Comparative Evaluation of Qualitative and Quantitative Biogas Production Potential of Oil Palm Fronds and Co-digestion with Cow Dung

Ossai, Ochonogor Samuel
Department of Vocational Education, Delta State University, P. O Box 1, Abraka Delta State, Nigeria
E-mail: ossaiochonogor@yahoo.com

Abstract

Investigation to determine the qualitative and quantitative biogas production potential of oil palm fronds (PF-alone) and its blend with cow dung (PF:CD) in a pre-determined ratio 1:1 was evaluated. Two 50 L capacity plastic jerry-can re-designed and retrofitted as a biodegesters were used for the digestion. The wastes were mixed in the ratio of 2:1 (water to waste) and subjected to anaerobic digestion at mesophilic temperature range of 27^0C to 39^0C. Results obtained after a retention period of 27 days indicated an optimization in gas production by co-digesting oil palm fronds with cow dung (PF:CD) with cumulative biogas yields of 187.4L as against 116L for PF-alone. Flammability of produced biogas revealed a time lag of 5 days for PF:CD with sustained flammable gas production throughout the retention period while time lag for PF-alone was 2 days with un-sustained flammability. Peak biogas production was recorded for both digesters at pH of 6.6-to-6.9. Co-digestion of abundantly available animals and plants residues is hereby recommended as an environmentally sound, economically viable and socially acceptable solution to the current energy and waste management quagmire.

Keywords: biogas, energy, anaerobic digestion, oil palm fronds, flammability

1.0. Introduction

Energy is an integral component of any socio-economic development and a key factor for eliminating poverty in the society. In Nigeria limited access to modern energy services has remained a major barrier to improving key indicators of human development, as millions of people still lack enough energy input to trigger economic and income generating activities (Onafeso, 2007).

Nigeria is blessed with unlimited natural energy carrier resources like natural gas, coal, crude oil hydropower, solar, wind, biomass, geothermal and huge potential for hydrogen utilization (Sambo, 2010). However firewood remains the predominant energy sources for domestic and agro-processing activities, accounting for 50.45 % of the total energy consumption value (Onafeso, 2007). Although petroleum products accounts for 41.28% of total energy consumption value, the remoteness of the rural population, poor road networks and lack of storage infrastructure has resulted in petroleum products scarcity and crippling price (Sambo, 2010). This has resulted in an alarming and unsustainable consumption of firewood by the rural and urban poor. The consequences are acute firewood shortage and energy deprivation, low productivity and inability of the rural population to escape from poverty. Additionally the unprecedented pressure on firewood has led to abrupt climate change due to emission of huge volumes of greenhouse and noxious gases (Jaegar *et al*., 2004), deforestation, erosion, loss of bio-diversity, pollution and ozone layer depletion (Mowete, 2010).

Furthermore huge volumes of biomass wastes are generated from diverse agricultural, domestic and industrial activities (Nnadi *et. al.,* 2011), most of which are dump indiscriminately in landfills and on unauthorized locations, additionally contributing to adverse environmental and health problems like: greenhouse gas emission, odor, photochemical smog and pathogen contamination (Ilori *et. al*., 2007). In the absence of appropriate wastes disposal method and obvious environmental problems associated with non-renewable energy sourcing and utilization; a shift to renewable energy technology with rural feasibility is imperative. Although Nigeria is blessed with diverse and untapped renewable energy resources like solar, wind, hydro and geothermal Table-3 (Sambo, 2010), they are expensive to set up and require specific conditions and expertise. For example wind and photovoltaic energy are intermittent or diffuse technologies which require storage to be effective. Hydropower is site specific and will not be available in all areas. On the other hand biomass technology via which biogas is produced through anaerobic digestion of biomass wastes offers a defined comparative advantage as the feedstock is unlimited, the technology simple and rural driven and prevailing temperature well suited for methanogenesis.(Eze, 1995; Parawira and Mshandete, 2009; Meena and Vijay, 2010).

Biogas is generated when bacteria degrade biological material in the absence of oxygen in a process known as anaerobic digestion (**Price and Cheremisinoff, 1981**). Anaerobic digestion is a complex physiochemical and biological processes involving different factors and stages of changes comprising hydrolysis, acidogenesis/acetogenesis and methanogenesis (Ofoefule *et. al*., 2010)

$(C_6H_{10}O_5)n + nH_2O \rightarrow n(C_6H_{12}O_6)$ - Hydrolysis

$n(C_6H_{12}O_6) \rightarrow n\,CH_3COOH$ -Acetogenesis/Acidogenesis

$3nCH_3COOH \rightarrow n\,CH_4 + CO_2$ – Methanogenesis

Biogas consists of mainly methane (50-70%), carbon dioxide (30-40%) and traces of other gases such as nitrogen, hydrogen, ammonia, hydrogen sulphide and water vapour Table-1 (Yadava,and Hesse, 1981). It is a smokeless, hygienic and high quality fuel which can be used directly for diverse energy services such as heat, combined heat and power or as fuel for internal combustion engines (Parawira and Mshandete, 2009). The effluent of this process is a bio-fertilizer rich in essential elements like nitrogen and phosphorous which are needed for plant growth (Ciborowski, 2004). Utilizing and optimizing these huge biomass volume forms the background of this study which seeks to evaluate the biogas production potential of oil palm fronds as a single feedstock and its co-digestion with animal residues. Palm oil tree (*Elaeis guineensis.)* is economic tree widely grown in Nigeria, most especially in the south-south and south east. Large quantity of solid waste in the form of fibres, shells, empty bunches and palm fronds are generated from oil palm processing. In the same vain large quantities of animal wastes are generated annually and remains largely under-utilized. This study focused on oil palm fronds as a potential feedstock. Oil palm fronds are wastes generated during fruit bunch harvesting or pruning management practices and re-planting operation. The study evaluated the performance characteristics of oil palm fronds for biogas production as a single feedstock and co-digestion with animal wastes in a pre-determined rato (1:1)

2.0. Materials and Methods

2.1. Substrate collection and preparation

The oil palm fronds used for this investigation were obtained from private oil palm tree plantations in Isemelu quarter - Ebedei community; Ukwuani local government area of Delta state, Nigeria. The palm fronds were sized reduced, sun dried for three days and kept in anaerobic condition (50 L plastic container) for 2 days for initial fermentation before digestion. It was agitated daily.

2.2. Digester charging and experimental procedure

Two 50 L plastic prototype bio-digesters were used for the digestion process. The digesters were labeled “A” and

"B". For "A-digester" 14kg of pre-fermented fronds was mixed with 28kg of water, while for "B digester" 7kg each of pre-fermented fronds and cow dung were blended and mixed with 28kg of water, obtaining equal water to wastes ratio of 2:1 for both digesters ("A"/ "B"). The wastes were charged up to ¾ of the digester volume leaving ¼ head space for collection of gas. To each digester 10% by volume of inoculums was added for faster microbial proliferation and covered tightly to enable anaerobic digestion process. The digesters were manually agitated daily to ensure homogenous dispersion of the constituents of the mixture. Biogas production was measured by water displacement method.

2.3. Analytical methods

Total and volatile solids were determined using Renewable Technologies (2005) method. Ash, moisture and crude fiber contents were determined using AOAC (1990) method. Carbon content was carried out using Walkey and Black (1934) method. Crude fat, protein and nitrogen were evaluated using Soxhlet extraction and micro-kjedhal methods described in Pearson (1976).

.pH was determined using a Jeanway 3020 pH meter, while the ambient and influent temperatures of all the wastes using thermometer (0^0 – 360^0C). Total viable counts (TVC) for the wastes slurries were carried out to determine the microbial load of the samples using the modified Miles and Misra method described by Okore (2004).

3.0. Results and Discussion\

The study was conducted within a retention period of 27 days (3 weeks). Ambient temperature range of 23 to 35^0C and slurry temperature range of 27 to 40^0C was observed during the experiment. Feedstock suitability was evaluated as a function of the following determined parameters: volatile and total solid reduction, carbon-nitrogen ratio, pH, biogas production rate and flammability. The cumulative biogas production during the study for the two digesters system is shown in Figure- 2. For both "A- PF" (oil palm fronds alone) and "B-PF:CD" (oil palm fronds and cow dung) biogas production started within 48 hours of charging, although there were variations in determined parameters. The palm fronds as a single feedstock "PF" was flammable in 2 days although gas production witnessed a slow progression at the start with almost a linear gas production between the 8^{th} and 11^{th} day after which an increased gas production was witnessed between 12^{th} to 18^{th} days; decreasing sharply towards the end of the retention period (27 days). The cumulative biogas yield of the palm fronds (PF116L) was lower than the blend (PF:CD-187.4L) The observed phenomenon could be attributable to feedstock composition and physicochemical properties of the palm fronds (Iyagba *et al*., 2007). Palm frond contains high percentage of cellulose, hemi-cellulose, pectin and ligno-cellulosic fibre which are difficult to degrade and convert to biogas (Eze, 1995; Kozo *et al*., 1996). This is evident from the result obtained from the proximate analysis carried out on the wastes which revealed a higher percent (%) of total solids but lower percent (%) of volatile solids for "PF" compared to the wastes blend of "PF: CD" with higher value for volatile solids (Table-2). The considerable increase in biogas production witnessed in this study by co-digestion of oil palm fronds and cow dung reaffirms previous findings that blending animal wastes and crop residues improves the blend digestibility and gas production arising from additional nutrients availability, and improved carbon-to-nitrogen ratio (C:N) ((Eze *et. al*, 2007; Iyagba *et. al*., 2009).

The short time lag between gas production and flammability for PF-alone is due to balanced "C:N" ratio in the "PF" alone which prevented excess ammonia formation and dilution of the target gas –methane (Stephanopoulos, 2007). Combustibility is crucial if generated biogas must satisfy the basic need for cooking and lighting. Flammability means that the methane content is 45% or above (Ofoefule and Uzodinma, 2006). The short time lag confirms the suitable of oil palm fronds as an idea feedstock for flammable biogas yield. The cumulative biogas yield of the blend of palm frond waste and cow dung generated a significantly higher quantity of flammable biogas (170.4L), than that of the palm frond alone (98.5L); however the time lag between biogas production and gas flammability was 5 days as against 2 day using palm frond waste as single feedstock. The improvement in cumulative gas production maybe ascribed to the synergy of the resulting mixture which favored gas production as well as optimizing the feedstock properties that apparently ensures adequate gas production like the volatile solids (which is the biodegradable portion of the waste), nutrients (crude fat and protein) and carbon to nitrogen (C/N) ratio (Agunwamba, 2001), as shown on Table 2.

Carbon to nitrogen ratio was also evaluated. The balance of carbon and nitrogen in a feedstock is critical in anaerobic processes and biogas production. An optimum C:N ratio of between 20:1 and 30:1 has been suggested in previous studies to be adequate for optimum gas production (Hills, 1980). If the C:N ratio is very high, the nitrogen will be consumed rapidly by methanogens to meet their protein requirements and will no longer react on the left over carbon content of the material leadings to less gas production (Merchaim, 1992; Fulford, 1998). On the other hand, if the C: N ratio is very low; nitrogen will be liberated and accumulated in the form of ammonia (NH_3). Ammonia (NH_3) increases the pH value of the digester contents and subsequently inhibits the growth of the bacteria through NH_3 toxic concentration (Braun, 1982). Although the C: N ratio of the palm fronds was within the optimum range required for gas production, C:N ratio of the blend (PF:CD) was relatively more suitable for optimum microbial activities resulting in higher cumulative gas production as microbes responsible for hydrolysis and methanogenesis of feedstock to biogas take up carbon 30 times faster than nitrogen. (Merchaim, 1992; Iyagba *et al.,* 2009). Furthermore the increased biogas production may also be attributable to the fresh cow dung used for co-digestion process. Fresh cow dung contains active and native microbial population which enhanced the blend total viable count (TVC) at point of charging (1.5×10^{13}) as against that of palm frond alone (3.5×10^{9})

The sequence of pH change is shown in Figure-3. A sharp decrease in the pH of the fermenting medium was noticed in the first 4 days of digestion, however the decrease was more pronounced with the blend of cow dung and palm fronds. The observed differential in pH change is explained by the high volatile solids such as proteins, lipids etc in the mixture (PF:CD) which were converted more intensely into volatile fatty acid and other acidic metabolites by the activities of aerobes and facultative aerobes which were subsequently metabolized by methanogenic bacteria to generate methane (Dennis and Burke, 2001; Iyagba et al., 2009). The initial pH decrease was responsible for decreased gas production on the first 4 day in the two digesters. Low pH as been reported in previous studies (Chynoweth and Isaacson, 1987; Mahanta et al., 2004) to inhibits methanogenic bacteria that are responsible for biogas production. pH value less than 5 or greater than 8 has been reported in previous studies to rapidly inhibits methanogenesis (Garba and Sambo, 1992). In this present study the pH range of 5.3 to 7.4 observed in the co-digestion of palm fronds and cow dung (PF:CD) and 5 to 6.5 for palm fronds alone (PF) were within the optimal range suitable for most methanogenic bacteria. Hence the relatively considerable biogas production recorded in the two digesters.

Conclusion

This study investigated the biogas generation potential of oil palm fronds as a single feedstock and its co-digestion with cow dung. The performance characteristics were evaluated by digesting PF alone in digester "A" and co-digesting with cow dung (PF:CD) in digester "B". Results revealed clearly that oil palm frond is a viable feedstock for flammable biogas at short time lag, however blending the oil palm fronds and cow dung in a pre-determined proportion enhanced the cumulative flammable biogas. The result also shows that pH range of 6.6 to 6.9 resulted in higher gas production for both digesters. Thus utilizing agricultural and animal waste which remains hugely unlimited in supply provides a relatively simple access to modern and alternative renewable energy. Arising from the increasing environmental concern and prevailing wastes management crises; optimizing biogas production by co-digestion of plants and animals residues represents a viable sustainable energy option.

Acknowledgement

I am sincerely gratiful to Dr. Ossai. N. Ossai, Member Representing Ukwuani/Ndokwa Federal constituency, Nigeria National Assembly, Abuja for funding the study. Also the immense contribution of Dr. I. J. Eze; Head Biomass Unit, Energy Research and Development Centre, University of Nigeria, Nsukka (U.N.N) is also highly appreciated.

References

Adelekan, B. A. (2002). Assessing Nigeria's Agricultural biomass potential as a supplementary energy source through adaption of biogas technology. *Nigeria Journal of Renewable Energy*, 10(1&2):145-150.

Agunwamba JC (2001) "Waste Engineering and Management Tool" Immaculate Publication Limited, Enugu.

AOAC, (1995). Official Methods of Analysis. Association of Analytical Chemist 17th Ed. Arlington Virginia 22209.

Braun, R. and Wellinger, A.. (2002). Potential of co-digestion, *IEA Bioenergy* (Task 37).

Chynoweth, D. P. and Isaacson, R. (1987). Anaerobic digestion of biomass, Elsevier applied science, London

Ciborowski, P (2004)Anaerobic Digestion in the Dairy Industry. *Minnesota Pollution Control Agency Air Innovations Conferene,* www.epa.gov, retrieved 10.08.2012

Dennis, A and Burke, P. E. (2001). Dairy waste anaerobic digestion handbook. Environmental Energy Companey 6007 Hill street Olympia, W. A 98516. P. 20.

Eze, J. I and Onwuka, N. D (2007). Biodegradation of poultry wastes in batch operated plastic biodigesters. *Nigeria Journal of Solar Energy*, 18:63-67

Eze, J. I. (1995). Studies on generation of biogas from poultry droppings and rice husk from a locally fabricated biodigester. *M. Sc. dissertation*, University of Nigeria, Nsukka. 64 – 65.

Fulford, D. (1998). Running a Biogas Programme. A hand book. "How Biogas Works". Intermediate Technology Publication. 103 – 05 Southampton Row, London. WC 1B 4H, UK. Pp. 33 – 34.

Garba, A. and Sambo, A. S. (1992). Effect of operating parameter or biogas production rate. *Nigerian Journal of solar Energy* Vol. 3, pp 36 – 44

Hills, D. J (1980). Effect of C: N ratio on anaerobic digestion of dairy manure. *Agri. wastes,* 1:247-320

Ilori, M. O, Adebusoye, A, Lawal, A. K, Awotiwon, O. A. (2007). Production of biogas from banana and plantain peels. *Adv. Environ. Biol.* 1: 33-38.

Iyagba, E.T., Mangibo, I.A., and Mohammed, Y.S (2009). The study of cow dung as a co-substrates with rice husk on biogas production. *Scientific J. Research and essays*. 4(9) : 861-866

Jaegar, C., Hare, B. and Battaglini, A (2004). What is dangerous climate change? *A press statement at the 10th UN climate change conferenc*e, Buenos Aires (COP 10: 1-2, www.european-climate-forum.net)

Kozo, I., Hisajima, S., Macer, D. R. J. (1996). Utilization of Agricultural wastes for biogas production in Indonesia, In: Traditional technology for environmental conservation and sustainable development in the Asia Pacific region. *Proceedings of the UNESCO*, 11 – 14 Dec. 1995, 134 – 138

Mahanta, P., Dewan, A., Saha, U.K. and Kalita, P., (2004). Effect of temperature and total solid concentration on the gas production rate of biogas digester. *Journal of energy in Southern Africa*. Vol. 15 (4):112-117

Mechaim, U. (1992). Biogas processes for sustainable Development. Rome. FAO Ag. Service Bulletin.

Meena, K. and Vijay, V. K. (2010). Biogas for overcoming energy scarcity and climate change in India. *Proceeding of the first international conference on New Frontier in Biofuels, DTU'* Jan., 18-19th

Mowete, A. I (2010). Influence of energy efficiency on the environment and climate change. *A paper presented at University of Lagos on a 2-day workshop on*: "energy efficiency and conservation reporting for the media" March 14-15

Nnadi, F.N., Chikaire, J., Ajaero, J.O., Nwakwasi, R.N. and 2Oguegbuchulam, M.N. (2011). Renewable Energy for Sustainable Food, Feed and Fibre Production: A Panacea to Nigeria's Energy Crisis. *Nature and Science* ; 9(11):76-82. http://www.sciencepub.net

Ofoefule, A.U., Nwankwo, J.I. and Ibeto, C.N (2011). Biogas production from paper waste and its blend with cow dung. *Adv. In applied science research*. 1(2): 1-8.

Okore, V. C. (2004). Surface viable count method: a standard Laboratory Technique in pharmaceutics and pharmaceutical microbioloty. (2nd edn). El' Demark Publishers. 24 – 26.

Onafeso, O. D. (2006). The need for government ownership of solar energy production in the achievement of the millennium development goals in Nigeria. *Nigeria Journal of Solar Energy,* 16:146-154.

Parawira, N. and Mshandete, N. N. (2009) Biogas Technology research in selected Sub-Sahara African countries- A Review: *Journal of Biogas technology,* Vol. 8(2): 116-125.

Price, E and Cheremisinoff, P. T (1981). Biogas Production and Utilization. Ann Arbor: Ann Arbor Science Publisher

Pearson, D.(1976). The Chemical Analysis of Food. (7th Edn.). Churchill Livingstone. New York, 11-12, 14-15.

Renewable Technologies (2005).. Standard formula for calculating total and volatile solids Biogas FAO.

Sahota, P. and Rajinder, K. J. (1997). Biogas yield from cow and rice husks wastes, *J. Plant Sci. Res.*, 1: 13.

Sambo, A.S. (2010) Renewable Energy Development in Nigeria. *Paper Presented at the World Future Council/Strategy Workshop on Renewable Energ*y. Accra, Ghana. 21st -24th June.

Stephanopoulos. (2007). Challenges in engineering microbes for biofuels production. *Science* 315(581): 801-804

Verma, S. (2002). Anaerobic digestion of biodegradable organics in MSW. *A report*. 1-56.

Walkey, A and Black, L. A, (1934). *J. Soil Science*, 37:29-38.

Yadava, L. S. and P. R. Hesse (1981) "The Development and Use of Biogas Technology in Rural. Areas of Asia" (A Status Report 1981). Improving Soil Fertility through Organic Recycling, FAO/UNDP Regional Project RAS/75/004, Project Field Document No. 10

Table 1 Composition of Biogas

Substance	Symbol	Percentage
Methane	CH_4	50-70
Carbon dioxide	CO_2	30-40
Hydrogen	H_2	5-10
Nitrogen	N_2	1-2
Water vapour	H_2O	0.3
Hydrogen sulphide	H_2S	Traces

Table-2: **Physicochemical properties of the wastes**

Parameter	PF-single	PF:CD-Blend
Moisture content (%)	7.7	14.3
Ash (%)	12.5	19.9
Total solids (%)	81.5	79.5
Volatile solids (%)	69	86.1
Crude proteins (%)	1.6	15.7
Carbon content (%)	19.5	41.4
Crude Nitrogen (%)	1.2	3.4
Crude fibre	81	51

Table-3: Renewable energy resources potential in Nigeria and energy estimate

Source of energy	Potential reserves	Energy capacity
Fuelwood	80 million m3/year	6.0 x 109MJ
Saw-dust	1.8 million tons/year	31, 433,00OMJ
Crop-residues	83 million tons/year	5.3 x 1011 MJ
Animal wastes	227,500 tons daily	2.2 x 109
Biogas	6.8 million m3 daily	2.7m3 production 79.11MJ
Wind	2.4 m/s at 10m height	5MW
Solar	6.25 hours daily	6.25 – 7.0 KWh/m2 per day
Small hydropower	0.143 billion tons	734.2MW

Source: Nnadi et al., 2011

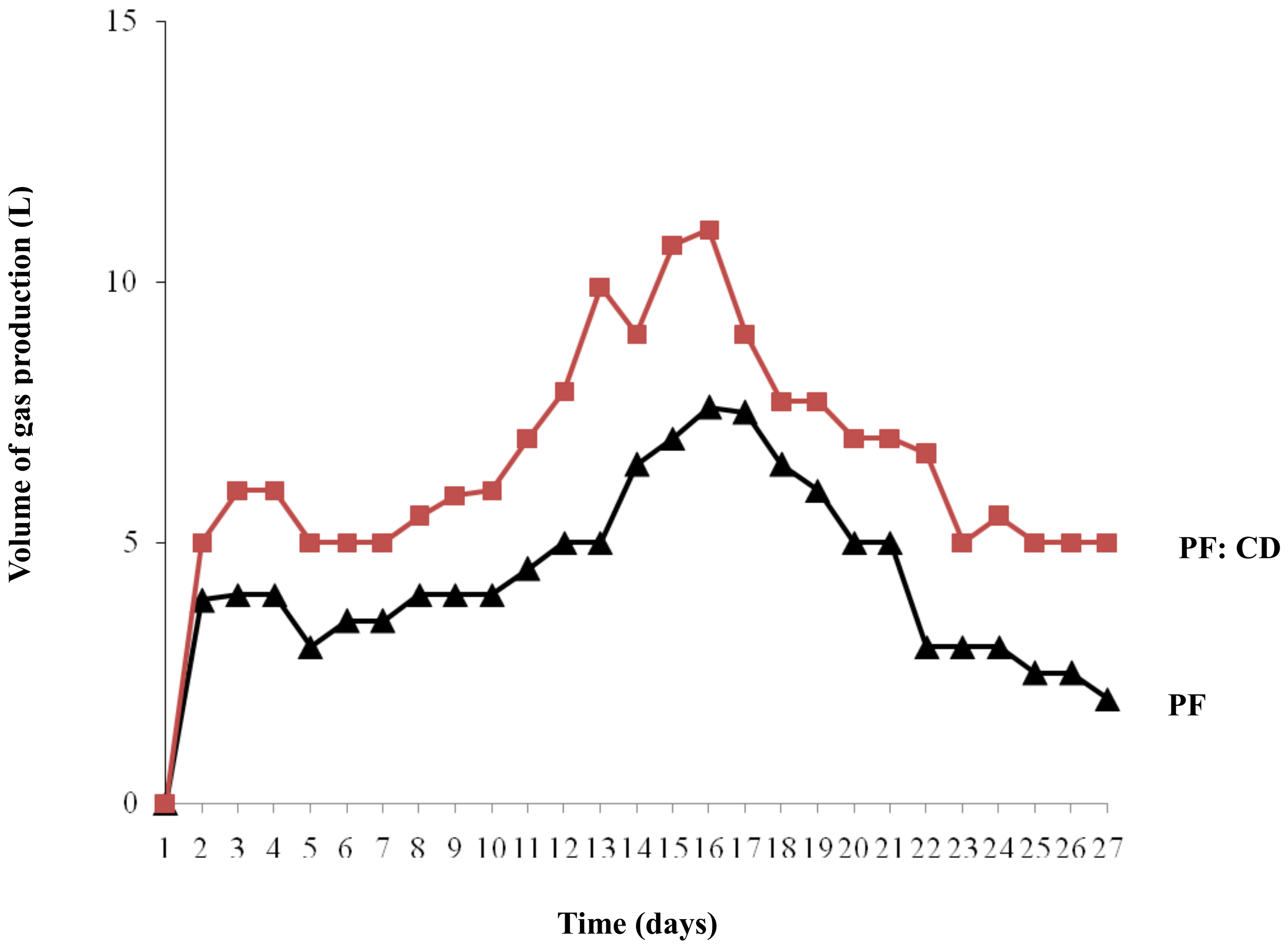
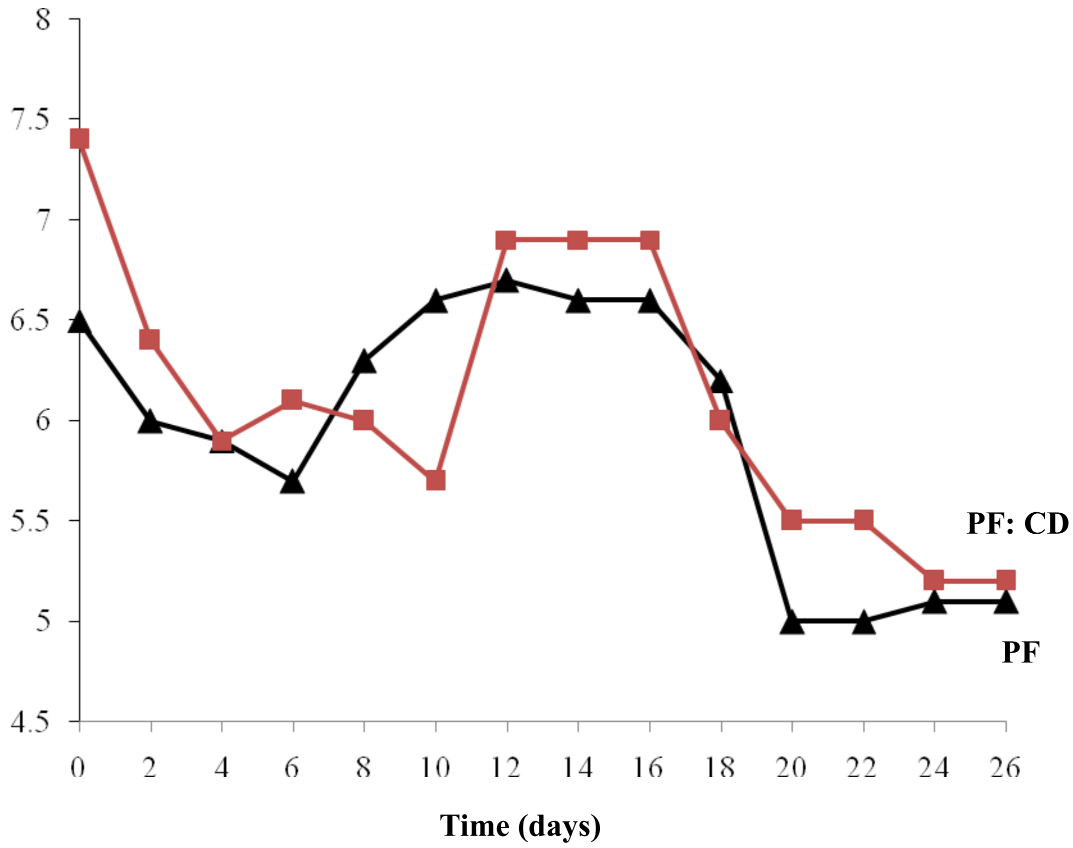


Figure-1: Daily biogas production profile PF (palm fronds) and PF:CD (blend of palm fronds and cow dung).



'

Figure- 2: Changes in pH profiles of feedstock during production of biogas;