Asian Journal of Water, Environment and Pollution, Vol. 14, No. 4 (2017), pp. 89–98.
DOI 10.3233/AJW-170039

Biogas Production from Blends of Cassava Waste Water and Cow Dung under Changing Meteorological Parameters

Cordelia Nnennaya Mama* and Jonah Chukwuemeka Agunwamba
Department of Civil Engineering, University of Nigeria, Nsukka, Enugu State, Nigeria
✉ cordelia.mama@unn.edu.ng

Received May 1, 2017; revised and accepted September 10, 2017

Abstract: Biogas production from cassava waste water (CWW) blended with cow dung (CD) in different proportions was studied in five treatments under changing meteorological conditions. The treatment cases A—100% CWW; B: 100% CD; C: 90% CWW + 10% CD; D: 70% CWW + 30% CD; and E: 50% CWW + 50% CD—were digested under anaerobic conditions in model batch, metallic biodigesters of 32.0 litres for 30 days within ambient conditions. The digester performances indicated that 100% CD system flamed on the 6th day, 70% CWW + 30% CD system flamed on the 16th day, 50% CWW + 50% CD system flamed on the 17th day while 100% CWW system and 90% CWW + 10% CD systems didn't flame at all. The cumulative gas yield from the five treatments was different: the 100% CWW had cumulative gas yield of 12.7 litres/24 kg mass of slurry; 100% CD had cumulative gas yield of 41.5 litres/24 kg mass of slurry; 90% CWW +10% CD had cumulative gas yield of 13.85 litres/24 kg mass of slurry; 70% CWW+30% CD had cumulative gas yield of 14.85 litres/24 kg mass of slurry while 50% CWW + 50% CD had cumulative gas yield of 7.55 litres/24 kg mass of slurry during the 30 days retention period. 100% CD had 79.9995% methane; 70% CWW + 30% CD produced 79.9995% methane while 50% CWW + 50% CD produced 88.499% methane. Daily biogas yields were also modelled as functions of meteorological parameters and results recorded.

Key words: Cassava wastewater, cow dung, ambient temperature, daily biogas production, cumulative biogas production, meteorological parameters.

Introduction

Cassava waste water (CWW) and cow dung (CD) 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 which is a crucial issue.

Literature contains substantial biogas production from different wastes in the locality. Ukpai and Nnabuchi (2012) carried out a study on biogas production from cow dung, cow pea and cassava peeling. They found

*Corresponding Author

Abbreviations: vog = Volume of gas, CD = 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

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 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 seven days. Ezekoye and Ezekoye (2009) researched on biogas produced from the anaerobic digestion of cow dung, spent grains 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. The 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.

Materials and Methods

The study adopted custom response design. Cassava waste water was collected from local processors of the product. The cow dung waste was collected from the abattoir in (Ikpa) market, Nsukka in Nsukka Local Government Area of Enugu State, Nigeria. Metallic model biodigesters (Figure 1) utilized for the study were each of 32.0 L 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 50 kg/110 Ibs), plastic water troughs, graduated transparent plastic buckets for measuring daily gas production, the pHep pocket-sized pH meter (Hanna Instruments), thermometers, pressure gauge, thermoplastic hose pipes, metallic beehive stand and biogas burner fabricated locally for checking gas flammability were used.

Figure 1: (Left) Cassava tubers; (Right) Container of cassava waste water.

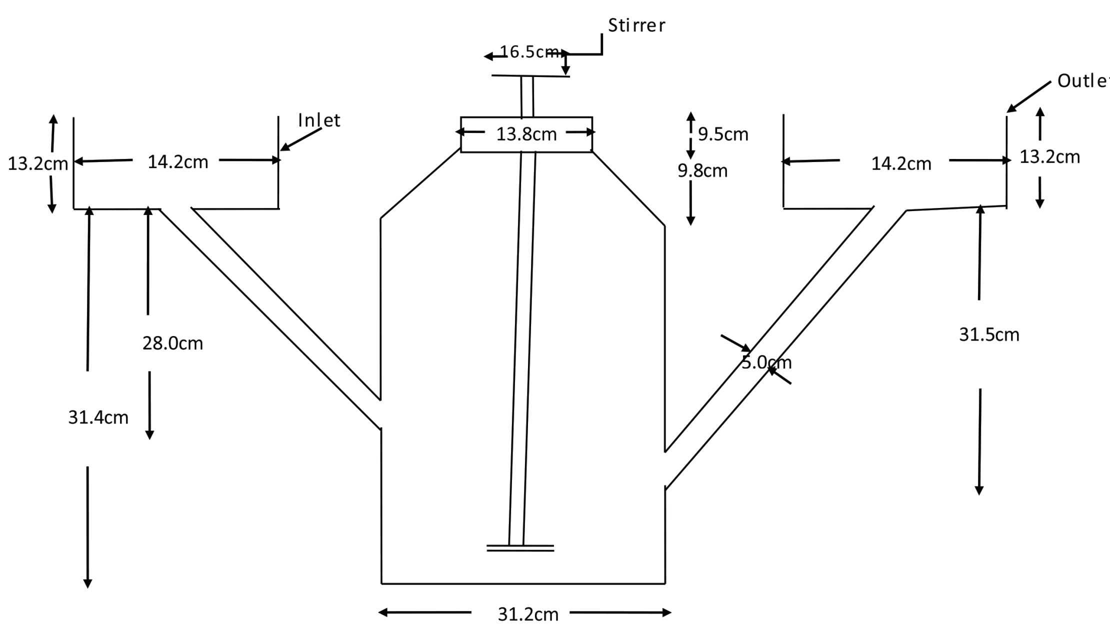

Figure 2: Schematic diagram of the biodigester.

Figure 3: The experimental set-up.

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 biodigesters. Cassava waste water (CWW) was co-digested with cow dung (CD) in the ratio of 9:1, 7:3 and 5:5 while the CWW alone and CD alone served as control resulting to the five treatment blends: A (100% CW), B(100% CD), C (90% CWW + 10% CD), D (70% CWW + 30% CD) and E (50% CWW + 50% CD). 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 SO_2 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% CD, 70% CWW + 30% CD and 50% CWW + 50% CD 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.

Results and Discussion

Table 1 shows the physicochemical properties of undigested cassava waste water and cow dung blends.

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

Digesters' Performance

The results of digester performances (from Table 2) indicated that 100% CD system flamed on the 6th day, 70% CWW + 30% CD system flamed on the 16th day, 50% CWW + 50% CD system flamed on the 17th day while 100% CWW system and 90% CWW + 10% CD systems didn‘t flame at all. By having lesser number of lag days, the 100% CD is better in biogas production technology (Nagamani and Ramasamy, 1999). The cumulative gas yield from the five treatments were different: the 100% CWW had cumulative gas yield of 12.7 litres/24 kg mass of slurry and a mean vog of 0.423 L; 100% CD had cumulative gas yield of 42.4 litres/24 kg mass of slurry and a mean vog of 1.383 L; 90% CWW + 10% CD had cumulative gas yield of 13.85 litres/24 kg mass of slurry and a mean vog

Table 1: Results of physicochemical analysis of undigested cassava waste water and cow dung blends

Parameter	*Systems*				
	100% CWW	*100% CD*	*90% CWW + 10% CD*	*70% CWW + 30% CD*	*50% CWW + 50% CD*
BOD (mg/l)	460	846	560	800	840
COD (mg/l)	36866.67	84222.33	37333.33	43712	48166.67
HCN (mg/l)	21.03	1.2	19.38	15.9	10.87
SO_2 (ppm)	0	0	0	0	0
TVC (cfu/ml)	1800000	28000000	6640000	12000000	27000000
Ash (%)	0.83	0.87	0.51	0.13	0.4
Moisture (%)	98.23	97.4	97.87	99	97.73
Crude fibre content (%)	0.1	0.67	0.12	0.9	9.03
Crude fat (%)	0.36	0.88	0.62	0.57	0.34
Crude nitrogen (%)	0.513	0.0552	0.289	0.175	0.181
Phosphorous (μg/g)	16.5	13.86	18.64	1.49	3.46
Potassium (ppm)	1.89	1.25	1.16	1.23	1.23
Crude protein (%)	0.21	0.08	0.12	0.2	0.11
Oxidizable organic carbon (%)	4.36	1.65	4.19	4.2	4.57
Energy (KCal/g)	5.37	8.65	9.84	6.09	5.03
Total solid (%)	1.75	2.58	2.1	1.01	2.27
Dissolved solid (%)	0.67	0.09	1.02	0.17	0.08
Suspended solid (%)	1.68	2.49	1.08	0.84	2.22
Carbohydrate (%)	0.55	0.29	1.51	0.05	0
Total organic carbon (%)	5.81	2.19	5.59	5.53	6.1
Organic matter (%)	10.01	3.78	9.64	9.54	10.51
Carbon-nitrogen ratio	8.5	29.9	14.5	24.0	25.2

Table 2: Field analysis of the digesters

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*
A (100% CWW)	-	30	12.7	-	-	-	-
B (100% CD)	6	30	41.5	17	0.0005	79.9995	3
C (90% CWW + 10% CD)	-	30	13.85	-	-	-	-
D (70% CWW + 30% CD)	16	30	14.85	17	0.0007	79.9995	3
E (50% CWW + 50% CD)	17	30	7.55	8.5	0.0002	88.499	3

of 0.462 L; 70% CWW + 30% CD had cumulative gas yield of 14.85 litres/24 kg mass of slurry and a mean vog of 0.495 L while 50% CWW + 50% CD had cumulative gas yield of 7.55 litres/24 kg mass of slurry and a mean vog of 0.252 L during the 30 days retention period. 100% CD had 79.9995% methane; 70% CWW + 30% CD produced 79.9995% methane while 50% CWW + 50% CD produced 88.499% methane.

Meteorological Conditions for Optimum Gas Yield

Figure 10 shows the optimization values for maximum of 10.0444 L/d vog as ST = 31.0°C, Pressure = 30 mm/Hg, pH = 4.430, Solar Rad = 392.70 W/m, Air Temp = 20.5°C, Windspeed = 1.140 m/s. The contour plots of vog are shown in Figure 11(a)-(c).

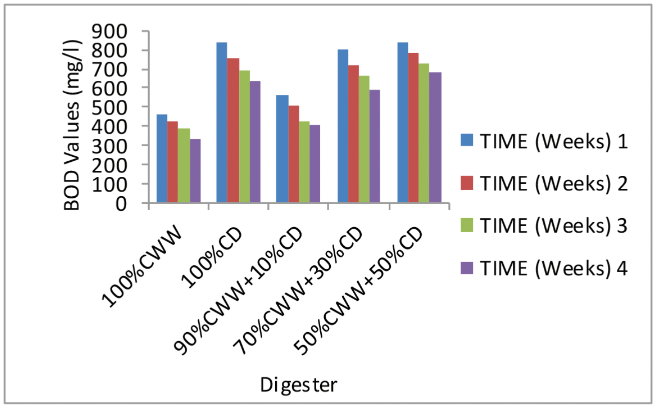

Figure 4: Weekly BOD values.

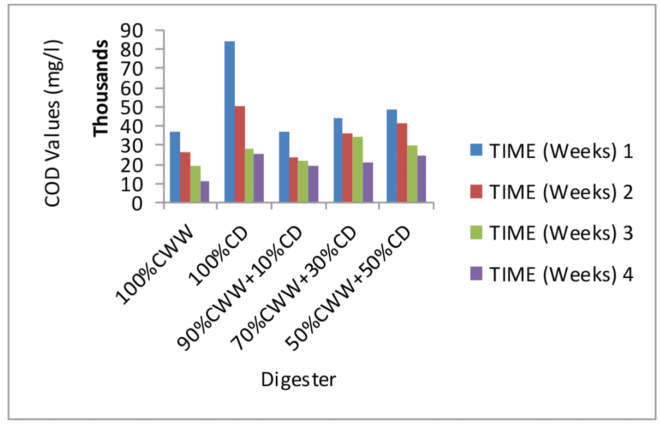

Figure 5: Weekly COD values.

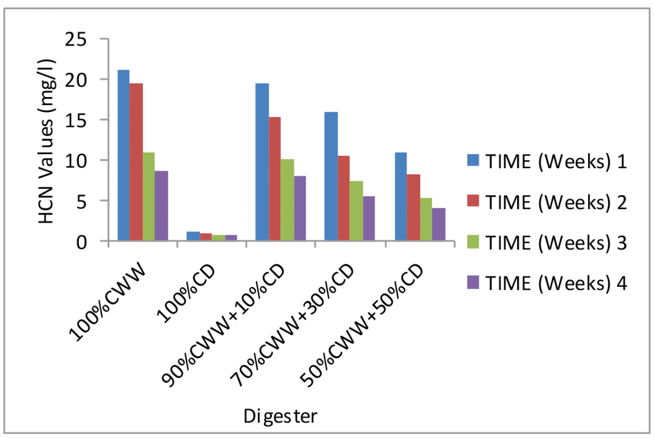

Figure 6: Weekly HCN values.

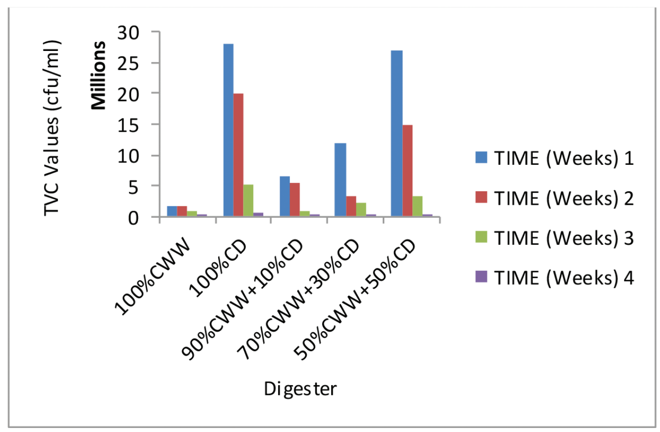

Figure 7: Weekly TVC values.

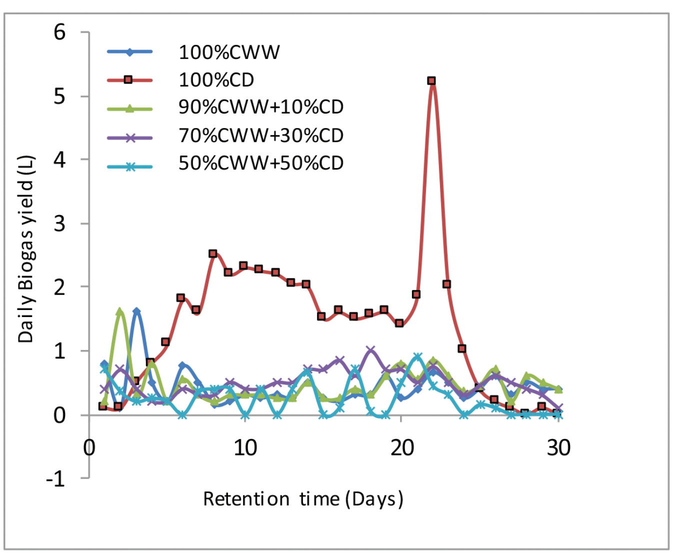

Figure 8: Daily biogas yield versus retention time for the wastes.

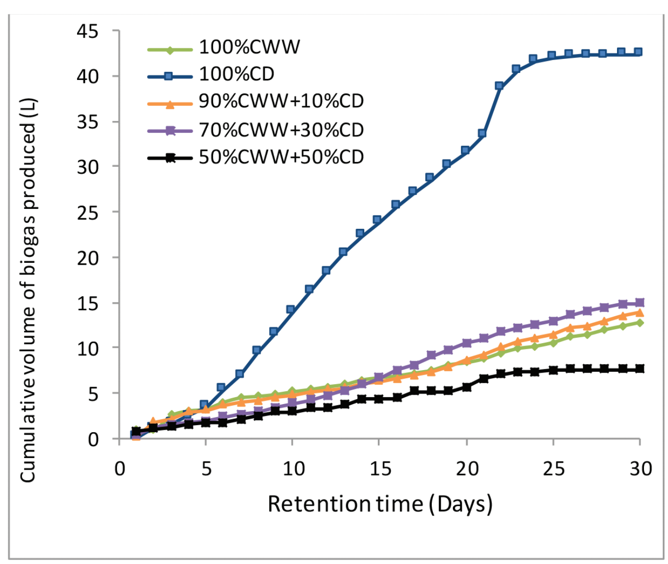

Figure 9: Cumulative volume of biogas produced versus retention time.

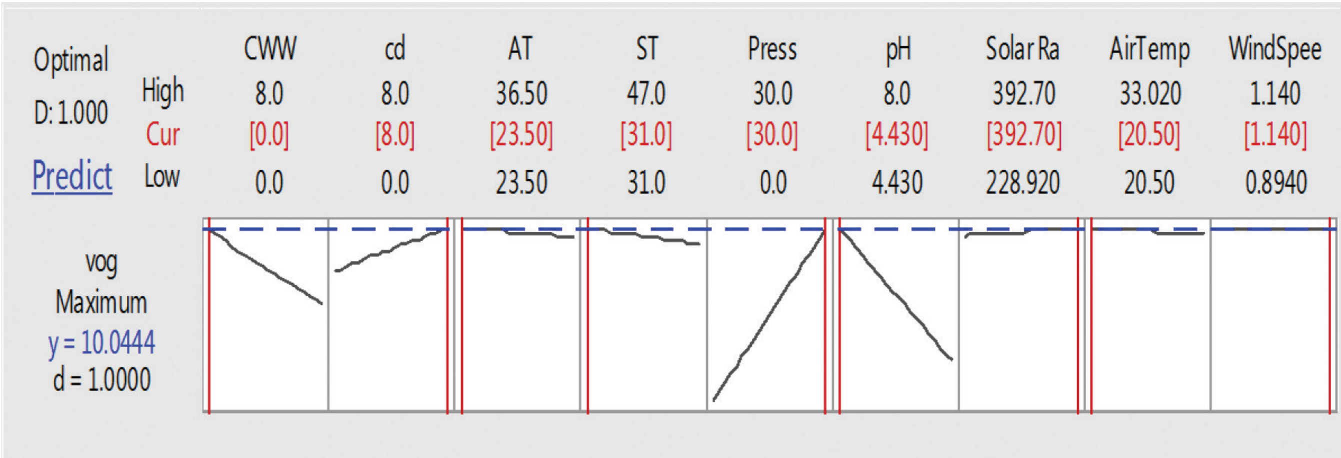

Figure 10: The optimization plot for the five digesters.

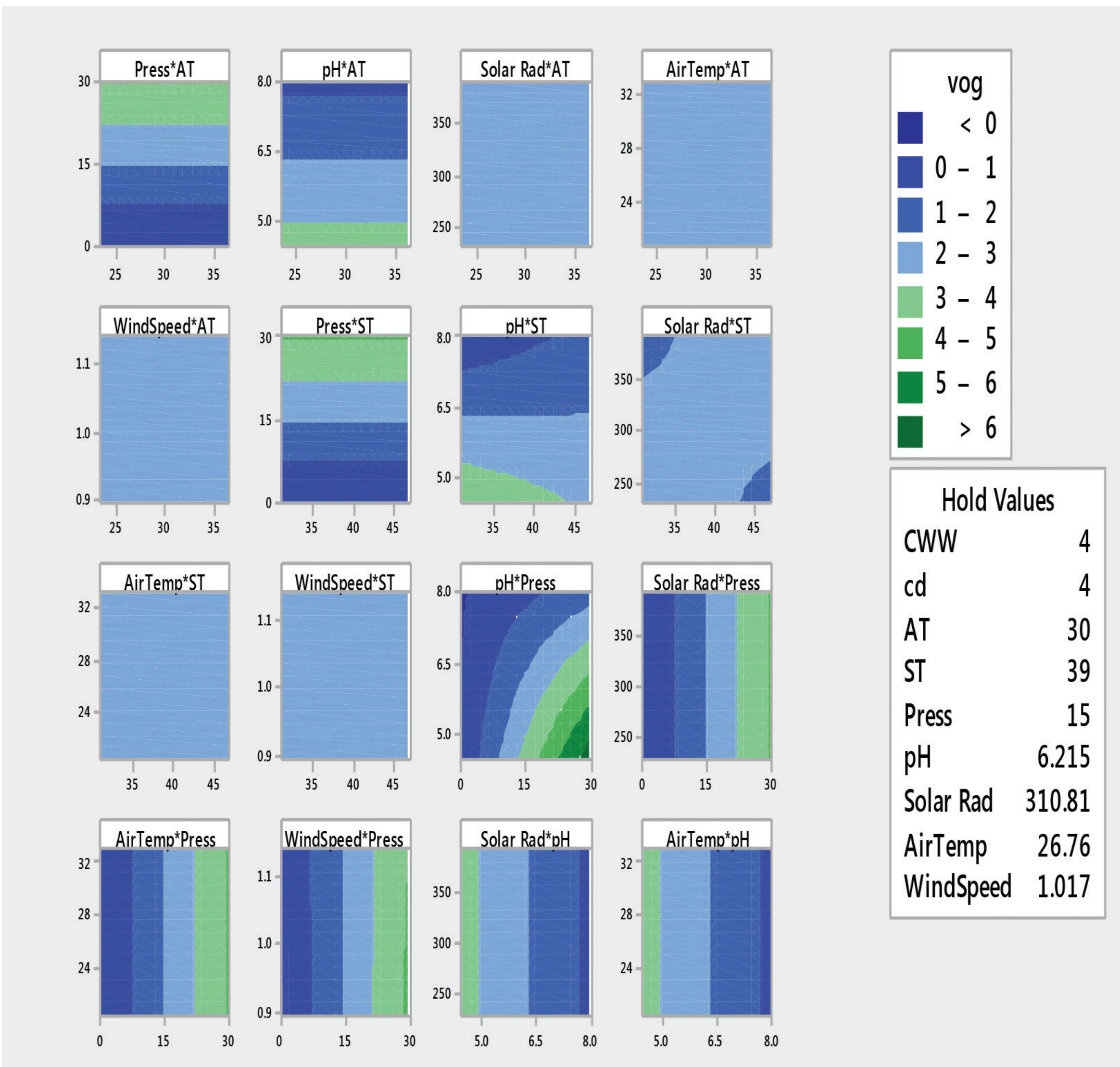

Figure 11(a): The contour plots of volume of gas.

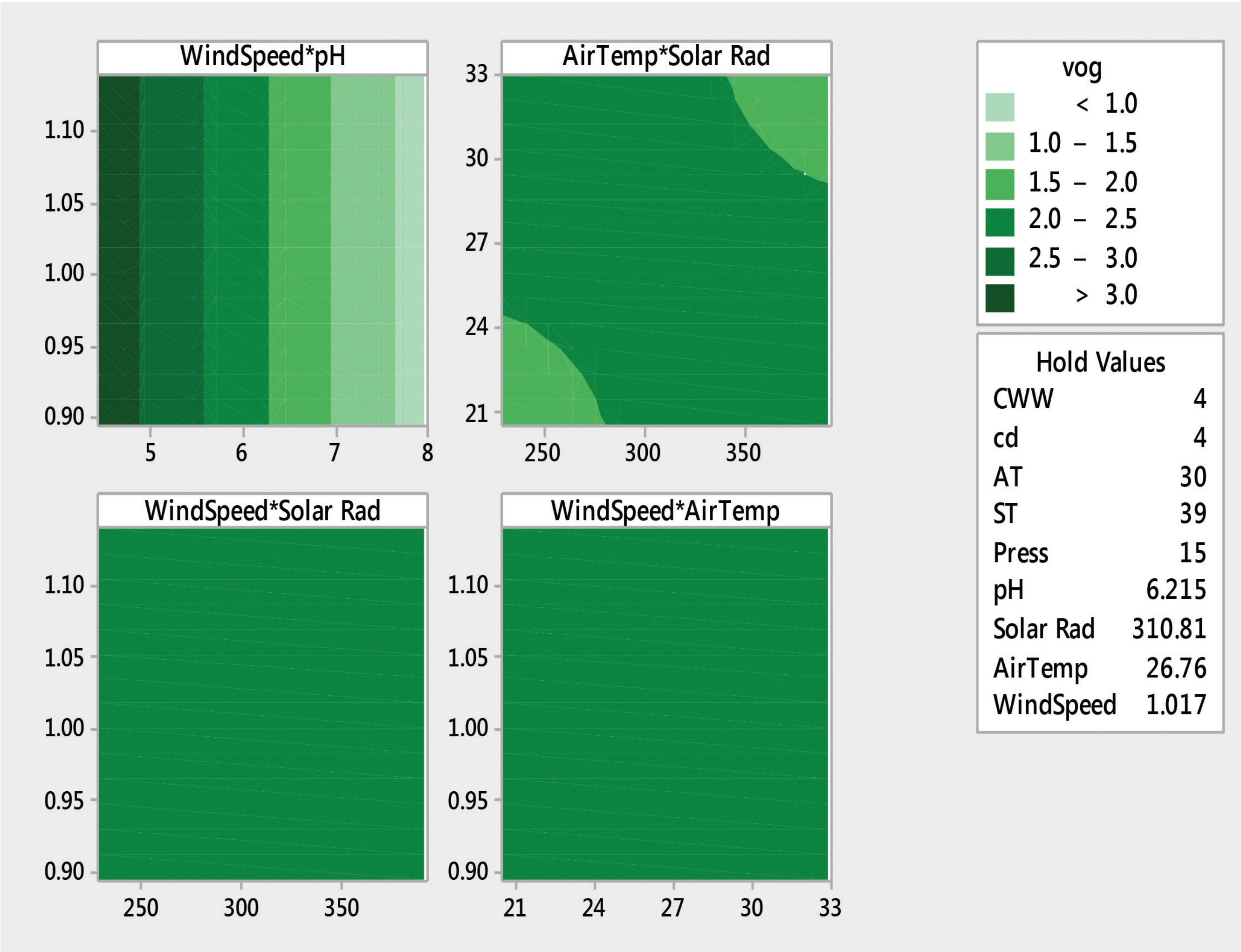

Figure 11(b): The contour plots of volume of gas.

Contour Plots

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 11c, for a vog greater than 5 L (with the hold values as stated in the figure), pressure will be 30 mm/Hg, CWW = 0 kg, cd = 8 kg and pH = 2.0.

Effect of C/N Ratio on the Systems

From the results of Table 1, the C/N ratio of 100% CD, 70% CWW + 30% CD and 50% CWW + 50% CD, were seen to be within the range of the optimum C/N ratio. Consequently, each of these digesters flamed. Digesters 100% CWW and 90% CWW + 10% CD 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.

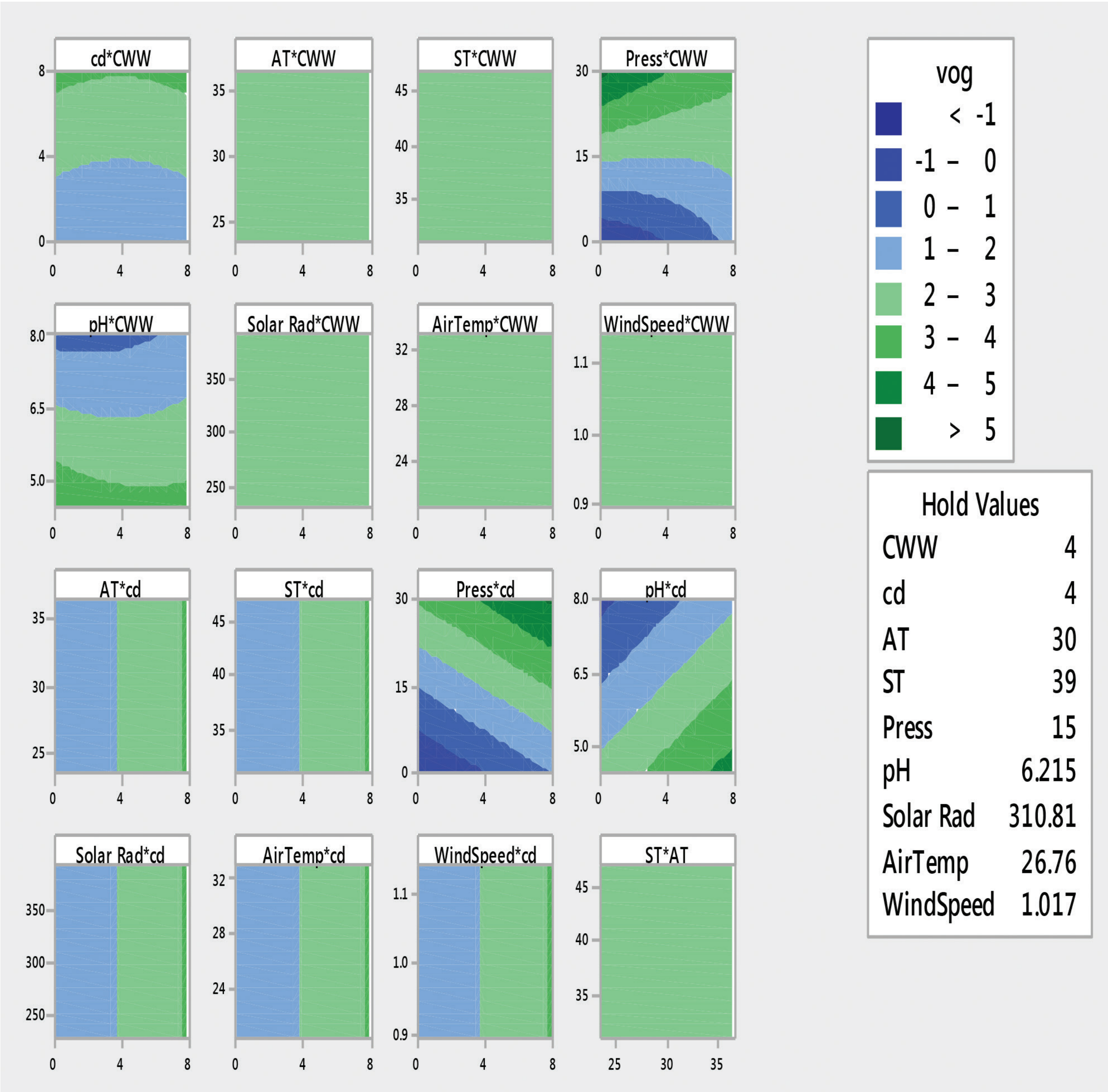

Figure 11(c): The contour plots of volume of gas.

Proximate Analysis of the Systems

The proximate composition includes the ash, moisture, crude fibre and crude fat contents of the wastes. The ash content of the wastes for each of the systems was minimal. The 50% CWW + 50% CD waste had the highest crude fibre content (9.03%). Each of the wastes for the systems had optimum moisture content because of the mix (which was two portions of water to one 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 appreciable.

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 affects 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% CD, 90% CWW + 10% CD, 70% CWW + 30% CD and 50% CWW + 50% CD each had a phosphorus content of 16.5 µg/g, 13.86 µg/g, 18.84 µg/g, 1.49 µg/g and 3.46 µg/g respectively. The potassium content of 100% CWW, 100% CD, 90% CWW + 10% CD, 70% CWW + 30% CD and 50% CWW + 50% CD are 1.89 ppm, 1.25 ppm, 1.16 ppm, 1.23 ppm and 1.23 ppm 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% CD, 90% CWW + 10% CD, 70% CWW + 30% CD and 50% CWW + 50% CD are 1.75% , 2.58% , 2.1% , 1.01% and 2.27% 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% CD waste had 4.57% oxidizable organic carbon content, 6.1% total organic carbon content and 10.51% organic matter content. This is followed by 100% CWW which had 4.36% oxidizable organic carbon content, 5.81% total organic carbon content and 10.01% organic matter content. It can be concluded that higher the oxidizable organic carbon content, higher the total organic carbon content and then higher the organic matter content (Navarro et al., 1993).

The Effect of Hydrogen Cyanide on the Substrates

Figure 6 shows concentration of HCN for each of the digesters. Each figure shows 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% CD 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 digesters 70% CWW + 30% CD and 50% CWW + 50% CD. This is confirmed by the fact that even though 100% CWW and 90% CWW + 10% CD had higher initial values of HCN (21.03 mg/l and 19.38 mg/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, SO_2, TVC and Anaerobic Digestion as a Waste Management Technology

Figures 4, 5 and 7 show 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) is 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

$$\text{Weekly vog (L)} = 0.448\ \text{HCN} + 1.516\ \text{E} - 007\ \text{TVC}$$

$$R^2 = 80.1\%$$

Operating Equations for Optimum Gas Yield

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

$$\text{Daily vog (L)} = 2.052 + 1.028\ \text{CD} + 2.033\ \text{Press}$$

$$– 1.274 \text{ pH} + 0.2225 \text{ CWW*CWW} + 0.2118 \text{ CWW*AT} – 1.043 \text{ CWW*Press} + 0.242 \text{ CWW*pH} – 0.1388 \text{ CWW*Solar Rad} – 0.1595 \text{ CWW*WindSpeed} + 0.503 \text{ ST*pH} + 0.1037 \text{ ST*Solar Rad} – 1.184 \text{ Press*pH} – 0.0837 \text{ Press*WindSpeed} – 0.1402 \text{ Solar Rad*AirTemp}$$

$$R^2 = 91.66\%$$

Conclusion

This study has shown that wastes such as cassava wastewater and 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 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. These wastes that are consumed in large quantities in homes can be used to produce biogas, thus helping them lose the name attached to them as being nuisance to the environment.

References

Angelidaki, I. and L. Ellegaard (2003). Codigestion of manure and organic wastes in centralized biogas plants. Status and future trends. *Applied Biochemistry and Biotechnology*, **109:** 95-105.

Appels, L., Baeyens, J., Degreve, J. and R. Dewil (2008). Principles and potential of the anaerobic digestion of waste-activated sludge. *Progress in Energy and Combustion Science*, **34:** 755-781.

Association of Official Analysis of Chemist (A.O.A.C.) (2005). Standard Official Methods of Analysis.15th ed. Washington D.C.

Diaho, I.C., Tunga, U.S. and M.K. Umar (2005). Effect of Abdominal Waste on Biogas Production from Cow Dung. *Bot. J. Tech*., **14:** 21-24.

Ezekoye, V.A and B.A. Ezekoye (2009). Characterization and Storage of Biogas Produced from the Anaerobic Digestion of Cow Dung, Spent Grains/Cow Dung, and Cassava Peels/Rice Husk. *Pacific Journal of Science and Technology*, **10(2):** 898-904.

Jones, D.A. (1998). Why are so many food plants cyanogenic? *Phytochemistry*, **47(2):** 155-162. doi:10.1016/S0031-9422(97)00425-1. PMID 9431670.

Lay, J.I., Noike, T., Endo, G. and S. Ishimoto (1997). Analysis of Environmental Factors affecting Methane Production from High Solid Organic Waste. *Water Sci. and Tech*., **36(6-7):** 639-650.

Nagamani, B. and K. Ramasamy (1999). Biogas Production Technology: An Indian Perspective. *Current Science*, **77(1):** 44-55.

Navarro, A.F., Cegarra, J., Roig, A. and D. Garcia (1993). Relationship between Organic Matter and Carbon Contents of Organic Wastes. *Bioresource Technology*, **44:** 203-207.

Ochei, J. and A. Kolhatkar (2008). Medical Laboratory Science, Theory and Practices. Tata McGraw-Hill.

Onwuka, G.I. (2005). Food analysis and instrumentation: Theory and practice. Naphathali Prints, Nigeria.

Pearson, D. (1976). Chemical Analysis of Foods. 7th Edition. Churchhill Livingstone, London.

Richards, B., Herndon, F.G., Jewell, W.J., Cummings, R.J. and T.E. White (1994). In situ methane enrichment in methanogenic energy crop digesters. Biomass and Bioenergy, **6(4):** 275-282. doi:10.1016/0961-9534(94) 90067-1.

Schumacher, Brian A. (2002). Methods for the Determination of Total Organic Carbon (TOC) in soils and Sediments. USEPA, Washington DC.

Ukpai, P.A. and M.N. Nnabuchi (2012). Comparative study of biogas production from cow dung, cow pea and cassava peeling using 45 litres biogas digester. *Advances in Applied Science Research*, **3(3):** 1864-1869.

Werner, U., Stoehr, U. and N. Hees (1989). Biogas Plants in Animal Husbandry. German Appropriate Technology Exchange (GATE) and German Agency for Technical Cooperation (GTZ) GmbH. PDF.

Yadvika, A., Santosh, A., Sreekrishan, T.R., Kohli, S. and V. Rana (2004). Enhancement of Biogas Production from Solid Substrates Using Different Techniques. *Bioresource Technology*, **95:** 1-10.