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Design of Three Stages Continuous Anaerobic Digestion (AD) Plant

P.O. Osunde[1], E.K. Orhorhoro[2], P.O.B. Ebunilo[2]
[1](Department of Engineering and Technical Service, Petroleum Training Institute (PTI), Effurun, Nigeria
[2](Department of Mechanical Engineering, Faculty of Engineering, University of Benin, Benin City, Nigeria)
Corresponding Authour: Ejiroghene Kelly Orhorhoro;
ejiroghene.orhorhoro@eng.uinben.edu,kelecom@yahoo.com

ABSTRACT : *The AD system is extensively acceptable as an efficient process for treatment and utilization of organic waste because it has proven to be promising method for waste recycling and energy generation. However, the major problems face with existing AD plants are long hydraulic retention time and low biogas yield. Redesigning of AD plant for performance can lead to improve biogas yield at shorter hydraulic retention time. This paper is focused on the design of three stagescontinuousanaerobic digestion (AD) plant. Key analysis and concern about the design considerations, design requirement, material selection, optimum operating condition of biogas production were carried out. The major components of the plant are; stirrer shaft, bearings, reactor vessels, valves, pH meter, pressure gauge, thermometer, etc. To ensure that an efficient plant is designed for performance, the following parameters were design for; volume of reactor vessel, stress induced by total internal pressure, slurry and gas pressure, torque, drag force, stirrer shaft diameter, bearing selection, power, etc. The plant was test for performance using 35kg of non-uniform multiple feedstock mainly obtained from food waste, water hyacinth, waste water, pig and cow dung and the following process and operation parameters (volatile solid, temperature, hydraulic retention time, pressure, total solid, pH, organic loading rate) of AD system were monitored. The results obtained show that hoop stress act on the reactor vessel that is cylindrical in shape. Besides, torque of 20.2958Nm (AD1/AD2) and 24.0543Nm (AD3), stirrer shaft diameter of 20mm, maximum shear stress of 110Mpa, yield stress of 220Mpa, total internal pressure of 2.2MPa, slurry pressure of 6662.25MPa, maximum gas pressure of 2.193MPa, drag force of 33.8263N (AD1/AD2) and 60.1357N (AD3) were obtained. The performance test results with non-uniform multiple feedstock confirm reduction in hydraulic retention time (25day), improve biogas yield, stable pH values, improved organic loading rate, percentage volatile solid of 95% and percentage total solid of 10.00%.*

Keywords-*Design,Anaerobic Digestion,Three Stages, Biogas Yield, Plant, Operation and Process Parameters*

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I. INTRODUCTION

Small scale anaerobic digestion (AD) plants are currently in use in rural Asia and Latin America for treatment of farmyard manure, animal waste, household food waste. Large scale AD plants for treatment of municipal solid waste (MSW) is currently in use in European countries such as Germany, Sweden, Switzerland, etc. Biogas, that is methane (CH_4), hydrogen sulphide (H_2S), carbon (IV) oxide (CO_2), water vapour (H_2O) and other constituents depending on the substrates used is produced from anaerobic digestion (AD) of organic fraction of municipal solid waste (MSW) and other feedstock such as wastewater [1,2]. The AD system is extensively acceptable as an efficient process for treatment and utilization of organic waste because it has proven to be promising method for waste recycling and energy generation [3,4]. However, the major problems face with existing AD plants is long hydraulic retention time (HRT), organic loading rate (OLR) and low biogas yield. With good design, improve organic loading rate, HRT can be reduce with optimum biogas yield achieve. AD plants are mainly classified as fixed dome plant and floating drum plant [5].

A fixed-dome AD plants consist of non-movable gas holder, which sits on top of the digester [6]. Fixed-dome AD plants are operated by charging manure mixed with water as slurry into an entrance pipe. The slurry flows by gravity into the bottom of the digester. The lower part of the digester contains a layer of biosolids and a layer of liquid above the biosolids[1,7]. As AD processes take place, volatile solid (VS) are consumed and biogasisproduced. Biogas is stored within the digester, creating gradual pressure buildup, push digested slurry from the bottom of the digester up where is collected in the tank. The slurry mass will accumulate, where is reduced from that of the slurry fed into the digester. The collection tank must be emptied when it becomes full [6,8].Floating drum AD plants consist of an underground digester and a moving gas holder [9]. The drum is mounted on a movable guide frame (which can float in the slurry or in a water jacket located outside the digester). As the pressure of biogas increases in the drum, the drum rises accordingly. The slurry flows down the inlet pipe and enters the bottom of the digester. There is a layer of biosolids on the bottom and a layer of liquid effluent above it. The floating-drum design includes a drum made of steel on a guide frame. The drum floats either in a water jacket surrounding the digester or directly in the digesting slurry [10]. The gas-holder floats either directly on the fermentation slurry or in water jackets of its own. The gas is collected in a gas drum, which rises or moves down, according to the amount of gas stored. The volume of stored gas is directly visible. The gas pressure is constant, and is determined by the weight of the gas holder [11].

Other existing AD plants have fixed range in complexity and vary from simple cylindrical reactor with no moving parts to fully automated mixed industrial facilities [12]. The available multitude of digester varieties are designed to optimize the process for specific geographic locations, types of waste and other considerations. Based on substrates composition, AD plants can be sub-divided into a variety of categories such as wet/dry processes, batch/continuous, plug flow, continuous stirrer (CSTR), etc. [13].The operation of CSTRs AD plants includes continuous introduction of slurry into the reactor and continuous removal of the liquid contents from the reactor [14]. In a CSTR, the growth of micro-organisms is continuously in the reactor. With present of microbes due to consistent feedstock input, all reactions occur at a fairly steady rate and this result in approximately constant biogas yield [15].A Lying plug flow (LPF) AD plants are a tubular reactor with effluent slurry entering continuously at one end (charging) and effluent slurry exiting (discharging) continuously at the opposite end of the reactor [16]. In an ideal plug flow AD plant, the flow moves through the reactor as a “plug,” in which no mixing occurs. For the fact that no mixing occurs in an ideal plug flow AD plants, the concentrations of substrate and micro-organisms change through the length of the reactor[16,17].

In batch AD plants, the reactors are filled once with fresh waste, with or without addition of seeding material and allowed to go through all degradation steps sequentially in range of 30-40% TS (i.e. dry mode). Though batch AD plants may appear as nothing more than a landfill, but in actual sense, it is 50 to 100-fold higher biogas production rates than those observed in landfills because of two basic design features [11].Due to continuous re-circulation of leachate, there is room for dispersion of inoculant, nutrients and acids and in fact is the equivalent of partial mixing.Also,in Batch AD plant, the systems are run at higher temperature than that normally observed in landfills.In a single-stage batch AD plants, the leachate can be re-circulated to the top of the same reactor where it is produced. It is used in Netherland to treat 35, 000 tonnes/year bio-waste. The two stage sequential batch AD plants is based on the fact that the substrate of a freshly filled digester contains high levels of organic acids. Thus, it can be re-circulated to another digester where methanogenesis takes place. The slurry of the first digester is freed of acids and is therefore loaded with pH buffering bicarbonates where is being pump back to the new digester where the AD process is completed [13]. Semi-batch operation consists of adding a substrate over a short period of time and this results in slurry exiting the digester within the same time period [15]. Within this period of time of which substrate is added, the reactor has continuous flow in and continuous flow out. For the remainder of the day, the reactor operates as a batch reactor, with no flows in or out. Nevertheless, the reaction does not go to completion before additional substrate.

A Polyethylene tubular (Balloon) AD plants consist of heat-sealed plastic or rubber bag (balloon). The inlet and outlet are attached directly to the skin of the balloon. Gas pressure can be increased by placing weights on the balloon. If the gas pressure exceeds a limit that the balloon cannot withstand, it may damage the skin, therefore safety valves are required [18]. If higher gas pressures are needed, a gas pump become mandatory. Since the material has to be weatherand UV resistance, specially stabilized, reinforced plastic is preferable. Other materials which have been used successfully include red mud plastic (RMP), Trevira and butyl [19]. Phased AD plants consist of more than one reactors operated in series or parallel. The gas is collected in two separate streams from more than one reactor [12]. A reactor in parallel is commonly used in large scale wastewater treatment facilities [20,21]. It can also be used when wastewater flow rate exceeds the capacity of the largest reactor unit obtainable [22]. When maintenance is required on a reactor, the remaining reactor(s) can continue to operate while one reactor is taken offline for maintenance [23]. In wet AD plants, the feed stock is a slurry with a sufficient amount of water to provide a dilute feed stock of 10-15% dry solids [24]. For a dry AD plant, the feedstock is usually a dry solid content of 25 – 40% [23]. In dry continuous AD plants, the plants are continuously fed with dry feedstock content of 20-40% [25]. Most of the industrial AD plants built in the 80's relied on wet AD plant systems. However, recent AD plants are evenly split between the wet and the dry systems [16]. In term of comparison for optimum performance, no sufficient information is available[26].Table 1 shows operations and performance data for different existing AD plants. This paper is therefore focused on the design of three stagescontinuousanaerobic digestion (AD) plant. Key analysis and concern about the design considerations, design requirement, material selection, optimum operating condition of biogas production were carried out. This present work will be an improvement on existing AD plants.

Table 1. Operations and Performance Data for Different Existing AD Plants[8,13,18,]

AD Plants	Feed	Temp (^{0}C)	OLR	HRT	Efficiency	Biogas Yield	% Biogas Yield
CSTR	PPW	55	0.8-3.4	NR	NR	NR	58
Fixed dome							
Tubular	FVW	35	6	20	75.9%	NR	57
Batch	FW	50	NA	28	81	0.435	73
ASBR (2L)	FVW	55	1.24	15	79	NR	60
2-Stage semi-Continuous	FW	50	NR	13	NR	NR	67.4
Batch (1.1L)	FW	55	NA	90	53	0.115	72.6
PFR	SSW	37	NR	23	70	NR	68
Semi-continuous (60L)	FEW	37	40	25	NR	0.55	53
Floating drum (200L)	FW	33	40	20	65	NA	50
Batch scale (5L)	FW	36–55	0.12-5.32	21–60	NR	0.84	60-65
Batch (200L)	FVW	28–46	NR	98	NR	0.387	65
2-Stage Semi-continuous	FW	35–55	8	12	78	3.3	58.9
ASBR (2L)	AW, FVW	55	2.56	20	73, 86	NR	NR
Batch	DW, MSW	35	0.52–4.3	26	87	0.3	NR
Semi continuous	SHW,F WSM	35	0.3–1.3	20	NR	0.3	56
Full Scale (2,000 m^3)	DW, MSW	50	1	20	80	0.39	NR
2-phase system (18L)	FVW	35, 55	7.5	20	96	NR	64.61
Batch and continuous (20 and 18L)	FW	35, 50	0.5, 1.0	28	80–97, 78–91	0.25–0.55, 0.35–0.78	47–68, 48–74

*FW-Food waste, *PPF-Processed Potato Waste, *FVW-Food and vegetable waste, *SSW-Semi solid waste, *FEW-Fruit and Vegetable waste, *AW-Activated sludge waste, *DW-Domestic waste, *MSW-Municipal solid waste, *SHW-Slaughter house waste, *FWS-Fruit and slaughter house waste, M-Manure, CSTR-Continuous stirred tank reactor, *ASBR-Anaerobic sequential batch reactor, *PFR-Plug flow reactor, *HRT-Hydraulic retention time, *OLR-Organic loading rate, *NR-Not reported.

II. MATERIAL AND METHOD

The plant was designed to overcome the effect of operation and process parameters such as organic loading rate(OLR), pH, Carbon/Nitrogen (C/N) ratio, total solid (TS), volatile solid (VS), hydraulic retention time(HRT), etc. that bring about drop in biogas yield if not properly control. According to Wang, et al. [21], once pH reading is stable and within neutral pH range, methane formation is expected to occur. Chrish [26] pointed out that at the start of AD process, the pH fluctuates between acidity and alkalinity and stability of pH within neutral range favour methane forming bacteria. Also, the rate at which substrates are added to the digester has to be adjusted for the growth rate of methanogens bacteria. Increase in biogas yield is as a result of improve mathanogens forming bacteria. Similarly, organic acids have to be removed at the rate at which they are produced. If more substrates are added than the bacteria are able to degrade, the process will become acidic. Substrates had to been fed to the digester at a uniform rate and volume. If feeding pattern has to change, this must be done gradually, so that bacteria can adapt to the new conditions. However, with three stages continuous AD plant, stable pH can be achieved due to initial pre-digestion with AD1 and AD2, thus favouringmethanogenesis stage in AD3. Charged substrates in AD1 and AD2 are discharged into AD3 prior to biogas yield. With this, the process and operation parameters of the AD system can be control using the additional reactors (AD1 and AD2). Besides, the rate at which substrates are added to the reactor can be adjusted for the growth of methanogens bacteria via AD1 and AD2. Thus, with three stages continuous AD plant, effect of organic loading rate can be control, stable pH can be achieved due to initial pre-digestion with AD1 and AD2, thus favouringmethanogenesis stage in AD3.

2.1 Design Consideration

This design will be an improvement on limitations discovered from existing AD plants. The new design is expected to employs pretreatment which will serve as an integrated part that will enhance fast digestion process. The process will be a continuous one at a shorter HRT and limitations resulting from OLR, particle sizes, pH, TS, VS, temperature, etc. will be eliminated. Stable pH will be maintained, mixing costs reduced, optimum mesophilic temperature range applied, grinded particle sizes of substrates used, volatile solid and total solid that will enhance improved biogas yield adopted. With separate reactors, the bacteria are expected to grow at a high rate. Besides, the bacteria required for seeding will be grown on left over slurry on each digester.The following factors were also consideredto address the problems facing existing AD plants.

i. The biogas production rate is expected to be maximized by increasing the bacterial population via additional reactors rather than increasing the quantity of substrates.

ii. The bacteria will be grown separately, thus adapting to each stages of AD processes (hydrolysis,acetogenesis and acidogenesis and methanogenesis).

iii. This design was based on the fact that pre-digestionof substrates guarantees an even distribution of bacteria and avoids flushing out of bacteria at early stages as in floating drum continuous AD plant and overcharging of substrate than the bacteria can digest as in fixed dome AD batch plant [11,27].

iv. This design has enclosures with proper insulated system thus optimum mesophilic temperature can be achieved.

v. Growing bacteria in separate reactor will brings about continuous seeding unlike existing fixed dome and floating drum AD plants. This will equally bring about acclimatization period to toxic components such as acid, and alkaline.

vi. The three stages continuous AD plant is connected in series with AD1 on top of AD2 and AD2 on top of AD3. So pump is not necessary thereby reducing cost and maintenance less intensive. Charging and discharging of reactors are achieved through gravitational process and is a continuous process with biogas evacuated once sufficient pressure build up is achieved.

2.2Design Requirement

Any design that satisfies all of the functional requirements will fulfill the aim and objectives of a research work. In this research work, the list of functional requirement for the design of three stages continuous AD plant ispresented in Table 2.

Table 2. Functional Requirements

Functional Requirements	Basis
Optimum mesophilic temperature suitable for biogas yield	Temperature range of 36^{0}C-38^{0}C will be required
pH suitable for optimum biogas yield	pH range of 6.8-7.4
To avoid excessive loading of substrates	Use of extra digester
Total solid of substrate appropriate for biogas yield	TS range of 9%-10%
Corrosion resistance, and better biogas yield	Use of stainless steel materials
Lagging	To prevent heat loss from the system, use of ply board
Indication of biogas yield	Use of sensitive pressure gauge (0-10bar)
Stirrer	For uniform mixing of slurry and contact of microbes with substrates
AD reactors	Fast digestion of substrates at shorter HRT
Design life	Life span of the plant
Machine cost	An overview of the fabrication cost

2.3 Material Selection

The material selection for this research work is based on;

i. Service Requirement

ii. Fabrication Requirement, and

iii. Economic Requirement

2.3.1 Service Requirement

Service requirement in material selection involves the properties a material should have, to serve the purpose for which it is designed for. Some of these properties include: corrosion resistance, conductivity, strength, toughness, resistance to heat, maintainability, safety, etc.

2.3.2Fabrication Requirement

Fabrication requirement entails workable properties a material should have, and they include machinability, forgability, malleability, ductility, weldability, castability, etc.

2.3.3 Economic Requirement

Economic requirement in material selection entails the affordability of the material for fabrication and commercialization. It would not be profitable to manufacture at a high cost and sell below the manufactured cost.

2.3.4Choice of Material

The following materials listed in Table 3 were selected for various component parts of the plant.

Table 3. Material Selection and Justification

S/N	Component Description	Materials	Justification
1	Stirrer	Stainless Steel	❖ Ability to resistance corrosion ❖ Ability to withstand shear force and compressive force.
2	Cylindrical Reactors	Stainless Steel	❖ Ability to resist corrosion ❖ Maintains strength. ❖ Good conductor of heat
3	Ball Bearings	High Carbon Steel	❖ Resistance to wear and corrosion, hard, tough and has high strength.
4	Discharge and Charge Valve	Thermoplastic	❖ Corrosion resistance and cheap
5.	Evacuation Valve	Stainless Steel	❖ Ability to resistance corrosion ❖ Ability to withstand pressure
6.	Angle Bar	Mild steel (Low carbon steel)	❖ Ability to withstand shear force and compressive force
7.	Thermometer	N/A	❖ N/A
8.	pH	N/A	❖ N/A
9.	Safety Valve	Stainless Steel	❖ Ability to resistance corrosion ❖ Ability to withstand pressure
10.	Bolt and Nut	Stainless Steel	❖ Ability to resistance corrosion ❖ Resistance to wear, hard, tough and has high strength.
11.	Frame	Mild Steel	❖ For strength, toughness, withstand shear force and compressive force
12.	Plant Cover	Ply Wood	❖ Good insulator and poor conductor of heat

2.4 Detailed Design

2.4.1Determination of Total Volume of Digesters

Three cylindrical reactorswere used; AD1, AD2 and AD3. The dimension of AD1 and AD2 are the same but differ from dimension of AD3. Thus, volume of AD1 will be equal to volume of AD2.

$$V_T = V_{AD\,1} + V_{AD\,2} + V_{AD} \qquad (1)$$

where,

V_T = Total volume of digesters

V_{AD1} = Volume of AD1

V_{AD2} = Volume of AD2

V_{AD3} = Volume of AD3

Figure 1 shows the dimension view of AD1, AD2 and AD3 reactors.

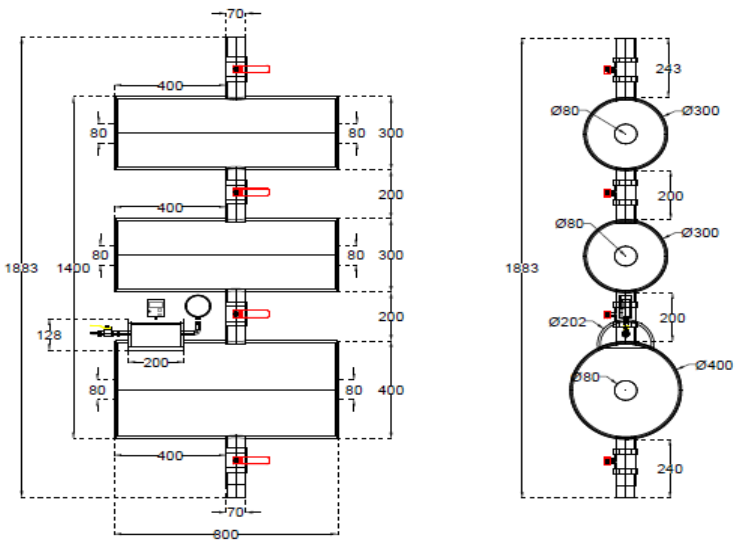

Figure 1. *Dimension View of AD1, AD2 and AD3 Reactors*

The reactors are cylindrical in shape. Volume of cylinder is given by Equation (2)

$$V = \pi r^2 h \quad (2)$$

Equation (3) and Equation (4) are used to calculate volume of AD1/AD2 and AD3.

$$V_{AD1/2} = V_{CV1/2} - V_{BGV} \quad (3)$$

$$V_{AD\,3} = (V_{CV\,3} + V_C) - V_{BGV\,3} \quad (4)$$

where,
V_{AD3} = Volume of AD3
V_{CV3} = Volume occupied by cylindrical vessel in AD3
V_C = Volume of gas collection chamber
V_{BGV} = Volume occupied by ball gate valve
$V_{CV1/2}$ = Volume occupied by cylindrical vessel in AD1/AD2
$V_{AD1/2}$ = Volume of AD1/AD2
The total volume of digester is given by Equation (5)

$$V_T = V_{AD\,1} + V_{AD\,2} + V_{AD} \quad (5)$$

2.4.2 Stresses Induced by Total Internal Pressure

The stresses induced by the total pressure are as follow;

i. Hoop Stress
ii. Longitudinal Stress
iii. Maximum shear stress

For the thin-walled, the vessel must have a wall thickness of not more than above one tenth of its radius. For thin wall vessel where hoop stress induces, Equation (6) and (7) are applied,

$$\frac{r}{t} \geq 10 \quad (6)$$

$$\sigma_{\Theta} = \frac{PD_m}{2t} \quad (7)$$

For thick wall where longitudinal stress induces, Equation (8) and (9) are used.

$$\frac{r}{t} \leq 10 \quad (8)$$

$$\sigma_z = \frac{Pd}{4t} \quad (9)$$

where,
r = Radius of the vessel
t = Thickness of the vessel
P = Total internal pressure
t = Wall thickness
D_m = Mean diameter of the cylinder
σ_{Θ} = Hoop or circumferential stress
σ_z = Longitudinal or Axial Stress

2.4.3Design for Drag Force

The drag force of the stirrer blade is given by Equation (10)

$$F_D = \frac{1}{2} C_D \rho \left(\frac{\pi D N}{60}\right)^2 A \quad (10)$$

where,
ρ = Density of Slurry (kg/m^3)
CD = Coefficient of drag =1.2
A = Area of stirrer blade =LB (m^2)
N = Speed in revolution per minute = 60rpm
F_D = Drag Force (N)
D = Diameter of rotation (m)

2.4.4Torque Required to turn Stirrer

The torque (T) required to turn the stirrer through 360^0 is given by Equation (11).

$$T = 2F_D \times R \quad (11)$$

where,
T = Torque required to turn the stirrer (Nm)
R = Turning distance (m)

2.4.5 Power Required to turn Stirrer

The power required to the turn the stirrer is given by Equation (12)

$$P = \frac{2\pi NT}{60} \quad (12)$$

where,

P = Power required to turn the stirrer (watt)

The dimensional view of the stirrer is shown in Figure (2).

2.4.6 Stirrer Shaft Design

The diameter of the stirrer shaft is given by Equation (13)

$$d^3 = \frac{16}{\pi S_S}\sqrt{(K_b M)^2 + (K_t T)^2} \quad (13)$$

where,

M=Bending moment

For suddenly applied load (heavy shock), the following values are recommended for K_b and K_t

K_b= 2 to 3

K_t= 1.5 to 3

Selecting material of stirrer shaft Fe 360 [28]

S_{ut}= 360MPa

S_{yt}=220MPa

$\tau_{max} \leq 0.30 S_{yt}$

$\tau_{max} \leq 0.18 S_{ut}$

where,

S_{ut}= Ultimate yield strength

Syt= Yield stress

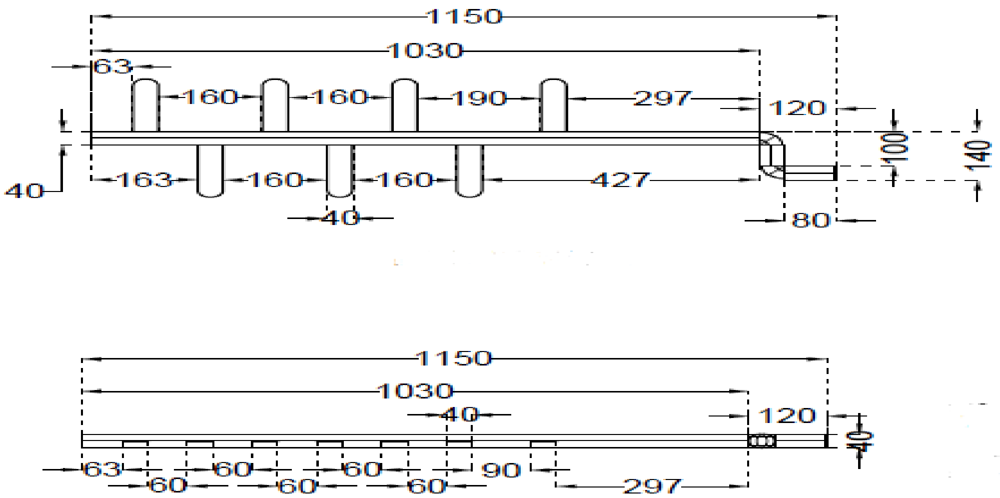

Figure 2. *Dimension View of Stirrer*

2.4.7 Design for Pressure

The AD vessel is treated as a thin wall pressure vessel, thus hoop stress is induced. The total pressure in the tank is the pressure develops by the gas and the slurry and is given by Equation (14)

$$P_T = P_G + P_{Sl} \quad (14)$$

where,

P_T = Total internal pressure

P_G = Gas pressure

P_{Sl} = Slurry pressure

But,

$$P_{Sl} = \rho g h_S \quad (15)$$

where,

ρ = Density of slurry

g = Acceleration due to gravity

hs_l = level of slurry in the plastic digester = 75% of total height

The yield stress of a stainless steel (Fe 360) is given as 220MN/m^2[28]. Maximum shear stress can be expressed as,

$$\tau_{max} = \frac{\sigma_y}{2} \quad (16)$$

Also,

$$\tau_{\max} = \frac{\mathrm{Pd}}{4t} \quad (17)$$

The expected maximum gas pressure is the difference between total pressure generated by the system and pressure generated as a result of slurry.

III. RESULTS AND DISCUSSION

In this research work, three stages continuous AD plant was successfully designed and fabricated (Figure 3 and Figure 4). Optimum performance of the plant was carried out using non-uniform multiple feedstock mainly obtained from food waste, water hyacinth, waste water, pig dung and cowdung. The process and operation parameters such as temperature, hydraulic retention time, volatile solid, organic loading rate, pressure build up, pH, etc. were closely monitored. Key analysis and concern about the design considerations, design requirement, material selection, optimum operating condition of biogas production were evaluated. The major components of the plant are; stirrer shaft, bearings, reactor vessels, valves, pH meter, pressure gauge, thermometer, etc. To ensure that an efficient plant is design for performance, the following parameters were design for; volume of reactor vessel, stress induced by total internal pressure, slurry and gas pressure, torque, drag force, stirrer shaft diameter, bearing selection, power, etc. The results obtained from detailed design show that the vessel has a wall thickness of not more than above one tenth of its radius, thus it is a thin-walled and hoop stress act on it. Besides, torque of 20.2958Nm (AD1/AD2) and 24.0543Nm (AD3), stirrer shaft diameter of 20mm, maximum shear stress of 110Mpa, yield stress of 220Mpa, total internal pressure of 2.2MPa, slurry pressure of 6662.25MPa, maximum gas pressure of 2.193MPa, density of slurry of 1133.08kg/m^3, drag force of 33.8263N (AD1/AD2) and 60.1357N (AD3), power of 127.1572watta (AD1/AD2) and 151.1572watts (AD3) were obtained. Furthermore, the volume of reactors (AD1, AD2, and AD3) were all design for and gotten as 0.0565m^3 and 0.104m^3, with total volume of reactors of 0.217m^3. The volume occupied by slurry which is seventy-five percent of total volume of the reactors were equally calculated for and obtained as 0.04238m^3 (AD1/AD2) and 0.0780m^3 respectively.

It was observed that the maximum pressure exerted by gas and slurry on the digesters (AD1, AD2 and AD3) is less than pressure generated as a result of hoop stress acting on the reactor vessel. Thus, the vessel is safe enough to withstand pressure resulting from biogas production. The following results in Table 4 and Table 5 were obtained from the detailed design of the three stages continuous AD plants and performance test evaluation using non-uniform multiple. The performance test results obtained with non-uniform multiple feedstock show fast rate of biogas yield evacuation frequency (Table 6), thus reduction in hydraulic retention time (25days), improve biogas yield, stable pH values, improvedorganic loading rate, percentage volatile solid of 95% and percentage total solid of 10.00%.

Table 4. Results of Detailed Design

S/N	Parameters	Symbol	Calculated Data
1	Volume of AD1	m^3	0.0565
2	Volume of AD2	m^3	0.0565
3	Volume of AD3	m^3	0.104
4	Total volume of digester	m^3	0.217
5	Density of slurry in AD1	kg/m^3	1133.08
6	Density of slurry in AD2	kg/m^3	1133.08
7	Density of slurry in AD3	kg/m^3	1133.08
8	Area of stirrer blade	m^2	0.056
9	Maximum mass of slurry occupied by either AD1 or AD2 digester	kg	48.02
10	Maximum mass of slurry occupied by AD3	kg	88.3802
11	Volume occupy by slurry (AD1 or AD2)	m^3	0.04238
12	Volume occupy by slurry (AD3)	m^3	0.0780
13	Density of Slurry	Kg/m^3	1133.08
14	Drag Force acting on the Stirrer Blade in Slurry (AD1 or AD2)	N	33.8263
15	Drag Force acting on the Stirrer Blade in Slurry (AD3)	N	60.1357
16	Torque Required to turn Stirrer (AD1 or AD2)	Nm	20.2958
17	Torque Required to turn Stirrer (AD3)	Nm	24.0543
18	Power Required to turn Stirrer (AD1 or AD2)	watt	127.5376
19	Power Required to turn Stirrer (AD3)	watt	151.1572
20	Pressure developed by slurry	N/m^2	6662.25
21	Total pressure	N/m^2	2,200,000

22	Yield Stress	N/m^2	220M/Nm^2
23	Maximum shear stress	N/m^2	110MN/m^2
24	Maximum gas pressure	N/m^2	2,193,337.75
25	Stirrer shaft diameter	mm	20

Table5. Summary of Performance Test Evaluation

HRT (Days)	Temperature (^{0}C)	Pressure (Bar)	pH	%VS	%TS	OLR	Biogas Yield (kg)
25	36-38	0.8-1.5	6.9-7.01	95	10.00	1kg-5kg	8.65

Table 6. Rate of Evacuation Frequency

Charge	N_e												P_p	B_{re}
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th		
Feedstock	7	3	2	2	1	2	1	1	1	2	1	2	25	0.4800

Equation (18) shows the rate of biogas evacuation;

$$B_{re} = \frac{N_e}{P_p} \quad (18)$$

where,
B_{re}= Rate of biogas evacuation
N_e= Number of evacuation
P_p = Period of production

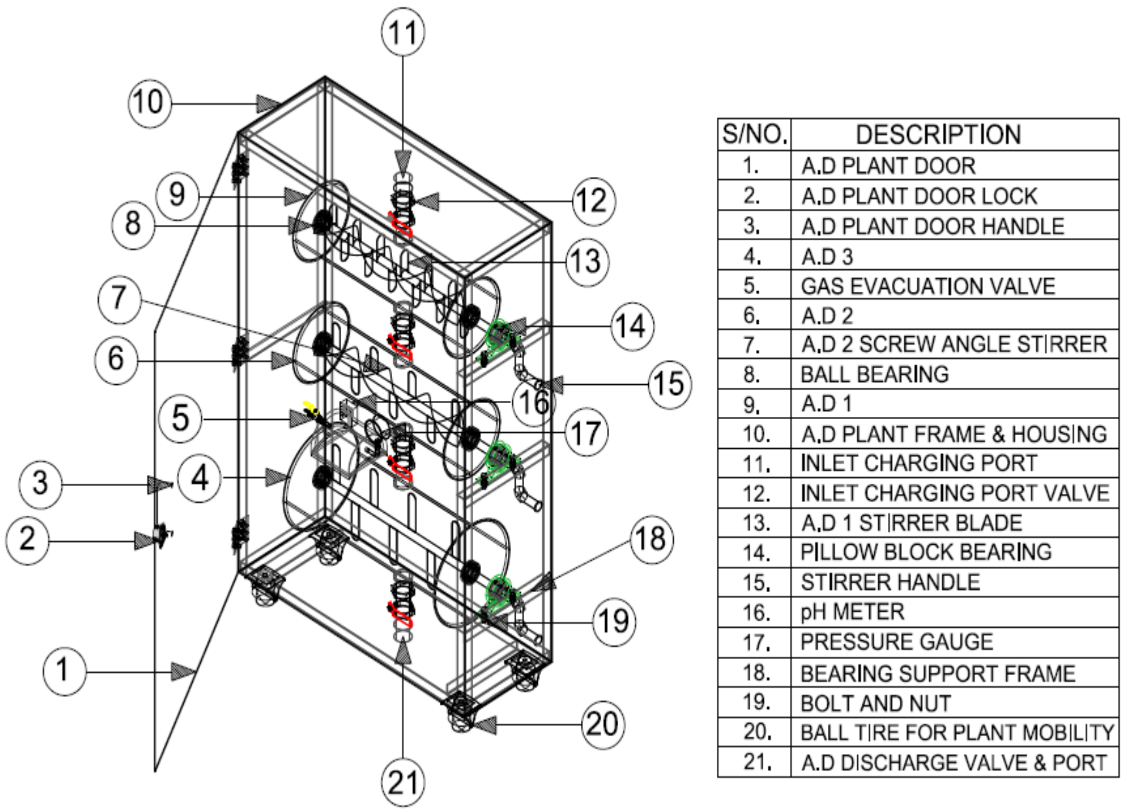

***Figure3.**Isometric Skeletal View of Three Stages Continuous AD Plant*

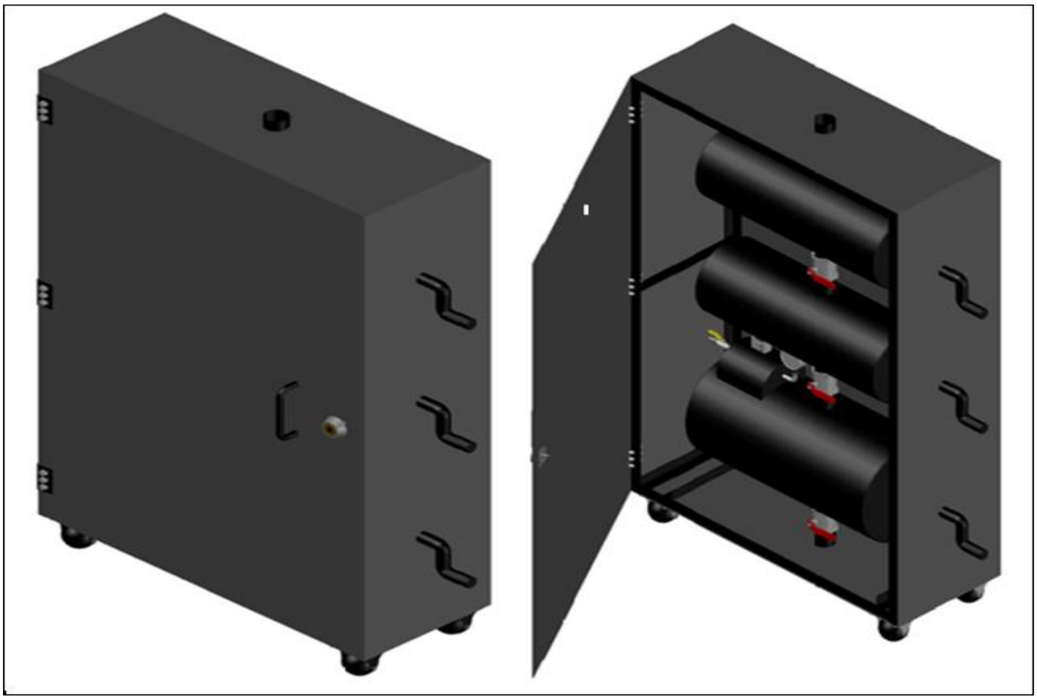

***Figure 4**. Isometric Model View of Three Stages Continuous AD Plant*

IV. CONCLUSION

This research work focused on the design of a three stages continuous AD plants. The fabrication of the plant was carried out using locally available materials. The plant was evaluated for performance using 35kg of non-uniform multiple feedstock mainly obtained from food waste, water hyacinth, waste water, pig dung and cow dung. The results obtained confirm increase biogas yielding rate at a shorter hydraulic retention time and this was as a result of improvement in the plant design. Finally, a stable pH valueswere obtained throughout, effect of organic loading rate was properly tackled and this was as a result of additional reactors, optimum mesophilic temperature andminimal percentage total solid achieved.

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