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Biogas Production from Municipal Sewage Sludge using Ultrasound Speeding Digestion Process

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Abstract- Biogas was produced using waste activated sewage sludge Sample of Wupa Abuja Sewage treatment plant. Two anaerobic reactors, U1 and U2 were designed with plastic transparent can with an ultrasound sonicator probe inserted into the digester with gas outlet connected to a measuring apparatus, allowing gas collection by volume of water displaced. Two Control reactors without ultrasound were also designed in same manner and named C1 and C2 respectively. Semi- continuous lab-scale digestion experiment was performed with the four reactors and results tabulated in each case. The sewage treatment plant at Wupa Abuja is an activated sludge system type and aerobic in nature without gas production and ultrasound treatment of sludge. This work investigated how the waste activated sludge sample could be utilized in an anaerobic arrangement with ultrasound treatment to facilitate improved gas production at a faster rate of sludge disintegration at reduced residence time. The ultrasound used was 420W capacity and the treatment time was set 6min, which corresponds to an energy input of $8.4KWh/m^3$.The physiochemical parameters of the sludge like the Total Solids (TS) of the activated sludge was investigated and found approximately 3.5%.The volatile solids (VS) and PH of the sludge were equally investigated. The concentration of filterable chemical Oxygen demand (*F*COD) was found to increase to 37.5% from 2.8% to 11% of total COD. The ultrasonic treatment caused an increase in gas production of 13% after speeding digestion process through hydrolysis and sludge disintegration.

Keywords- *Anaerobic reactor, Digestion, Hydrolysis, Sewage, Sludge Disintegration, Ultrasonic treatment*

I. INTRODUCTION

The sewage treatment plant at Wupa Abuja is the activated sludge system type and of aerobic process. It draws sewage (wastewater) from F.C.T Abuja populants of over 649,100 people on a land area of 7315 km^2. The plant capacity is of 700,000-population equivalent. For average dry weather flow (ADWF), the design flow is $131,250m^3$ per day and present flow is $40,000m^3$ of sewage per day. The plant has six aerobic bioreactors of $27,700m^3$ capacity each, making a total of $156,200m^3$ reactor capacities. The Solid Retention Time (SRT) is 20 days and the pH for the inlet and outlet of the wastewater is 7.2 and 7.4 – 6.9 respectively on the average.

In this treatment plant, sewage is treated and remaining residue (sludge) which has high volume of total solids (TS) and volatile solids (VS) is thickened in a thickener and then used as organic fertilizer without achieving gas production because the system is aerobic.

Energy plays an important role in human development and welfare (Enaburekhan and Salisu, 2007). There is also a great need to ease the pains and troubles of the energy crisis facing our people due to much dependency on petroleum as can be seen in the Niger Delta. Oil spillage to the water resources could be controlled by efficient wastewater treatment coupled with biogas production. The process of wastewater treatment and biogas production has to be sped up for higher yield and enhanced usage and this is quite the heart of this research. Use is made of ultrasound to give positive results for enhanced gas production and utilization.

Nigeria has much wastewater and this constitutes environmental pollution when channeled to the freshwaters body. Some wastewater (domestic and municipal) has to be treated before channeling them into waterways and in doing this, biogas can be tapped from the system, if anaerobic digesters are designed and incorporated into the treatment plants.

Biogas could be the answer to this Nigerian problem. The sources of energy in the country have to be diversified. Considerable number of industries producing wastewater exists in Nigeria today. Substantial quantities of wastewater arising from them pose serious environmental pollution and disposal issues. This wastewater can be used to produce biogas through a process called anaerobic digestion or fermentation (Enaburekhan and Salisu, 2007).

Sewage sludge contains about 90% of water. Sewage, such as domestic sewage and municipal sewage constitute the wastewater. Wastewater drained out from residential areas is called domestic sewage. The bathroom, latrine and kitchen are the locations from which sewage is obtained (Sen, 1981). The domestic sewage combined with different types of wastewater produced in a municipal area, is called municipal sewage (Sen, 1981).

The sewage sludge contains a large variety of disease producing organisms (bacteria, protozoa, and cysts), originating from human intestines. Typhoid, cholera, paratyphoid, dysentery, diarrhea etc., are the diseases caused by using contaminated water for domestic and drinking purposes (Sen, 1981).

Sewage treatment plant at Wupa Abuja generates sludge as the single largest residual product of the sewage treatment process. Although rich in nutrients, sewage sludge is not yet generally accepted for use as organic agricultural fertilizer in Abuja. The resistance from the farming industry concerns mostly fears of heavy metals and other presumably toxic compounds. As long as no definitive solution to the sludge problem exists, means of minimizing the amount of sludge are highly desirable because this will reduce the amount of sludge-heavy metals disposable to the environment.

One of the byproducts of sewage treatment process is biogas, but this has not been tapped, due to aerobic process utilized in the activated process plant. Biogas is a mixture of methane and carbon dioxide. Methanogenic archea produce biogas in anaerobic digestion of the sludge (Kparaju P. et al, 2008). Biogas can be utilized to produce heat and electricity or be upgraded to motor vehicle fuel. As the interests in non-fossil fuels increase, ways to produce more biogas from the same amount of sludge become more attractive.

Luckily, the strive for decreasing the amount of residual sludge often naturally coincides with the desire to increase the amount of biogas produced. If more matter leaves the anaerobic digestion process in form of biogas, less is left as sludge. However, a reduced sludge mass with the same amount of toxic compounds results in raised concentrations of the toxic compounds although the actual amount is the same.

After anaerobic digestion, the digested sludge is often allowed to degas for one or two days. This gas is seldom utilized, and acts as a greenhouse gas if released into the atmosphere. However, if the degassing could be accelerated, utilization would be easier.

The use of ultrasonic pretreatment of waste activated sludge has been investigated extensively over last decade. Ultrasound has a disintegrating effect on the sludge and causes lysis of bacteria present in the sludge. Records in the literature demonstrate increased concentrations of soluble organic material, increased reduction of organic material, and increased gas production after ultrasonic treatment. Another common application of ultrasound is the degassing of water-based liquids. Biogas production using sewage sludge of Abuja sewage treatment plant with ultrasound speeding digestion process has not been investigated. Thus, this study aims to investigate the effect of ultrasound treatment on the waste activated sludge of the Abuja sewage treatment plant.

A lot of research has been done on the generation of biogas from animal wastes such as cow dung, pig droppings, chicken droppings and even plant materials. Researches have also been embarked on industrial wastewater but only few researchers have given attention to the use of municipal sewage sludge for gas production due to the nature of the sewage, smell, social and traditional reasons.

The Abuja Sewage treatment plant at Wupa is a new plant that was commissioned in 2011, and being a new plant, not much research has been carried out on the plant, especially on the generation of biogas from the sewage sludge sample and on the physiochemical analysis of key parameters of the aerobic sludge sample. In addition, no researcher has tried to test the sewage sludge in an anaerobic fermenter incorporated with an ultrasound to investigate the potentiality of biogas production and degradability of the sewage sludge with lower residence time.

This research work tries to bring innovation which may be adopted in the FCT plant in the future, by incorporating an ultrasound into the system of anaerobic fermenter on a lab-scale, to see its effects and also open up a new idea of a more compact and faster technique for treatment of sewage sludge with improved degradability and for the purpose of tapping the biogas resources from the sewage sludge.

II. MATERIAL AND METHODS

Fresh waste activated sludge and partly digested sludge sample were collected from Wupa Abuja sewage treatment plant from the six aerobic reactors respectively before treatment and were divided into four portions. Four experimental reactors were designed, and numbered. They were numbered U_1, U_2 and C_1, C_2. A measured proportion of the sludge was fed into each reactor. All the four reactors were covered with black plastic to prevent light from entering the digester and the digester was placed in a 37^oC water bath.

Two reactors were test reactors U1 and U2 receiving waste activated sludge (WAS) treated with ultrasound. The other two reactors C1 and C2 were control reactors receiving untreated sludge. The reactors were operated in a semi-continuous mode with feeding once a day, six times per week.

Biogas was produced in reactor without ultrasound treatment and also in the reactor incorporated with ultrasound sonicator probe with sonication of 420W. Gas was collected over acidified water to avoid CO2 absorption. The volume of water displaced measured the volumes of gas produced. The gas was tapped, pressurized and stored. The physiochemical parameters of the sludge like, TS, VS, FCOD, and pH were determined using APHA (1997 & 1998) Standards. Most parameters were expressed in percentage.

Data were analyzed graphically and conclusions drawn. Microscopic examination was also carried out on the sludge for both ultrasonically treated and untreated sludge and observations were recorded. General conclusion was drawn on the effect of the ultrasound on the sludge and gas production.

A. Experimental Design

To establish the effect of ultrasonic treatment on waste activated sludge, a semi-continuous digestion experiment was performed. The reactors were made of plastic can, and had an approximate volume of 5 L. The stirrers were equipped with 4-bladed propellers. Sludge was introduced to the can through the inlet at the top right side of the reactor. Digested sludge was removed through the down outlet of the can at down right side of the reactor. There is also a gas outlet incorporated at the top right- side of the reactor and rubber tubing, ultrasound sonicator probe was made to pass inside the can, and it was then sealed and made airtight. . Rubber stoppers were used to plug the reactors, and when there was leakage, hard bond has used to seal it properly. Syringes and needles (Micro lance) TM were used for gas and sludge sampling. Gas measurement arrangement by acidified-water (pH<2), was incorporated to the reactor, see fig.1 and fig.2.

The main experiment was complimented with two sub-experiments, focusing on the release of filterable chemical oxygen demand (FCOD) and microscopic examination of sludge.

B. Digestion Experiment

Four reactors comprised the set up. Each reactor had two openings one small for feeding and withdrawal of sludge and one large plugged with stopper. The stopper was equipped with two entrances one for a propeller axis and one for a gas outlet tube.

On the tube, there was a three-way valve for gas sampling. All four reactors were covered with black plastic to prevent light from entering the reactor and placed in a 37^{o}C water bath. Fig.1 and Fig.2 Show the experimental equipmentation.

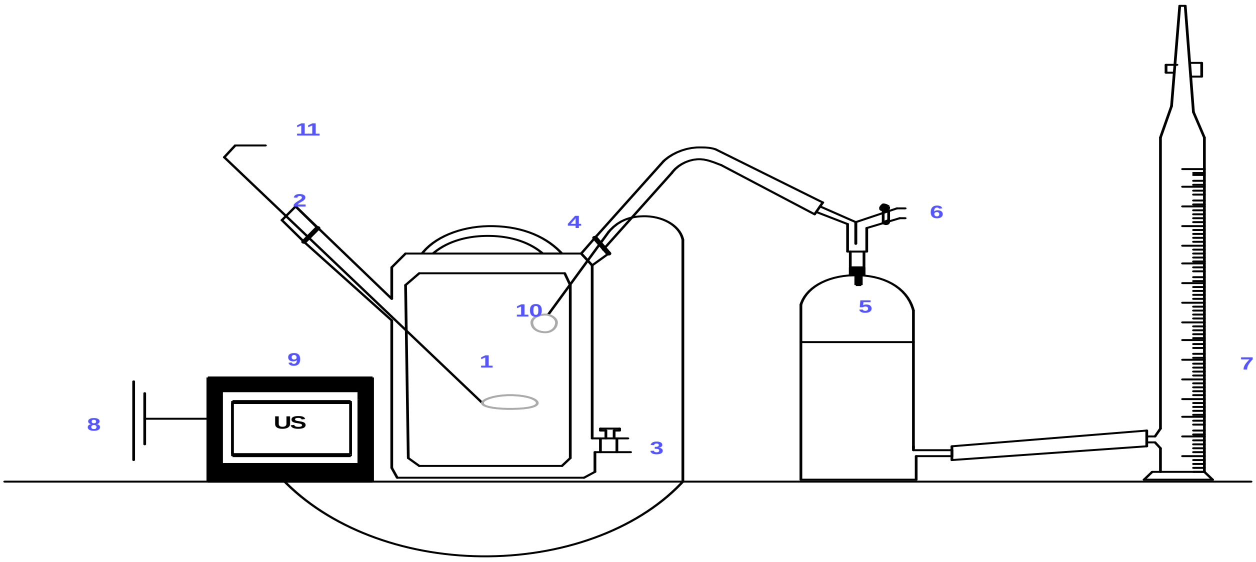

Figure 1. Illustration of the biogas reactor with ultrasound. 1.Digester (V = 5 L) capacity, 2.Feed inlet and effluent outlet, 3.Sludge outlet, 4.Gas opening, 5.Water displacement jar, 6.Gas outlet 7.Measuring jar, 8.Power source, 9.Ultrasound Machine, 10.Ultrasound sonicator probe, 11.Stirrer/ propeller

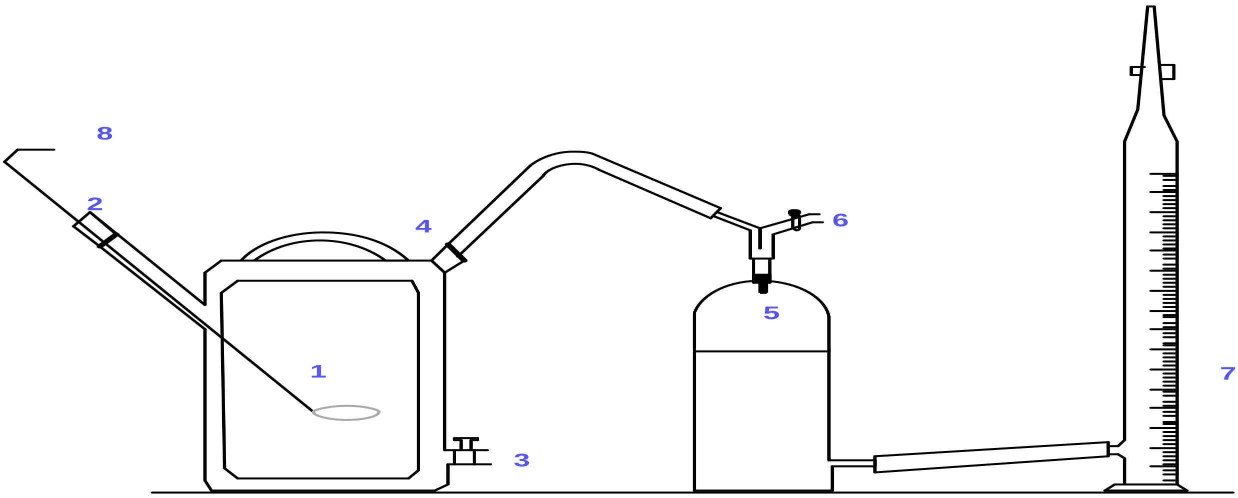

Figure 2. Illustration of the biogas control experiment set up. 1. Digester (V = 5 L) capacity, 2.Feed inlet and effluent outlet, 3.Sludge outlet, 4.Gas opening, 5.Water displacement jar, 6.Gas outlet 7.Measuring jar, 8.Stirrer/ propeller

Inoculum: The inoculums consisted of a mixture (1:1) of digested sludge from the six reactors of Abuja sewage treatment plant. The sludge was taken fresh from the Wupa Abuja aerobic reactors and subsequently poured into the reactors designed for the experiment. Afterwards, the experimental reactors were immediately sealed and placed in the water bath and allowed to degas under stirring for 24hrs.

Substrate: The substrate was partly waste activated sludge (WAS) and partly digested sludge (DS). Even though the full-scale aerobic digestion chambers at Abuja were run on a mixture of primary sludge and waste activated sludge, primary sludge was excluded in this experiment. Primary sludge varies heavily in both composition and quality and would have meant an unnecessary source of variation in gas production. Digested sludge as a part of the substance ensures that the digestion process is not affected by lack of nutrients, which in the full-scale process are found in the primary sludge. It also assures the presence of an active microbial community like the one in the full-scale process. The organic matter (i.e. volatile solids (VS)) present in the digested sludge should not affect the biogas production to any considerable extent.

Start-up Period: The reactors were inoculated on 22-09-2009 and the first feeding took place the following day (day1). At the beginning of the start-up period T_R was 16 (22.9) days and the proportion of waste activated sludge in the substrate was 70% (see fig.1). All reactors were fed with untreated sludge. On day 6, T_R was slightly increased to 17.8 (25.4) to better agree with the full-scale process.

In the second week, it was noted that the waste activated sludge was unusually wet (total solids (TS) ≤1%). The sludge was in fact lacking addition of polymer; explaining the low TS. After a couple of days, polymer usage was resumed in the sludge thickening processing and at the beginning of the third week, the sludge had TS of 4%. On day 15, TR was decreased to 14.5 (16) days and the proportion of waste activated sludge were increased to 90% in an effort to get a higher gas production. It was also noted that the stirring propellers were not all on the same height so they were adjusted accordingly (lowered). At day 19, all the propellers were raised to a new height of 1/3 of the sludge height. On day, 21 the test reactors started receiving material. The treatment time was 45 s (after which 55% of the sludge had been treated at least once). On day 33, the ultrasonic treatment time was increased to 2 min and 14s (corresponding to three retention times in the ultrasonic treatment equipment, or 91% of the sludge being treated at least once). Since there were still problems with foaming, the volume of digested sludge in the substrate was increased to make sure a sufficient amount of (active) microorganisms was present. TR was lowered to 10 (16) days and the proportion of waste activated sludge were decreased to 62.5%. This was a suitable combination of T_R and sludge proportions, which were maintained further. On day 61 all, the reactors gas measuring apparatus was measuring gas at a sufficient resolution and the experimental period then began.

TABLE I. RETENTION TIMES (T_R), PROPORTION OF WASTE ACTIVATED SLUDGE (WAS) AND DURATION OF SONICATION TIME DURING THE START-UP PERIOD OF THE DIGESTION EXPERIMENT

Day	T_R(days)[a]	WAS proportion (%)	Sonication time (mm:ss)
1	16.0 (22.9)	70.0	00.00
5	17.8 (25.4)	70.0	00.00
15	14.5 (15.0)	90.0	00.00
21	14.5 (15.0)	90.0	00.45
33	10.0 (15.0)	52.5	02.14

"a" is the values in parenthesis with regard to only the volume of the waste activated sludge. The values without parenthesis are with regard to the total amount of exchanged sludge (digested and wasted activated sludge).

The retention time (T_R) is defined as the ratio between the total volume (V) and the volume of exchanged sludge per day (r):

$$T_R = \frac{V}{r} \quad (1)$$

Experimental Run: T_R was 10 (6) and the proportion of waste activated sludge was 62.5% at the second day of the 16-day experimental period, and the ultrasonic treatment time was increased to 6 min, raising the possibility of getting a difference in gas production more easily to measure. The test reactors received treated sludge for twelve days. During the last three days, all reactors were fed untreated sludge.

The sludge was treated with ultrasound for 53 min, in intervals of 3 min with 1.5 min breaks in between, to prevent overheating of the sonicator. Thus, the effective treatment time was 36 min. The treatment began 17 min after the can had been filled but space was allowed, as the can was not completely filled. An effective treatment time of 36 min means that approximately 75% of the sludge was treated at least once. The trial went on for 50hrs and data of gas measurements were collected during the three periods. Gas production was the only parameter measured.

Method Validation: During a start-up period of 61 days, mainly two problems were dealt with the stability of the reactors and accuracy in gas-production measurements.

Stable Reactors: Due to foaming and occasional overflows, three parameters were modified. 1. The retention time (T_R), 2. The proportion between waste-activated sludge and digested sludge used for feeding, and 3. The height of the propeller in the reactor. When an overflow took place, the reactor was opened and refilled with fresh digested sludge. An overview of T_R and sludge proportions is given in Table 1, while the different propeller heights are summarized in Table 2.

TABLE II. PROPELLER HEIGHTS (MEASURED FROM THE BOTTOM) IN THE REACTORS DURING THE START-UP PERIOD OF THE DIGESTION EXPERIMENT

Height (cm)			
Reactor	Day 1	Day 15	Day 19
C1	1.8	1.6	3.3a
C2	3.9	1.6	3.3
U1	3.8	1.6	3.3
U2	1.6	1.6	3.3

"a" is at height of 1/3 of the reactor

The volume of exchange sludge would traditionally be seen as the sum of waste activated sludge volume and the digested sludge volume fed to the reactor. However, one could argue that only the volume of the waste activated sludge should be used. Since the digested sludge in the substrate is partially the same as the sludge withdrawn from the reactor it can be viewed only as background material being replaced. Both points of view are valid since we want to know how much sludge in fact is replaced and how much of waste is activated sludge – the material of interest. During the first part of the start-up period, retention times were looked upon from the viewpoint of the total volume. For the second part, they were seen from the viewpoint of only the waste activated sludge. Henceforth, when presenting retention time the ditto with regard to only the waste activated sludge will be given in parenthesis.

C. Accuracy in Gas-production Measurements

To increase the accuracy of measurements, two approaches were used: physical modification of the gas meters and increased gas production from increase of the organic loading.

1) Sub-experiment 1: Filterable chemical oxygen demand (FCOD)

The concentration of filterable chemical oxygen demand (FCOD) was used as a direct measurement of cell lysis. *FCOD* is defined as the COD of the remaining filtrate after centrifugation and filtration of sludge. When cell walls are disintegrated due to ultrasonic cavitations, the material inside the cell is released into the reactor suspension. An increased FCOD after ultrasonic treatment of sludge is an indication of cell lysis. *FCOD* of waste activated sludge was analyzed five times, pre -and post- ultrasonic treatment. Once double samples were used to measure the spread of the results. An analysis of the total COD was made twice. Treatment lengths ranged from 45 s to 10min. After 1200 rpm of the sludge in a centrifuge, the supernatant layer was filtered through a medium grade filter paper with pore size 1.2µm. Two of the *F*COD measurements were also accompanied by measurements of sludge temperature at different treatment lengths.

2) Sub-Experiment 2: Microscopic Sludge Analysis

To see if filamentous bacteria were affected by ultrasonic treatment, samples of waste activated sludge with different treatment times were examined in a light microscope. Floc size and length of filaments were studied at 100-x magnification. The reactor effluent was also studied to see if the prevalence of filamentous bacteria differed between the reactors receiving ultrasonically treated sludge and the control reactor. Extended filament length, total filament abundance and floc firmness were studied and remarks made.

Sampling and Analysis: Gas production was measured by water displacement method, the burette was already calibrated and error of parallax was avoided while taking readings on the burette. Gas flow was calculated using stopwatch, and volume of gas produced was found to be at the rate of 3.5 mL/min. Prior to feeding (i.e. six times a week) readings on the burette and stop watch were taken at same time and recorded and later subtracted from the previous reading. Syringes and needles (Micro lance) TM were used for gas and sludge sampling.

- **Methane** was sampled once a week from the reactor. Appendix ii describes the analysis and the following calculations in detail.
- **COD** was analyzed using the APHA (1997) Standard methods. Samples were heated in a thermostatically controlled oven.

FCOD samples were centrifuged at 1200 rpm and the supernatant layer was filtered through a medium grade filter paper with a pore width of 1.2 µm. FCOD samples were diluted five or ten times. Samples analyzed for total COD were diluted 500 times.

Temperature of the ultrasonically treated waste activated sludge was measured with a standard liquid in-glass thermometer. *TS* were analyzed according to APHA (1997) Standards. The reactor effluents were analyzed twice a week. Collective samples of the waste activated sludge were analyzed weekly. *VS* were analyzed according to APHA (1997) Standards. The reactor effluents were analyzed twice a week. Collective samples of the waste activated sludge were analyzed weekly. *pH* was analyzed with a pH meter according to APHA (1997) standards. The reactor effluents were analyzed twice a week.

III. RESULTS AND DISCUSSION

Inoculum: The digested sludge from digestion chambers one and two, comprising the inoculum, had total solids (TS), volatile solids (VS) and pH according to Table 3.

TABLE III. TOTAL SOLIDS (TS), VOLATILE SOLIDS (VS) AND PH OF THE TWO SLUDGE MAKING UP THE INOCULUM

Digestion chamber	TS (%)	VS (%)	PH
1	3.3	62	7.4
2	1.1	63	7.5

Substrate: During the experiment period, the TS and VS of the waste activated sludge were in the range of 2.8 – 3.8% and 74-75% with mean value of 3.5% and 76%, respectively. These TS and VS values gave a mean organic load of 1.7gVSL-1d-1 for the experimental period.

1) *Method Validation*

a) *Stable Reactors*

For the first part of the start-up period foaming usually occurred several times a week and occasionally there was an overflow. The reactors overflow was due to a combination of frequent foaming and the fact that the gas-outlet tubes were two long inside the reactor. This led to relatively thin layer of foam plugging the tube; gas could not escape from the reactor; pressure was built up and sludge flowed out through the stirring hole. When an overflowing reactor was opened and refilled with fresh digested sludge, the tube was shortened to prevent future foaming in the reactors C1 and U2. On day 15, the propellers were adjusted to a height too low to give sufficient mixing. On day 19, when discovered that there was excess foaming, the pipes were shortened in the two affected reactors and all propellers were placed at a height of 1/3 of the sludge volume. As a result, the foaming tendency was abated.

Furthermore, different combination of retention time (T_R) and proportion between waste activated sludge and digested sludge were investigated in an effort to minimize foaming. The best reactor performance was achieved with a TR of 10 days with regard to the combined volume of waste activated sludge and digested sludge, equivalent to a TR of 16 days with regard to only the volume of the waste activated sludge. The best proportion of waste activated sludge was found to be 63%.

b) *Accuracy in gas-production measurements*

The resolution of the measurements of gas with water displacement method is due to unavailability of gas meter as at the time of experiment in the lab. The physical modification with pieces of polystyrene to decrease the active volume of the burette actually helped for good measurement, as there are no options. An increased resolution (15-28 mL) was achieved, but the measurements were very fluctuating. This was probably due to the porous and soft structure of polystyrene making the measurement unreliable. The second modification with solid plastic can worked much better. The decreased TR leading to an increase of organic loading and daily gas production also improved the accuracy of the gas production measurements.

Experiment Run: Fig.3, fig.4, and fig.5, Show the biogas yield over the experimental period. During day, 1 – 5 there was a general increase in gas production and the increase seemed to be stronger for the two reactors receiving sludge treatment with ultrasound for 6 min. For day, 7 – 12 the difference in gas yield did not increase further. During day 14-16, when all reactors received untreated sludge, the difference in gas yield disappeared – a confirmation that the deviation in gas yield was due to the ultrasonic treatment.

The gas yield for the control reactors, a mean of 293 mL/gVS for day 7-12 was in the lower range of the reference values cited by Brown et al (2003) and lower than the value presented in the report on Wupa Abuja sewage sludge . Still, the values are in the same range, confirming that the gas measurement was correct.

TABLE IV. GAS YEILD (ML/GVS) FOR EACH DAY FOR REACTORS C1, C2, U1, U2, FOR 6MINS ULTRASOUND TREATMENT

GAS YEILD (ml/gVS)				
DAY	REACTOR C1	REACTOR C2	REACTOR U1	REACTOR U2
1	256	270	245	261
2	256	279	280	268
3	281	289	297	292
4	281	289	315	292
5	290	298	323	308
6	295	298	335	328
7	325	300	350	361
8	314	282	342	344
9	285	285	302	322
10	304	257	322	344
11	295	257	302	310
12	322	285	332	355
13	325	295	335	358
14	322	314	332	355
15	311	309	329	336
16	311	285	305	309

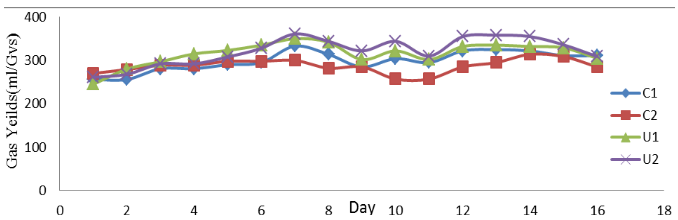

Figure 3. The graph of Gas yeild (ml/gVS) and Day for control reactors C1 and C2 after received untreated sludge and test reactors U1 and U2 after 6min of ultrasound treatment

TABLE V. GAS YIELD FOR TEST REACTOR U2 AND CONTROL REACTOR C1

	Gas yield (ml/gVS)	Gas yield (ml/gVS)
	REACTORS	
DAY	C1	U2
7	333	361
8	314	344
9	285	322
10	304	344
11	295	310
12	322	344

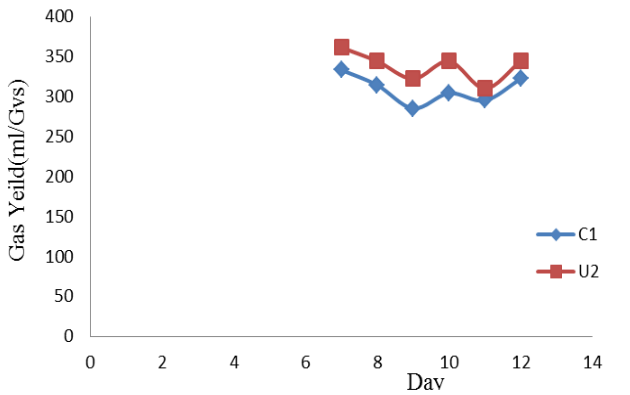

Figure 4. Gas Yeild (Ml/Gvs) for Test Reactor U2 and Control Reactor C1

TABLE VI. GAS YIELD FOR TEST REACTOR U1 AND CONTROL REACTOR C2

	GAS YEILD (mL/gVS)		
	REACTORS		
DAY	C2	U1	
7	300	350	
8	282	315	
9	265	302	
10	257	295	
11	257	302	
12	275	315	
13	292	335	
14	314	339	
15	309	329	
16	285	305	

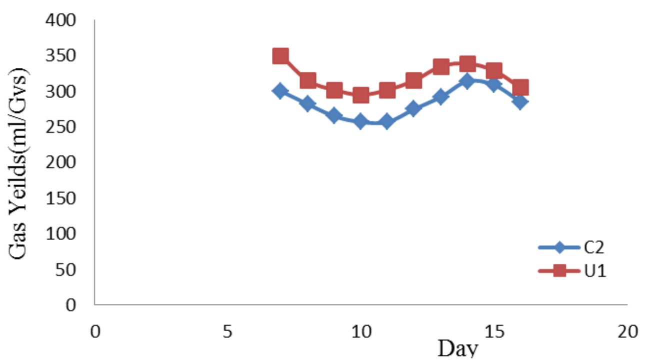

Figure 5. Gas Yeild (Ml/Gvs) for Test Reactor U1 and Control Reactor C2

The methane content: The methane content (58.5%) of the biogas was stable throughout the test and control reactors.

pH value: The pH was neutral throughout the experiment for both tests (pH of 7.3-7.7) and control (pH of 7.4-7.6) reactors. Neutral pH values correspond well with the low, <100 mg/L, concentrations of organic acids. From the neutral pH and the low concentration of organic acids, it can be concluded that the reactors were not overloaded.

TS: TS of the reactor effluents was fairly constant (at about 2.5%) over the experiment and equal among the reactors. There was a minor general decrease of VS in the reactor effluent, which shows that there was no buildup of un-disintegrated organic material in the reactors. However, to be able to draw further conclusion from the decrease in VS a longer experiment is required. Graphs of TS and VS of the reactor effluents are shown in fig.6 and fig.7.

TABLE VII. TS (%) AND VS (%) FOR REACTOR EFFLUENTS OF CONTROL REACTOR C1

DAY	TS (%)	VS (%)
1	2.4	64
4	2.6	64
8	2.6	64
11	2.4	64
15	2.5	63

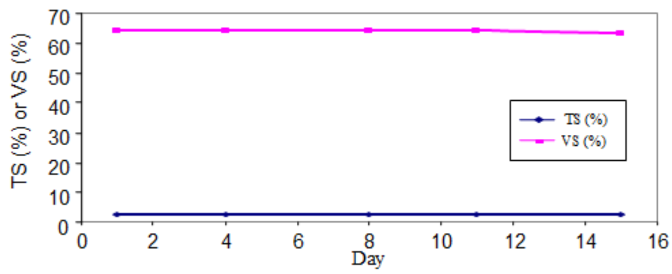

Figure 6. Graphs of Ts (%) And Vs (%) for Reactor Effluents of Control Reactor C1

TABLE VIII. TS (%) AND VS (%) OF ULTRASONIC REACTOR U1 DURING DIGESTION EXPERIMENT

	REACTOR U1	
DAY	TS (%)	VS (%)
1	2.5	64
4	2.6	65
8	2.6	64
11	2.5	64
15	2.6	64

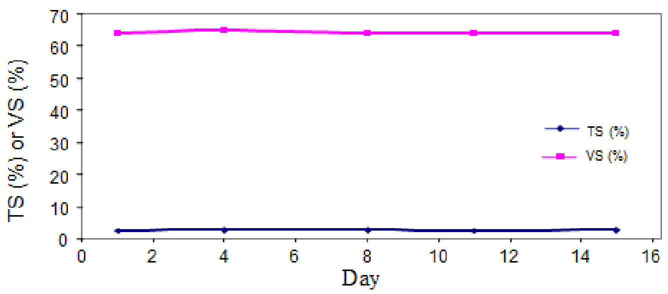

Figure 7. Graphs of Ts (%) And Vs (%) of Ultrasonic Reactor U1 during Digestion Experiment

VS Reduction: In fig.6, and fig.7, there were no difference in VS reduction between the test reactors and the control reactors. VS reduction for C1, C2, U1 and U2 was 31%, 33%, 31% and 33% respectively. The increase in gas production of 12.8%, in this case corresponds to approximately 0.1g more VS being degraded per day. Thus, no detectable difference in VS reduction was expected, since an increase of 0.1g VS being degraded is rather difficult to measure. This experiment, with its high throughout of organic matter was designed primarily for the study of gas production. For a better study of VS reduction, a large experiment is needed and preferable with a longer retention time.

1) sub-experiment 1: filterable chemical oxygen demand (FCOD)

Three out of five FCOD trials were successful. One trial failed due to too short sonication times and problems with the COD analysis. The other unsuccessful trial was made with sludge with low TS (2.5%). The three successful trials are shown in fig.8. For the trial where double samples were used, the sample standard deviation was low, in all cases <0.7% of the sample mean.

TABLE IX. TS (%) AND FCOD (MGO2/L) FOR SUB-EXPERIMENT 1 FOR 10MINS ULTRASONIC TREATMENT

TIME (MM:SS)	TS (%)	FCOD (mgO2/L)
0:00	3.1	730
0:13	3.1	1410
0:45	3.1	1110
1:00	3.4	1120
2:14	3.4	1660
5:00	3.4	2940
8:00	3.8	5770
10:00	3.8	6760

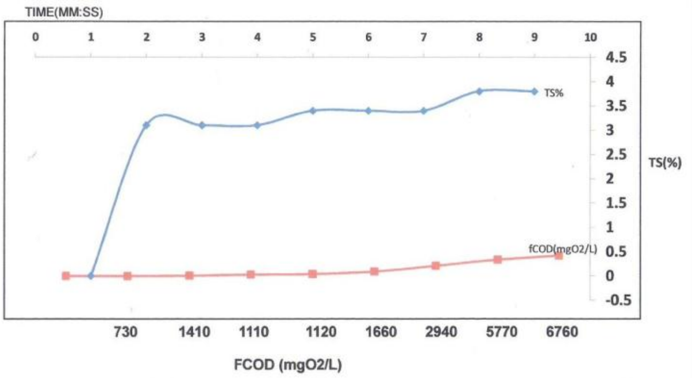

Figure 8. Graphs of TS(%) and FCOD (mgO_2/L) for 10Mins. Ultrasonic Treatment

There was a clear and linear increase of FCOD with increasing treatment time. Even when the treatment time reaches 10 min, no attention of the increase was seen. A 6 min

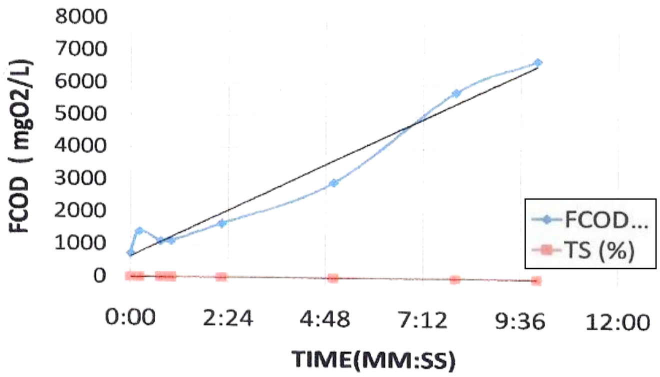

Figure 9. Graph of TS(%) for 10Mins.Utrasonic Treatment for Sub-Experiment-1

treatment, as used in the digestion experiment, of the sludge with approximate TS of 3.8% (fig.9) raised the FCOD to 37.5% of the untreated sludge. If FCOD is expressed as a percentage of the total COD, a rise from 2.8% to 10.6% resulted from the 6 min treatment. The enhanced FCOD values are distinctly visible to the natural sight.

Filtrates from sludge with longer treatment times are much darker in color, due the elevated concentration of organic material. The enhanced FCOD values are distinctly visible to the natural sight. Filtrates from sludge with longer treatment times are much darker in color, due to the elevated concentration of organic material. This is illustrated in Fig.10.

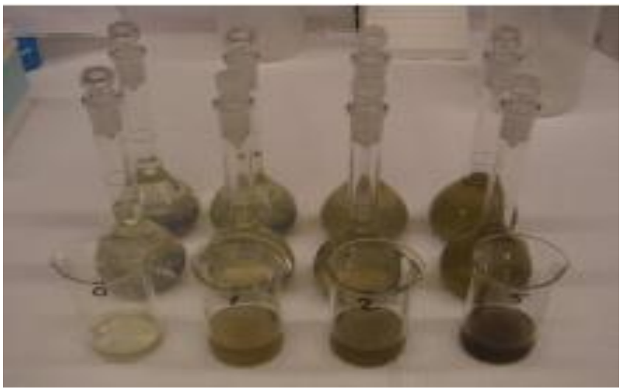

Figure 10. Waste activated sludge filtrate for fCOD analysis (From left to right, samples are treated 0, 1, 2, 3, 4, and 5 min, respectively)

Note that cell debris larger than 1.2 μm are not included in the FCOD numbers even though they are available for methane production. Thus, more organic matter is available for anaerobic digestion than the FCOD values show. Nevertheless, FCOD is a good indicator of the sludge disintegration, especially together with a digestion experiment. The temperature of the sludge increased during treatment time, though not linearly, because heat was transferred to the cold equipment. After 2 min and 14 s, the temperature had risen from 12°C to 13.5°C, but after 10 min, the temperature had reached 25.5°C.

2) sub-experiment 2: microscopic sludge analysis

The microscopic sludge examination showed that the flocs of the waste activated sludge exhibit signs of disintegration even at low sonication times like 45 s. At sonication, times of 2 min the flocs were disintegrated to some extent, but the filaments showed no signs of effect. There were fewer areas with a high degree of compaction. For longer sonication time of 6 mins (8.4KWh/m^3), there was a shortening effect on the protruding filaments (extended filament length) and the areas with a high degree of compactness were smaller and fever. After 10 min (14KWh/m^3), the flocs were clearly disintegrated and all filaments were shorter. Areas with a high degree of compactness were almost not found. Fig.11 and 12 show the untreated sludge and the sludge after 10 min of ultrasonic treatment respectively.

When handling and pouring the treated waste activated sludge it was clearly noticed that the viscosity decreases with increased treatment time. Thus, the ultrasonic treatment started to break up the floc structure of waste activated sludge relatively quick. To shorten the filaments takes longer, six minutes or more with the equipment used in this study. However, it should be noted that the occurrence of filamentous bacteria in the sludge was not extremely high. Abuja sewage treatment plant did not have any foam related problems. A more prominent effect might have been seen in sludge with more and longer filaments.

The study of the reactor effluents showed no difference in the prevalence of filaments bacteria between the reactors receiving ultrasonically treated sludge and the reactors receiving untreated sludge. Both the control and the test reactors had low occurrences of filamentous bacteria.

Figure 11. Untreated waste activated sludge at 50x magnification. (Mixture of 20ml sludge and 60 ml water)

Figure 12. Waste activated sludge treated with ultrasound for 10min at 50 x magnifications. (Mixture of 20ml sludge and 60ml water)

The increase of treatment time from 45 s to 2 min 14 s and finally to 6 min was probably necessary to reach a conclusive estimate of the increase in gas production, with the material and equipment at hand. Even after successful modification of the gas meters, it is doubtful that a gas-production increase originating from one of the shorter treatment times could have been measured with desired accuracy.

For the few references from which the energy inputs can be calculated, they are generally higher (> 100 kWh/m3) than in this study. Chu et al (2001) saw an increase of FCOD from 0.5% to 20% of total COD, with an energy input of 660 kWh/m^3. In the present study, an energy input of 8.5 kWh/m^3 raised the FCOD 375%, which is similar to the study by Lafitte-Tronque and Forster (2002), where the energy input and FCOD increases were 12 k Wh/m^3 and 354% respectively. Other comparisons, of increased gas production, are difficult to do due to unclear presentation of parameters in other studies.

A suitable way to continue the work on ultrasonic pretreatment of waste activated sludge would be to perform digestion experiments on a thicker sludge, ie TS of 5-7% on a larger scale than in this experiment, which would make it easier to get a more reliable gas measurement.

Gas samples need to be analyzed to determine the methane content, because it is the loss of methane that is most important – both economically and environmentally. It would be better to treat a sub flow of digested sludge with ultrasound and then lead it back into the digestion chamber. In this way, the post-digestion effects would be utilized inside the digestion chamber.

IV. CONCLUSION

The pertinent questions on anaerobic digestion of waste activated sludge treated with ultrasound have being answered as follows: For Biogas production from municipal sewage sludge using ultrasound speeding digestion process,

- Treated waste activated sludge produce more gas. The gas yield is increased by 13% at an energy input of 8.1 kWh/m^3.
- The methane content of the gas is not affected by treatment, but a longer study is needed for conclusive results.
- The filtrated chemical oxygen demand (FCOD) is increased by the treatment; an energy input of 8.4 kWh/ m^3 increased the FCOD by 37.5% compared to untreated sludge or from 2.8% to 16% of total, COD.
- The filamentous bacteria are affected by treatment but a relative long treatment time (6-10 min, is.e. 8.4-14 kWh/m^3) is needed to shorten the filaments.
- There was no difference in the occurrence of filaments between ultrasonically treated or control reactors. However, the occurrence of filaments was generally low in all the reactor effluents.
- There seemed to be no increase in VS reduction, but the parameter needs to be studied over a longer period to verify the observation.

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