Anaerobic Co-Digestion of Cassava Waste Water and Abdominal Cow Dung under Changing Meteorological Parameters

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Abstract— Anaerobic co-digestion of cassava waste water (CWW) and abdominal cow dung (ACD)in different proportions was studied in five treatments under changing meteorological conditions. The five treatment cases T1: 100% CWW; T2: 100% ACD; T3: 90%CWW +10%ACD; T4:70%CWW+30%ACD; T5: 50%CWW+50%ACD were digested under anaerobic conditions in model batch, metallic bio digesters of same working volume (32.0 liters) for 30 days retention period. Results indicated that T2 system flamed on the 20th day, T5 on the 20th day while T1, T4 and T3 systems didn't flame. T1 had cumulative gas yield of 12.7 liters; T2 had 28.85 liters; T3 had 12.5 liters,T4 had 11.1 liters while T5 had cumulative gas yield of 15.8 liters per 24kg mass of slurry. T2had 91.20% methane; while T5 produced 92.999% methane. Daily biogas yields were modeled as functions of meteorological parameters. Results indicated that many parameters showed good correlations with ambient temperature.

Keywords— Cassava Wastewater, Abdominal Cow Dung, Ambient Temperature, Daily Biogas Production, Cumulative Biogas Production, Meteorological Parameters.

Abbreviations— vog = volume of gas, ACD = Abdominal Cow Dung, press = pressure, CWW =Cassava Waste Water, AT = Ambient Temperature, ST = Slurry Temperature, Solar Rad = Solar Radiation, Air Temp = Air Temperature, HCN = Hydrogen Cyanide, TVC = Total Viable Count, COD = Chemical Oxygen Demand, BOD = Biochemical Oxygen Demand

I. INTRODUCTION

Global warming is a crucial issue that cannot be neglected. Methane biogas is primarily extracted from the co-fermentation of energy crops mixed with animal manure in an anaerobic digester instead of letting them decompose and increase global warming gases. Cassava is one of the most important staple food crops grown in tropical Africa. It plays a major role in efforts to alleviate the African food crises because of its efficient production of food energy, year-round availability, tolerance to extreme stress conditions, and suitability to present farming and food systems in Africa (Hahn and Keyser 1985, Hahn et al, 1987). Cassava waste water is the effluent gotten from the fermentation of peeled or unpeeled cassava tubers(immersed in a vessel containing water until the roots become soft).

Anaerobic digestion is a collection of processes by which microorganisms break down biodegradable material in the absence of oxygen. The process is used for industrial or domestic purposes to manage waste and/or to produce fuels. Cassava wastewater and abdominal cow dung may constitute environmental nuisance, if not handled properly. These wastes can be fed into an anaerobic digester to produce biogas. Co-digestion refers to the anaerobic digestion of multiple biodegradable substrates in a digester. The idea is to maximize the production of biogas in the digester by adding substrates that produce much more biogas per unit mass than a base substrate. Biogas is a mixture of gases produced by the breakdown of organic matter in the absence of oxygen. During the process, an air-tight tank transforms biomass waste into primarily methane (CH_4), carbon IV oxide (CO_2) and small amounts of hydrogen sulphide (H_2S), moisture and siloxanes(Richards et al, 1994). Biogas technology produces renewable energy that can be used for heating, electricity and in many gas engine operations. Principally, it reduces global warming.

Literature contains substantial biogas production from different wastes in the locality.Ukpai and Nnabuchi (2012) carried out a study on the "Comparative Study of Biogas Production from Cow Dung, Cow Pea and Cassava Peeling using 45 Litres Biogas Digester". They found out that cow pea has the highest methane content followed by cow dung and cassava peeling. Cow dung had the highest cumulative biogas yield followed by cow pea and cassava peeling, respectively. Diaho et al. (2005) carried out a research on "The Production of Biogas from

the Mixture of Cow Abdominal Waste and Its Dung". They found out the mixture of cow abdominal waste and its dung yielded biogas within 24 hours.The pure dung yielded appreciable biogas after 7 days. Ezekoye and Ezekoye (2009) researched on "Characterization and Storage of Biogas produced from the anaerobic digestion of cow dung, spent grains/cow dung and cassava peels/rice husk". They discovered that cow dung yields biogas faster than spent grains/cow dung and cassava peels/rice husk.Spent grains/cow dung were found to produce larger amount of biogas on complete digestion of the three wastes. These studies focused on the rate of biogas production and ultimately the cumulative biogas yield. Model predictions, meteorological information and operating factors that could lead to higher biogas production were not investigated. Hence, the objective of this study is to obtain the mix of the feedstock and operating conditions for optimum gas yield.

II. MATERIALS AND METHODS

The study adopted custom response design. Cassava waste water was collected from local processors of the product. The abdominal cow dung waste was collected from the abattoir in Ikpa market, Nsukka in Nsukka Local Government Area of Enugu State, Nigeria. Metallic model bio digesters, figure 3, utilized for the study were each of 32.0L working volume (fabricated locally at the National Centre for Energy Research and development, University of Nigeria, Nsukka). Materials such as top

loading balance (Camry Emperors Capacity 50kg/110 Ibs), plastic water troughs, graduated transparent plastic buckets for measuring daily gas production, Pen-type thermo-hygrometer (CE), pHep pocket-sized pH meter (Hanna Instruments), thermoplastic hose pipes, anemometer, Am-4822, metallic beehivest and, biogas burner fabricated locally for checking gas flammability, were used. Figures 1(a) - (d) show the materials used in the research and the schematic diagram is shown in figure 2.

Fig.1 (a): Cassava tubers Fig.1 (b): Cassava wastewater

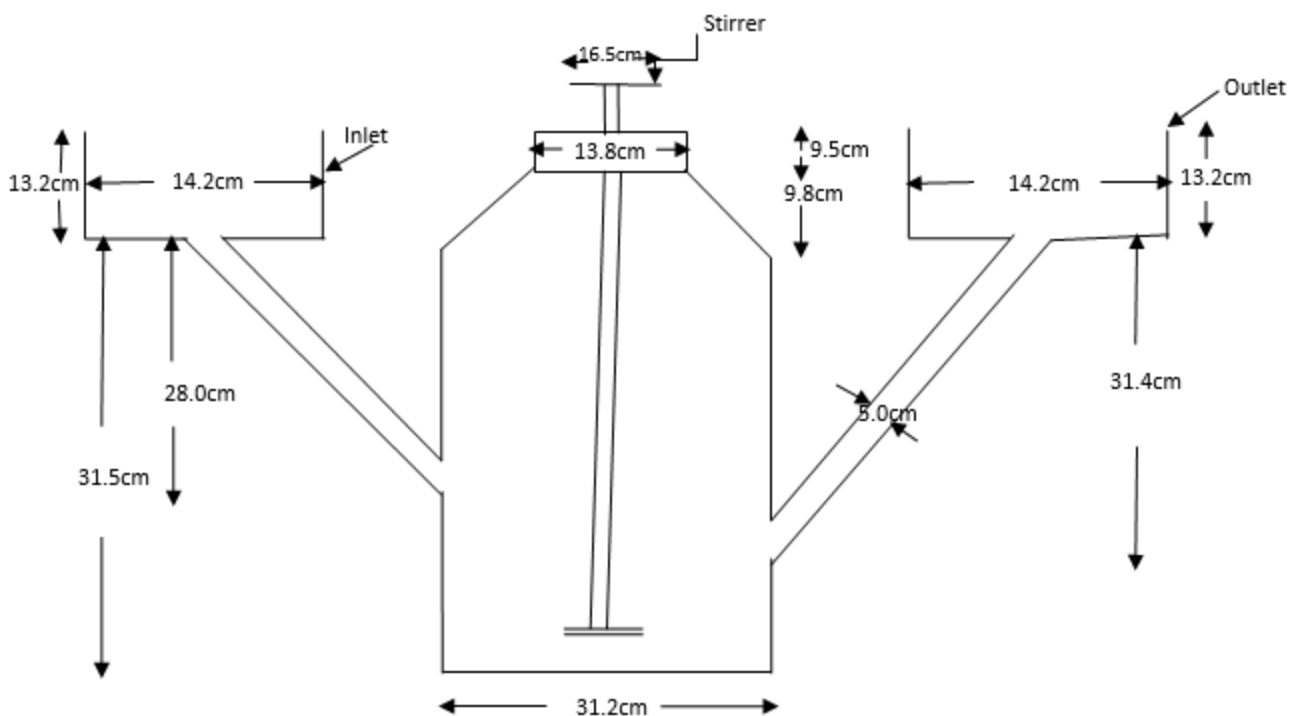*Fig.1(c): Cow Fig.1(d): Abdominal cow dung*

Fig.2: Schematic Diagram of the Biodigester

Fig.3: The experimental set-up

III. EXPERIMENTAL STUDY

The fermentation of the blends took place for 30 days at the prevailing ambient mesophillic temperature range of 23.5 to 36.5°C. The ratio of the water to waste in each charging was 2:1. This was based on the moisture content of the organic wastes at the point of charging the bio digesters. Cassava waste water (CWW) was co-digested with abdominal cow dung (ACD) in the ratio of 9:1, 7:3 and 5:5 while the CWW alone and ACD alone served as control resulting to the five treatment blends: T1 (100% CWW), T2(100% ACD), T3(90% CWW + 10%ACD), T4(70% CWW+30%ACD) and T5 (50% CWW + 50%ACD). Co-digestion is used to increase methane production from low-yielding or difficult to digest materials. The moisture content of the respective wastes determined the waste to water ratios used. Volume of gas produced, ambient and slurry temperatures, relative humidity and wind speed, insolation, pH and slurry pressure were monitored on daily basis throughout the period of digestion. Flammability check was also carried out on daily basis until the system produced flammable biogas and occasionally till the end of digestion period. The study was carried out at the exhibition ground of National Centre for Energy Research and Development, University of Nigeria, Nsukka.

Physicochemical and Microbial Analyses

The physical and chemical compositions of the undigested wastes were determined before the digestion. Ash, moisture, crude fibre, crude nitrogen, crude fat, crude protein, BOD, COD, total solid and suspended solid contents were determined using AOAC method of 2005. Phosphorus, potassium, energy and SO2 contents were determined using methods described in Pearson (1976). HCN was determined using method described by Onwuka (2005). TVC was determined using methods described by Ochei and Kolhatkar (2000). Carbon content was determined using methods described by Schumacher (2002). Proximate analysis was done using AOAC method (2005). The population of the microbes in each of the treatment cases was determined at different times (at charging, flammable, peak of production and end of digestion), during the period of study to monitor the growth of the microbes at the various stages.

Gas Analysis

The flammable gas compositions from the 100% ACD and 50% CWW+50% ACD were analyzed using BACHARACH (PCA2)Gas Analyzer, made in United States.

Data Analysis

The data obtained for the volume of gas production from each of the systems were subjected to statistical analysis using SPSS ver.20, Microsoft Excel XP 2007 and Minitab 17 software. Meteorological parameter data were obtained from Centre for Basic Space Science, University of Nigeria, Nsukka.

IV. RESULTS AND DISCUSSION

Table 1 shows the physicochemical properties of undigested Cassava waste water and AbdominalCow Dung blends.

Table.1: Results of Physicochemical Analysis of Undigested Cassava Wastewater and Abdominal Cow Dung Blends

Parameter	Treatment Cases				
	100%CWW	100%ACD	90%CWW+10%ACD	70%CWW+30%ACD	50%CWW+50%ACD
BOD (mg/l)	460	720	580	650	715
COD (mg/l)	36866.67	86833.33	24379.33	34000	40000
HCN (mg/l)	21.03	1.3	20.38	16.6	11.47
SO_2 (ppm)	0	0	0	0	0
TVC (cfu/ml)	1800000	29000000	6700000	13000000	27500000
ASH (%)	0.83	0.47	0.45	0.67	0.65
MOISTURE (%)	98.23	98.42	99.73	99.15	98.47
CRUDE FIBER CONTENT (%)	0.1	0.37	0.3	0.47	0.63

CRUDE FAT (%)	0.36	0.49	0.25	0.49	0.61
CRUDE NITROGEN (%)	0.513	0.0552	0.289	0.12	0.181
PHOSPHOROUS (Ug/g)	16.5	4.86	0.85	3.05	4.3
POTASSIUM (ppm)	1.89	1.73	1.15	1.37	1.22
CRUDE PROTEIN (%)	0.21	0.03	0.04	0.05	0.05
OXIDIZABLE ORGANIC CARBON (%)	4.36	1.65	4.19	2.1	4.57
ENERGY (KCal/g)	5.37	5.46	5.01	1.31	4.05
TOTAL SOLID (%)	1.75	1.58	0.27	0.85	1.53
DISSOLVED SOLID (%)	0.67	0.14	0.06	0.03	0.04
SUSPENDED SOLID (%)	1.68	1.44	0.21	0.82	1.49
CARBOHYDRATE (%)	0.55	0.22	0.2	0.18	0.14
TOTAL ORGANIC CARBON (%)	5.81	0.27	1.45	0.85	1.55
ORGANIC MATTER (%)	10.01	0.46	2.5	1.47	2.67
CARBON-NITROGEN RATIO	8.5	29.9	14.5	17.5	25.2

The cumulative volume of biogas (vog) and methane contents for the various waste combinations are presented in table 2

Table.2: Field Analysis of the Treatment Cases

Digester/Waste	Flammable Time/Lag Time (Day)	Retention Time (Day)	Cumulative Volume of biogas (L)	Component of Biogas (%)			
				CO_2	CO	CH_4	Other components
T1 (100%CWW)	-	30	12.7	-	-	-	-
T2 (100%ACD)	20	30	28.85	5.8	0.0001	91.20	3
T3 (90%CWW+10%ACD)	-	30	12.5	-	-	-	-
T4(70%CWW+30%ACD)	-	30	11.1	-	-	-	-
T5 (50%CWW+50%ACD)	20	30	15.8	18.3	0.0001	92.999	3

DIGESTERS' PERFORMANCE

The results of digester performances (from table 2) indicated that both 100% ACDand 50% CWW+50% ACD systems flamed on the 20th day while 100% CWW, 70% CWW+30% ACD and 90% CWW+10% ACD systems didn't flame at all. The cumulative gas yield from the five treatments were different: the 100% CWW had cumulative gas yield of 12.7 liters/24kg mass of slurry and a mean vog of 0.423 L; 100% ACD had cumulative gas yield of 28.85liters/24kg mass of slurry and a mean vog of 0.962 L; 90% CWW +10% ACD had cumulative gas yield of 12.5 liters/24kg mass of slurry and a mean vog of 0.417 L; 70% CWW+30% ACD had cumulative gas yield of 11.1 liters/24kg mass of slurry and a mean vog of 0.37 L while 50% CWW+50% ACD had cumulative gas yield of 15.8 liters/24kg mass of slurry and a mean vog of 0.54 L during the 30 days retention period. 100% ACD had 91.20% methane; while 50% CWW+50% ACD produced 92.99% methane.
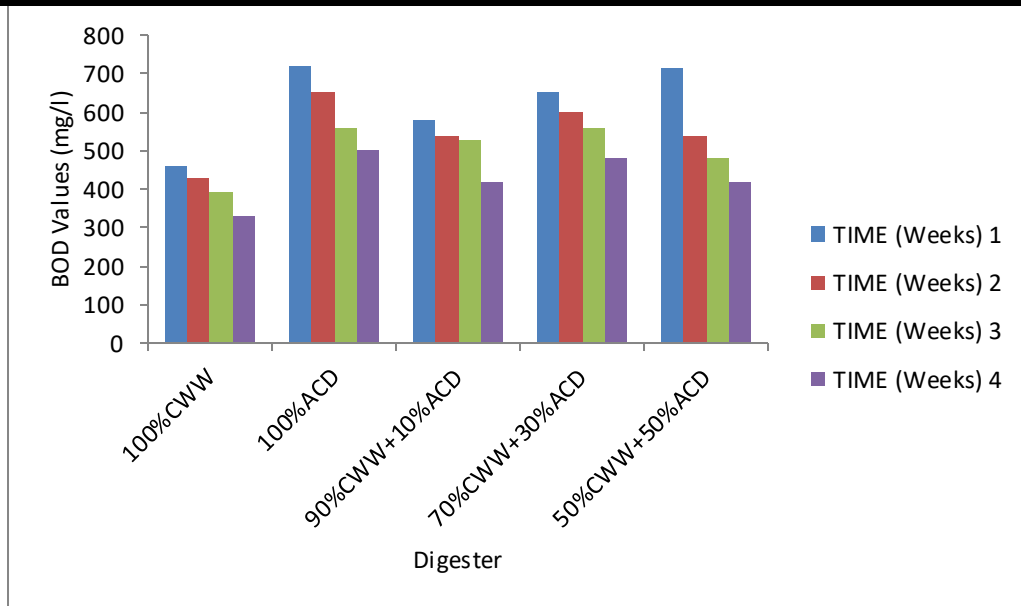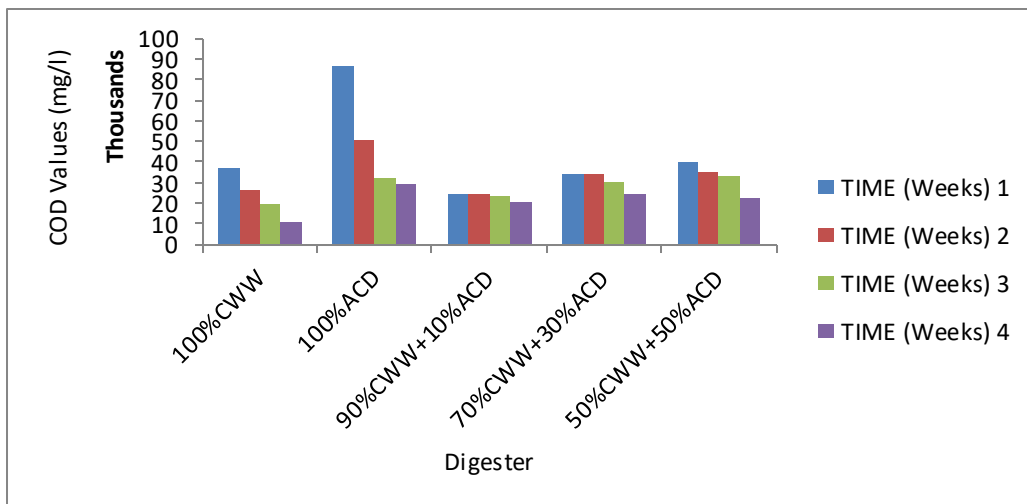
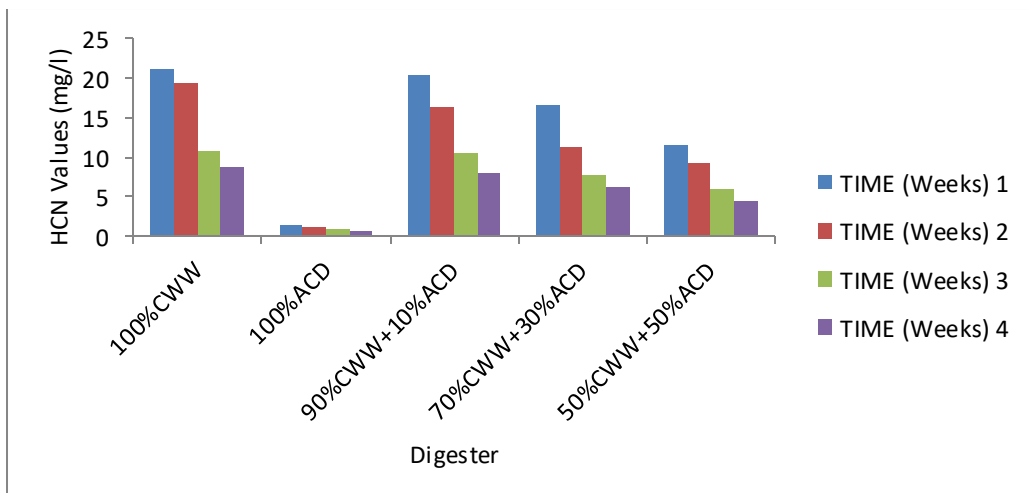*Fig.4: Weekly BOD Values*

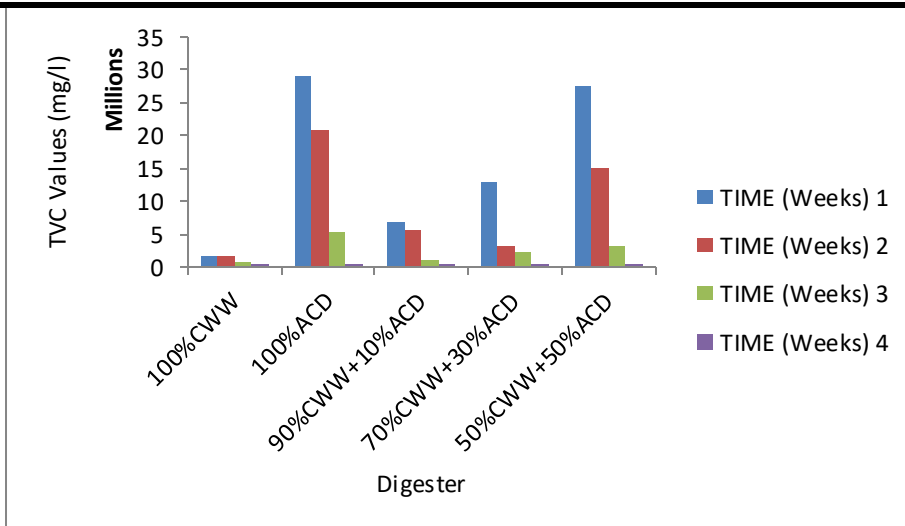*Fig.5: Weekly COD Values*

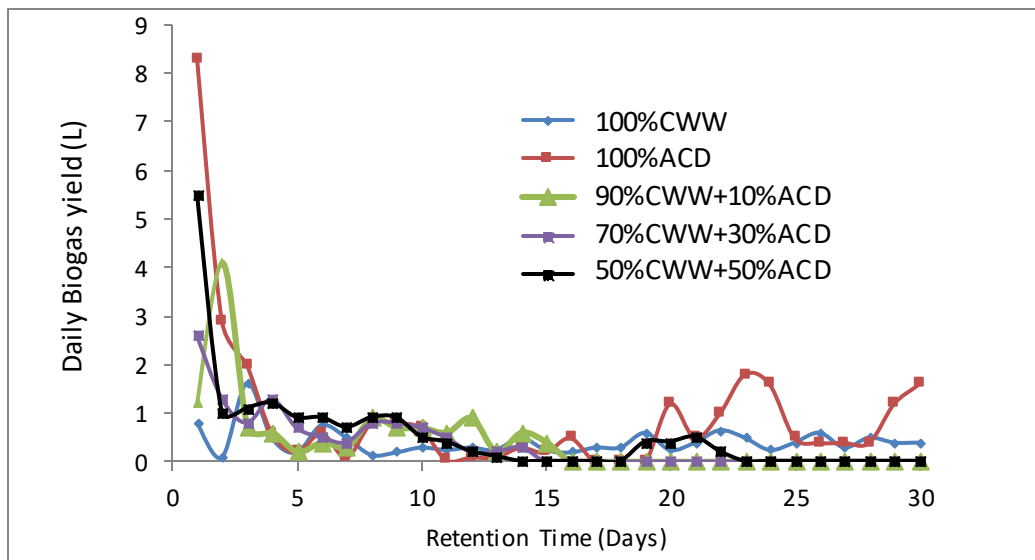*Fig.6: Weekly HCN Values*

Fig.7: Weekly TVC Values

Fig.8: Daily biogas yield versus Retention time for the wastes
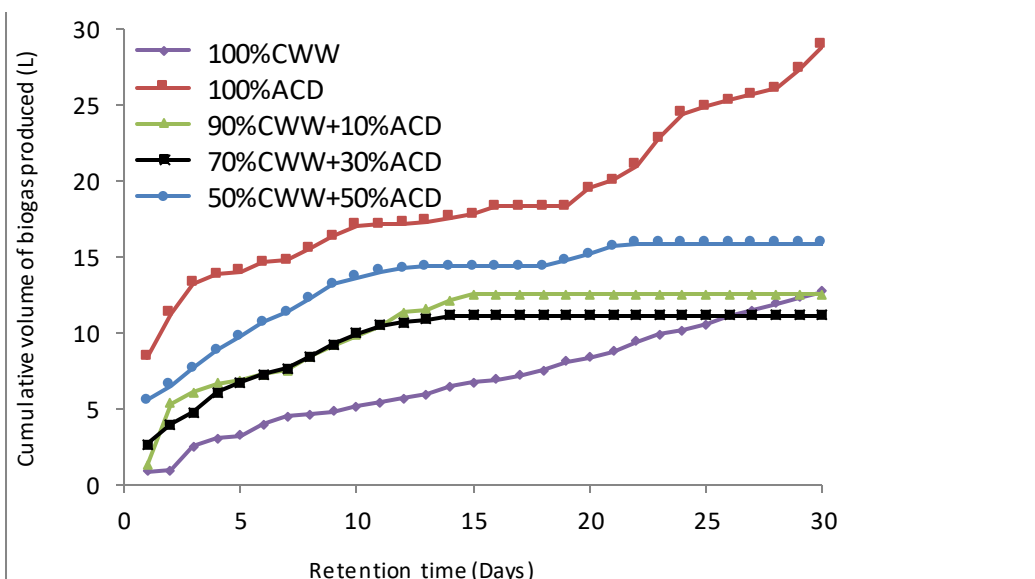

Fig.9: Cumulative volume of biogas produced versus Retention time
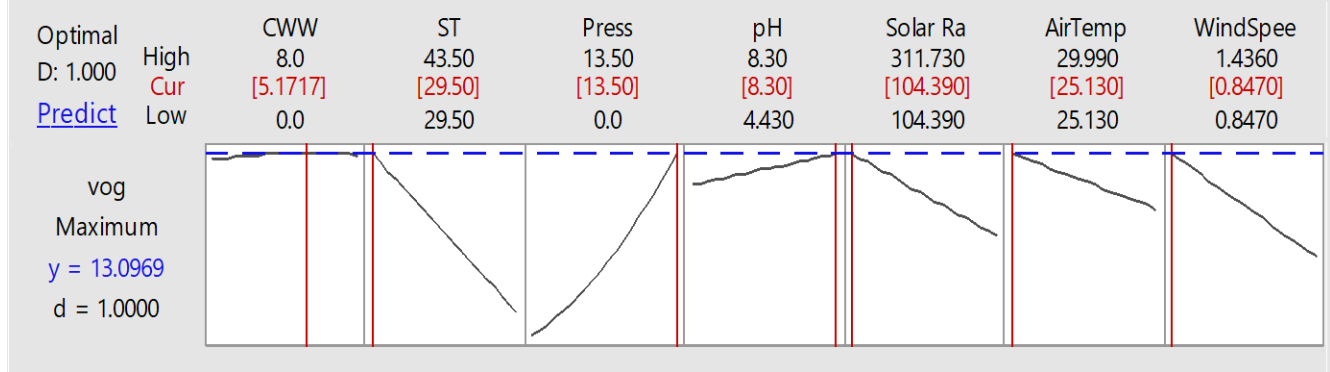
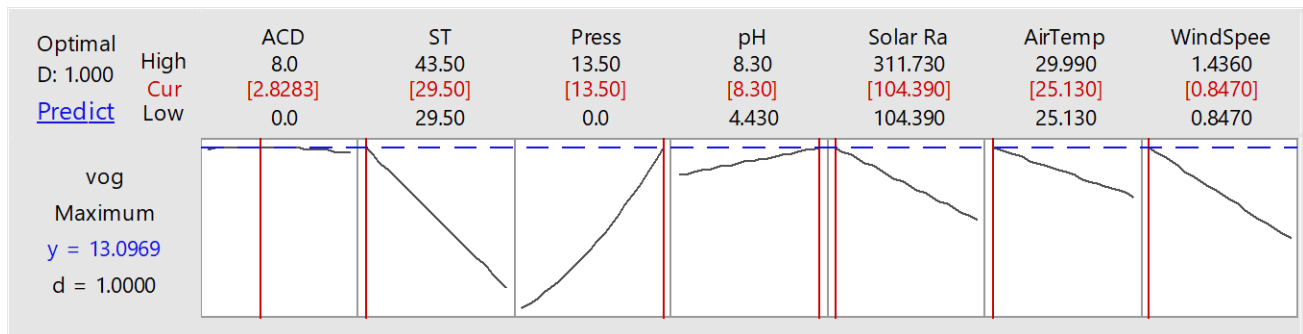*Fig.10(a): The optimization plots for the five digesters*

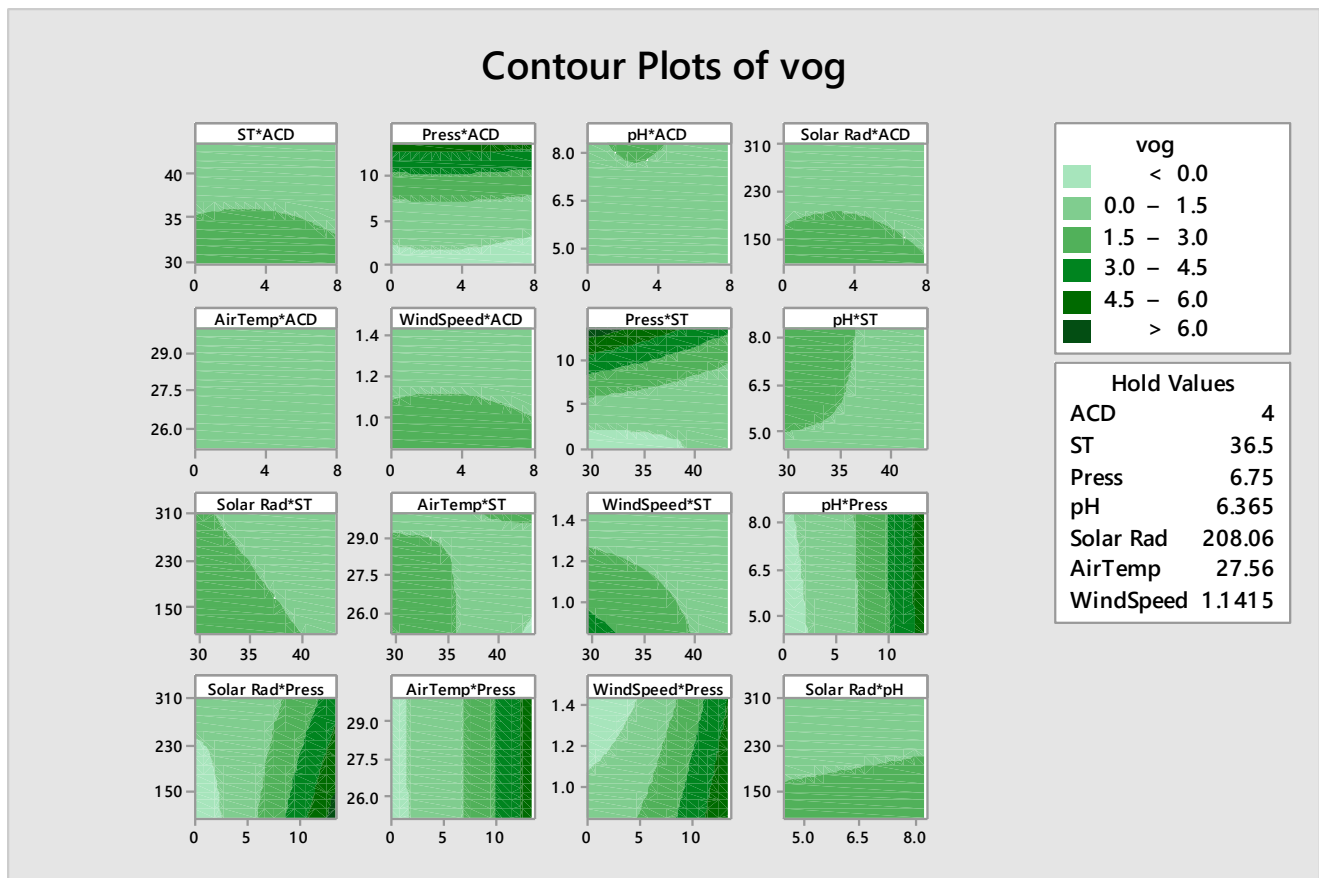*Fig.10(b): The optimization plots for the five digesters*
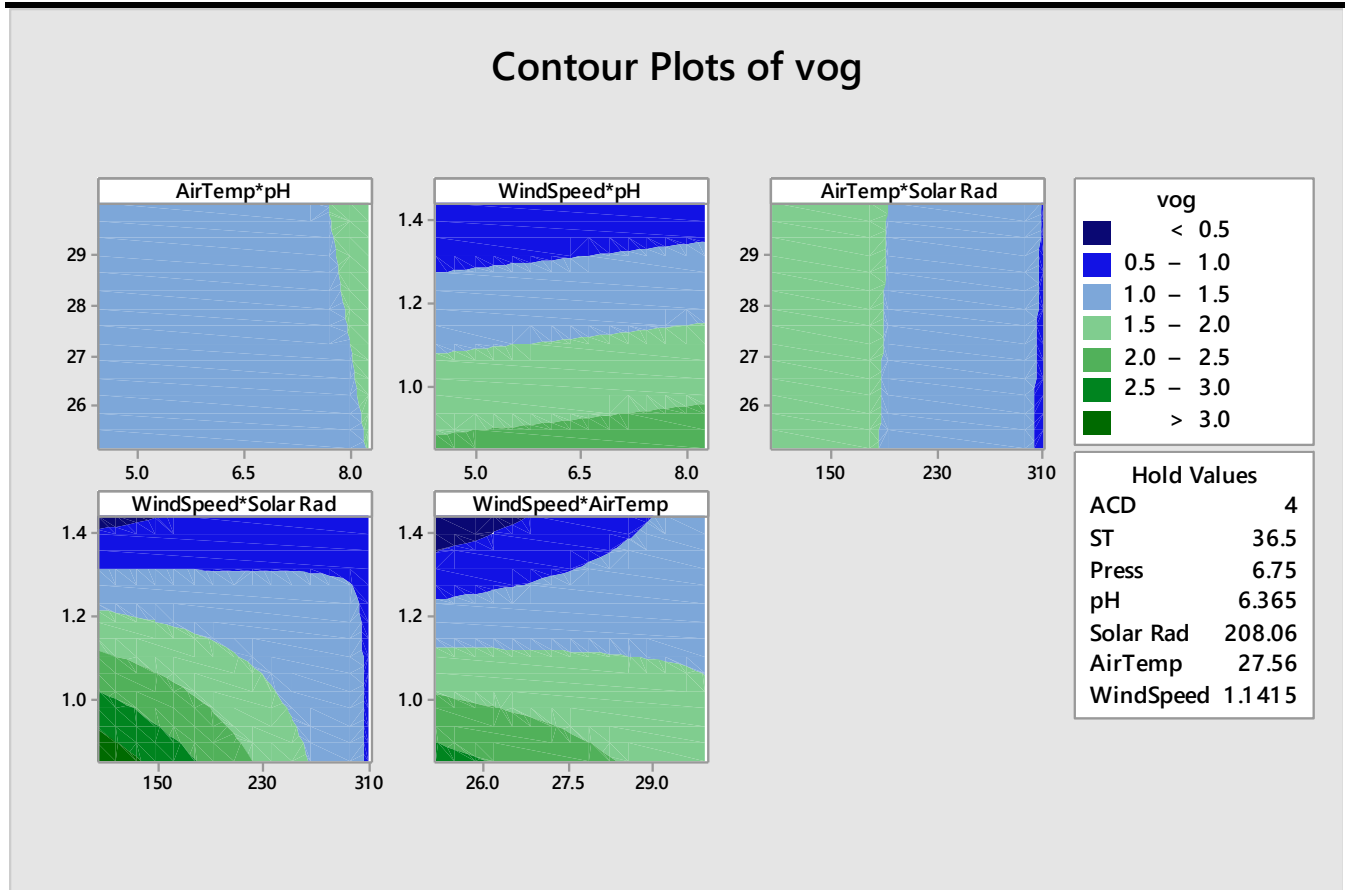

Fig.11(a): The contour plots of volume of gas

Fig.11(b): The contour plots of volume of gas

EFFECT OF C/N RATIO ON THE SYSTEMS

From the results of table 1, the C/N ratio of 100% ACD and 50% CWW+ 50% ACD, were seen to be within the range of the optimum C/N ratio. Consequently, each of these digesters flamed. Digesters 100% CWW, 90% CWW+10% ACD and 70% CWW+30% ACD each had low C/N ratio that possibly led to ammonia accumulation and consequently could not flame. C/N ratio is an important indicator for controlling biological systems. High C/N indicates rapid nitrogen consumption by methanogens and leads to lower gas production while low C/N ratio results in ammonia accumulation and an increase in pH values, which is toxic to methanogenic bacteria (Moller et al., 2004). During anaerobic digestion, microorganisms utilize carbon 25 to 30 times faster than nitrogen (Yadvika et al., 2004). To meet these requirements, microbes need 20 to 30:1 ratio of C to N.

PROXIMATE ANALYSIS OF THE SYSTEMS

The proximate composition includes the ash, moisture, crude fibre and crude fat contents of the wastes. The ash and crude fibre contents of the wastes for each of the systems were minimal. Each of the wastes for the systems had optimum moisture content because of the mix (which was 2 portion of water to 1 portion of waste).

Biological activities are increased when digester fluid are mixed to provide homogenous temperature and nutrient condition throughout the digester (Lay et al, 1997). The crude fat for each of the wastes was also minimal.

PHOSPHORUS AND POTASSIUM CONTENTS OF THE TREATMENT SYSTEMS

Cationic elements such as phosphorus and potassium are required for microbial growth in anaerobic digestion of waste, but can be inhibitory to microbial activity if present in high concentrations (Appels et al., 2008). The metal contents are however low in this case therefore, their presence effects the microbial growth positively. From table 1, there is the presence of phosphorus and potassium which are the nutrients contained in the digestate. Digestate is an excellent biofertilizer (Werner et al, 1989). 100%CWW, 100%ACD, 90%CWW+10%ACD, 70%CWW+30%ACD and 50%CWW+50%ACD each had a phosphorus content of 16.5μg/g, 4.86μg/g, 0.85μg/g, 3.05μg/g and 4.3μg/g respectively. The potassium content of 100%CWW, 100%ACD, 90%CWW+10%ACD, 70%CWW+30%ACD and 50%CWW+50%ACD are 1.89ppm, 1.73ppm, 1.15ppm, 1.37ppm and 1.22ppm respectively.

THE SOLID CONTENT OF THE WASTES

Total solid shows the total solid matter constituent of the entire organic waste both degradable and non-degradable. The total solid content of 100%CWW, 100%ACD, 90%CWW+10%ACD, 70%CWW+30%ACD and 50%CWW+50%ACD are 1.75%, 1.58%, 0.27%, 0.85% and 1.53% respectively.

ENERGY, OXIDIZABLE ORGANIC CARBON, TOTAL ORGANIC CARBON AND ORGANIC MATTER CONTENT OF THE WASTES

From table 1, it can be seen that 50%CWW+50%ACD waste had 4.57% oxidizable organic carbon content, 1.55% total organic carbon content and 2.67% organic matter content. 100%CWW had 4.36% oxidizable organic carbon content, 5.81% total organic carbon content and 10.01% organic matter content. It can be concluded that the higher the oxidizable organic carbon content, the higher the total organic carbon content and then the higher the organic matter content(Navarro et al, 1993).

THE EFFECT OF HYDROGEN CYANIDE ON THE SUBSTRATES

Figure 6 showed concentration of HCN for each of the digesters. Each figure showed reduction trend in weekly HCN with digester 100% CWW having the highest initial HCN, followed by each of 9:1, 7:3 and 5:5 combinations of the wastes over the 30 days retention time. Digester 100% ACD had little or no appreciable HCN. It could not be said that its biogas production and flammability was as a result of the effect of HCN. However, HCN had positive effect on biogas production and flammability of digester 50% CWW+50% ACD. This is confirmed by the fact that even though 100% CWW and 90%CWW+10%ACD and 70%CWW+30%ACD had higher initial values of HCN (21.03mg/l, 20.38mg/l and 16.6mg/l respectively), they could not produce flammable gas. Total cyanide includes both bound and free cyanide but the free cyanide is labile (volatile) in the form of hydrogen cyanide. The cyanide determined is majorly the bound cyanide since the hydrogen cyanide which is free cyanide is labile such that on collection of sample and exposure, the free cyanide is lost (Jones, 1993). The cassava wastewater is known to have high level of cyanide and also known to have the capacity to produce linamarase which is an enzyme that metabolizes cyanide to hydrogen cyanide that becomes volatile.

WEEKLY BOD, COD, SO₂, TVC AND ANAEROBIC DIGESTION AS A WASTE MANAGEMENT TECHNOLOGY

Figures 4, 5 and 7 showed reductions in weekly BOD, COD and TVC, respectively. This is expected as the wastes stabilized. However, it was observed that there were no traces of SO_2 in all the wastes and their combinations. Anaerobic digestion is the most important method for the treatment of food waste because of its techno-economic viability and environmental sustainability. The use of anaerobic digestion technology generates biogas and preserves the nutrients which are recycled back to the agricultural land in the form of slurry or solid fertilizer. The relevance of biogas technology lies in the fact that it makes the best possible utilization of food wastes as a renewable source of clean energy since there is always reduction in BOD, COD and TVC. Total Viable Count (TVC) a quantitative idea about the presence of microorganisms such as bacteria, yeast and mold in a sample. To be specific, the count actually represents the number of colony forming units (cfu) per g (or per ml) of the sample. A TVC is achieved by plating dilutions of the culture until 30-300 colonies exist on a single plate. Microorganisms (mainly bacteria and fungi) are involved in decomposition, the chemical and physical processes during which organic matter is broken down (in the absence of oxygen) and reduced to its original elements.

The relationship between volume of gas and cassava waste water using linear regression was obtained as

$$WEEKLYVog \ (L) = 8.948E\text{-}005COD + 6.116E\text{-}008TVC \quad [1]$$

$$R^2 = 81.7\% \quad [2]$$

METEOROLOGICAL CONDITIONS FOR OPTIMUM GAS YIELD

Figure 10(a) and (b) show the optimization values for maximum of 13.0969L/d vog as CWW = 5.1717kg, ACD = 2.8283kg, ST=29.50°C, Pressure= 13.50mmHg, pH=8.3, Solar Rad=104.390W/m,Air Temp=25.13 °C, Windspeed= 0.847m/s.

The operating equation for optimum gas yield using Response Surface Regressionfor the five digesters (from field test) are given by:

$$
\begin{aligned}
DailyVog \ (L) = \ &85.5 + 0.1167\,CWW - 1.512\,ST \\
&+ 1.250\,Press + 2.07\,pH - 0.0237\,Solar\,Rad \\
&- 2.885\,AirTemp \\
&- 40.7\,WindSpeed - 0.01127\,CWW*CWW \\
&+ 0.02470\,Press*Press - 0.02436\,ST*Press \\
&- 0.0554\,ST*pH + 0.0560\,ST*AirTemp \\
&+ 0.339\,ST*WindSpeed - 0.001403\,Press*Solar\,Rad \\
&+ 0.0253\,Solar\,Rad*WindSpeed \\
&+ 0.743\,AirTemp*WindSpeed \quad [3]
\end{aligned}
$$

$$R^2 = 82.68\% \quad [4]$$

DailyVog (L) = 85.7 + 0.0635 ACD - 1.512 ST + 1.250 Press + 2.07 pH - 0.0237 Solar Rad - 2.885 AirTemp - 40.7 WindSpeed - 0.01127 ACD*ACD + 0.02470 Press*Press - 0.02436 ST*Press - 0.0554 ST*pH + 0.0560 ST*AirTemp + 0.339 ST*Wind Speed - 0.001403 Press*Solar Rad + 0.0253 Solar Rad*Wind Speed + 0.743 Air Temp*WindSpeed [5]

$$R^2 = 82.68\% \qquad [6]$$

CONTOUR PLOTS

The contour plots of vog are shown in figures 11(a) and (b). The contour plots are used to find the factor level settings that provide the response one wants. A contour plot provides a two-dimensional view in which the settings that produce the same response are shown as contour lines of constant responses. Contour plots are used to explore the potential relationship between three variables. Contour plots display the 3-dimensional relationship in two dimensions, with x- and y-factors (predictors) plotted on the x- and y-scales and response values represented by contours. The darker regions identify higher z-values (that is, the response increases). It can be used to find the best operating conditions. For example, from Figure 11(a), for a vog greater than 3 L, the hold values are ACD = 4kg, ST = 36.5^{o}C, Press = 6.75mmHg, pH = 6.365, Solar Rad = 208.06W/m^2, Air Temp = 27.56^{o}C and Wind speed = 1.1415m/s.

V. CONCLUSION

This study has shown that wastes such as cassava wastewater and abdominal cow dung which have been termed nuisance to the environment can be utilized to produce biogas which can be used as an alternative to the widely known and used fossil fuel. The digestate after biogas has been produced can also be used as fertilizer to enrich the soil and improve plant growth. From the research even though cassava wastewater is poor in methane production, it can be co-digested with abdominal cow dung which is rich in methane production. Therefore, it can be concluded that co-digestion of the wastes resulted in improved biogas production.

This study has shown a new source of wealth creation and at the same time a means of decontaminating the environment by waste recycling and transformation. It is important to suggest that apart from abdominal cow dung, other abdominal animal dungs such as swine, rabbit and poultry wastes can also be utilized to optimized biogas production. This wastes that are consumed in large quantities in homes can be used to produce biogas, this will help them lose the name attached to them as being nuisance to the environment.

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