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Experimentation and Design Analysis of Anaerobic Sequencing Batch Reactor for Kano Abattoir

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Abstract— The study determines the treatment of Kano abattoir wastewater to provide a sustainable wastewater treatment mechanism, energy recovery through biogas production and integrating an anaerobic digestion plant for the abattoir. Anaerobic Sequencing Batch Reactor (ASBR) was chosen and explored for the treatment of the abattoir wastewater. The ASBR was subjected to a preliminary phase of 120 days and activated phase for 60 days at a HRT of 16 h. The pilot scale experiment showed that the average biogas production was 0.39L/d while laboratory analysis results for the abattoir wastewater treatment showed that suspended solid (SS) removal efficiency was 10%. Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD) and Fats removal efficiencies were 56%, 88% and 65.6% respectively. The proposed ASBR plant for the case study was designed to correspond to three-tank system for domestic wastewater treatment which included primary clarification before ASBR treatment and a sludge digester for primary and excess sludge. Each one of the three anaerobic sequencing batch reactors had the total volume of 150 m^3 and has the same treatment capacity. Cycle time of 24 h was considered for each reactor, while reacting time was calculated to be 13.2 h at a flow rate of 5.6 m^3/h. Kano abattoir have an average of 250 cattle, 43 camels, 173 sheep and 210 goats being slaughtered per day in the abattoir from 2009 till date, the quantity of influent generated was found to be 416 m^3 per day and 151,480 m^3 per year. However, ASBR will serves as sustainable wastewater treatment for Kano abattoir.

Keywords— Anaerobic Sequencing Batch Reactor (ASBR); Abattoir Wastewater Treatment; Anaerobic Digestion; Biogas Production; Kano abattoir.

I. INTRODUCTION

Inappropriate management of waste is one of the serious issues standing up to development. This is on the grounds that expansion in industrial, business, agricultural and environmental activities has resulted in the generation of large quantities of wastes [1]. When such waste are not well managed and appropriately oversaw, it add to unhygienic ecological conditions that breed pathogenic microorganisms. Pathogens and substantial metals cause sickness and poisoning in people and animals that interact directly with the water. It could also result to insufficiency of oxygen that makes for a unfavourable living condition and might cause hypoxia in human beings [15] [10]. Aside from the wellbeing suggestions, waste can make a domain disagreeable and ugly. Nonetheless, these wastes can be overseen appropriately by transformation into helpful and greater condition well-disposed forms called biogases.

ENERGY FROM WASTE

At the point when wastewater is treated in a wastewater treatment plant the suspended solids are isolated out as sludge. This slop contains a high measure of natural issue just as various supplements and pathogens, which can make an issue whenever discharged, untreated to the earth. One method for handling this issue is to process the sludge [3]. Absorption in an anaerobic situation can diminish the sludge volume, as the microorganisms expend the natural material and pathogens are decimated. [2] Explored the financial benefits of introducing 6 m^3 family-sized biogas digesters in Nigeria. As an oil-exporting nation with simple access to fossil fuels, it is significant for any elective fuel to be monetarily alluring in the event that it is to be a realistic elective. [18] Have investigated the impediments to broad establishment of household unit biogas digesters in the sub-Saharan zones since it has the potential to improve energy supply, sanitation and food security. [7] Talked about the possibility of associating open toilets to biogas digesters to improve environmental sanitations.

ANAEROBIC DIGESTION

Anaerobic treatment is the utilization of biological procedures, without oxygen, for the breakdown of organic matter and the adjustment of these materials by transformation to methane and carbon dioxide gases and a nearly stable residue [8]. Waste from animal can be utilized as nutrient, feed to microorganisms and as fuel energy source, they contain elevated level of natural issue that could be changed over into energy as supplement for fossils. Animal waste are inexhaustible everywhere throughout the world with Nigeria delivering around 227,500 tons of new waste every day, [16] that a kg of animal waste produce about 0.03 m^3 of gas every day. This shows hypothetically that Nigeria can deliver 6.8 million m^3 of biogas every day, which as far as energy, is proportional to about 3.9 million liters of oil. The utilization of biogas is fit for giving an uncommon catalyst in both provincial and urban regions. Biogas plant can be worked by utilizing materials which are locally accessible in most developing nations [6]. The anaerobic processing of metropolitan waste can have positive ecological incentive since it can consolidate waste expulsion and adjustment with net fuel (Biogas) generation. The strong or fluid buildup can additionally be utilized as feed or as biomass briquette for cooking [6].

In principle, anaerobic processing innovation is a perfect natural method for the expulsion of natural toxins in waste and wastewater. The innovation has two critical points of interest over the conventional aerobic biological treatment: initially, it is financially savvy since air circulation isn't required and a limited quantity of overabundance muck is created, and also, it by and large delivers vaporous methane as energy resource reserve [13].

SEQUENCING BATCH REACTORS

A sequencing batch reactor (SBR) accommodates time sequencing of activities which incorporate equalization, organic change, sedimentation and explanation across the board total cycle. The SBR procedure has four fundamental stages, for example fill, react, settle and decant. A fifth discretionary stage is the idle stage, which could conceivably be joined into a system (Figure 1).

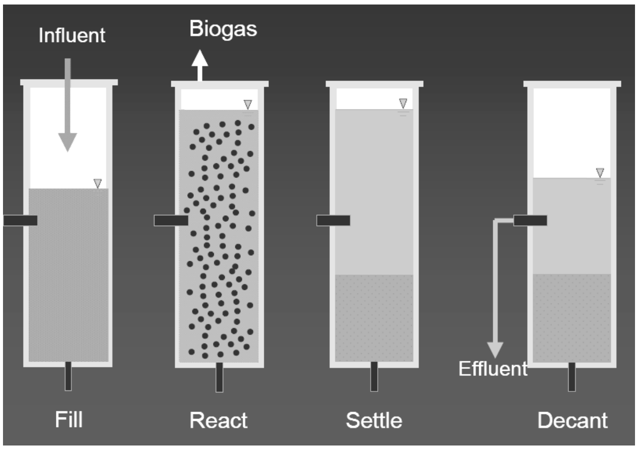

Figure 1: Phases of a batch reactor in one working cycle.

II. RELATED WORK

RESEARCH WORK ON ANAEROBIC DIGESTION TECHNOLOGY FOR PRODUCTION OF BIOGAS AND WASTEWATER TREATMENT.

[11] Results show that Iranian slaughterhouse wastewater can be effectively managed to produce methane. His study has shown the feasibility of treating slaughterhouse wastewater using an UASB anaerobic process. It removed 75 - 85% of the organic materials and provided the opportunity to utilize the CH_4 as a renewable energy and the digestate as a liquid fertilizer in agriculture. Total wastewater generated by two slaughterhouses Soleimani and Karaj Raak which he used as a case study equals 338 m^3 per day and 123,370 m^3 per year. Accordingly, 932 m^3 biogas was estimated which can yield 1,770 kWh electricity per day and 646,050 kWh electricity annually, 3,541 kWh heat per day and 1,292,465 kWh heat annually.

[17] Investigated biogas production potential of abattoir waste from Sokoto central abattoir in Sokoto metropolis. He worked on diverse retention time and the microorganisms related with the creation just as the pH of the slurry when the biogas generation was resolved. His outcome shows that the most noteworthy volume of biogas (2240 cm^3) was gotten in week 2 while the least volume (1820 cm^3) was acquired in week 4. Huge contrast ($p < 0.05$) was seen in the volume of biogas created in the first and second week just as to that of third and fourth week. In any case, no such contrast ($p <0.05$) was seen in the volume of biogas created in the third and fourth weeks.

[12] Investigated biogas plant being installed at Bodija Abattoir at Ibadan, South-Western Nigeria with over 1000 heads of cows slaughtered daily. His result shows wastewater volume production of 3.500 m^3/day from the abattoir. The chemical oxygen demand (COD) concentration is 5,500 mg/l. Moreover, the size of the digester is 3000 m^3 and biogas production (methane only) rate was 1,800 m^3/day and the power generation equivalent for off-grid lighting was 200KW.

[5] Worked on a proposed plant for treating the slaughterhouse waste and biogas production in Vingunguti slaughterhouse of Tanzania. The system is a complete treatment plant for a wastewater stream. The daily waste stream produced by the slaughterhouse includes the rumen, stomach, and intestinal content of 300 cows and 300 sheep/goats. Several parts of the animals that are not traditionally used are utilized, including the hides and the blood. Additionally, 40,000 liters of water are used by the slaughterhouse daily that also enter the waste stream. He used mass of volatile solids to estimate biogas production, and estimation for a biogas electricity generating plant is based on power production of 1,350,500 kWh/year operating continuously, divide by 365 and 24 to obtain power production of approximately 150 kW.

[9] Analytical overview approach was utilized to assess waste generated at the abattoir and its management in Minna, North Central Nigeria. This was researched utilizing survey and individual correspondence. Water tests were taken from water sources in the abattoir and were evaluated for physico-synthetic investigation. From the study, it was seen that a sum of 289 and 382 dairy animals and goats separately are butchered day by day in Minna abattoirs. This creates 3.92ton of blood, 2.9ton of intestinal substance, 4.2ton of bone and 2.2ton tissues as abattoir

squander day by day. High microbial burden in the abattoir wastewater further affirmed the need to treat this wastewater instead of releasing it to the earth. All the water tests have their physico-chemical parameters that were tested higher than WHO limit aside from tests from boreholes.

[4] Worked on a unique model of the enacted slime process that was utilized to dissect and streamline the activity of a SBR treating slaughterhouse wastewater. The model was utilized to assess whether the SBR plant would meet the profluent quality and the reactor blended alcohol suspended solids (MLSS) necessity (under 3000 mg/L) with the first cycle settings. This assessment was directed at 3 unique temperatures (10^{o}C/50^{o}F, 13^{o}C/55^{o}F, and 20^{o}C/68^{o}F) for both the "normal" (30,000 m^3/d, 7.9 MGD), and "peak" (49,000 m^3/d, 12.9 MGD) stream rates. In situations where the presentation prerequisites were not met, the model was utilized to change and improve the cycle setting to meet the effluent and reactor MLSS necessities.

[14] Studied the capability of biogas generation from cow manure (digestion waste content). It researched utilizing a batch procedure lab size of one liter's digester size. Three repeat of all out strong convergence of (5%, 7%) of cows paunch compost were blended in with (10%v/v) inoculums with control units for every fixation at room temperature. The aggregate sum of biogas delivered after the 49 days of analyses were, 12.678, 11.544, 8.154 and 5.724 lit for, 7% ,5% TS seeded sample,7% and 5% all out strong control separately. The outcomes show that rate of biogas generation increment with increment of total solid, pH and temperature.

III. METHODOLOGY

PILOT SCALE EXPERIMENTATION

The materials for the pilot scale set-up which consist a 200L feed tank, 87L steel cylinder suitable to act as an ASBR reactor, one 92 L influent feed tank, one 32 L gas collector. Other materials include influent feed pump, gas pressure gauge, PVC fittings, pipes of different diameters and their associated joint fittings, ball gauge for effluent and sludge outlet. The biogas line from the reactor was connected to the biogas collector. The fill point was positioned at the top of the reactor, while the decant points were located 0.22m and 0.52m respectively from the base of the reactor, this is to enable the reactor operation at different HRTs. The cover cap was secured to the reactor cylindrical body using 18 pieces of bolts and nuts symmetrical arranged and cautiously fixed to ensure the reactor was water/air proof. After the ASBR framework was completely set up, a hydro test was performed utilizing tap water to guarantee there was no leakage.

SUBSTRATE

The feed wastewater was collected at Kano abattoir. The sample was collected through the wastewater exit channel of the abattoir. From the flow channel towards the exit, hair and other solids were removed and 60L volume of the wastewater was prepared. A 10ml of sodium hydroxide (NaOH) alkaline was added to adjust the pH to a desirable value and from the mixture the initial pH was examined. A manually controlled mixing was done at 10 rpm in order to maintain a uniform appearance and composition and the temperature was conserve at 30^{o}C using a temperature gauge. Then the influent pump was powered and used to transfer the abattoir wastewater into the reactor during the Fill phase. During the Decant phase, the ball gauge pump was used to pass out the treated wastewater into the effluent tank. Biogas produced in the reactor was channeled into the gas collector using water displacement method. The gas produced was read and recorded at 12 noon of every ten days.

Figure 2: ASBR set-up (Top), Feed tank containing abattoir wastewater (bottom left), ASBR reactor (bottom right).

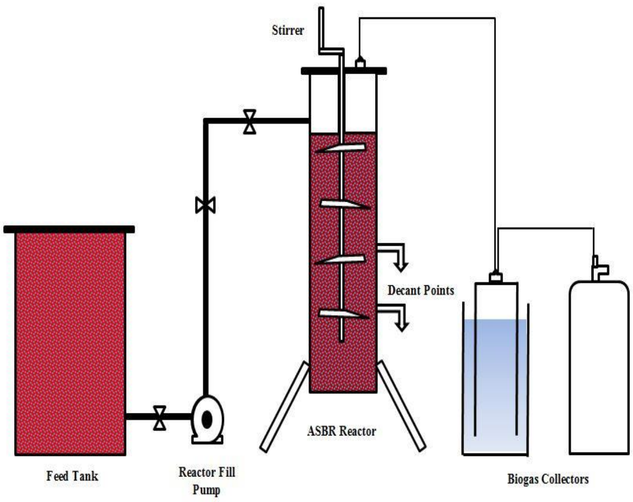

Figure 3: Schematic diagram of ASBR set-up

Table 1: Operating parameters at HRT of 16 h

Parameter	Preliminary phase	ASBR (Activated Phase)
HRT	16 h	16 h
Effective Volume	50 L	50 L
Duration	120 days	60 days
No. of cycles per day	2	2
Fill/Decant volume per cycle	20 L	20 L
Total Cycle time	12 h	12 h
Cycle Times for ASBR phases	Fill 0.25 h React 10.5 h Settle 1 h Decant 0.25 min	Fill 0.25 h React 10.5 h Settle 1 h Decant 0.25 min

INFLUENT WASTE STREAM GENERATED IN KANO ABATTOIR

Specification data are based on the fact that an average of 250 cattle, 43 camels, 173 sheep and 210 goats were slaughtered per day in Kano abattoir slaughterhouse in Kano state Nigeria. (Kano Abattoir, Slaughter figures for year 2009).

Table 2: Water consumption of the Kano abattoir (2009), (Source: Kano abattoir).

Animal	NAS/d	W/h (l)	W/d (m^3)	W/y (m^3)
Cattle	250	875	219	79,935
Camel	43	900	39	14,235
Sheep	173	412	71	25,915
Goat	210	412	87	31,755
Total	676	2,599	416	151,480

NAS/d: Number of animals slaughtered per day
W/h: wastewater generated/head
W/d: wastewater generated per day
W/y: wastewater generated per year
Total wastewater generated by the abattoir equals 416 m^3 per day and 151,480 m^3 per year.

ANALYTICAL TESTS

The laboratory test analysis of the abattoir wastewater was conducted at Federal Ministry of Water Resources, Department of Water Quality Control and Sanitation, Kano state zonal office. The influent and effluent was analyzed for soluble COD, BOD, solid content, total Kjeldahl nitrogen (TKN), pH, and alkalinity according to methods of wastewater test and analysis.

DESIGN OF ASBR PLANT FOR KANO ABATTOIR.

The ASBR System components include: 3 reactor tanks, decant system and influent pump, aeration and mixing equipment, feed pump, effluent collection chamber, level sensors, computer controller for cycle times and on/off controls, Influent valves for multiple tanks. The Plant layout was shown in Figure 4.

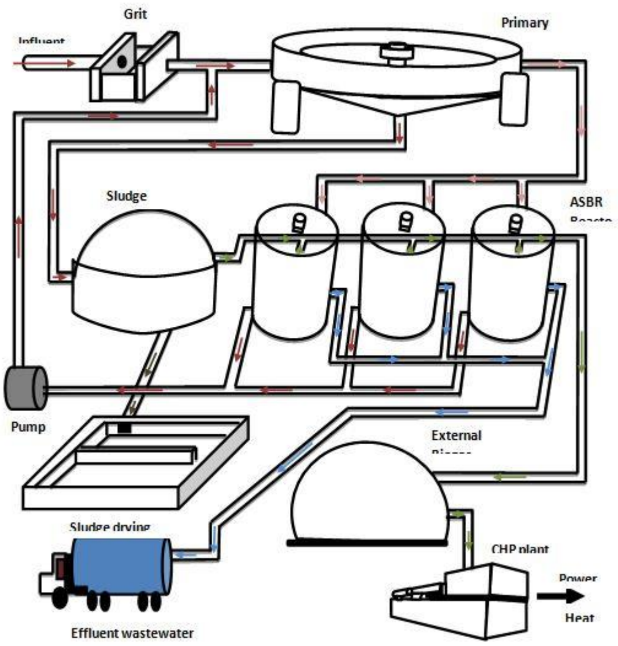

Figure 4: ASBR Plant layouts showing main components and general flow process of biogas to energy production.

DESIGN APPROACH OF ASBR FOR KANO ABATTOIR

Table 3: Desired Effluent Characteristics (Effluent Quality from well-designed well operated ASBRs)

Parameter	Design Objective (mg/L)
Effluent CBOD	< 8.0
Effluent TSS	< 8.0
Effluent NH_4	< 1.0
Effluent NO_3	<10.0

Table 4: ASBR Physical Design Parameter

Design Parameter	Value
Number of Reactor Tanks	3
Volume of Each Reactor Tanks	150 m^3
Total Reactor Volume	450 m^3

REACTOR DESIGN PARAMETER

Volume of gas collecting chamber (V_C), Liquid volume (V_L), Sludge volume (V_S), Useful volume $(V_L + V_S)$, Total volume of digester V_T, $(V_H + V_L + V_S)$, Diameter (D), Total Height (H_T), Height of gas collecting chamber (H_1), and Height of sludge chamber (H_2).

Table 5: Assumptions for volume and geometric dimensions

For volume	For geometrical dimensions
$V_T = 150\ m^3$ (*Volume of Each Reactor*)	$D = 5.6\ m$ *
$V_C = 10\%\ V_T$	$H_T = \frac{V_T \times 4}{\pi D^2} = 6\ m$
$V_L = 60\%\ V_T$	$H_1 = \frac{D}{5} =$

	$1.12\ m$ **
$V_S = 30\%\ V_T$	$H_2 = \frac{D}{2} =$ $2.8\ m$ **

* Diameter (D) of digester is mostly determined according to ground layout of the location.
** Geometrical dimensions of cylindrical shaped biogas digesters. (Source: Renewable Energy Practices in Bangladesh (2008))

Table 6: Characteristics of the ASBR units

Reactor	ASBR
Material	Steel
Volume of gas collecting chamber (V_C)	15 m^3
Liquid volume (V_L)	90 m^3
Sludge volume (V_S)	45 m^3
Useful volume $(V_L + V_S)$	135 m^3
Total volume V_T $(V_H + V_L + V_S)$	150 m^3
Total Height (H_T)	6 m
Height of gas collecting chamber (H_1)	1.12 m
Height of sludge chamber (H_2)	2.8 m
Diameter (D)	5.6 m
Mixing in react step	Mechanical
Equipment for mixing (model)	Mixers (Turbine, blades)

OPERATING CHARACTERISTICS IN ASBR PROCESSES

(Fill, React, Settling, Decant and Total time per cycle).
The total cycle time (t_C) is the sum of all the phases as presented below

$$t_c = t_F + t_R + t_S + t_D \quad (1)$$

Where:
t_C: Total cycle time, h
t_F: Filling time, h
t_R: Reacting time, h
t_S: Settling time, h
t_D: Withdrawal time, h

The number of cycles (N_C) per day can be determined through the total cycle time, as in (2):

$$N_C = \frac{24}{t_C} \quad (2)$$

Throughout the cycle, an ASBR can operate with different volumes due to the fill and withdraw phases. Then, total reactor volume (V_T) is defined as the maximum working volume and the filling volume (V_F) as the volume of wastewater filled and discharged every cycle. The difference between filling volume and total reactor volume is the minimum volume (V_{min}), as shown in (3).

$$V_{min} = (V_T - V_F) \quad (3)$$

A parameter related to volume is the exchange ratio per cycle $\left(\frac{V_F}{V_T}\right)$ between fill volume and total reactor volume, which is found in the ASBR design.
Exchange ratio per cycle, $\left(\frac{V_F}{V_T}\right)$ (4)

The definition of hydraulic retention time (HRT, h) for an ASBR is based on (5) which is defined in a continuous system.

$$\text{HRT} = \frac{V_T}{Q} \quad (5)$$

Where: HRT: hydraulic retention time

The flow rate (Q, m^3/h) in an ASBR equals the product of filling volume (V_F) and number of cycles per day(N_C).

$$Q = V_F \text{ x } N_C \quad (6)$$

Q: Influent flow rate, m^3/hr

Combining equation (5) and (6), the HRT (h) can be expressed as (7).

$$HRT = \frac{t_C}{\left(\frac{V_F}{V_T}\right)} \quad (7)$$

To determine the total cycle time (t_c) and the time of all the ASBR Phases:

Data:
Estimated wastewater flow per day = $416\ m^3$
$V_T = 150\ m^3$
$V_F = 135\ m^3$
$Number\ of\ reactors = 3$

The number of cycles per day for multiple reactors can be expressed as

N_C , No of cycles per day/tank = $\frac{\text{Estimated wastewater flow per day}}{V_F \text{ x Number of reactors}}$

$$N_C = \frac{416}{(135 \times 3)}$$

$N_C = 1.027 = 1$ Cycle per day per reactors

From equation (2)

$$N_C = \frac{24}{t_C}$$

$$t_C = \frac{24}{1}$$

Total cycle time, $t_C = 24\ h$

From equation (6), Q Influent flow rate, m^3/h

$$Q = V_F \ x\ N_C$$
$$Q = 135\ x\ 1 = 135\ m^3/day$$

$$Q = 5.6\ m^3/h$$

The hydraulic retention time HRT can now be determined from (5)

$$HRT = \frac{150}{5.6}$$

$$HRT = 26.7\ \text{h}$$

Therefore,

$$t_c = t_F + t_R + t_S + t_D = 24\ h$$

Where fill time, t_F

$$t_F = \frac{V_F\ (m^3)}{\text{Estimated wastewater flow per hour}}$$

$$t_F = \frac{135}{17.3}$$

$$t_F = 7.8\ \text{h}$$

Assuming:
Settling time, $t_S = 2$ h
Withdrawal time, $t_D = 1$ h
Therefore the reacting time, t_R(h)

$$t_R = 24 - 7.8 - 2 - 1$$
$$t_R = 13.2\ \text{h}$$

SLUDGE DIGESTER AND GAS HOLDER

Upright standard digester was considered for the treatment of sludge and excess biomass. The standard size is between 500 and 1,500 m³. The height is often between 5 and 6m; the diameter varies between 10 and 20m. The tanks are equipped with a heating system which delivers hot water into tubes fixed along the walls. The mixer is either completely immersed or equipped with a motor located outside the tank. Gas holder roofs type will be compatible with the upright standard digester. They are installed on top of the digester. The better version is a double membrane roof.

IV. RESULTS AND DISCUSSION

RESULT OF BIOGAS PRODUCTION

The activated phase of the setup (60 days) was considered for the collection of biogas parameters. During HRT of 16 h, biogas production was only detected at day 10. Day 19 to 20 of the pilot scale experiment was able to start up the production of biogas; there was a progressive rise in the volume of biogas produced on day 30. There was reduction in the volume of biogas produced from day 40 and continues to day 50. Therefore, it was deduced that methane producers are often directly or indirectly involved in process malfunctions, along with settling in of the methane-producing microorganisms after the hydrolysis of the abattoir wastewater within the first 20 days by the hydrolysing organisms. The maximum production of biogas was attained on day 30 and the activity of biogas producing organisms reduced and also decreases in the total amount of organisms in the process, since the food is insufficient to maintain a full population. The quantity of biogas produced by the ASBR set-up was not to a large extent affected by the increase in organic loading due to the fact that the pH was maintained within 6.8 to 7.2 using Sodium hydroxide and coupled with long HRT, the wastewater had adequate alkalinity to buffer the development of acids. The biomass was able to adjust to the shock loading and the methanogenesis rate increased rapidly to overcome the acid production.

Biogas production in the system was measured and read directly from the gas pressure gauge every 10 days during the experimentation. The gauge (Sensitivity of gauge; gas gauge) gradually deflects to show that gas production has commenced. The setup of the digester was made to undergo anaerobic digestion for a retention period of 8 weeks. The average biogas production was 0.39 L/d. Pretreatment by addition of 100g NaOH had significant effect on the biodegradability and methane yields of the wastewater as the startup of the biogas production commenced before day 11. The start-up is the phase during which the anaerobic bacteria are being attune to new environmental conditions and substrate.

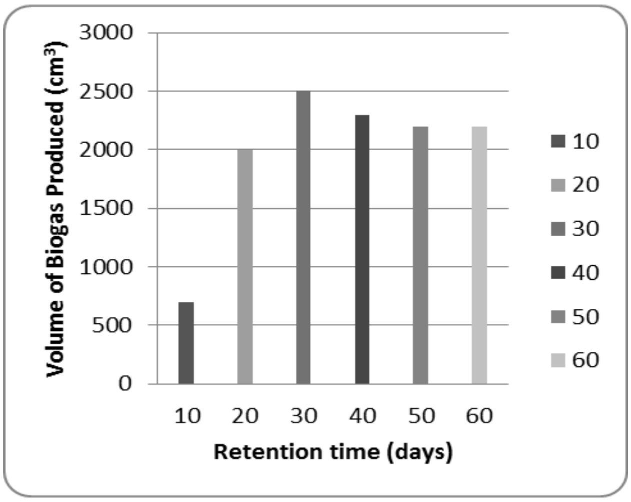

Figure 5: Volume of Biogas produced against Retention Time

ANALYTICAL TEST RESULTS FOR LABORATORY ANALYSIS OF KANO ABATTOIR WASTEWATER

The Laboratory test of the abattoir wastewater was conducted at Federal Ministry of Water Resources, Department of Water Quality, Kano State. Samples of the effluent were collected 0.52 m above the surface of the reactor sludge bed. The collection was made after the anaerobic system has gained a rather stable performance in the activated phase setup.

Table 7: Laboratory test result for characteristics of abattoir wastewater.

Parameter	Unit	Influent	Effluent	Removal (%)	Method
PH	-	6.1	7.8	-	HANNA pH Meter
BOD	Mg/L	49.3	5.72	88	ALPHA 5210B: 5-Day BOD Test
COD	Mg/L	256	112	56	ALPHA 5220B: Open Reflux Method
Alkalinity	Mg/L	140	100	29	ASTM D 1067B
Suspended Solid	Mg/L	170	153	10	ALPHA 2540D
Total Solid	Mg/L	2083	2078	0.24	Gravimetric
Fats	Mg/l	48	16.5	65.6	Method 2540D
Total Nitrogen	Mg/L	32	21	34	Kjeldahl

The laboratory test results shows that treatment of abattoir wastewater using ASBR anaerobic system was able to remove 10% efficiency of suspended solid (SS), from the laboratory analysis conducted. The COD, BOD and Fats removal efficiencies were 56%, 88% and 65.6% respectively.

RESULTS FOR ASBR DESIGN OPERATING CHARACTERISTICS

The filling and mixing time was calculated to be 7.8 h while the react, settling and decant time were 13.2 h, 2 h and 1 h respectively, based on each reactor volume of 150 m^3. However, it does not require additional biomass settling stage or solids recycle. Operational total cycle-time for the ASBR was 24 hours with biomass granulation to be achieved.

Table 8: Cycle settings for designed ASBR process

ASBR Phases	Phase length
Filling and Mixing	7.8 h
React	13.2 h
Settling	2 h
Decant	1 h
Total Cycle time	24 h

V. CONCLUSION

The result of the pilot scale experiment shows an average of 0.39 L/d of biogas production, operated at HRT of 16 h for two different phases: a preliminary phase of 120 days and activated phase of 60 days. The anaerobic treatment of the abattoir wastewater treatment was able to achieve 56% COD, 88% BOD and 65.6 Fats removal efficiencies. The react time for the designed ASBR was calculated to be 13.2 h at flow rate of 5.6 m^3/h and a total cycle time of 24 h. The result signifies the suitability of utilizing ASBR for abattoir wastewater treatment, while the designed ASBR reactor serves as an energy producer through biogas production and treatment of large volume of abattoir wastewater.

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