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Biogas Production from *Jatropha Curcas* Leaf and its Blends with other Wastes under Changing Meteorological Parameters

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Abstract - *Biogas production from Jatropha curcas leaf and its blends with other wastes: Jatropha/carrot leaf (J-Ct) and Jatropha/carrot leaf/cow dung (JCt/Cd) under changing meteorological parameters was investigated. The waste blends were combined in the ratio of J: Ct (1:1) and JCt-Cd (1:1) and digested under anaerobic conditions in prototype batch, metallic biodigesters of same working volume (41.0 dm^3). The waste blends were allowed to ferment anaerobically for 36 days within the prevailing ambient conditions of pressure, temperature, rainfall, relative humidity, irradiance, wind speed, etc. Summary of the results of digester performances indicated that JCt/Cd system became flammable on the 12th day of digestion period while J/Ct system became flammable on the 36th day. The cumulative gas yields from the two systems were also different: the JCt/Cd system had cumulative gas yield of 5.48dm^3/TS.kg (175.20dm^3/day) while the J/Ct system had a total of 2.34 dm^3/TS.kg (75.00dm^3/day) during the same period. Daily biogas yields of the two systems were modeled as functions of the aforementioned meteorological parameters using computer-aided non-linear regression software (NLREG Ver. 6.3). Results indicated that with the exception of gas yield from J/Ct system, other parameters such as insolation, wind speed and relative humidity including gas yield from JCt/Cd system, were highly correlated with ambient temperature, which varied between 22^{o}C and 29^{o}C. There was little or no rainfall during the period of study.*

Keywords - ambient temperature, biogas production, meteorological parameters

1. INTRODUCTION

Biogas obtained from biomass materials through anaerobic digestion process is a relatively cheap renewable resource if properly harnessed. Biogas technology is embraced in most places of the world such as Bangladesh, China, Germany, Sweden, and UK, amongst others, as a result of its appropriateness in the context of technical, socio-economical and resource development of the places. The technology has also been developed because of waste management, agricultural production, cooking, electricity generation, correction of impact of negative effects of climate change and transportation amongst others. However, the producing facultative and obligate anaerobic bacteria are highly influenced by ambient conditions which can slow or halt the process if they do not lie within fairly narrow band (Werner et al., 1989). Out of the variety of environmental factors (weather conditions, location, pH, toxicity, retention time, etc.) that affect the rate of digestion, qualitative and quantitative biogas yield, the most critical is temperature (Chang et al., 2006). Biogas production is possible at three temperature ranges namely: psychrophilic (<25^{o}C), mesophilic (25-40^{o}C) and thermophilic (45-60^{o}C) (El- Mashad, 2004). Mesophilic degradation seems to be most feasible in the tropics since its temperature range is relatively maintained round the year. Psychrophilic range results in poor biogas production while the thermophilic is too expensive because of additional heating costs amongst other disadvantages. Biogas production increases with higher temperature within the allowed range and retention time. The retention time of mesophilic range is between 30 and 60 days (Werner et al., 1989). A decrease in gas production had also been reported on the investigation carried out in winter where lower ambient temperatures led to extra heating of the biogas digester plant with mesophilic bacteria (Yadvika et al., 2004). Hence, most of the weather parameters affect biogas production directly or indirectly through temperature changes. Biogas production is carbon neutral. This is because CO_2, one of the main products from the gas production was originally organic plant material and it is just completing the cycle: from the atmosphere to plant, to animal and human being and back to the atmosphere. Besides, optimization of biogas energy production within ambient conditions in the form of recycling of slurry, variation in operational parameters, reduction of particle size of substrates, use of additives, blending etc. had been carried out (Radhika et al., 1983; Yadvika et al., 2004; Uzodinma et al., 2007; Ofoefule et al., 2009).

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This is because the biochemical characteristics of the organic materials utilized for biogas production vary and hence their gas production potentials even within the same ambient temperature and atmospheric pressure conditions, also vary, (FAO/CMS, 1996). Although researches on effect of meteorological parameters on biogas production are still being developed, a report has been made on comparative investigation carried out during winter and summer periods using culture independent approach (Gurdeep et al., 2008). The findings showed that there was significant reduction in the daily biogas yield in the winter period as compared to summer months which resulted from lowering of ambient temperature and associated shift in microbial community. The present report compares biogas energy yield from *Jatropha*/Carrot leaf (J/Ct) and *Jatropha*-Carrot leaf/Cow dung (JCt/Cd), under changing meteorological factors considered within the digestion period. The wastes were combined in a definite proportion of J: Ct and JCt: Cd (1:1) and the daily biogas yields from the two systems were modeled as functions of the prevailing meteorological conditions within mesophilic range of temperatures.

2. MATERIALS AND METHODS

Fresh Jatropha was collected around the University of Nigeria, Nsukka Campus, Enugu State of Nigeria. Carrot and cow wastes were obtained from a local market in Nsukka town. Biodigesters (Figure 1) utilized for the study were each of 41.0dm^3 working volume. Materials such as top loading balance of 50kg capacity (“Five Goats”-model Z051599, England), gas collection accessories, Pen-type thermo-hygrometer (CE), Pocket-sized pH meter model 02895AI (Hanna Instruments, Italy), thermoplastic hose pipes, anemometer, Am-4822, metallic beehive stand and biogas burner fabricated locally, were also used.

Fig. 1: Biodigester

2.1 Fermentation Studies

The fermentation of the blends of J: Ct (1:1) and JCt: Cd took place for 36 days at the prevailing ambient mesophilic temperature range. The ratio of waste to water in each charging was 1:3 which was based on the moisture content of the organic wastes at the point of charging the biodigesters while pH levels of the single wastes (Table 2) formed the basis for the blending. The waste to waste ratio was obtained as follows: J: Ct (1:1), JCt: Cd (1:1) (Srinivasan et al., 1997). Volume of gas production, ambient and slurry temperatures, relative humidity and wind speed were monitored on daily basis while pH of each of the systems was checked at two days interval 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 between May and June, 2009 at the National Centre for Energy Research and Development, University of Nigeria, Nsukka.

2.2 Analyses of the Wastes

2.2.1 Physicochemical Analysis

The physical and chemical compositions of the undigested wastes were determined before the digestion. Ash, moisture and fiber contents were carried out using AOAC method of 2010. Crude fat, nitrogen and protein contents were determined using Soxhlet extraction and micro-Kjedahl method described in Pearson (1976), respectively. Total carbohydrate was obtained by difference (Onwuka, 2005) while Cellulose and lignin analyses were carried out using the methods of Crampton and Maynard and; Morrison, described in Ezeonu et al. (2002). Organic carbon content was obtained using modified Walkey and Black method described in Mylanarapu (2009) while total and volatile solid contents were carried out using the method of Bhatia (2009).

2.2.1.1 Microbial Analysis

The population of the microbes in each of the digester systems 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. Modified Miles and Misra method described in Okore (2004) was used to determine the microbial content.

2.2.1.2 Data Analysis

The data obtained for the volume of gas production from each of the systems were subjected to statistical analysis using SPSS ver.15.0, Microsoft Excel XP and Genstat software package (Discovery Edition 3). Meteorological parameter data for insolation, relative humidity, wind speed and ambient temperature, were obtained from Centre for Basic Space Science, University of Nigeria, Nsukka, which is registered with NECOP: Nigeria’s First Wireless Meteorological Telemetry Solutions. The data were analyzed using computer aided non-linear regression software NLREG version 6.3.

2.2.1.3 Gas Analysis

The flammable gas composition from the JCt: Cd system was analyzed using Unigas 3000+ (E Instruments Group LLC).

3. RESULTS AND DISCUSSION

This experimental study was carried out under prevailing atmospheric conditions particularly at the ambient temperature range of 22 to 29°C. Production of non-flammable biogas resumed within 24 h of charging the digesters. The variants as earlier stated were digested under same period and conditions. Each of the systems produced flame at different times. The J/Ct became flammable on the 36th day of the digestion period while JCt/Cd produced flame on the 12th day (Figure 2, Table 1). Their total volumes of gas production also varied: while JCt had cumulative volume of gas as 2.34dm^3/TS.kg, JCt/Cd had total volume of gas yield of 5.48dm^3/TS.kg where the total mass of slurry-TS.kg (waste solids) and water amounted to 32kg (Table 1).

Table 1: Summary of Biodigester Performances during the Fermentation Period

Parameters	J: Ct	JCt: Cd
Lag days	35	11
Retention time (Days)	36	36
Cumulative gas yield (dm^3/day)	75.0	175.20
Cumulative gas yield (dm^3/TS.kg)	2.34	5.48
Mean Volume of gas yield (dm^3/day)	2.08	4.87
Standard deviation	±2.83	±1.81
Coefficient of variation	133.66	37.15

TS.kg—total mass of slurry=32kg

Table 2: Physicochemical Properties of Undigested Single and Blended Wastes

Parameters	J	Ct	Cd	JCt	JCt/Cd
Moisture (%)	14.7	4.0	22.62	13.0	40.65
Ash (%)	0.13	4.20	42.05	11.50	0.70
Crude Fiber (%)	trace	35.65	21.25	21.2	33.50
Crude Fat (%)	0.25	1.40	0.45	1.10	1.60
Crude Nitrogen (%)	1.05	1.05	1.40	1.85	1.13
Crude Protein (%)	6.56	6.57	8.75	11.55	7.09
Total Solids (%)	85.30	96.0	77.38	87.0	59.35
Volatile Solids (%)	25.50	21.10	35.33	51.59	29.33
Organic Carbon (%)	95.05	36.31	26.87	48.6	31.84
C/N Ratio	90.52	34.58	19.20	26.87	23.76
Total Carbohydrate %	78.36	83.83	27.13	62.85	49.46
Cellulose (%)	1.5	Trace	-	-	-
Lignin (%)	1.03	1.63	-	-	-
pH at Charging	5.70	7.25	8.11	8.70	8.10

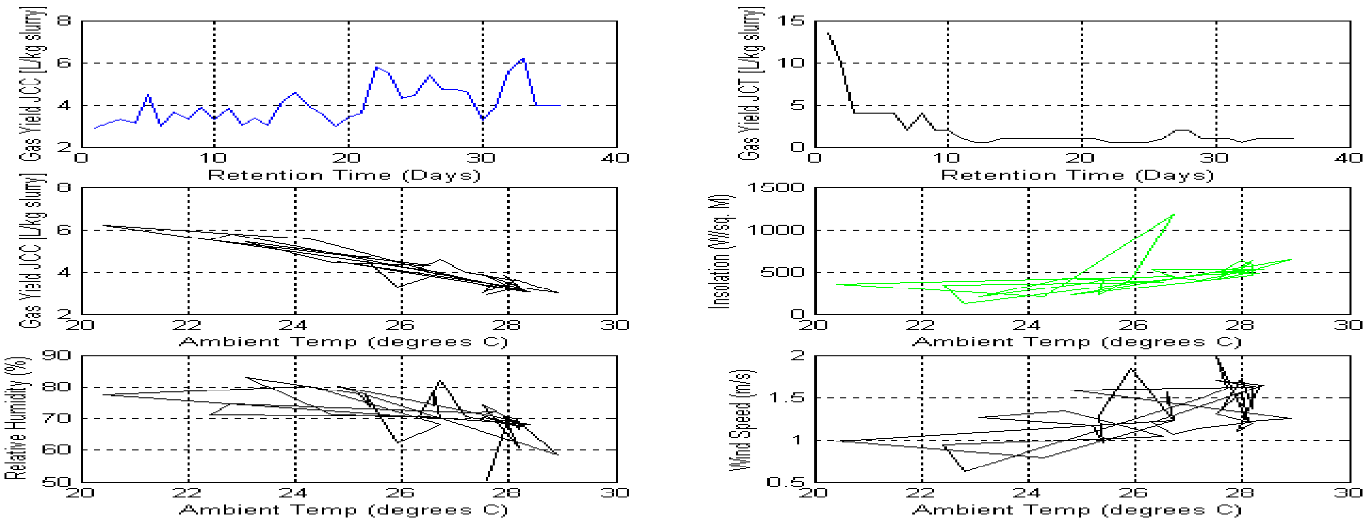

Fig. 2: Graphs of (i) Gas Yield (JCC-JCt/Cd) vs. Retention Time, (ii) Gas Yield (JCT-JCt) vs. Retention Time, (iii) Gas Yield vs. Ambient Temperature, (iv) Insolation vs. Ambient Temperature, (v) Relative Humidity vs. Ambient Temperature and (vi) Wind Speed vs. Ambient Temperature for the duration of the digestion.

The J/Ct system that became flammable on the last day of the retention period could be due to toxicity introduced into the system by spore forming anaerobes during microbial proliferations or toxins from *Jathropha curcas* leaves (Ezemonye and Kuruwa, 2011), among other factors. Therefore, the system in addition to the blending would require other pretreatments before digestion process since the undigested wastes (J and Ct) contain lignin, Table 2. However, performance of the system when inoculums from cow dung were added was higher. An inoculum is a biologically active liquid or partially digested organic waste medium rich in micro-organisms (Maishanu and Maishanu, 1998). Addition of inoculum to the system could help to establish anaerobic microbial flora, reduce lag phase and hence increase biogas production and methane content of the system as long as there is existence of synergy between the waste blends (Kanwar and Guleri, 1994). The onset of flammable gas production from the J/Ct system was also confirmed by the result obtained from total microbial viable count (TVC)-Table 3, and pattern of the pH changes of its system during the digestion period (Figure 3). The JCt/Cd system gave a higher total volume of gas and shorter onset of flammable gas production among the two variants (Table 1). This may be as a result of adequate physico-chemical properties of the undigested waste blends such as volatile solids, carbon to nitrogen ratio (C/N ratio), pH, fat content etc. (Table 2), and these are known to enhance biogas production process (Kanu, 1988, Anunputtikul and Rodtong, 2004). The result of its performance affirms the superiority of cow dung waste in quality and quantity of biogas production over the other organic wastes (Aurora, 1983). Besides, many researchers have established cow dung as a good biogas producer and thus blended it with other wastes in anaerobic digestion process (Radhika *et al.*, 1983, Uzodinma *et al.*, 2007, Ofoefule *et al.*, 2009), amongst others. Flammable gas component analysis was also carried out using JCt/Cd system (Table 4). Further, the pH changes as shown in Figure 3 for the two systems indicate that biogas production on daily basis under uncontrolled/controlled mesophilic conditions is a function of both external environmental factors (weather conditions) and internal factors arising from the microbial community and waste under fermentation (Hashimoto *et al.*, 1980).

Table 3: Total Microbial Viable Counts for *Jatropha curcas* leaf Waste blends (Cfu/ml)

Period	J: Ct	JCt: Cd
At Charging	$6.80x10^8$	$1.10x10^9$
At Flammability	$2.76x10^7$	$8.40x10^7$
At Peak of gas	$5.67X10^6$	$9.0x10^7$
At End of digestion	$2.76x10^7$	$8.13x10^8$

Table 4: Analysis of Components of Flammable gas from Jatropha-carrot leaf-cow dung waste system

O_2 (%)	CO (%)	CO_2 (%)	NO_2 (%)	NOx (%)	Wet CH_4 (%)
3.8	0.00	29.33	0.01	0.01	65.85

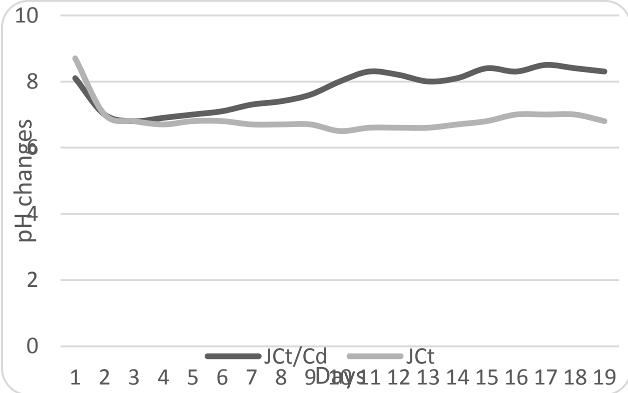

Fig. 3: pH Changes at Two Days Intervals for the Blended Waste Systems During Digestion Period

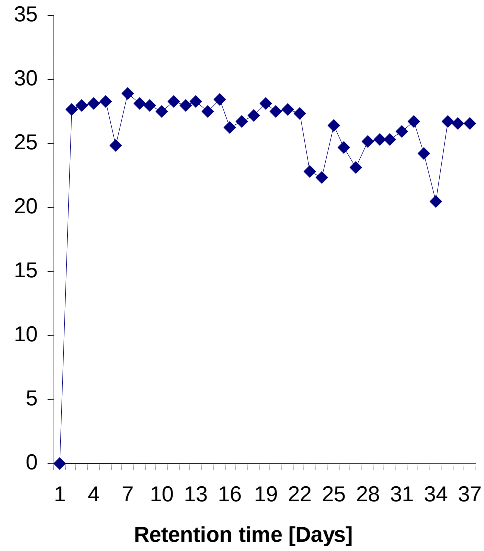

Fig. 4: Ambient Temperature (^{O}c) versus Retention Time (Daily).

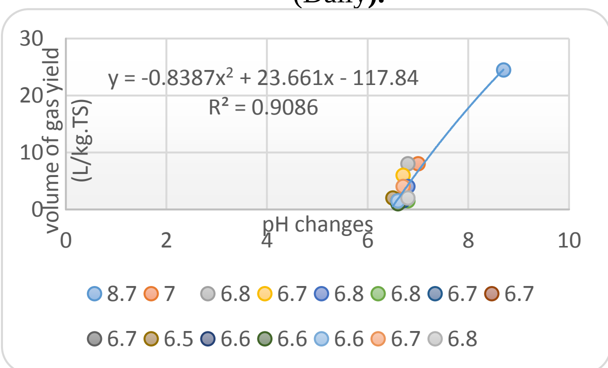

Fig. 5: Relationship Between Volume of Gas Production from J/Ct System and the Ph Changes at Two Days Intervals During Digestion Period

The model (Y= $-0.838x^2+23.66x-117.8$) obtained from the relationships of Figure 5 showed that the coefficient of determination, R^2 was 0.908, an indication that the model is quite useful for predicting volume of biogas yield based on pH changes for J/Ct system during the experimental period. However, R^2 of Figure 6 for JCt/Cd system was poor–0.193. Anaerobic microbes are slow growth obligate anaerobes that survive optimally within the pH range of 7.0-7.2 and in some instances up to 8.5 (Hashimoto *et al*., 1980; FAO/CMS, 1996). The volume of gas production for J/Ct system decreased with gradual reduction in pH (Figure 3) of its system during the digestion period. Coefficient of variation from the software analysis (Table 1) shows the amount of random errors operational from each system during the period that may be dependent on the reaction of each system to the harsh uncontrollable diurnal atmospheric variations (Figures 2 and 4). In addition to the above explanation on the behavior of each system in terms of volume of gas production within the retention time (gas yield against retention time – Figure 2), attempts were made to establish relationship between gas yield and external environmental parameters such as temperature, relative humidity, wind speed and insolation using computer aided non-linear regression analysis (NLREG Version 6.3). This indicated no clear correlations. Rather, the modeling (Equations 1-5) revealed that the environmental parameters studied had some correlation with ambient temperature. For this reason, the influence of insolation, relative humidity and wind speed on ambient temperature using the software, even though their plots against temperature (Figure 2) did not reveal clear dependence, was carried out as shown in the equations. Research work investigated earlier in Canada under mesophilic degradation indicated that a decrease in gas production occurred due to lower temperatures during winter periods (Yadvika *et al*., 2004). Besides, the relationship between ambient temperatures and the above mentioned weather parameters for insolation could be explained by equation 1 below. Although, Stefan-Boltzman equation correlates the temperature of any hot surface with the radiation (W/m^2) obtainable from such a surface at a given distance, accurate relationships between insolation and ambient temperature are not common in literature. However, the insolation and ambient temperature during the period of this experiment were correlated to obtain the following model:

$$Ins = 0.012Ta^{3.2} \qquad (1)$$

In this model (equation 1), the adjusted coefficient of the multiple determination R^2 = 0.89, an indication that the model is quite useful for predicting insolation based on ambient temperature.

The relationship between ambient temperature and relative humidity was also investigated using the software.

The following model was obtained:

$$R_H = 70.24Ta^{5.15\times10^{-10}} \qquad (2)$$

Lawrence (2005) reported that the dew point temperature (t_d) decreases by about 1^oC for every 5% decrease in relative humidity (Rh) starting with the t_d value as at RH = 100%.

Nevertheless, equation 2 above has an R^2 value of 0.96 and predicted the values not used in developing the model with very high accuracy. For the wind speed, there was no clear relationship between wind speed and ambient temperature. However, during the study period, the values of the two parameters were found to correlate by the equation:

$$W_s = 0.11Ta^{1.46} \qquad (3)$$

Equation 3 was also obtained through non-linear regression analysis. In this case R^2 = 0.84.

Furthermore, correlation between volume of gas yield and ambient temperature was verified since it has been observed by many authors that there is a relationship between gas yield and ambient temperature, although it is not clear if the correlation is within the uncontrolled or controlled mesophilic temperature range. Hence, gas production from the two blended waste systems namely; JCt/Cd waste and J/Ct systems were correlated with ambient temperature. The gas yield from the JCt/Cd system was shown to be highly correlated with temperature according to the equation:

$$Gy = 3.96Ta^{5\times10^{-13}} \qquad (4)$$

R^2 = 0.81

This correlation was also to be compared with pattern of average daily ambient temperature changes shown in figure 4. However, for the J/Ct system, the relationship is quite unclear as buttressed by the model.

$$Gy = 3.7\times10^{-10}Ta^{6.84} \qquad (5)$$

R^2 = 0.18

Equation 5 is a very poor model in comparison with equation 4. This result suggests that different wastes according to internal environmental factors within the microbial community during digestion can correlate positively or negatively with the external environmental parameters in quality and quantity of biogas production. The volume of gas production for J/Ct system could be predicted based on pH changes (Figure 5) while this prediction was not the same for the JCt/Cd system (Figure 6).

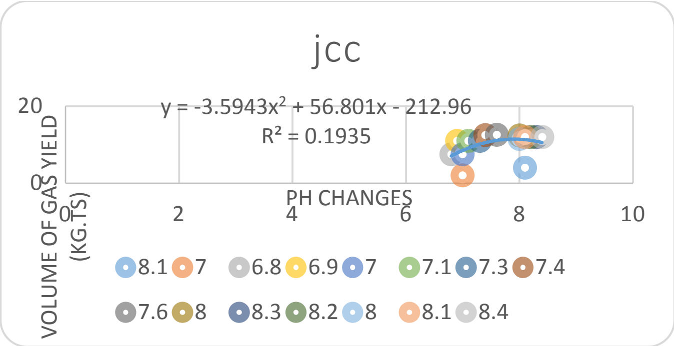

Fig. 6: Relationship Between Volume of Gas Production From Jct/Cd System and the Ph Changes at Two Days Intervals During Digestion Period.

4. CONCLUSION

This investigation has shown that meteorological parameters such as relative humidity, insolation and wind speed affect ambient temperature that influenced the rate, quality and quantity of biogas production from *Jatropha curcas* waste blends: *Jatropha*-carrot leaf and *Jatropha*-carrot leaf-cow dung. However, gas yield on daily basis from *Jatropha*-carrot leaf-cow dung correlated positively with the daily ambient temperature within the mesophilic range while that of *Jatropha*-carrot leaf waste blend was negative. Biogas production from *Jatropha*-carrot leaf-cow dung system was better in terms of onset of flammable gas production, quantity of gas and retention time. The study therefore, indicates that both external and internal environmental factors must be favorable for optimum gas production from a biogas system. Biogas production from *Jatropha*-carrot leaf-cow dung waste blend could be a leeway for renewable energy resource recovery and environmental sustainability where the wastes are readily available.

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