DESIGN, CONSTRUCTION AND PERFORMANCE EVALUATION OF A PORTABLE BIOGAS DIGESTER USING COW DUNG AND POULTRY DROPPINGS AS SUBSTRATES

BY

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DECLARATION

I declare that the work in the thesis entitled "Design, construction and performance evaluation of a portable biogas digester using cow dung and poultry droppings as substrates" has been performed by me in the Department of Mechanical Engineering under the supervision of Prof. A.I. Obi and Prof. S.Y. Aku.

The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree or diploma at any university.

Mamuda Muhammad	______________________	______________________
	Signature	Date

CERTIFICATION

This thesis entitled "DESIGN, CONSTRUCTION AND PERFORMANCE EVALUATION OF A PORTABLE BIOGAS DIGESTER USING COW DUNG AND POULTRY DROPPINGS AS SUBSTRATES" by Mamuda Muhammad meets the regulation governing the award of the degree of MASTERS of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

This work is dedicated to my wife and children for their endurance and understanding throughout my stay in Zaria

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ABSTRACT

This research work presents the design, construction and performance evaluation of 100 litre capacity portable biogas digester, which was used in anaerobic degradation of agro-based wastes to produce biogas. A 100 litre capacity biogas digester was designed and constructed using locally available engineering materials such as galvanized iron sheet, mild steel, rods, valves, hose and laboratory wares. Cow dung and chicken droppings served as source of biogas generation. A fermentation process was employed in assessing the potentials of the waste in biogas generation within a 30 day period. Gas chromatography was used to identify and quantify the various components of the biogas generated. Generated biogas was temporarily stored in a gas holder which was subsequently used directly for cooking. An average of $0.04m^3$/day of biogas was produced using cow dung as source with peak production of $0.075m^3$ on day 17. Similarly, $0.06m^3$/day of biogas was produced on the average with peak production of $0.092m^3$ of gas was observed at day 20 when chicken droppings were used. Analyses of the generated gases from both sources revealed the gas mixture was composed of methane, CO_2 and traces of H_2S and H_2. It can be concluded from the experimental results that chicken droppings is a better source of biogas and a potential source of the combustible methane gas commonly used for house hold cooking.

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LIST OF ABBREVIATIONS

C/N	Carbon:Nitrogen ratio
GI	Galvanized Iron
H	height (m)
LPG	Liquefied Petroleum Gas
BOD	Biochemical Oxygen Demand
pH	Acidity degree value
PVC	polyvinyl chloride
V	volume (m^3)
r	radius (m)
ρ	density (kg/m^3)
AD	anaerobic digestion
Ts	total solid
TVS	total volatile solid
S	substrate concentration (mg/L)
t	time
RT	Retention Time
T	temperature ^oC
v	volumetric flow rate (m^3/day)
V_T	Total volume of digester
V_d	Digester volume
V_g	Gas volume
S_d	daily substrate

CHAPTER ONE

1.1 General Introduction

Most of the world's problems are related to the generation, supply and distribution of energy. The rate at which energy is consumed has rapidly increased because of the high demand for it. If this situation continues, there is the fear that the conventional liquid and the gaseous fuels, which constitute about 92% of the world total energy source will be rapidly depleted. The importance of energy in national development cannot be overemphasized. Energy is the hub around which the development and industrialization of any nation revolve.

It is a fact that any distortion in the energy supply chain at any point in time would result into serious economic and social hardship. The significance of energy in the provision of goods and services and the elevation of the standard of living of mankind, and the role it plays in industries for sustainability of production is a well known fact (Sambo, 2005).

The increasing evidence that current global policies, which promote the inefficient use of fossil fuels and energy are environmentally irresponsible and unsustainable since they cause significant environmental degradation at the local, regional and global levels. Several studies have shown that by incorporating renewable energy resources into the overall energy mix or unit of nations, any of these negative environmental impacts of energy use could be avoided or minimized. The cost of energy for domestic, commercial and industrial uses in Nigeria has risen automatically in the past few years following the liberalization and reform of the oil industry and the energy sector as a whole. The cost of energy is a very significant factor which determines the price paid by end users of commodities (National Energy Policy, (NEP) 2005).

Biogas, which is a biomass resource, is said to be ideal in deciding alternative sources of energy for rural people, in the sense that it is cheap and local in origin and production. It is also an energy source that is useful for multiple purposes; heating, lighting, small scale electric power generation, etc. (Tambawal, 2002).

Biogas is a colourless mixture of methane (60-70%), carbon dioxide (20-30%) and trace amounts of hydrogen sulphide (Martin, 2005). There is therefore, the need to popularize biogas technology in Nigeria to reduce the environmental pollution caused by the burning of fossil fuels.

Anaerobic digestion (AD) is the decomposition of organic matter in the absence of oxygen. During this decomposition, which is due to microbial activity, a gaseous mixture of methane, carbon dioxide and trace amounts of hydrogen sulphide and hydrogen is produced hence, anaerobic digestion systems are often referred to as 'biogas systems'. This process can be found in many naturally occurring anoxic environments including water course, sediments, waterlogged soils and the mammalian gut. It can be used to produce biogas from a wide range of wastes including industrial and municipal waste water, agricultural, food industry wastes, and plant residues.

Adopting anaerobic digestion has both construction and economic benefits. The construction benefits include: ease of construction and operation, odour control, pathogen reduction, improved water quality and reduced greenhouse gas (GHG) emissions. While the economic benefits of adopting anaerobic digestion include: inexpensiveness, power generation, fertilizer or compost production and reduced landfill usage, with power generation being the most attractive.

Biogas technology converts 20.70 million kilograms of human wastes per day, which can produce about 0.62 million cubic metres of biogas in a day (ESCAP, 1996). This alone can meet the cooking requirement of 266,667 persons in a day (O'Rourke, 1968). Table 1 shows the prospect of various types of wastes for biogas production.

Table 1.1: Prospects of biogas production for various types of wastes

Waste type	Biogas yield per kg of waste input m^3/kg	Population (million)	Fresh waste production per kg/day	Feedstock production/day)	Biogas production/day
Cattle	0.025	12.10	9.00	108.90	3.27
Pig	0.045	1.30	4.00	5.20	0.26
Poultry	0.075	160.00	0.04	6.40	0.51
Human	0.025	115.00	0.18	20.70	0.62

Source: ESCAP (2006).

Pronto and Curt (2008) produced ethanol from different agricultural wastes, while Birse (1999) carried out some studies on the production of fuel from solid wastes. Martin (2008) used *saccharomyces spp*. that were produced from fermented beverages gotten from Samaru village in the Northern Nigeria in the production of ethanol from corn wastes and grass straw. Table 1.2 shows the biogas generating capacities of different agricultural wastes in Nigeria (Odeyemi, 1987).

Table 1.2: Biogas generating capacities of some agricultural wastes in Nigeria

Organic materials	Biogas (kg/day)
Water lettuce	108
Water hyacinth	98
Cow dung	90
Sheep manure	94
Goat manure	200
Swine manure	306
Poultry manure	312
Cassava leaves	55
Leguminous wastes	62
Waste from flour mills	62

Source: Odeyemi (1987).

Much research has been conducted in Asian countries in assessing the conversion of livestock manure and human faeces into methane gas. Research on portable biogas digester is relatively new and has not been exploited in this country for sourcing energy.

The sizes of digesters depend on the power requirement of the engine and the operating time. An average of dual biogas /fuel (78 – 80% replacement of diesel oil) uses about 0.050m^3 of biogas per horse power per hour (ECN, 1998). To operate a refrigerator, an average of 0.5m^3 of biogas will be necessary per day. A biogas lamp uses 0.12 – 0.15m^3 of biogas per hour, while a burner (cooking stove) requires 0.2 – 0.4m^3 per hour. The different requirements for family size digester are shown in table 1.3 (ECN, 1998).

Table 1.3: Biogas Requirement and Digester Capacity Needed per Given Number of Persons

Number of persons in the family	Requirement of Biogas for cooking and lighting (m^3) per day	Volume of Digester required (m^3)	Number of cattle needed
Up to 4 persons	1	4	2 – 4
5 – 6	1.5	6	4 – 5
7 – 9	2	8	5 – 7
10 – 13	2.5	10	7 – 9
14 – 18	3.75	15	9 – 12
19 – 25	5	20	13 – 15

* Source: ECN (1998)

Research on the use of cow dung and chicken droppings for energy generation has been exploited in this country (Eze, 2001). Besides, the findings by Hess (1982), that biogas generated from wastes has a heating value of about 18,836.1 kj/m^3 to 26,370.54kj/m^3 justifies its relevance to the Nigerian situation. On the basis of this heat value, Hess (1982) estimated that on complete combustion, 1m^3 of biogas is sufficient to:

i. run a 1 horse power engine for 2 hours;

ii. provide heat for cooking 3 meals a day for family of five

iii. provide 6 hours of light equivalent to a 60 Watt bulb;

iv. run a refrigerator of 1m^3 capacity for 0.5 hours.

v. run an incubator of 1m^3 capacity for 0.5 hours.

This research exploited this renewable energy source in order to address the cooking, drying, and lighting problems including epileptic electric power supply to a minimal level.

1.2 Statement of Research Problem

According to the National Energy Policy (NEP, 2005), the cost of energy is now a very significant factor which determines the price paid by the end – users of commodities. The injudicious use of primary biofuels in most developing countries had caused many problems such as deforestation, desertification, erosion and reduced biodiversity (Twindell and Weirs, 1986).

A number of factors emanating from utilization and public acceptance of biomass resource to generate gas for heating, lighting and small scale electric power generation include low gas production or over production of gas. These barriers limit the utilization of the sustainable systems. The past and the ongoing research to reduce these problems is by proper design.

The applications of biogas digester are still limited due to unreliable performance and high cost relative to production capacity. A reduction of losses and improvement of product and investment cost are also essential criteria dictating the adoption and widespread of the digester systems, of which a number of the digesters do not meet these criteria. As such, the development of a biogas digester with good performance is of significant importance (Ann Arbor Science, 1981). It is important to note that for any successful use of biogas digesters, the choice of right technology and the availability of materials for constructing the digester are essential (Bassey, 1999). Consequently, a lot has to be done to improve the performance of biogas digester. A possible area of improvement is on the design by making it portable and cheaper for common man's affordability.

1.3 Significance of the Study

The importance of energy in the provision of goods and services to mankind, and the role it plays in industries for sustainability of production cannot be overemphasized. The performance of the portable biogas digester may be improved by low construction sophistication.

Therefore, this research work will boost the zeal of both the rural and urban people, simply because the development of the digester is affordable and efficient.

1.4 Aim and Objectives

The aim of this research is to design, construct and evaluate the performance of a portable biogas digester. This will be achieved through the following specific objectives:

i. Designing and constructing of the required portable biogas digester.
ii. Evaluating the performance of the digester with regards to biogas generation.
iii. Quantifying and identifying the various gas components in biogas and estimate their calorific value.

1.5 Scope and Limitation

The scope of this research work covers the following:

i. Designing and constructing the digester and
ii. Studying the composition of biogas produced from cow dung and poultry droppings
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CHAPTER TWO

2.0 Literature Review

2.1 Introduction

Biogas is a colourless, odourless gas produced by the decomposition of organic waste known as biomass. Biogas is generated by the anaerobic process which takes place in the absence of oxygen, through which the organic matter is converted into methane and carbon dioxide as well as gives excellent organic fertilizer as a by-product. The composition by volume of different gases in biogas is given in Table 2.1 below:

Table 2.1: Percentage composition of biogas constituents

Constituents	**Composition**
Methane (CH_4)	55 – 70 %
Carbondioxide (CO_2)	30 – 45 %
Hydrogen sulphide (H_2S)	Traces
Nitrogen (N_2)	1 – 0 %
Hydrogen (H_2)	1 – 0 %
Carbonmonoxide (CO)	0 – 1%
Oxygen (O_2)	0 – 1%

(Source: Sambo, 2005)

The composition of organic wastes most suitable for anaerobic digestion varies from one literature to another. All organic wastes contain proteins, fats, fibers, and inert material that cannot be digested as well as different macronutrient compositions (see Table 2.1). Biogas can be obtained from any organic material after anaerobic fermentation, and this occur in three main phases namely:

1. *Hydrolysis*: - During this stage complex organic polymers are broken down into their monomer intermediates amino acids, volatile fatty acids (VFA) and sugar as

shown in Figure 2.1. Reactions that lead to the production of N_2 and H_2S are not included because they account only for a small portion of the biogas produced and organic wastes consumed.

2. *Acetogenesis*:- During acetogenesis, these intermediates are converted into acetate with carbondioxide and hydrogen as by-products.
3. *Methanogenesis*:- Finally, in the methanogenesis stage, hydrogen and acetate are converted into methane and carbondioxide.

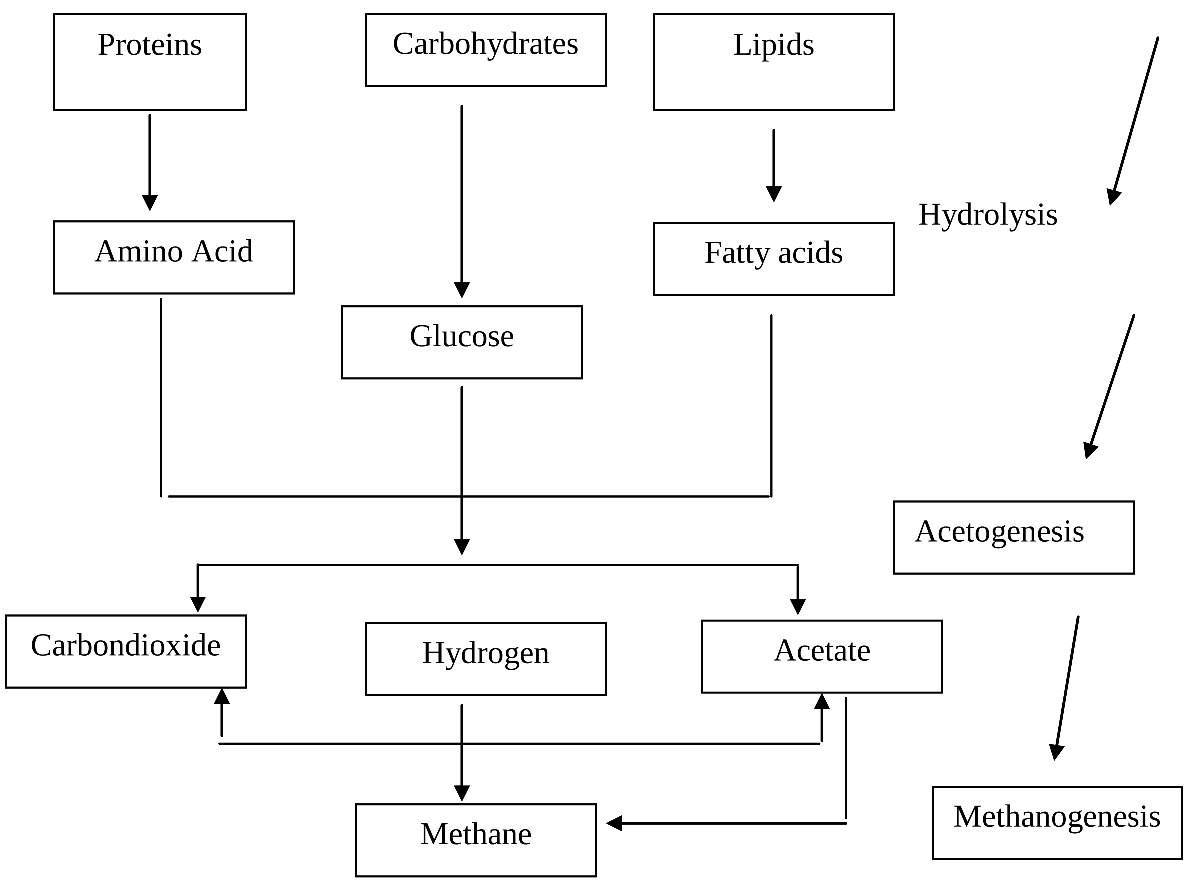


Figure 2.1: A Scheme of anaerobic digestion pathways.

(Source: Martin, (2005).

Table 2.2: Macronutrient composition of certain types of manure

Manure	Composition (%)		
	N	P	K
Human faeces	1.0	0.2	0.3
Cattle dung	0.3	0.1	0.1
Diary manure	0.7	0.1	0.5
Pig manure	1.0	0.3	0.7
Poultry manure	1.6	0.5	0.8

Source: adapted from Greenland (1997)

2.2 Reaction of Anaerobic Digestion

Table 2.2 below is a brief summary of the main reactants and products during each step. In general, the microorganisms involved in hydrolysis and acetogenesis grow more rapidly than the microorganisms involved in methanogenesis. As a result, methanogenesis tends to be the rate limiting step. However, for some materials such as grasses and newsprint, which contain more recalcitrant cellulose, hydrolysis may be very slow and rate-limiting (Mc Carty, 1964).

Table 2.3: Reactants and products involved in the three phases of anaerobic digestion

Step	Reactants	Products
Hydrolysis	Organic material	$C_6H_{12}O_6$, volatile acids
Acetogenesis	$C_6H_{12}O_6$	CH_3COOH, CO_2, H_2
	CO_2, H_2	CH_3COOH
Methanogenesis	CH_3COOH	CH4, CO_2
	CO_2, H_2	CH_4

The stoichiometry equation describing the overall anaerobic digestion varies with reactants (Cheremisinoff, 1994; Buvel *et al*., 1982).

Acetic Acid: $CH_3COOH \longrightarrow CO_2 + CH_4$

Fat, Oil: $C_{52}H_{104}O_2 + 26H_2O \longrightarrow 38CH_4 + 14CO_2 + 2H_2$

Lipids: $C_6H_{10}O_5 + H_2O \longrightarrow 3CH_4 + 3CO_2$

Proteins: $C_{16}H_{37}N_3O_{10} + 2H_2O \longrightarrow 7CH4 + 4CO_2 + C_5H_7NO_4 + 2NH_3$

Urea: $CO(NH_2)_2 + H_2O \longrightarrow CO_2 + 2NH_3$

Stearic acid: $CH_3(CH_2)_{16}COOH + 8H_2O \longrightarrow 13CH_4 + 5CO_2$

$$4H_2 + CO_2 \longrightarrow CH_4 + 2H_2O$$

During the last century, researchers have developed many overall stoichiometry equations for an arbitrary substrate. Assuming very little new biomass is generated through anaerobic digestion, the following stoichiometry equation (Buswell and Nearve, 1980) is fairly accurate.

$$C_aH_bO_cN_d \quad + \frac{4a + b - 2c - 3d}{4} \; H_2O \longrightarrow$$

$$\frac{4a + b - 2c - 3d}{8} \; CH_4 + \quad \frac{4a - b + 2c + 3d}{8} \quad CO_2 + dNH_3$$

Source (Buswell and Nearve, 1980 pg. 28).

Using general formula for proteins, carbohydrate and fats in the above equation, the theoretical methane yields for these three types of biochemicals are 0.7, 0.83 – 0.96 and 1.4m^3 /Kg respectively. In addition to increased yields, the composition of methane is higher in biogas produced from fats (71% versus 50% for carbohydrates and 38% for proteins)

Biogas is a form of biological energy that can be synthesized. In nature, there are many raw materials from which biogas can be extracted. These include human and animal manures, leaves, twigs, grasses, stalks from crops, garbage, aquatic plants and also some agricultural and industrial wastes whose organic content is greater than 2%. These materials when placed out of contact with air and disintegrated by microbes can produce biogas. Biogas produced can then be used for cooking, lighting, and running of internal combustion engines (ICE) (Eze, 2001)

Also, the solubility of methane in water is very low. At 20-25^{0}C and 1 atmospheric pressure, only 3 units of methane by volume can be dissolved in 100 units of water. Methane has a chemical formula CH_4 and a molecular weight of 16.04. It is a very stable hydrocarbon compound. Its complete combustion produces a blue flame generating a great amount of heat.

2.3 Generation of Biogas

The quantity of biogas that can be generated should depend on how effective it can be utilized. There exists a range of digester capacities depending on the number of users and the applications for which the gas can be put. Hence, the capacities of the digesters for use in the households, rural communities, farms and industrial set ups differ. Therefore, digesters can be classified into small, medium and large scale capacities.

Two main designs of biogas plants are: the floating gas holder and fixed dome types. Any of these designs can be either batch fed, semi-batch or continuous. The merits and demerits of each design need to be considered while selecting a particular type of digester. In addition, the selection depends on the technical, climatic, geographical and economic factors prevailing in a given area. These should include the availability of water, the nature and availability of fermentable materials, characteristics of building materials and construction know how.

2.4 Determination of the Size of Biogas Production Plant

Size determination of the digester should be based on the gas requirements for certain applications and the potential gas production from the available feed stock. There exists a range of plant digester capacities, depending on the number of users and applications for which the gas can be put. Hence, the capacity or size of the digester for use in household, rural community, farms and industrial set-up differ. Depending on this, therefore, digesters can be small, medium and large capacity. Plants having capacities ranging from $4m^3$ to $20m^3$ are normally used to generate biogas in rural households and fall within the small scale capacity (NEP, 2005). Medium–size digesters have capacities ranging from $50m^3$ to

500m^3. These digesters are normally ideal as community biogas digesters. Industries that produce a lot of agro-based residues and other waste products that are organic in nature have the option of building bigger digesters of up to 5000m^{3}capacity or even more, depending on the quantity of the industrial waste products (Martin, 2005). Such industries may be sited just near the farm where agricultural waste products are readily at hand. In this case, the digester(s) fall under the large scale capacity and can be sited near the outlet of the waste products (NEP, 2005). Averagely, an individual requires 0.2 to 0.3m^3 of biogas for cooking, heating, and lighting in a day. The production of this quantity requires either a continuous digester of 0.1m^3 or a batch type of 0.1 – 0.2m^3 (Martin, 2005).

2.5 Sources of Waste

One of the sources of agricultural waste is from animal production. Animal waste refers to the faecal and urinary excretion of livestock and poultry together with added bedding, rain, soil and waste feed materials as well as milk-house waste and other washing water not necessarily associated with manure (MWP, 1983).

The chief sources of animal waste production are beef, dairy and poultry operations and abattoirs. Other sources of waste for anaerobic digestion include effluents from sugar and food industries, abattoirs, as well as waste from farms such as husks, straw, leaves and saw dust.

Generally, the more digestible the feed, the smaller the quantity of manure produced; implying as indicated by Loehr (1984), that from the point of view of waste abatement and treatment, greater emphasis may be on the ration with less roughage and non-digestible material rather than least cost. Faeces of livestock consist chiefly of undigested cellulose, fibre and protein, excess minerals (mostly nitrogen, potassium and phosphorus) and residues from digested fluid (Loehr, 1984). It also contains worn out cells from intestinal lining, mucus, bacteria, foreign materials ingested with feed as well as other inorganic materials such as additives to feeds to increase the productive performance of animals.

2.6 Fermentation Materials

Biogas fermentation materials provide the material base for metabolism of biogas microbes. Fermentation materials are distributed widely and they are of great variety. It is thought that all waste materials can be converted into methane through biogas fermentation, except lignin and mineral oils. Researches which have been made in the last fifteen years show that the intermediate products (more than ten aromatic hydrocarbon derivatives) that result from the degradation of lignin can also be degraded anaerobically to yield methane (Hashimoto and Chang, 1981). Therefore, nearly all the organic substances in nature can be degraded and used for biogas fermentation. They are readily available in our rural locations.

2.7 Nutrient Balance

In the metabolism of any organic structure, various organic and inorganic substances play a role. Such a role may be stimulatory, in which the growth rate of the organism increases with increase in the concentration of the substance, or inhibitory in which the growth rate declines with concentration. Generally, most substances play an active role at high concentration. Substances which at normal concentration produce a stimulatory effect on micro-organisms are considered as nutrients. They include carbon, nitrogen, sodium, potassium, calcium and magnesium. Trace amounts of iron, cobalt, phosphorus and sulphur are also necessary for the maintenance of optimum growth anaerobes (Jeris and Kugleman 1985). The organic nutrients provide the carbon compound that is converted to methane and also serves as source of energy while the nitrogen component serves as the food source.

The relative proportion of various nutrients is very important in determining the amount of biogas yield. Martin (2005) reported that a 60 to 70% increase in methane yield was obtained when the C:N ratio was increased from 6 to 25. Methane, as well as bacterial yield also varies in relation to the proportions of carbohydrates, proteins and lipids that comprise the degradable fraction of the volatile solids content of the waste (http:///www.renewable-energyconcepts.com/biogas-bioenergy/biogas-basics/biogas-calculator.html).

Carbohydrates yield the highest quantity of anaerobic bacterial cell mass per unit mass of ultimate Biochemical Oxygen Demand (BOD) as well as the least quantity of methane per kilogram of dry substrates; lipids yield the lowest and highest quantities of bacterial cell mass and methane respectively.

2.8 Solid Contents

The concentration of solids in the substrate determines to a large extent, the amount and rate of biogas production. The amount of methane that can be generated during anaerobic digestion is a function of the fraction of biodegradable component of the total solids. Soluble volatile solids are commonly used to estimate the amount of biodegradable portion of the waste. It is therefore an important parameter in estimating potential methane production. Total solids concentration of fresh wastes range from 12.7% for dairy to 25.5% for poultry (Pronto, and Curt, 2008).

2.9 Organic Loading

Organic loading refers to the mass of organic matter added per unit volume of digester per unit time. It is usually expressed as kilogram volatile solids (kg/m^3 per day) as presented in Table 2.3. It may also be expressed as kg (TOD)/m^3 day if the waste is soluble (Grandy and Lim, 1980)

Table 2.4: A Typically Loading Rate for Anaerobic Digesters

Type of manure	Loading rate (Kg/m^3day)
Beef cattle	1.6 – 8.0
Dairy cattle	1.6 – 8.0
Poultry	1.6 – 5.0
Swine	1.1 – 5.0

*Source: Hashimoto *et al* (1977).

2.10 Seeding and Start-up Performance

Seeding is recommended as a start-up procedure for anaerobic digestion. It consists of the addition of actively digesting materials to a new digester to ensure that a good culture of all species of anaerobic bacteria is present for start up (ESCAP, 1996). The time required for start-up is inversely proportional to the amount of seeding materials provided; thus, increasing the quantity of seeding materials as observed by (Hashimoto and Cheng, 1981), results in the acceleration of start-up process of both batch and continuous flow digesters. In the absence of adequate seeding materials, digester failure may occur. It is suggested that the recommended loading rate be reduced by 90% at the start –up, increasing gradually to full loading as the digestion process is established. Performance can be monitored by monitoring the gas production, volatile acid content, pH, alkalinity, temperature and gas composition of the digester regularly (www.manuremnagement.cornell.edu).

Any imbalance will usually be indicated by sudden changes in the parameters. Also, to be monitored periodically are the total solids, volatile solids, ammonia and organic nitrogen and the Chemical Oxygen Demand (COD) of the digester, mixed liquor and the sludge. These materials with high carbon content produce biogas rather slowly and they gain the highest speed of biogas production very late; the amount of biogas they produce in the first 40 days of fermentation accounts for more than three quarters of the total biogas they produce in 60 days (EPA, 2008). Generally speaking, materials with high content in nitrogen produces biogas rapidly, the anaerobically degradable matter they contain can be converted into methane within a rather short period of time

2.11 Retention Time

Solids Retention Time (SRT) is a fundamental design parameter used in process control of anaerobic digestion (see Table 2.4). Solids Retention Time (SRT) is the theoretical time that microbial cells are retained in a biological system. It is determined as the ratio of mass of biomass in the system to the amount of biomass leaving this system per given time.

$$SRT = \frac{\text{Mass of microorganisms in the system (mg)}}{\text{Mass of microorganism leaving the system per unit time (mg/day)}}$$

Table 2.5: Optimum Retention Time and gas production at different temperature

Biomass	Operating temperature (^{0}C)	Optimum retention time (days)	Gas production (L/L – day)	Volatile solids destroyed (%)
Chicken	15	55	0.48	50.8
Manure	25	30	1.38	61.6
Cattle	15	60	0.24	40.0
Manure	25	30	0.66	65.0

Source: Hawkes, (1979).

Preliminary tests must be undertaken on the particular waste at various retention times to obtain a loading rate of various gas yield relationships. A study carried out in Korea (Hawkes, 1979) investigated the optimum retention times for optimum gas production for different temperatures with chicken manure and cattle manure fed to 20 laboratory digesters. Results obtained showed that the optimum retention time falls rapidly at higher temperatures.

Fundamentally, Solids Retention Time (SRT), which is also known as Mean Cell Residence Time (MCRT), or sludge Age in the case of municipal waste, should be determined using the quantity of active biomass in the system. In a continuous stirred tank reactor with no recycle, SRT equals the Hydraulic Retention Time (HRT) which is the mean theoretical time that the liquor spends in the system. HRT is determined as the ratio of the reactor volume to the effluent flow rate, i.e.

$$\text{HRT} = \frac{\text{Reactor Volume } (m^3)}{\text{Out flow rate of effluent } (m^3/\text{day})}$$

The minimum SRT is the minimum microbial reproduction time. Long SRT results in a more complete destruction of volatile solids and hence, higher methane yield per unit organic matter metabolized at any given temperature (Hashimoto and Cheng, 1981).

Long retention time also maximizes the potentials for acclimation to toxic environment as well as minimizing the severity of response to toxicity (Hawkes, 1979).

2.12 Temperature

Microorganisms display a wide variety of responses to temperature and are therefore, classified into three groups according to the temperature range in which they function best. Generally, bacteria that grow best at lower than 20^0C are identified as psychrophiles; those that prefer temperature higher than 45^0C are called thermophiles while those that grow best at temperature between 20^0C and 45^0C are referred to as mesophiles (Stanley Associates, 1979).

Anaerobic bacteria are believed to be extremely sensitive to fluctuations in temperature – temperature changes of only a few centigrades could lead to catastrophic failure, implying that thermal stability is very important. Although, the response of species of microbes to changes in temperature may be qualitatively similar, they differ quantitatively. For example, while all species of anaerobes, such as have been mentioned, are known to be extremely sensitive to temperature fluctuations, relatively modest reduction in temperature below the optimum does slow down fermentation more than acid formation (Jeris and Kugleman, 1985) leading to unbalanced conditions. Similarly, slight increase in temperature above the mesophilic optimum of 35^0C has been reported to stimulate methane production to a greater extent than it did for acid formation (www.manuremanagement.cornell.edu/ocs/skcase%20studyoriginal.htm).

2.13 pH and Alkalinity

Anaerobic bacteria are quite sensitive to changes in pH. Fluctuation in pH can be accommodated through proper control of temperature and/or loading rate and adequate mixing. However, effective and tight control of pH requires the availability of sufficient alkalinity to form buffer in the system.

Alkalinity is a measure of the buffering capacity of the digester content and consists of bicarbonate and hydroxide components (Hashimoto and Chang, 1981). Buffers usually form naturally in anaerobic system through the production of CO_2 and through the release of positively charged ions such as ammonium ions and cations of acids into the solution. If wastes contain carbohydrates only, buffer formation may not take place since cations are not released in the decomposition of carbohydrates (Jeris and Kugleman, 1985). It is important to have sufficient buffer to maintain the pH as close to 7.0 as possible since organic acids are always formed during anaerobic decomposition of organics.

2.14 Mixing

Biological activities are increased when digester fluids are mixed to provide homogeneous temperature and nutrient conditions throughout the digester and to allow for optimal interaction between micro-organism and waste constituents. Generally, mixing is carried out to achieve the following objectives.

(a) Maintenance of uniform temperature throughout the system,

(b) Dispersion of potential metabolic inhibitors such as high concentrations of volatile acid, ammonia or sulphide;

(c) Disintegration of coarse organic particles and bioflocs to make for greater net surface area available for bacterial attack; and

(d) Distribution of influent substrate uniformly throughout the digester.

Generally, most of the digester designs are based on batch or continuous operation mode. In the batch operation, the digester is filled completely with organic matter and the process of decomposition is allowed to proceed for a long time until gas production is completed. In continuous digester operation, the feeding and removal of organic matter takes place continually.

Factors that influence the selection of a particular design of a biogas plant are:

- **Economic:** An ideal biogas plant should cost as low as possible
- **Utilization of local materials**: Use of easily available local materials should be emphasized in the construction of a biogas plant.
- **Durability:** The construction of biogas plant requires a certain degree of specialized skills necessary to construct plants that are more durable although this may require a higher initial investment.
- **Suitability for the types of inputs:** The design should be compatible with the type of inputs that would be used.
- Feed materials to be used.
- Knowledge and experience of the technician constructing the biogas plant.

2.15 Review of Related Past Works

There are two tested and field – worthy designs of biogas units. These are:

(i) Floating gas holder type and

(ii) Fixed dome type.

About 250,000 floating gas holder type units and 200,000 fixed – dome types biogas plants have already been set up in Asian countries.

The floating gas holder type design was first developed in India in 1954. There are two models of this type of design:

(a) Vertical type and

(b) Horizontal type.

Most research works on biogas technology in Nigeria are limited to laboratory production and analysis of the biogas. This research work therefore seeks to use cow dung and chicken droppings for the production of biogas and use the produced gas for domestic cooking and to determine its suitability as substitute for wood and fossil fuels.

A study carried out in Korea (Hawkes, 1979) investigated the optimum retention times for optimum gas production for different temperatures with cattle and chicken manure fed to 20 laboratory digesters. Results obtained showed that the optimum retention time falls rapidly at higher temperatures. Eze (2001) designed and constructed a batch – operated biogas digester, the result obtained showed that the anaerobic degradation efficiency depends on the characteristics of the effluents used within the system.

It could also be observed that the total solids, volatile solids, total carbon, carbon to nitrogen ratio and the pH of the three sets of effluents are in the correct proportions. Meynell (1982) noted that encouraged degradation of wastes under anaerobic conditions, carbon and nitrogen are expected to be in their correct percentages in order to encourage faster proliferation of methanogenesis.

Ahmadu *et al.,* (2009) investigated the comparative performance of cow dung and chicken droppings for biogas production. They established that from cow dung alone, Nigeria can produce biogas sufficient to meet the daily cooking needs of about 2.3 million people.

Ezekoye and Okeke, (2006) investigated the performance of plastic biogester using spent grain and rice husks mixed together in 1:3 ratio (waste and water). They observed that the waste started producing combustible gas on the 20th day after it was charged. The maximum volume of biogas obtained from the waste was 150 litres on the 47th day.

Eze (2001) designed and constructed 500 litres capacity batch-operated metal biogas digester. He harvested cassava roots, peeled and the pulp fermented for 4 days at ambient conditions. The resultant unwanted liquid and cassava peels were used to charge the digester at a ratio of 3:1 (liquid waste to cassava peels) and allowed to ferment for 21 days. Results obtained showed generation of a combustible gas (biogas) after three days of charging.

Many researches have been conducted in the field of biogas digesters, but more intensive collective effort is needed on the system optimization, efficiency and putting in place achievable goals through strong community campaigns, micro-loan schemes enhancement and government subsidies. This piece of research came up with a number of feasible solutions from materials selection, and biogas energy generation for cooking.

CHAPTER THREE

3.0 Materials and Methods

3.1 Materials

The materials to be used for the construction of the digester are as follows:

Galvanized iron sheet, circular hollow section galvanized pipe, PVC pipes, control valve, socket and plug, brazing rod, electrode and laboratory wares.

Cow dung and poultry droppings were collected fresh from Kara and Taibat poultry farm in Sokoto State. The loading of the digester and subsequent gas production was carried out starting with cow dung as feed materials. A retention time of 30 days was allowed, during which gas produced was tested directly for use. At the 30th day, the digester content was emptied and the digester was cleared. Poultry-droppings were then loaded as feed material. It was allowed for 30days retention time. Gas produced was tested directly.

3.2 Methodology

3.2.1 Design theory

The type of design adopted in this work is the floating gas holder type. The digester is a separate component with the gas holder inserted and floating in a separate water jacket. The theory behind the design is simply "downward delivery and upward displacement". The Slurry on fermenting in the digester produces gas and this gas is delivered to the bottom of the water jacket via a pipe. The pipe extends above the surface of the water level in the water jacket.

3.2.1.1 *Design consideration*

Minimizing cost is an important design consideration. The biogas plant has three major components these include the digesting tank, gas holder and the water jacket. The basic information required for determining the design selection was based on climatic, economic and substrate conditions. The digester is to be constructed above the ground and is in cylindrical form with an inlet into which the fermentable mixture is introduced in the form of a liquid slurry. The gas holder is normally an airproof steel container, that floats like a ball on the fermentation mix, cut off air to the digester (anaerobiosis) and collects the gas generated.

3.2.1.2 *Design parameters*

The Following design parameters were considered in the construction of the biogas digester:

i. Materials selection

ii. Total Solid (TS): This contains calculations of organic materials.

iii. Favourable temperature PH value and C/N ratio for good fermentation

3.2.1.3 Justification of the choice of materials for construction

The choice of materials used for construction of the digester was based on the reliability and availability of the materials.

3.2.1.4 *Cross-section of the digester:*

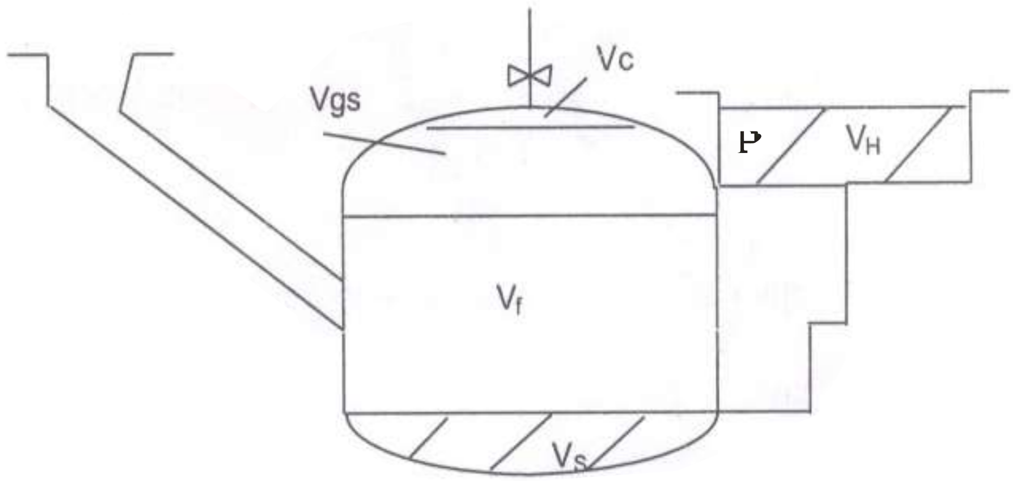


Fig. 3.1: Cross-section of the digester

Where

Vc = Volume of gas collecting chamber

Vgs = Volume of gas storage chamber

V_f = Volume of fermentation chamber

V_H = Volume of hydraulic chamber

V_S = Volume of sludge layer

Total volume of digester V = Vc+Vgs+V_f+V_S

3.2.1.5 Volume calculation of digester:

Assumptions:

For Volume	**For Geometrical Dimensions**
$Vc \leq 5\% \ V$	$D = 1.3078 \ V^{1/3}$
$Vs \leq 15\% \ V$	$V_1 = 0.0827D^3$
$Vgs + V_f = 80\% \ V$	$V_2 = 0.05011 \ D^3$
$Vgs = V_H$	$V_3 = 0.3142 \ D^3$
$Vgs = 0.5 \ (Vgs + V_f + Vs) \ K$	$R_1 = 0.725D$
Where K = Gas production rate per m^3	$R_2 = 1.0625D$
	$f_1 = D/5$
	$f_2 = D/8$
	$S_1 = 0.911D^2$
	$S_2 = 0.8345D^2$

Given: 6 cows of body weight 200 Kg each;

Temperature = 30^0C (average)

Let HRT = 40 Days (for temp. 30^0C)

Total discharge = 10Kg x 6 = 60 Kg/day

TS of fresh discharge = 60Kg x 0.16 = 9.6 Kg.

In 8% concentration of TS (to make favourable condition)

8 Kg. Solid = 100 kg. Influent

1Kg. Solid = 100/8 Kg influent

9.6Kg Solid = 100 x 9.6/8 = 120 Kg Influent

Total Influent required = 120Kg.

Water to be added to make the discharge 8% concentration on

TS = 120 Kg - 60Kg = 60 Kg

Working Volume of digester = $V_{gs} + V_f$

$V_{gs} + V_f$ = Q.HRT

= 120 Kg/day X 40 days

= 4800Kg (1000Kg = $1m^3$) = 4.8 m^3

From geometrical assumptions:

$V_{gs} + V_f = 0.80\ V$

Or V = 4.8/0.8 = $6.0m^3$ (putting value $V_{gs} + V_f = 4.8m^3$)

& D = 1.3078 V1/3 = 2.376m ≅ 2.40m

Again

$$V_3 = \frac{3.14 \times D^2 H}{4}$$

(Putting $V_3 = 0.3142D^3$)

Or $$H = \frac{4 \times 0.3142 \times D^3}{3.14 \times D^2} = 0.96m$$

Say H = 1.00m

Now we find from assumption as we know the value of 'D' & 'H'

f_1 = D/5 = 2.40/5 = 0.480m

f_2 = D/8 = 0.30m

R_1 = 0.725 D = 1.74m

R_2 = 1.0625 D = 2.55m

V_1 = 0.0827 D^3 = $1.143m^3$

Vc = 0.05V = $0.3m^3$

3.2.1.6 Pressure within the cylinder

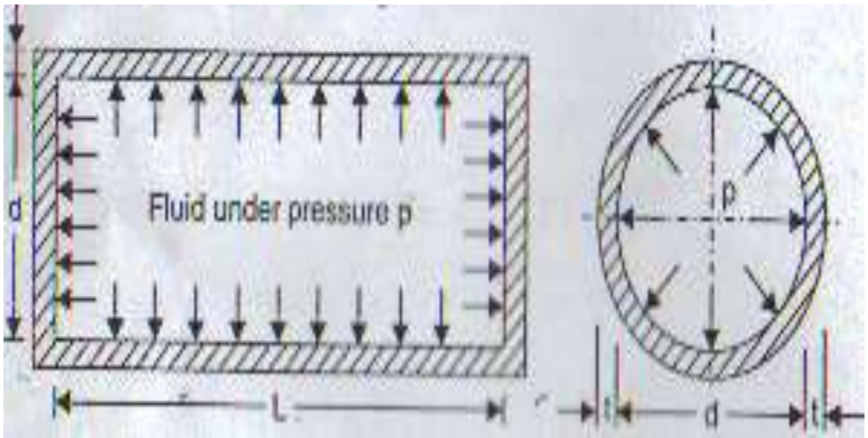


Figure 3.2: Pressure within the cylinder. (Bansal, 2007 pg. 740)

In the case of thin cylinders, the stress distribution is assumed uniform over the thickness of the wall.

$let\ d =$ internal diameter of the thin cylinder

$t = Thickness\ of\ the\ wall\ of\ the\ cylinder$

$p =$ internal pressure of the fluid

$L =$ length of the cylinder

Force due to fluid pressure

$=`pxArea\ on\ which\ p\ is\ acting$

$= p\ x \frac{\pi}{4} d^2$

Resisting force

$= \sigma_2\ x\ Area\ on\ which\ \sigma_2\ is\ acting$

$= \sigma_2\ x\ \pi d\ x\ t$

:. Hence in the limiting case

Force due to fluid pressure=Resisting force

$p\ x \frac{\pi}{4} d^2\ x\ \pi d\ x\ t$

$$\sigma_2 = \frac{p\ x \frac{\pi}{4} d^2}{\pi d\ x\ t} = \frac{pd}{4t}$$

3.2.1.7 *Determine the thickness of the cylinder*

Let the cylinder internal diameter be 0.50m containing air at a pressure of 7N/mm^2 (gauge). When the maximum permissible stress induced in the material is 80N/mm^2.

Internal diameter of cylinder, $d = 0.50m$

Let $t = Thickness\ of\ the\ cylinder, p = \frac{7N}{mm^2}$

$$\sigma_1 = \frac{pd}{2t}$$

$$t = \frac{pd}{2 \times \sigma_1} = \frac{7 \times 0.50}{2 \times 80} = 0.02187m \qquad = 2.188\text{mm}$$

3.2.2 General layout of the biogas plant

The general layout of a biogas plant consists of pretreatment, digester, biogas storage, biogas utilization and the effluent disposal (Figure 3.3). The effluent of the digestion can be separated into solid and liquid products. For biogas plants on farm sites, the solid products can be used for bedding and the liquid product can be spread as fertilizer. The flexibility of the system enables direct utilization of the entire gas (biogas) without separation if the need arises.

The gas collection system design was such that the volatile nature of the digestion product, the amount of gas to be collected as well as the provision for a means of releasing the gas at will are provided without compromising the leak proof nature of the entire system.

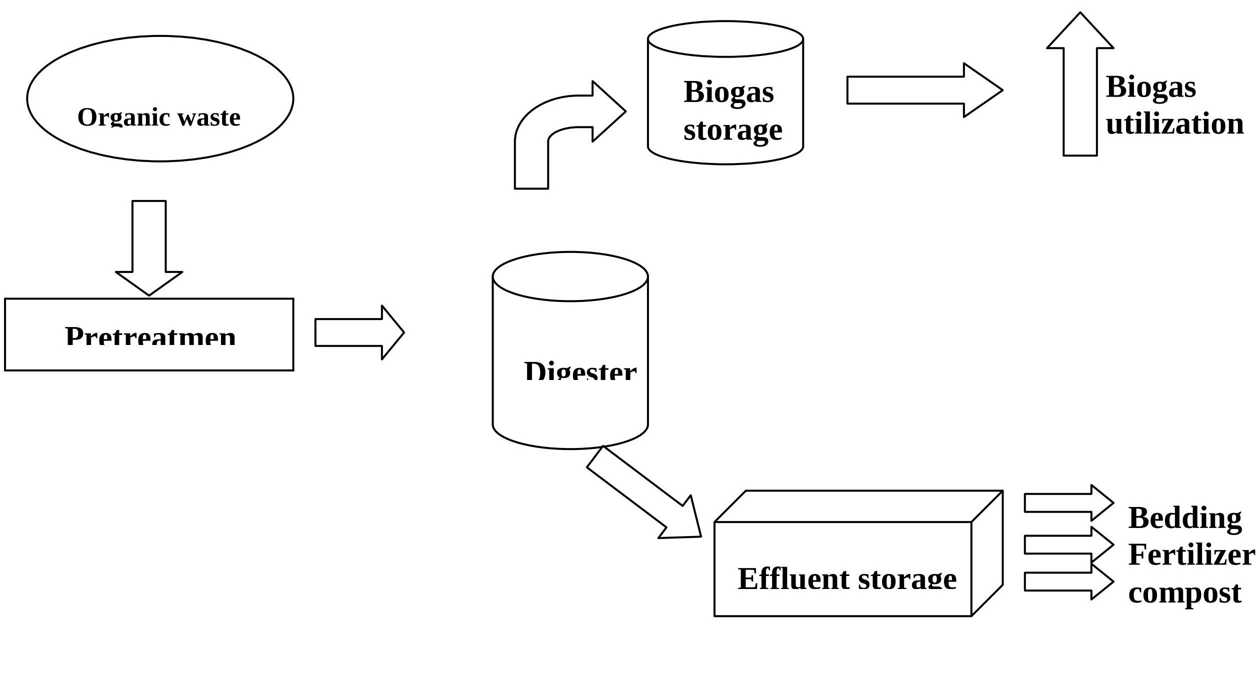


Figure 3.3: General layout of biogas plant

3.2.2.1 *Basics of a biodigester*

Figure 3.4 below is a sketch of the profile of a biodigester to better visualize the concept. In the picture, A represents the biodigester tank where the water and manure mixture is digested by the bacteria. B and C represent the entrance and exit tubes respectively. The entrance tube should enter the tank near the bottom and the exit tube should be connected to the tank just beneath the first row. The entrance tube is where the prepared slurry enters into the fermentation tank and the exit tube could serve as effluent discharge tube.

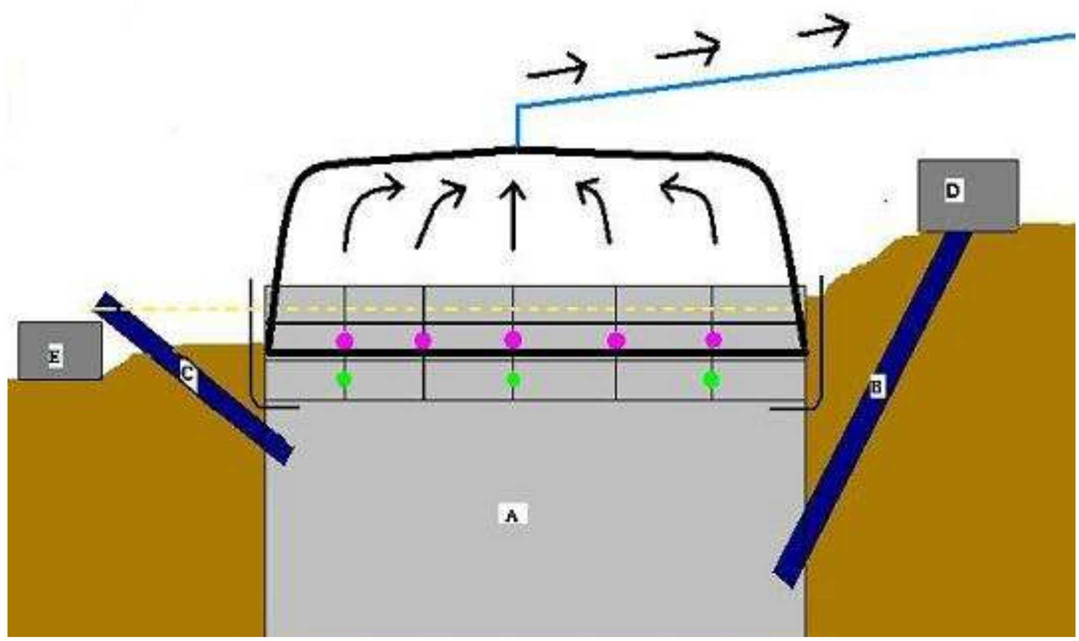


Fig 3.4: Basics of Biodigester. (Meynell, 1982)

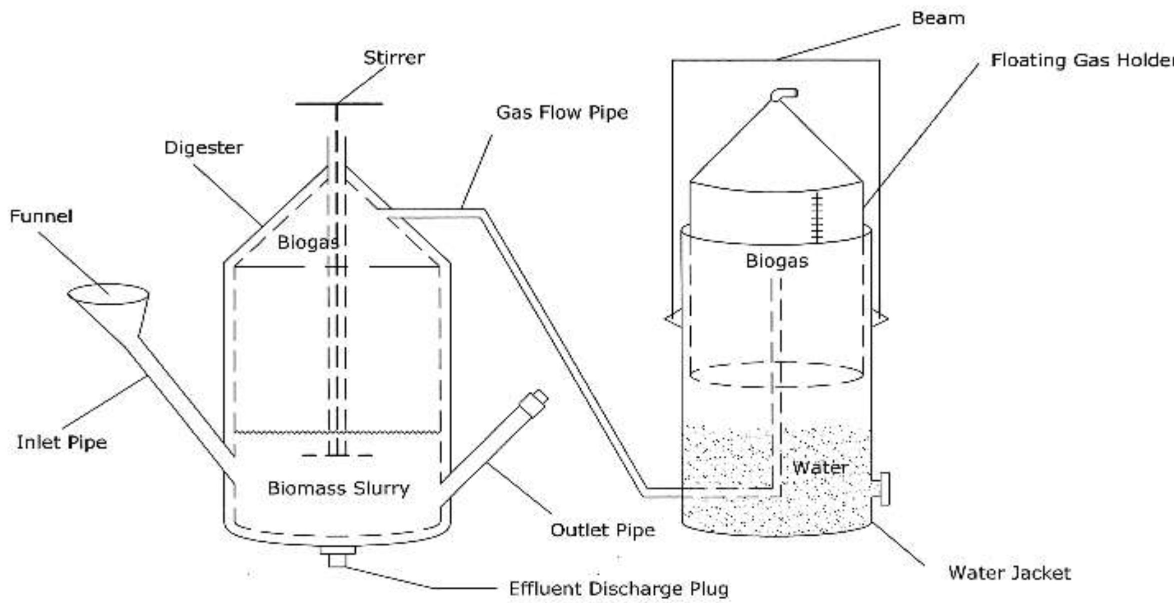


Figure 3.5: Floating Gas Holder Biogas Plant

3.2.3 Design Basis

3.2.3.1 *Digester operating volume*

The operating volume of the digester depends on the volume of slurry in the digester. The operating volume of the digester (V_o) is determined on the basis of the retention time (RT) and the daily substrate input quantity (Sd)

This is given as:

V_o = SdxRT ----------(1)

Substrate input (sd) = Biomass (B) + water (W)

Sd = B + W…………(2)

3.2.3.2 *Digester total volume*:

The total volume of the digester (V_T), is greater than the operating volume. This is to give room for the biogas produced and rise of the slurry during fermentation.

The total volume is thus given as:

$$V_T = \frac{V_O}{0.9}$$

3.2.3.3 *Volume of gas holder* (V_g)

The gas holder volume (V_g) depends on the relative rates of gas generation and gas consumption. The gas holder was deigned to

(a) cover the peak consumption rate (gc_{max}) for the period of maximum consumption (tc_{max}).

$V_g = V_{g1}$ ______________(4)

(b) Hold the gas produced during the longest production time.

Zero-consumption period (tz)

$V_g = V_{g2}$ ____________(5)

From equation (4)

$V_{g1} = gc_{max} \times tc_{max}$ _____(6)

And from equation (5)

$V_{g2} = G_h \times tz_{max}$ _______(7)

Where gc_{max} = maximum hourly gas consumption (m^3/h)

tc_{max}= time of maximum consumption (hr)

VC_{max} = maximum gas consumption (m^3)

G_h = hourly gas production (m^3/h) = G ÷24h/d

G = daily gas production (m^3/day)

TZ_{max} = maximum zero consumption time (h)

The larger V_g-value (V_{g1} or V_{g2}) determines the size of the gasholder. A safety margin of 10-20% should be added (Ahmadu *et al.*, 2009)

vg=1.15 ($\pm$ 0.5) x max (vg_1, vg_2)

The ratio vd ÷ vg (digester volume ÷ gas holder volume) is a major factor with regard to the basic design of the biogas plant. For a typical agricultural biogas plant , the vd/vg -ratio amounts to somewhere between 3.1 and 10.1 , with 5:1 -6:1 occurring most frequently.

From Bernoulli's equation

$\Delta P_d = \rho_{slurry}\, g(H_2-H_1)$ ________(8)

Slurry inlet pipe

Area of material for slurry inlet pipe A = $\pi \Delta h$____________________(9)

3.2.3.4 *Digester Inlet Pipe*

The design of the pipe is such that its position and height above the exit must take full advantage of the pressure differential between the exit and inlet sections. The pipe diameter will be moderate enough to avoid clogging by the influent. While the angle of the pipe or height with respect to the digester should be on an inclination of 45^o as shown in Figure 3.4 below. For a digester height of 0.8m and pipe diameter of 0.089m, let the length of the inlet pipe be 0.3m.

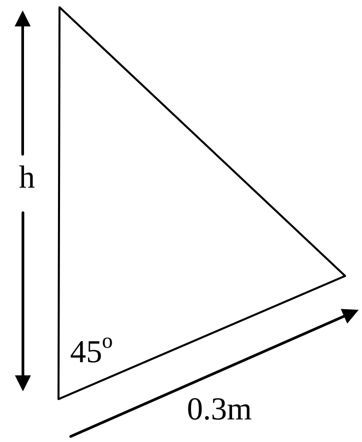


Figure 3.6: Digester inlet pipe

Since the pipe is on inclination of 45^0, the height of inlet pipe with respect to the digester is given as 0.30 Cos 45^0 = 0.212m.

But maximum waste volume of 75% of the total digester volume was assumed.

Therefore, 75% of total height of digester is 75/100 x 0.80 = 0.60m.

Therefore, if x is height of inlet pipe from base of digester, then

(x + 0.089 + 0.3) m = 0.60m

x = (0.60 – 0.407) m = 0.193m.

A standard pipe of length 0.30m and diameter of 0.089 was chosen. The pipe thickness was 0.02m.

Considering the corrosive tendency of the slurry, the position should be 0.19m from the digester base.

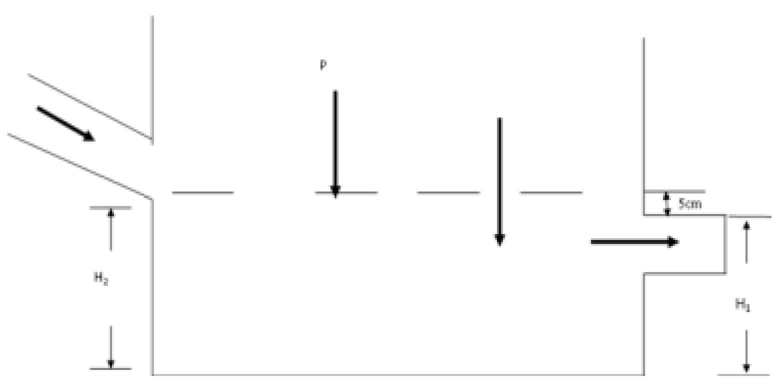
3.2.3.5 ***Digester Out let***

Due to the corrosive nature of the slurry and the fact that only pressure differential between the inlet and exit can be used for its discharge, the effluent piping will be designed from a 3 inch socket and plug of galvanized steel located at the bottom of the tank. From inlet design, the inlet pipe is located at a distance of 0.19m from the digester base. Let P_p be the pressure differential required for slurry discharge.

3.2.4 Component design calculations

Table 3.1 Below summarizes the design calculations used to construct the various component parts:

Table 3.2: Component design calculations

Initial data	Calculation and sketches	Results
H_2 = 20cm, H_1 = 15cm, g = 9.8ms^{-2}	 Body diagram of fermentation tank Where H_2 = 20cm H_1 = 15cm	$\Delta P_d = 0.490\ \rho_{slurry}$

	$g = 9.81 m/s^2$. From Bernoulli's equation $P_2 = P_A + \rho_{slurry} \times H_2$ Where $\rho_{slurry} = \dfrac{\text{Mass of total digester content}}{\text{Volume of Digester}}$ $P_1 = P_A + \rho_g \times H_1$ The differential $\Delta P_d = P_2 - P_1$ $= (P_A - P_A) + \rho_{slurry}\, g\, (H_2 - H_1)$ $\Delta P_d = \rho_{slurry}\, g\, (H_2 - H_1)$ Substituting values from eqn 8 $\Delta P_d = \rho_{slurry}\, g\, (H_2 - H_1)$ $\Delta P_d = \rho_{slurry} \times 9.8 (m/s^2) \times (20 - 15) \times 10^{-2} m$ $\Delta P_d = \rho_{slurry} \times 0.490\, (m^2/S^2)$ Therefore, if the total density of the slurry contained within the digester can be determined, the pressure head required for slurry discharge through 3^{11} Socket is $\Delta P_d = 0.490\, \rho_{slurry.}$	

Initial data	Calculation and sketches	Results
$\Delta = 0.089$, $h = 0.30m$, $\pi = 3.142$, $t = 0.004m$	**Slurry Inlet Pipe** Area of material, $A = \pi \Delta h$ Where Δ = volume of inlet pipe Density of steel = 7860 kg/m^3	$A = 0.0839 m^2$ $W_p = 2.62 kg$. $WP_o = 4.62 kg$.

density of steel = 7860kg/m^3	Δ = 0.089, h = 0.30m, t = 0.004m From equation 9, $A = \pi\Delta h$ Therefore $A = \pi(0.089)(0.30)m^2 = 0.0839m^2$ Axt Where t = thickness = (0.0839 x .004) = 3.336 x10^{-4}m^3 Mass of inlet pipe (7860 x 3.336 x 10^{-4}) kg = 2.62kg Therefore, Wp = 2.62kg. Total Mass of Inlet Pipe section = mass of inlet pipe + mass of pipe cover But mass of pipe cover (3 inches socket and plug) = 2.0kg Therefore, WP_c = 2.0kg Total Mass of inlet pipe section = (W_P + WP_o) Kg = (2.62 + 2.0)kg Therefore, WP_o = 4.62kg	

Initial data	Calculation and sketches	Results
t = 0.22, A = 0.11 ρ =7860Kg/m^3	**For the stirrer** The volume of baffles V = Area x thickness of steel sheet = (0.11 x 0.22) x 1.2 x 10^{-3} = 2.904 x 10^{-5}m^3 Density of Steel = 7860 kg/m^3 Mass of baffles = (7860 x 2.904 x 10^{-5}) kg = 0.228kg.	V=2.904x10^{-5}m^3 Mass of baffles = 0.228kg.
	Digester cover	
Area of digester cover = 0.196m^2, t = 1.2mm Using 18 gauge steel	Volume of digester cover material = Axl V = 0.196x1.2x10^{-2}m^2 = 2.352x10^{-4} W_d = 1.85 Kg	W_d = 1.85 Kg

3.3 Temperature and Pressure Gauges

Due to the effect of temperature and pressure variations on digester performance and the need for their systematic monitoring, simple and easy to read temperature and pressure gauges are to be mounted on the digester cover.

3.4 Fermentation Process

The fermentation process is entirely anaerobic in nature. The digester is completely sealed and does not allow air to escape into the fermentation chamber. Following initial charging with the slurry, a 3 inch socket and plug is used to completely seal the inlet pipe.

3.5 Measurement of Produced Biogas

The height of gas holder floating above water level was read off using a meter rule attached to the gasholder. Volume of biogas produced was obtained as the product of the height of gas holder above water level and its base area.

3.6 Gas Exit Valve

Since the product of the digestion process is volatile, the gas exit provided must be such that it can be closed at will without chances of gas leakages and must not interfere with the stirrer.

3.7 Gas Collection System

Based on the fact that the volume of biogas produced per weight of organic matter fed into the digester is variable and depends, among other factors on the nature of the waste, operating temperature and pH, etc. The design of the gas storage system took into consideration those factors that influence biogas production from the system.

3.8 Analysis of Produced Biogas

The biogas produced was analyzed qualitatively using gas chromatography. Biogas produced was evacuated from the gasholder bottles (cylinders) and taken to the laboratory for analysis. The biogas was passed through solutions of lead acetate and potassium hydroxide. Hydrogen sulphide (H_2S) and carbon dioxide (CO_2) were absorbed respectively, leaving methane (CH_4) gas to be collected at the exit.

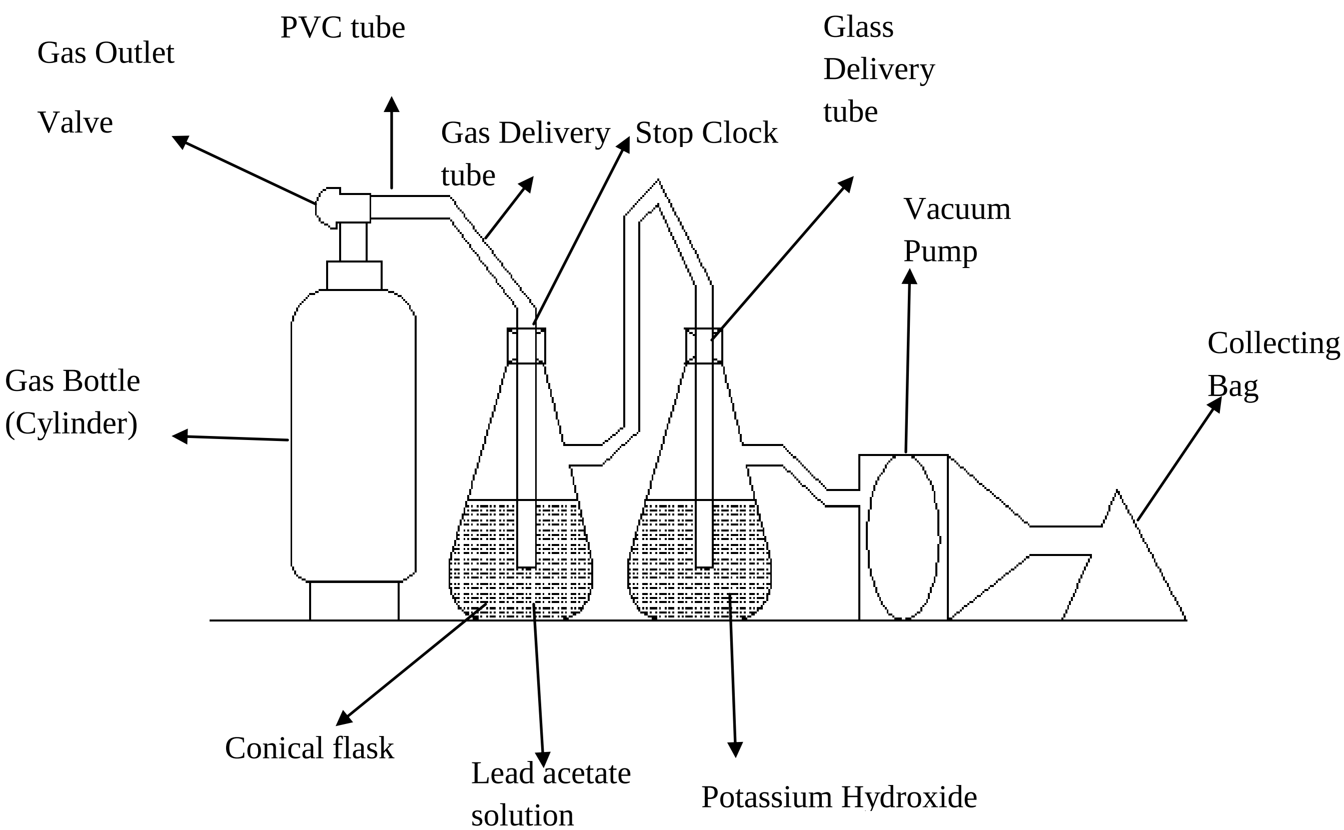


Figure 3.7: Diagram of experimental set up for biogas analysis

3.9 Design Specification

Following a careful analysis of the design computations as well as the conditions that determine the materials selected for this project, the following specifications were used for the final biogas construction.

3.9.1 Fermentation tank material

i. GI Sheet

ii. Specification Gauge 18

iii. Thickness 1.2mm

iv. Coating: Red oxide

v. Dimensions: Internal diameter, d= 0.5m, Internal height, h= 0.6m.

vi. Surface area

(a) Area of Cylindrical Surface

$A_s = \pi dh$

$A_s = \pi(0.5)\,(0.6)m^2$

$A_s = 0.942m^2$

(b) Area of base surface

$A_b = \frac{\pi d^2}{4}$, $A_b = \frac{\pi(0.5)^2}{4} = 0.196\ m^2$

$A_r = A_s + A_b = (0.942 + 0.196)\ m^2 = 1.138\ m^2$.

vii. Volume, $V_d = \frac{\pi d^2 h}{4}$

$= \frac{\pi\ (0.5)^2\ (0.6)\ m^3}{4}$

Therefore, $V_d = 0.118\ m^3$.

3.9.2 Slurry inlet pipe

i. Material : galvanized iron pipe

ii. Specification: 3 inch; thickness: 4mm

iii. Dimensions: Internal Diameter = 0.089m; Length = 0.30m

iv. Surface Area = $\pi dl = (0.089)\ (0.30)m^2$

$$= 0.027m^2$$

v. Volume = $\frac{\pi d^2 L}{4} = \frac{\pi (0.089)^2\ (0.35) m^3}{4}$

$$= 0.0022m^3$$

3.9.3 Stirrer assembly

(a) Bolt and nut

i. Material: galvanized steel

ii. Specification: M20

iii. Thread pitch = 2.5mm

iv. Quantity = 1

(b) Shaft (1) material: Galvanized steel pipe

Dimension: length = 1.40m

External diameter = 0.016m

3.9.4 Slurry Inlet Pipe Cover

i. Material: Galvanized

ii. Specification: 3 inch socket plug

3.9.5 Slurry outlet

iii. Material: Galvanized Steel

iv. Specification: 3 inch plug and socket

3.9.6 Gas valve assembly

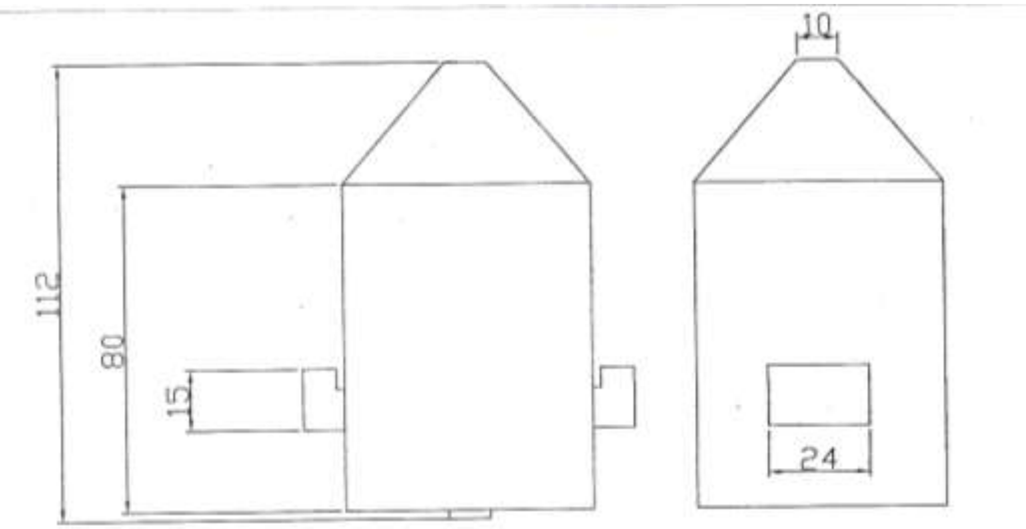
(a) Ball Valve

i. Material: Brass

ii. Specification 3/8 inch

3.10 Construction

The designed biogas digester was constructed at the Sokoto Energy Research Centre workshop. The manufacturing process involved in the construction is galvanized iron sheet metal works, drilling and welding. Different components were separately fabricated and later assembled. After assembling the sharp edges were chamfered and the structure was painted. The digester consists of the digester tank, gasholder, water jacket, slurry inlet and outlet pipe, stirrer and the gas outlet as presented in the working drawings:

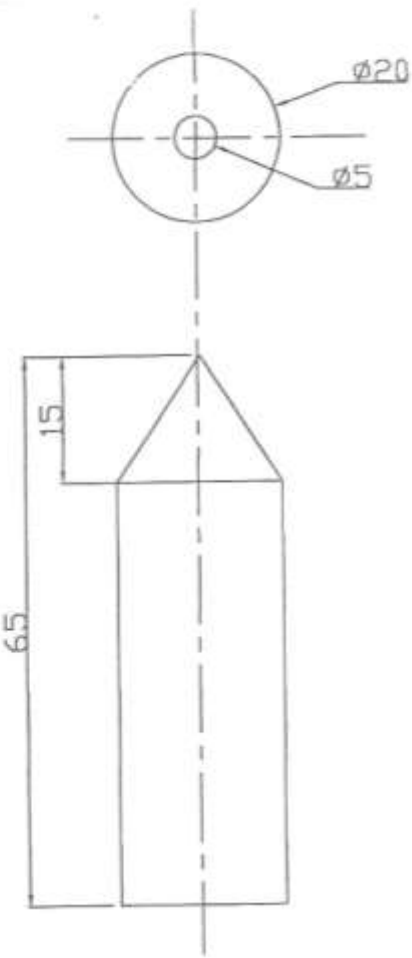


AHMADU BELLO UNIVERSITY ZARIA
DEPARTMENT OF MECHANICAL ENGINEERING

Title: Digester

Drawing No: 1
Scale: 1: 10
Units: mm

	NAME	SIGN	DATE
Drawn	Eng. Mamuda Muhammad		
CAD By	Eng. Mamuda Muhammad		
Checked	Prof. A. I. Obi		
Approved			



AHMADU BELLO UNIVERSITY ZARIA DEPARTMENT OF MECHANICAL ENGINEERING				
Title: Gas Holder				Drawing No: 2 Scale: 1: 10
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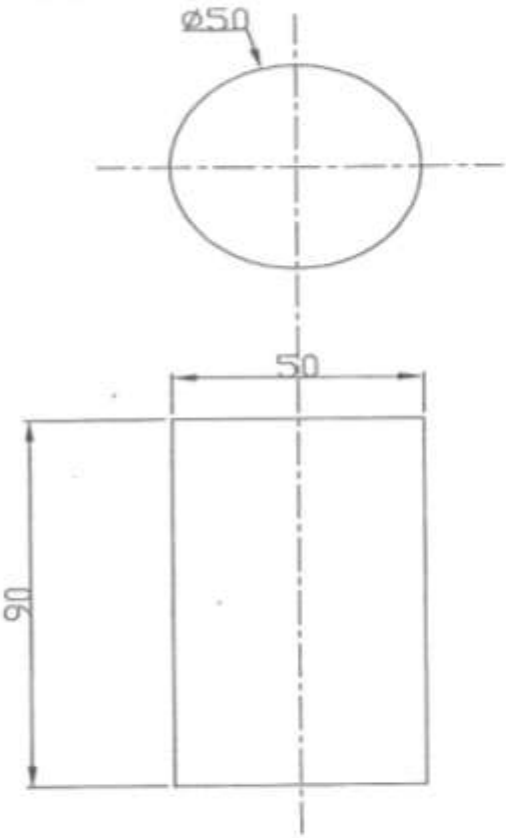
Drawn	Eng. Mamuda Muhammad			
CAD By	Eng. Mamuda Muhammad			
Checked	Prof. A. I. Obi			
Approved				



AHMADU BELLO UNIVERSITY ZARIA DEPARTMENT OF MECHANICAL ENGINEERING				
Title: Water Jacket				Drawing No: 3 Scale: 1: 10
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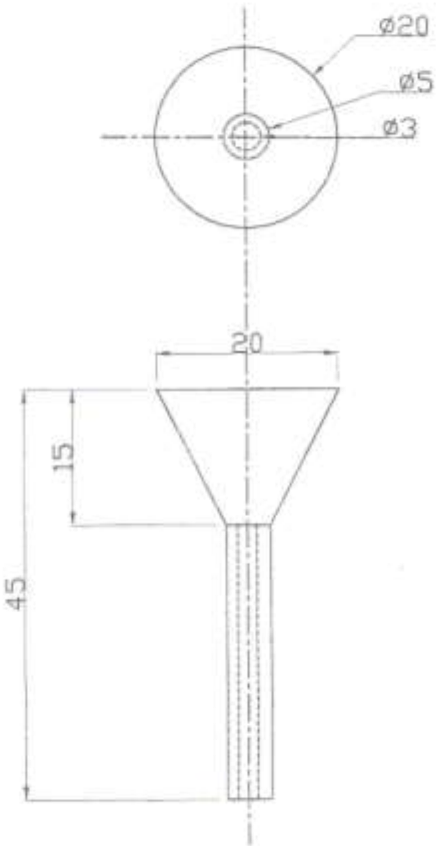
Drawn	Eng. Mamuda Muhammad			
CAD By	Eng. Mamuda Muhammad			
Checked	Prof. A. I. Obi			
Approved				



AHMADU BELLO UNIVERSITY ZARIA DEPARTMENT OF MECHANICAL ENGINEERING				
Title: Inlet Pipe				Drawing No: 4
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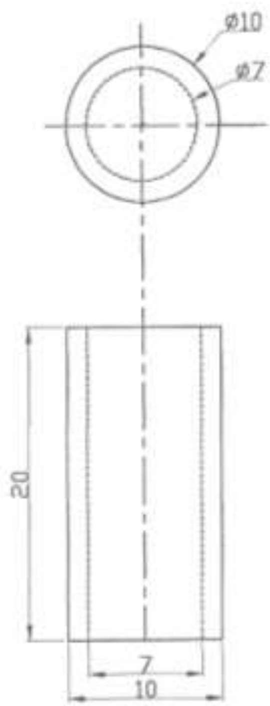
Drawn	Eng. Mamuda Muhammad			
CAD By	Eng. Mamuda Muhammad			
Checked	Prof. A. I. Obi			
Approved				



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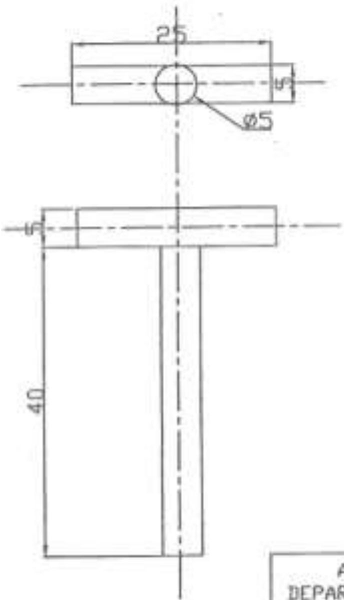
Title: Outlet Pipe				Drawing No: 5 Scale: 1: 10
	NAME	SIGN	DATE	Units: mm
Drawn	Eng. Mamuda Muhammad			
CAD By	Eng. Mamuda Muhammad			
Checked	Prof. A. I. Obi			
Approved				



AHMADU BELLO UNIVERSITY ZARIA DEPARTMENT OF MECHANICAL ENGINEERING				
Title: Stirrer				Drawing No: 6
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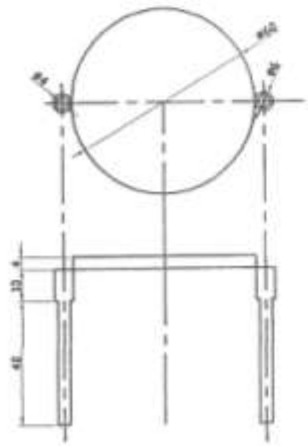
Drawn	Eng. Mamuda Muhammad			
CAD By	Eng. Mamuda Muhammad			
Checked	Prof. A. I. Obi			
Approved				



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Title: Guide Beam				Drawing No: 7 Scale: 1: 10
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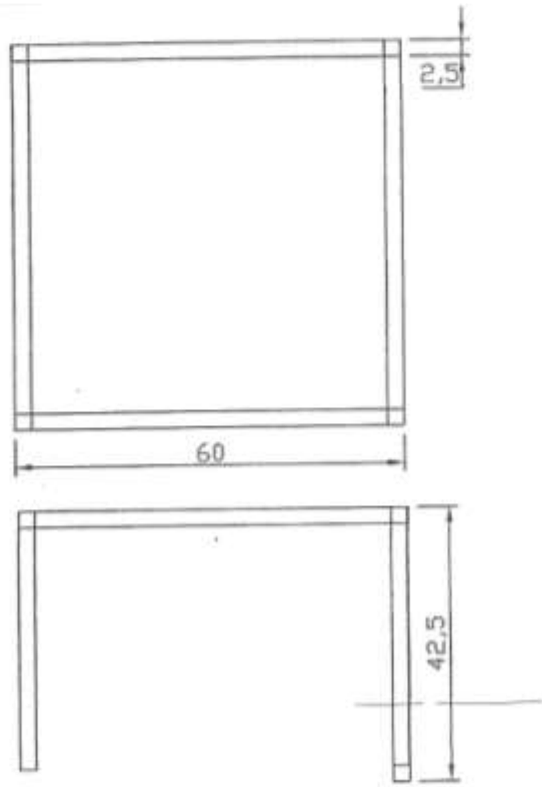
Drawn	Eng. Mamuda Muhammad			
CAD By	Eng. Mamuda Muhammad			
Checked	Prof. A. I. Obi			
Approved				



AHMADU BELLO UNIVERSITY ZARIA
DEPARTMENT OF MECHANICAL ENGINEERING

Title: Digester Stand				Drawing No: 8
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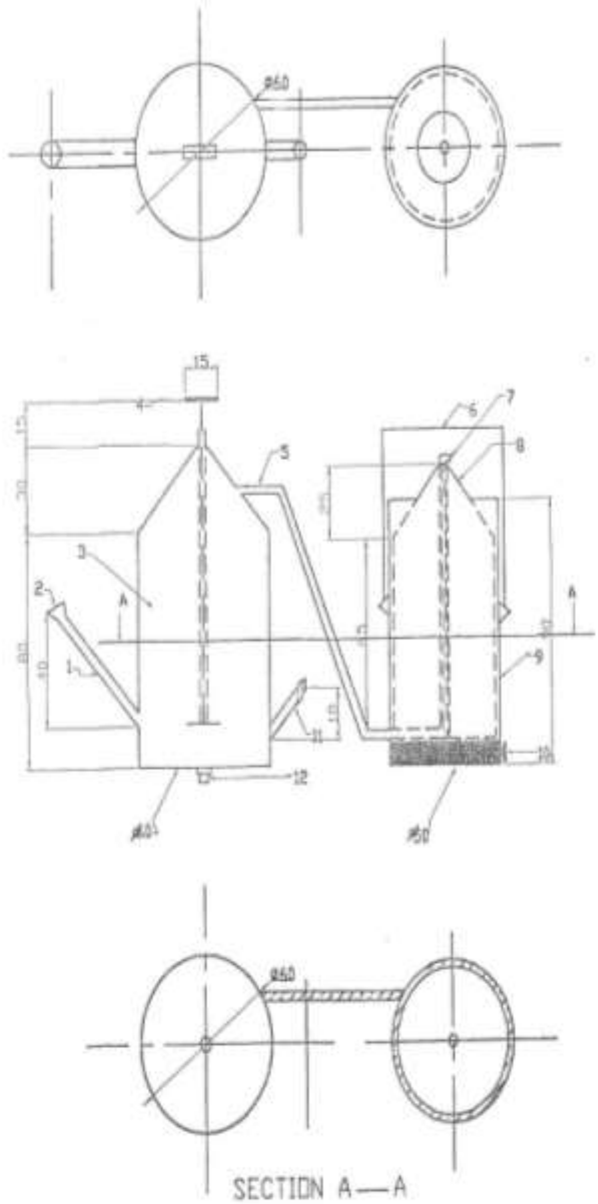
Drawn	Eng. Mamuda Muhammad			
CAD By	Eng. Mamuda Muhammad			
Checked	Prof. A. I. Obi			
Approved				



S/N	DESCRIPTION	QTY	MATERIAL	DRAWING OR STANDARD
12	Effluent Discharge	1	Galvanised Steel	STANDARD
11	Outlet pipe	1	Galvanised Steel	CONSTRUCTED
10	Control Valve	1	Galvanised Steel	STANDARD
9	Water Jacket	1	Galvanised Sheet	CONSTRUCTED
8	Floating gas Holder	1	Galvanised Sheet	CONSTRUCTED
7	Gas tap	1	Galvanised Steel	STANDARD
6	Guide beam	1	Mild Steel	CONSTRUCTED
5	Gas flow pipe	1	Galvanised Steel	STANDARD
4	Stirrer	1	Mild Steel	CONSTRUCTED
3	Digester	1	Galvanised Sheet	CONSTRUCTED
2	Funnel	1	Galvanised Sheet	CONSTRUCTED
1	Inlet Pipe	1	Galvanised Steel	CONSTRUCTED

AHMADU BELLO UNIVERSITY ZARIA
DEPARTMENT OF MECHANICAL ENGINEERING

Title: Design and construction of 0.1m3 Biogas digester Front View Design			Drawing No: 9
			Scale: 1: 10
	NAME	SIGN	DATE	Units: mm
Drawn	Eng. Mamuda Muhammad			
CAD By	Eng. Mamuda Muhammad			
Checked	Prof. A. I. Obi			
Approved				

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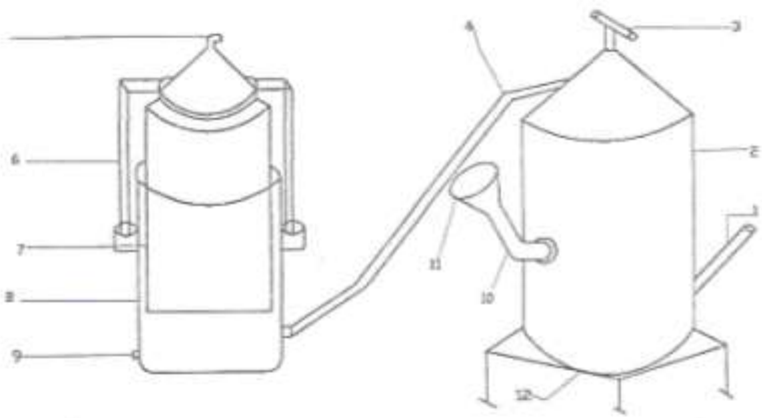

S/N	DESCRIPTION	QTY	MATERIAL	DRAWING OR STANDARD
12	Effluent Discharge	1	Galvanised Steel	STANDARD
11	Funnel	1	Galvanised Steel	CONSTRUCTED
10	Inlet Pipe	1	Galvanised Steel	CONSTRUCTED
9	Control Valve	1	Galvanised Sheet	STANDARD
8	Water Jacket	1	Galvanised Sheet	CONSTRUCTED
7	Floating gas Holder	1	Galvanised Steel	CONSTRUCTED
6	Guide beam	1	Mild Steel	CONSTRUCTED
5	Gas tap	1	Galvanised Steel	STANDARD
4	Gas flow pipe	1	Mild Steel	STANDARD
3	Stirrer	1	Galvanised Sheet	CONSTRUCTED
2	Digester	1	Galvanised Sheet	CONSTRUCTED
1	Outlet pipe	1	Galvanised Steel	CONSTRUCTED

AHMADU BELLO UNIVERSITY ZARIA
DEPARTMENT OF MECHANICAL ENGINEERING

Title: Design and construction of 0.1m3 Biogas digester (Isometric)

Drawing No: 8
Scale: 1: 10
Units: mm

	NAME	SIGN	DATE
Drawn	Eng. Mamuda Muhammad		
CAD By	Eng. Mamuda Muhammad		
Checked	Prof. A. I. Obi		
Approved			

CHAPTER FOUR

4.0 RESULTS

4.1 Stage Design of the Digester

One sheet of 18 gauge galvanized steel sheet (1000x800) was used for the construction of the digester. Each part of the digester was cut to shape, formed, seamed and later brazed and welded accordingly. Two and half sheet of the same material were used in the construction of the water jacket and the gas holder. The gas holder was of the same geometrical shape as the water jacket with clearance for sliding in the water jacket.

Leakage tests were conducted on the digester, water jacket and gas holder by filling the components with water and allowed to stay for some time. It was observed after 24 hours that there was no leakage in any of the components.

4.2 Slurry Preparation

In slurry preparation 50kg each of cow dung and chicken droppings were each thoroughly mixed with an equal volume of water.

4.3 Temperature Measurement

The ambient temperature was measured by means of a thermocouple. The thermocouple was also used to monitor temperature fluctuations in the slurry. The highest temperature recorded during cow dung fermentation was $42^{o}C$ (Figure 4.1) while for chicken dropping fermentation, the highest temperature observed was $41^{o}C$ (Figure 4.2). the lowest temperatures recorded for both biomass fell within the thermophilic range.

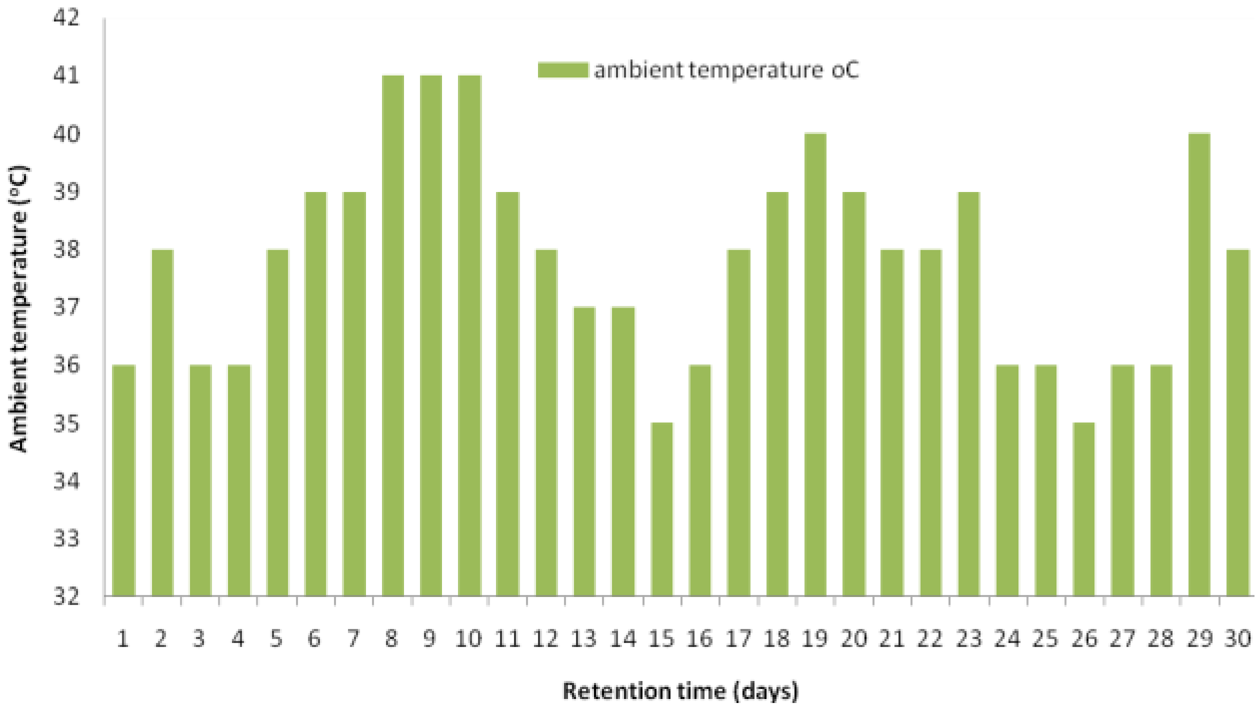

Figure 4.1: Temperature changes versus retention time for cow dung biomass fermentation

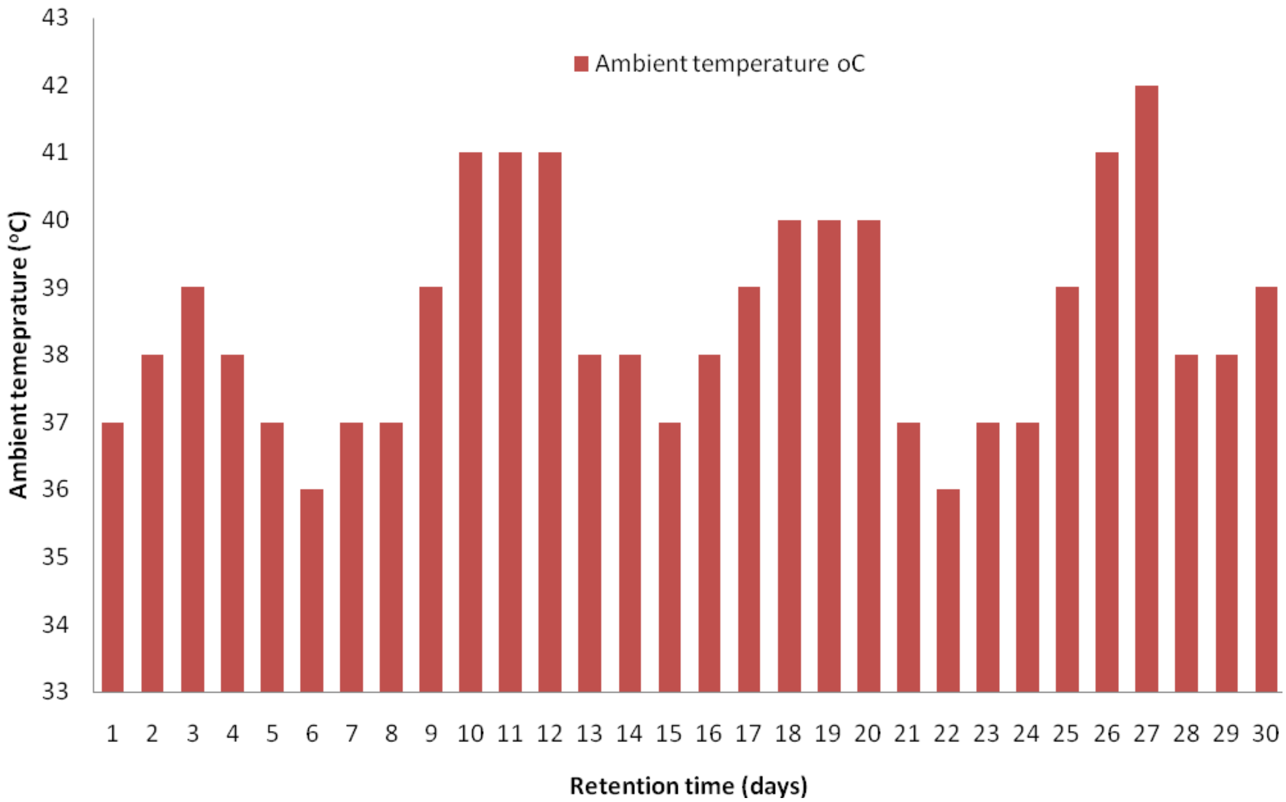

Figure 4.2: Temperature changes versus retention time for chicken droppings fermentation

4.4 Biogas Production

Figure 4.3 shows the daily monitoring of biogas production from cow dung biomass. A total of 1.197m^3 of biogas was produced within a 30 day period. Average daily production was 0.04m^3/day from an average of 1.167kg of dung. Peak gas production was observed at day 17 with 0.075m^3 of biogas.

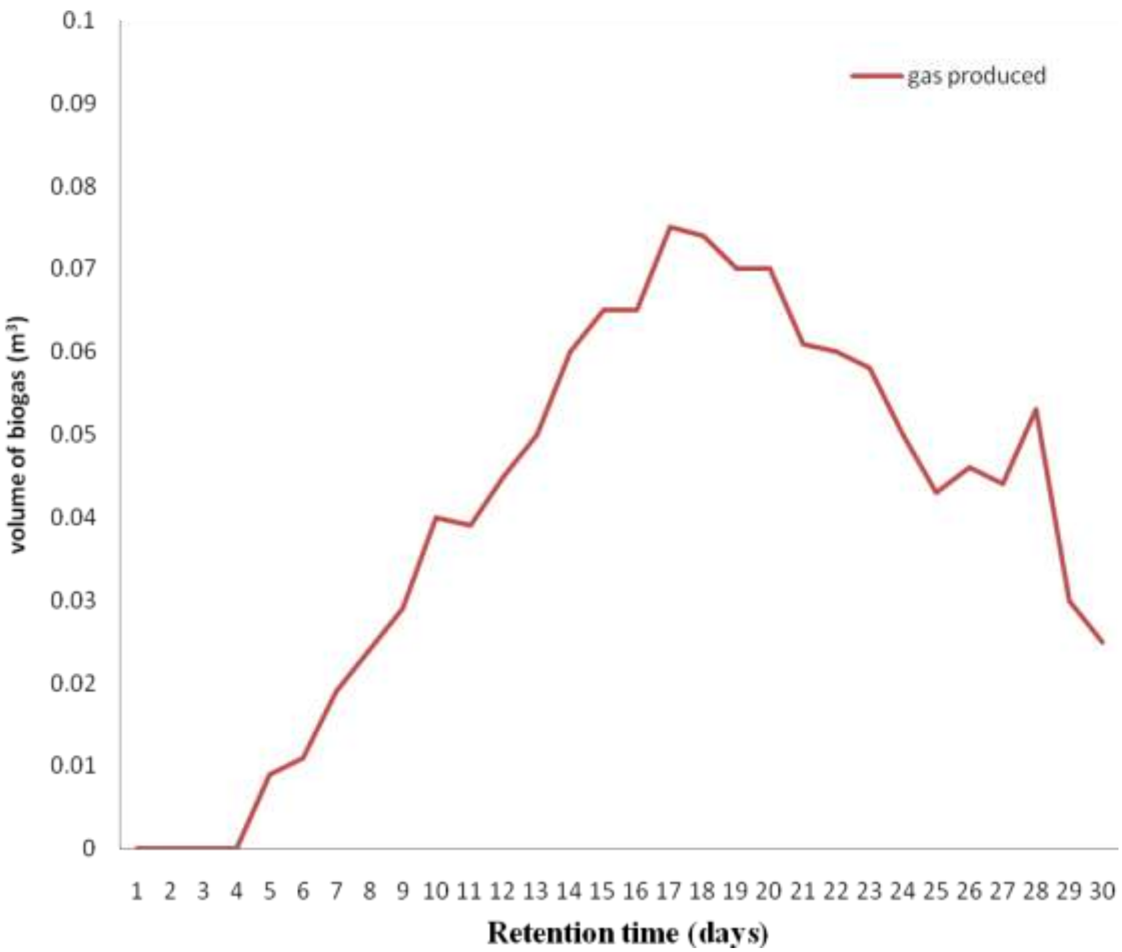

Figure 4.3: Biogas production from cow dung biomass

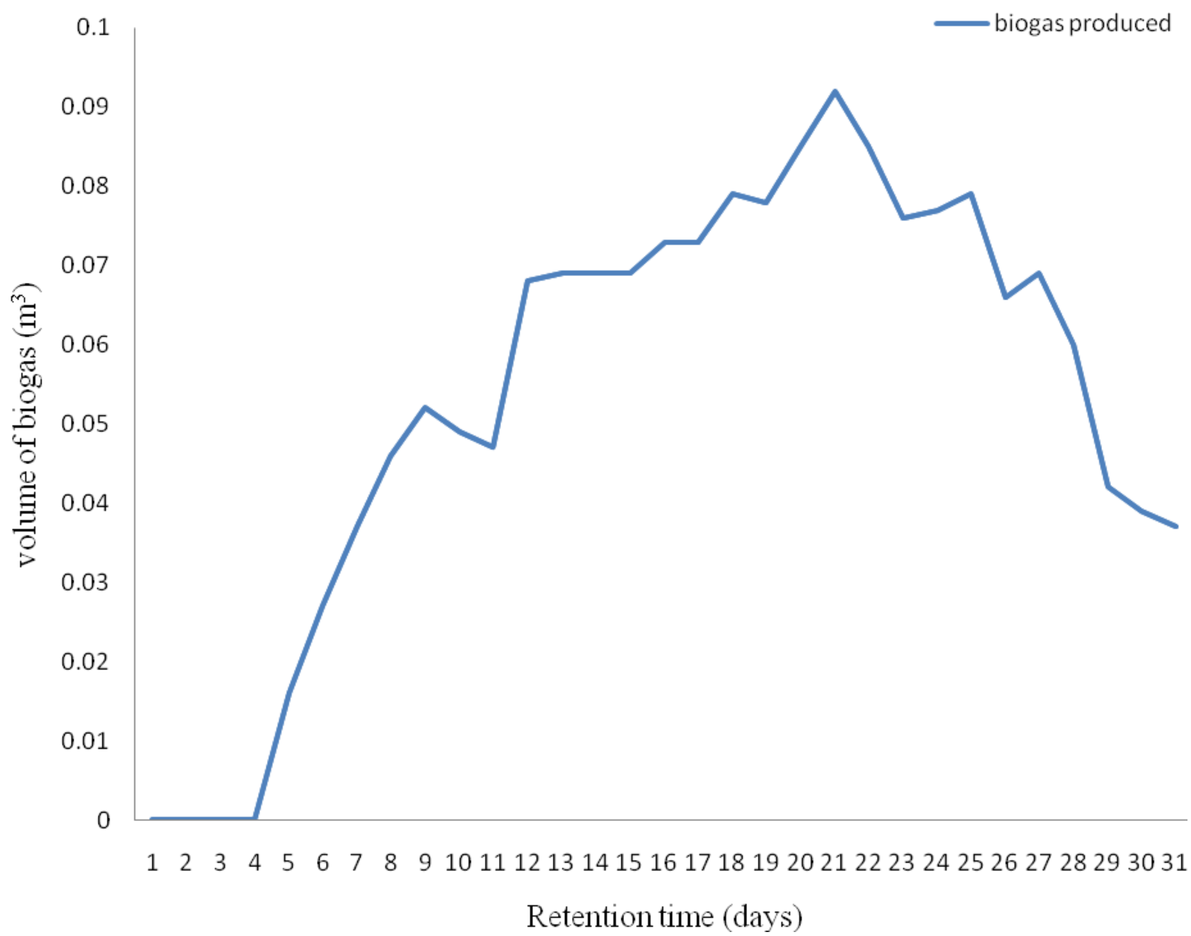

Figure 4.4: Biogas production from chicken droppings biomass

Figure 4.4 shows the 30 day period of biogas production using chicken dropping as biomass. Total gas produced was 1.659m^3 that is 0.06m^3/day from an average of 1.167kg of chicken droppings. Peak gas volume of 0.092m^3 was observed at day 20. The results show that chicken droppings had higher gas yield than cow dung.

4.5 Qualitative Analysis of Produced Biogas

The laboratory analysis of biogas gave the following percentage constituent compositions of biogas produced, assuming that water vapour and other trace gasses are negligible.

Biogas produced from cow dung contained CH_4: 60% CO_2:37%, H_2S:3.0%; The Biogas produced from chicken droppings contained CH_4:65% CO_2 30.5% H_2S: 3.0% (Table 4.1 and Table 4.2). Chicken droppings had higher percentage of combustible gas compared to cow dung produced within the same fermentation period.

Table 4.1 Percentage compositions of biogas produced using chicken droppings as biomass

Component	Percentage %
Carbon Dioxide (Co_2)	30.5
Hydrogen sulphide (H_2S)	3.0
Methane	65.0

Table 4.2 Percentage compositions of biogas produced using cow dung as biomass

Component	Percentage %
Carbon Dioxide (Co_2)	35.5
Hydrogen sulphide (H_2S)	3.0
Methane	60.0

4.6 Cooking With Produced Biogas

The biogas produced was directly piped from the gas holder by a PVC pipe attached to the gas outlet valve on the gas holder as shown in plate 5.1. This was then channeled into the adopted natural gas burner.

The gas produced was used for cooking and water boiling test. The volume of food was chosen on the basis of an average of meal sufficient for five people. The quantity of gas used was measured by reading the height of the gas holder above water level before cooking commenced and reading the height again after cooking. The drop in level of gas holder above water obtained was used to compute the volume of gas used in cooking. The time taken to cooking was noted. Table 4.3 shows the cooking test results using the biogas produced.

4.6.1 Reasons for adopting the natural gas burner

i. It provides a high turn down so that it does not shut off over the full range of boiler load demands.

ii. It also burn the fuel in the most efficient way possible to keep fuel consumption low.

Table 4.3 Produced biogas cooking test

	Cooking test	Procedure	Gas consumption Cow dung gas Volume use (m^3)	Time taken (min)	chicken dropping (m^3)	Time taken (min)
1	Maximum capacity biogas test	The maximum capacity of gas holder was connected to the burner, turned on and allowed to burn until gas holder was at a minimum capacity	0.119	30	0.119	32
2	Water boiling test	1.5 litres of water in a stainless steel pot was placed on a lightened burner . The water was allowed to reach boiling point	$0.09m^3$ was consumed to bring the water to boiling point	11 mins was taken to bring the water to the boiling point	$0.07m^3$ was consumed to bring the water to boiling point	8 mins was used to bring the water to the boiling point
	Food cooking test	2 tins of rice was washed and put in a stainless steel pot containing 190ml of water. The burner was allowed to burn until the rice was cooked	$0.110m^3$ was consumed	25 mins were used	$0.118m^3$ were consumed	20 mins were used

CHAPTER FIVE

5.0 Discussion

5.1 Engineering Design and Construction

Design and construction of the biogas digester plant was conceived and constructed using locally sourced materials. One major advantage is the ready availability of the materials and expertise of technicians for mass production to meet the rural domestic energy needs. In Nigeria, more than 70% of the population live in rural settlements where 80% of energy used for cooking and other domestic needs come from the burning of fire wood and other fossil fuels (Sambo, 2005). The common occupation of rural settlers in Nigeria is basically farming and raising live stock. These activities serve as potential sources of biomass which could be harnessed for cheap energy. Chicken droppings have been shown to be a good biomass source for biogas production (Table 4.1).

The size and portability of the digester was also taken into consideration. The digester is 80cm high, the water jacket is 90cm high and the gas holder is 60cm high all of which occupy a space of 3.5 m^2. Thus, the digester is portable and occupies little space giving it the advantage to be accommodated in small family settings.

A relief valve was incorporated into the digester which serves as a control for reducing pressure during digestion. A beam guard was also constructed alongside to hold the floating gas holder in place to prevent the holder from falling off the water jacket in the event of excess gas production. This set up was built to withstand a pressure of 0.00-0.35 bar. The safety operation of the biogester was considered since it was especially designed to be used in rural settings where the educational and technical knowhow is generally low. Singh *et al.*, (1987) emphasized the need for safety in the design and citing of biogas digester. The gas produced from the digester is combustible and the gasholder needs to be airtight. The gasholders for the fixed-dome models of biogas digester are located outdoors and underground.

5.2 Performance of the Biogas Digester

The biogas generated was assessed by downward displacement of water using a calibrated gas holder. The temperature of the slurry was observed daily through the thermocouple wire that was inserted into the digester.

Temperature and pH monitoring during digestion is very significant to the sustainability and reliability of biogas production. Under conditions of temperature within the range of 35^o-37^oC and proper pH, it is possible to produce about $1.166m^3$ of biogas per day at atmospheric pressure from dung of 454kg weight. Extreme pH and high temperatures have detrimental effect and subsequently low biogas production.

High pH may prove corrosive to construction material and even death of microorganisms that enable the digestion. pH is largely dependent on CO_2 concentration but is also influenced by the quantity of volatile fatty acids and ammonia in the slurry. The bacteria for each stage of the digestion process operate optimally at different pH values. Sathianathan (1975) stated that while the acidogens can operate at pH levels as low as 5.5, the methanogens cease to operate below pH value of 6.5, and work optimally at pH values of 6.8-7.2. Hobson, et al., (1981) concluded that optimal pH of methanogenic bacteria is pH7.2. High temperatures speed up growth cycle of microorganisms, hence, the death phase may persist within the digester. It is necessary to maintain the fermentation environment for optimal bacterial growth for high gas output. Biogas production is fastest in the thermophilic range as a result of the high temperatures, though the methanogens are sensitive to sudden changes in temperature. Choorit and Wisarnwan, (2007) noted that it can take ‘a few days’ to recover an initial drop of biogas production of up to 20% after a sudden change of just 3^{o}C. Gas production in the mesophilic range is stable, with no notable drops in gas production for small changes in temperature (Choorit and Wisarnwan, 2007). Maximum daily gas production observed for cow dung biomass was 0.075m^{3} at a temperature of 38^{o}C. Similarly, maximum daily gas output for chicken dropping biomass had a corresponding temperature of 40^{o}C. The temperature range observed for both biomass peak gas generation fell within thermophilic range. Temperatures above 40^{o}C (Figures 4.1 and 4.2) influenced biogas production negatively (Figures 4.3 and 4.4) probably due to excessive ambient heat which may slow down bacterial growth. The drop in biogas production may also be attributed to the death phase of bacterial growth cycle. This phenomenon is expected in a batch-operated biodigester.

The observed pH of the constructed digester fell within the range of 5.90 to 7.70. This was constantly monitored using Jeanway 3020pH meter during the period under study. Ambient temperature readings fell within the thermophilic temperature range of 35^{o} to 45^{o}C (Figure 2). This was monitored with a digital thermocouple thermometer.

5.3 Cooking Test of Biodigester Produced Gas

5.3.1 Volume of biogas used in domestic cooking

Table 4.3 shows the results obtained from cooking tests. Maximum capacity biogas test for both cow dung and chicken droppings biomass was sustained for 20minutes and 25 minutes respectively. This shows that gas produced at 4 to 5 hourly intervals under normal conditions of temperature and pH, would support full combustion for 35-37 minutes. This was demonstrated in the food cooking test as presented in Table 4.3. Boiling of water only took 18 and 19 minutes for cow dung and chicken droppings biomass gas respectively.

The total volume of biogas produced as shown in Tables 1 and 2 was in conformity with research conducted by Ahmadu *et al.*, (2009) who stated the suitability of biogas from cow dung and chicken droppings for domestic cooking. They were able to show biogas production from both cow dung and chicken droppings were $1.92m^3$ and $1.93m^3$ respectively. This research is also in agreement with the findings of Eze, (2001) who designed and constructed a batch-operated biogas digester. His results showed that anaerobic degradation efficiency depends on the characteristics of the effluent within the system. According to UNO (1984) $0.1m^3$ of biogas will cook meals three times a day for a family of five. For experiments carried out in this research for both cow dung and chicken droppings, the gas produced from the designed $0.1m^3$ capacity digester will produce gas sufficient to cook a square meal for a family of five (Figure 4.1 and Figure 4.2). Plate 5.1 shows the set up of the direct use of biogas produced connected to a gas burner while plate 5.2 shows blue flame from the burner.

Plate 5.1: Generated gas supply from gas holder to burner

Plate 5.2: Flame generated from the burner

5.4 Cost Analysis

Costing is an important aspect of engineering design and construction. The evaluation of the cost of biodigester design and construction was based on three parameters viz: material, labour and overhead costs.

Material cost involves the detailed breakdown of material costs of all materials. Labour cost is what has been spent on the manufacturing process. Overhead costs involve transportation and other miscellaneous expenses. Below is a breakdown of the biodigester cost:

S/no	Component	Material	Dimension	qty	Unit cost (₦)	Total cost (₦)
1.	Metal sheet	GI sheet	1000x800x1.2	3	6,500	19,500
2.	Metal sheet	Mild steel	1500x2000x3	1	5000	500
3.	Pipe	GI pipe	2 inch	1	1200	1200
4.	Pipe	GI pipe	½ inch	1	900	900
5.	Socket and plug	Socket and plug	2 inch	3	700	2100
6.	Tap	Gas tap	½ inch	3	500	1500
7.	Elbow	Elbow		3	400	1200
8.	Nipple	½ nipple		3	250	750
9.	Brazing rod			40	30	1200
10.	Welding electrode		Gauge 10	2 pkts	750	1500
11	Paint	Autobase		2	1500	3000
12.	Sand paper	Rough/smooth		15each	30 each	900
13.	Labour					15,000
15.	Miscellaneous					4,000
16.	Total					61, 350

CHAPTER SIX

6.0 Conclusion and Recommendation

6.1 Conclusions

This research work has been able to demonstrate the production of combustible gas produced from the digestion of locally available biomass specifically cow dung and chicken droppings. The design and construction of the biodigester was done using locally sourced materials. The portability and safety design of the digester has the advantage of its use in small family setting with an average daily gas output of $0.06m^3$ and $0.04m^3$ from chicken droppings and cow dung respectively, sufficient to prepare a meal of five per day.

Both cow dung and chicken droppings were shown to be suitable for use as source of biogas generation. However, chicken droppings had better performance under experimental conditions.

This research also demonstrated that anaerobic fermentation is an environmentally friendly technology that could be used to generate biogas for cooking.

In developing countries like Nigeria, where more than 70% of the population lives in rural areas and more than 80% of the energy being consumed comes from non commercial sources, the increasing cost of conventional fuel in urban areas necessitate the need to explore other energy sources. Animal and plant wastes are abundant in rural areas. Besides having the advantage of waste management strategy, biogas can be produced from these wastes as a substitute to fossil fuels.

This work established that by harnessing 50% of cow dung and chicken droppings obtainable in this country for biogas production, Nigeria can meet the daily domestic cooking needs of about 29.7million people. The search for alternative energy sources such as biogas should be intensified so that ecological disasters like deforestation, desertification, and erosion can be reduced to a minimal level.

6.2 Recommendations

For comprehensive utilization of biogas technology the following recommendations were drawn.

- An awareness campaign for potential user should be undertaken to encourage the use of biogas
- Financing channels should be enhanced and expanded by Government agencies to encourage the use of biogas
- Normative and industrialized development should be put forward for digester production

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APPENDICES

Appendix 1

Experimental set up of the Biogas Digester before feeding

Appendix 2

Experimental set up of the Biogas Digester After Feeding

Appendix 3

Generation of Gas in the First Week

Appendix 4

Gas fully generated in the Gas Holder.

Appendix 5

Retention time (day)	Ambient Temp (^0C)	Biogas Production (M^3)
1.	36	
2.	38	
3.	36	
4.	36	
5.	38	0.009
6.	39	0.011
7.	39	0.019
8.	41	0.024
9.	41	0.029
10.	41	0.040
11.	39	0.039
12.	38	0.045
13.	37	0.050
14.	37	0.060
15.	35	0.065
16.	36	0.065
17.	38	0.075
18.	39	0.074
19.	40	0.070
20.	39	0.070
21.	38	0.061
22.	38	0.060
23.	39	0.058
24.	36	0.050
25.	36	0.043
26.	35	0.046
27.	36	0.044
28.	36	0.035
29.	40	0.030
30.	38	0.025
	Total	$1.197m^3$

Daily gas production 30 day trial from cow dung

Appendix 6

Retention time (day)	Ambient Temp (^0C)	Biogas Production (M^3)
1.	37	
2.	38	
3.	39	
4.	38	0.016
5.	37	0.027
6.	36	0.037
7.	37	0.046
8.	37	0.052
9.	39	0.049
10.	41	0.047
11.	41	0.068
12.	41	0.069
13.	38	0.069
14.	38	0.069
15.	37	0.073
16.	38	0.073
17.	39	0.079
18.	40	0.078
19.	40	0.085
20.	40	0.092
21.	38	0.085
22.	36	0.076
23.	37	0.077
24.	37	0.079
25.	39	0.066
26.	41	0.069
27.	42	0.06
28.	38	0.042
29.	38	0.039
30.	39	0.037
	TOTAL	1.659

Daily gas production 30 day trial from chicken dropping