,000 each. The cost of the tank is related to the volume it will hold which is about 250 litres and the desire for materials of proportionate properties that can stand the test of time. The cost of the electrical cables is nonetheless attributed to the special function it performs wherein it serves as the gateway of electricity transmission to the process that will enable the proper working of the automated mixer. The next cost is of the shafts which cost about ₦ 6,000. The shaft is a needed component of the automated mixer since it is the medium through which mixing occurs. In additional, the design and fabrication procedure incurred a miscellaneous cost of ₦170,000 which is tied to situational circumstances like travelling to purchase equipment's, freight and other subsidiary payment that is accrued during the fabrication. In all, the total estimated cost for the design and fabrication of the automated mixer for a bio-digester to be employed in the production of biogas was ₦281,000.

4. RESULTS AND DISCUSSIONS

Having established the design methodology, it is imperative to review results obtained from testing the machine and discuss such based on the real time significance to the aim and objective of the work. Herein the following sections reveal the results for this study and their evaluation.

4.1 Mixing Operation Results

Volume - The result from experimentation were obtained accordingly using measuring cylinder. 50 litres of water was added to 50kg of organic matter (cow dung) which produced 74 litres of slurry matter. Subsequently, the mass of organic matter (cow dung) and volume of water were increased to 70kg and 70 litres accordingly which in turn gave a corresponding increase in the Volume of Slurry Matter formed.

Processing Time/rate - The processing time/rate were calculated using a digital stop watch based on the speed of the agitator. For the first experimental result, the processing time/rate was observed at 150seconds (about 3minutes of highspeed agitation). This time was obtained with respect to the quantity of composition of organic matter (cow dung) and water. This continued until the last experiment which gave 294seconds (about 5minutes of highspeed agitation). Therefore, the processing time/rate increased with increase in mass of organic matter (cow dung) and volume of water to achieve a desired slurry matter.

The obtained results from the mixing operation are provided below in table 7 with effects of parameter changes.

Table 7: Practical Results of Various Mixed Masses.

S/N	Mass of Organic Matter (Kg)	Volume of Water (L)	Mixing Time (seconds)	Volume of Slurry Matter (L)
1	50	50	150	74
2	70	70	172	104
3	90	90	232	133
4	120	120	262	177
5	150	150	294	221

Table 8: Practical result of Mass of Organic Matter against Mixing Time.

Mixing Time (sec)	Mass of Organic Matter (kg)
150	50
172	70
232	90
262	120
294	150

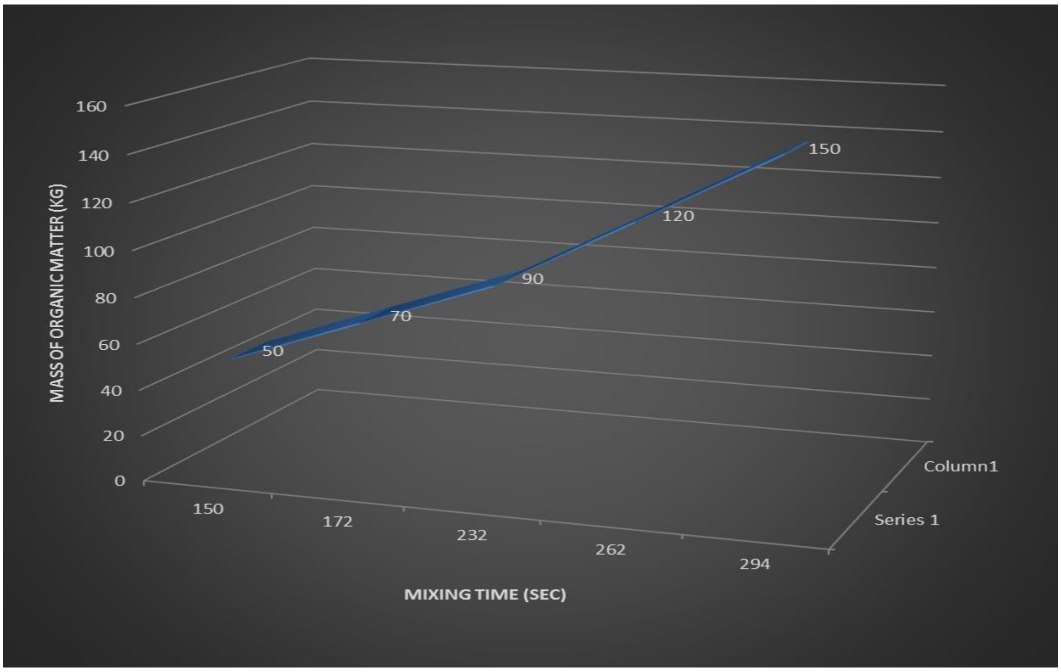

Figure 8: Mass of Organic Matter against Mixing Time.

Table 9: Practical result of Volume of Slurry against Mixing Time.

Mixing Time (sec)	Volume of Slurry (l)
150	74
172	104
232	133
262	177
294	221

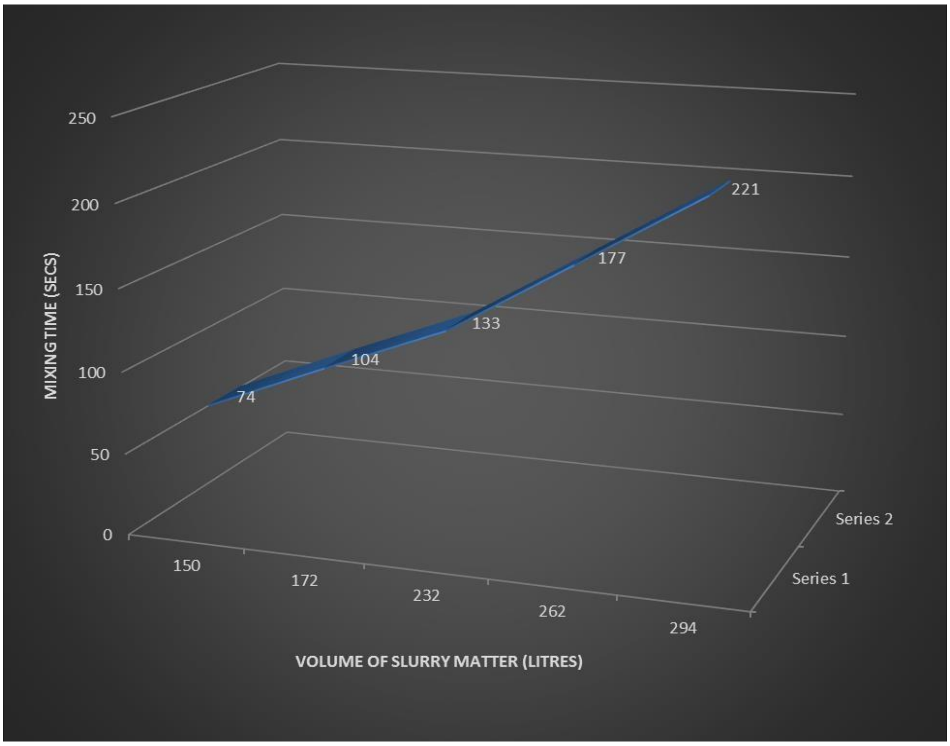

Figure 9: Graph showing Mixing Time against Volume of Slurry Matter.

Table 10: Practical result of Volume of Slurry against Mass of Organic Matter.

Volume of Slurry (l)	Mass of Organic Matter (kg)
74	50
104	70
133	90
177	120
221	150

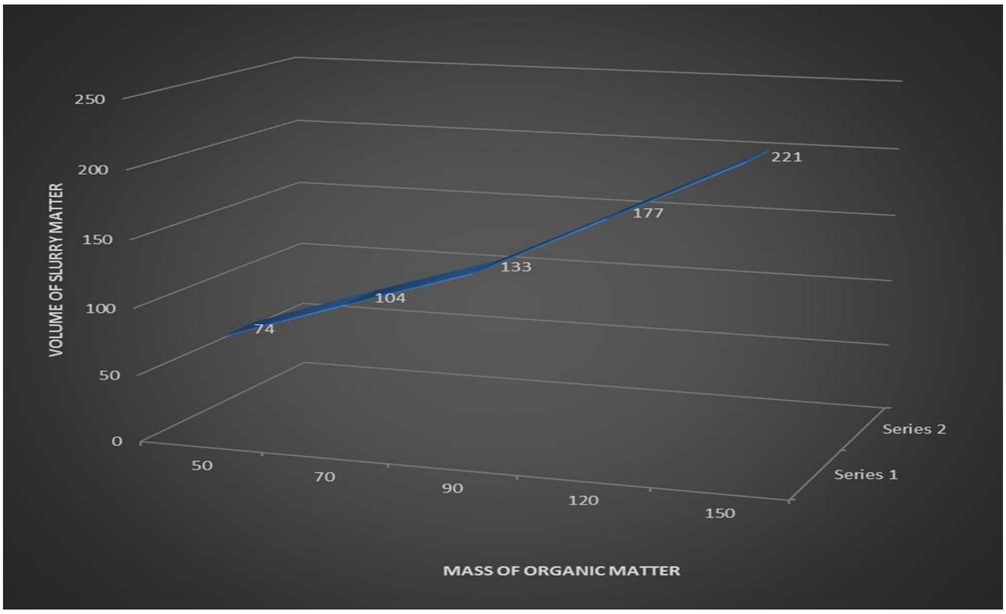

Figure 10: Graph showing Volume of Slurry Matter against Mass of Organic Matter.

4.1.1 Mixing Operation Result Discussion

The obtained results obtained from the mixing operation has been laid out with reference to Table 7 through 10 and Figure 8 to Figure 10. Nonetheless, by observation, it is shown from Table 8 and Figure 9, that the mixing time is in direct proportion to the mass of organic matter. This result is expected in that as the mass of the feed (cow dung) is increased, there will be a direct relationship to time increase. This result further implies that the higher the mass feed to the mixer, the greater the mixing time required to lead to the homogeneity of the total mixturesbefore being transferred into the digester to have maximal effectiveness in the production of biogas. Also, with reference to Table 10 and Figure 9, it was found that as the mass of the feed content is increases so does the volume of slurry matter recovered. This result is self-explanatory in that as the feed content is fed into the mixer with additional water, the slurry mass must increase for which a decrease will be an abnormality. This invariably gives a direct proportionality with the mixing time. Furthermore, the preceding Table shows the effect the mass of organic matter has on the volume of slurry matter. The less the organic matter, the decrease in volume of slurry recovered. Therefore, Figure 10 shows how directly the proportional mass of organic matter is to its slurry volume.

4.2 Material and Energy Balance of the Mixing Process

In the intent of evaluating the overall efficiency of the automated mixer design, it is imperativeto evaluate the material and energy input and output from the mixing system. This will enable the determination of the overall efficacy of the automated mixer in reference to the produced biogas from the bio-digester. The obtained result through simulation for the overall mixing process is given below:

Table 11: Results Obtained for The Material and Energy Balance for The Mixing Process.

Parameters	Input	Output
Energy	1.48 Kwh/year	1691760 Kwh/year
Biogas	-	445200 m^3/year
Feed Content (Slurry)	10,608 m^3/year	-
Feed (Cow Dung)	7200 kg	-

Material and Energy Balance Results Discussion

By evaluating the obtained results with respect to Table 10 and Figure 9, some interesting indications is observed. The result is indicative of the biogas comparative volume which is produced on a one-year operating basis. The results indicate a volume of 445200 m^3/year of biogas is produced from a maximum feed input of 7200 kg of feed biomass (cow dung). This amount of produced biogas can be supplied to 371 households. Also, the electricity equivalentfor the produced biogas amounted to 1691760 Kwh/year. This result is worthwhile in that only 1.48 Kwh/year of energy was expended for the automated mixer during same period. The difference in energy consumed to the energy produced is enormous. The comparative difference amounts to 1691755 Kwh/year of energy which can supply 563 households electricity. The definitive opinion is that the biodigester mixer will be an effective equipment in generating a great volume of slurry for day-to-day generating of power for various purposes.

4.3 Effect of results obtained on environmental sustainability

The key fact in the obligation to design and fabricate a mixer utilized for producing biogas is tailored towards the means of alternative or green energy sources that can efficiently replace and outperform current sources of energy. Nonetheless, the design of the mixer incorporates an automated mixing mechanism that requires the utilization of electricity. However, an examination of the design and the obtained results shows a comparative good outlook on the green sustainability mantra. This is because with reference to Table 10, the difference in the total energy output was in the positive which entails the consumption of energy is well replaced and there is more for utilizations in other sectors that deems fit. Nevertheless, because of the volume of gas treated, it can be argued that there is absence of direct infrastructure to incorporatesuch mechanism.

5. CONCLUSION

The Automated Organic Matter Slurry Mixer for Biodigester was successfully designed, fabricated and tested successfully with satisfactory results. From the experimental results discussed in the previous chapter it can be concluded that there is a direct proportionate relationship between the mass of the organic matter (cow dung) to the corresponding volume of water needed for mixing. Similar result was also observed in the volume of slurry formed. Also, it was discovered that increasing the organic matter (cow dung) and water leads to a direct proportionate increase in processing time/rate to achieve a desired slurry matter. This is because, mixing 50kg of biowaste (cow dung) with 50litres of water, produced 74litres of slurry matter while increasing the mixture to 150kg of organic matter with a corresponding volume of 150litres of water, produced 221litres of slurry matter. It is recommended that to improve the performance quality of the machine, the following should be put into consideration: A flushing system should be installed to the machine. This would make cleaning of the tank after use to be easy and more effective; For easy mobility while in use, tires should be installed Making the machine fully automated will be a preferred option. But on the other hand, going mechanical may also be considered (bicycle pedaling system can be installed) due to the unstable power supply in the nation; For distance pumping of the slurry matter into the digester, a mechanical pump is required for supply rather than a hose; Alternatively, a conversion of Mechanical energy to Electrical energy by incorporating a bicycle pedalling system would be most suitable due to instability of available power while using a direct electric motor system which is solely dependent on constant power source. This would provide the necessary constant power required for consistent mixing of the organic matter.

Suggestion for further studies

Besides incorporating additional components which will improve the overall quality performance of this machine, further research on the effect of including heat during the mixing operation and incorporating a biodigester to the machine, so that it can be operated as a continuous process machine should be carried out with the aim of improving the quality of biogas which can be produced, while reducing time of operation.

REFERENCES

1. Omoregbee H., M.O. Okwu, L.K.Tartibu, B.Edward. Effect of Process Parameter on Biogas Yield: A review. “Advances in Biofeedstocks and Biofuels” Book Series to be published by Scrivener-John *Wiley & Sons publication*. Chapter, 2022; 3. DOI: 10.1002/9781119785842.ch3
2. Mbachu V. Igboanugo A.C., Okwu M.O. Enhanced Biogas Production from Fresh Elephant Grasses, Using Liquid Extract from Plantain Pseudo Stem. International Journal of Scientific and Technology Research *(IJSTR)*, 2022; 10(3): 122-127.
3. Bond, T., & Templeton, M. R. History and future of domestic biogas plants in the developing world. Energy for Sustainable Development, 2011; 15(4): 347–354. doi:10.1016/ j.esd.2011.09.003
4. Otanocha O., Okwu M.O., L.K. Tartibu (2021) Modified Biogas Tank for Production of Gas from Decomposable Organic Waste. *Biomass Conversion and Bio refinery, Springer*. DOI: 10.1007/s13399- 020-01195-x
5. Mbachu, V.M., Ovuworie, G.C., Tartibu L.K. (2021) Modelling and Sustainability of a

Demand-Based Biomass to Biogas Conversion System: a Bio-mimicry Feedstock Inventory-Based Approach. *Biomass Conv. Bioref. Springer* https://doi.org/10.1007/s13399-021-01581-z

6. Chinwe P Okonkwo, M.O Okwu. Feedstocks for Sustainable Biodiesel Production: Characterization, Selection, and Optimization, A book published by John Wiley & Sons, 2024; 1-464.
7. Kougias, P. G., & Angelidaki, I. Biogas and its opportunities—a review. *Frontiers in Environmental Science*, 2018; 12(13): 14. https://doi.org/10.1007/s11783-018-1037-8
8. Alengebawy, A., Ran, Y., Osman, A.I. (2024). Anaerobic digestion of agricultural waste for biogas production and sustainable bioenergy recovery: a review. Environ Chem Lett. https://doi.org/10.1007/s10311-024-01789-1
9. Nwokolo, Nwabunwanne, Patrick Mukumba, KeChrist Obileke, and Matthew Enebe. "Waste to Energy: A Focus on the Impact of Substrate Type in Biogas Production" Processes, 2020; 8(10): 1224. https://doi.org/10.3390/pr8101224
10. Kaparaju, P., Buendia, I., Ellegaard, L., & Angelidakia, I., "Effect of mixing on methane production during thermophilic anaerobic digestion of manure: Lab-scale and Pilot-scale studies," *Bioresour. Technol.*, 2008; 99(11): 4919-4928.
11. Náthia-Neves G, Berni M, Dragone G, Mussatto SI, ForsterCarneiro T. Anaerobic digestion process: technological aspects and recent developments. Int J Environ Sci Technol, 2018; 15: 2033–2046. https://doi.org/10.1007/s13762-018-1682-2
12. Rocamora I, Wagland ST, Villa R, Simpson EW, Fernández O, Bajón-Fernández Y. Dry anaerobic digestion of organic waste: a review of operational parameters and their impact on process performance. Bioresour Technol, 2020; 299: 122681. https://doi.org/10.1016/j.biortech.2019.122681
13. Wang Z, Hu Y, Wang S, Wu G, Zhan X. A critical review on dry anaerobic digestion of organic waste: characteristics, operational conditions, and improvement strategies. Renew Sustain Energy Rev., 2023; 176: 113208. https://doi.org/10.1016/j.rser.2023.113208
14. Agyeman FO, Tao W. Anaerobic co-digestion of food waste and dairy manure: efects of food waste particle size and organic loading rate. J Environ Manage, 2014; 133: 268–274. https://doi. org/10.1016/j.jenvman.2013.12.016
15. Meegoda JN, Li B, Patel K, Wang LB A review of the processes, parameters, and optimization of anaerobic digestion. Int J Environ Res Public Health, 2018; 15: 2224. https://doi.org/10.3390/ ijerph15102224

16. Yadav M, Balan V, Varjani S, Tyagi VK, Chaudhary G, Pareek N, Vivekanand V. Multidisciplinary pretreatment approaches to improve the bio-methane production from lignocellulosic biomass. Bioenerg Res., 2022; 16: 228–247. https://doi.org/10.1007/ s12155-022-10489-z
17. Latif MA, Mehta CM, Batstone DJ Infuence of low pH on continuous anaerobic digestion of waste activated sludge. Water Res., 2017; 113: 42–49. https://doi.org/10.1016/j.watres.2017.02.002
18. Panigrahi S, Dubey BK A critical review on operating parameters and strategies to improve the biogas yield from anaerobic digestion of organic fraction of municipal solid waste. Renew Energy, 2019; 143: 779–797
19. Kothari R, Pandey AK, Kumar S, Tyagi VV, Tyagi SK Diferent aspects of dry anaerobic digestion for bio-energy: an overview. Renew Sustain Energy Rev., 2014; 39: 174–195. https://doi. org/10.1016/j.rser.2014.07.011.
20. Chatterjee B, Mazumder D. Role of stage-separation in the ubiquitous development of anaerobic digestion of organic fraction of municipal solid waste: a critical review. Renew Sustain Energy Rev., 2019; 104: 439–469. https://doi.org/10.1016/j. rser.2019.01.026
21. Matheri AN, Sethunya VL, Belaid M, Muzenda E. Analysis of the biogas productivity from dry anaerobic digestion of organic fraction of municipal solid waste. Renew Sustain Energy Rev., 2018; 81: 2328–2334. https://doi.org/10.1016/j.rser.2017.06.041
22. Kumar A, Samadder SR Performance evaluation of anaerobic digestion technology for energy recovery from organic fraction of municipal solid waste: a review. Energy, 2020; 197: 117253. https://doi.org/10.1016/j.energy.2020.117253
23. Van DP, Fujiwara T, Tho BL, Toan PPS, Minh GH A review of anaerobic digestion systems for biodegradable waste: confgurations, operating parameters, and current trends. Environ Eng Res., 2020; 25: 1–17. https://doi.org/10.4491/eer.2018.334