INTERNATIONAL JOURNAL OF PLANT, ANIMAL AND ENVIRONMENTAL SCIENCES
IJPAES
Volume-5, Issue-3, July-Sept-2015 Coden:IJPAJX-CAS-USA, Copyrights@2015 ISSN-2231-4490
Received: 20th May-2015 Revised: 20th June -2015 Accepted: 24th June-2015
Research article

ENHANCEMENT OF BIOGAS PRODUCTION THROUGH SUSTAINABLE FEEDSTOCK UTILIZATION BY CO-DIGESTION

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ABSTRACT: Commercialization of biogas is a finite concern that desires scientific development to assure significant biogas production from various feedstocks. Though, the employment of wastes and lignocellulosic materials in a sustainable manner to accomplish substrate availability is an imperative criterion that enforces economic development and environmental welfare. Since, the present study has been designed to meet enhanced biogas and methane production from various substrates through co-digestion with cow dung. In spite of optimum C/N ratio, the substrate mixtures like poultry waste-cow dung (1:1), municipal solid waste-cow dung (1:2), fruit-vegetable waste-cow dung (1:1), agricultural waste-cow dung (1:2) and kitchen waste-cow dung (1:1) were prepared and then allowed to digest in a laboratory scale anaerobic digester, until 30th day. The quantitative analysis of biogas production through water displacement method showed that the highest water displacement of 171 ml was achieved in poultry waste- cow dung mixture at 27th day. The parameters such as pH and temperature were increased during the digestion process. The biochemical characterization of initial and final substrate showed that there was a gradual decrease in chemical characteristics except nitrogen content from 0th day to 30th day. The characterization of biogas at different time intervals revealed that poultry waste- cow dung mixture produced biogas with highest methane content of 72.6% at 30th day. However, it was explored that the co-digestion assist to enhance biogas production from various substrates used, where the poultry waste–cow dung (1:1) mixture showed significant methane and biogas production. Hence the present study concluded that a mixture of poultry waste–cow dung (1:1) can be promising for efficient production of biogas to accomplish economic feasibility in the meanwhile.
Key words: Co-digestion, Feedstock, Digester, Water displacement, Biogas.

INTRODUCTION

Growing energy demand and impacts of fossil fuel contribute towards the commercialization of biogas as a finite energy source. Organic waste materials are the major attraction for biogas production; even as biogas production through anaerobic digestion ensures alternative fuel, biofertillizer, electricity production, waste recycling, greenhouse gas reduction and environmental protection [1]. Methane is the combustible fraction of biogas, whereas relatively lower methane content of typical biogas in contrast to conventional energy sources is an added drawback that restrains the acceptance of biogas for commercial purposes. However, the ordinary waste materials or feedstock could not provide sufficient biogas in earlier [2]. Since further scientific advancement is obvious to increase the quantity and quality of biogas from various feedstocks. The major aspect for sustainable feedstock utilization is united with the characteristics of the substrate. Substrate availability is another concern has to be assured for commercialization of biogas in future [3]. In spite of this criterion animal manure was the most frequently used feedstock than agro-industrial wastes until recent past. On the other hand, it may due to the fact that manures possess low lignocelluloses content and can be effortlessly degradable by the microorganisms inhabited with it [4]. The accessibility of complex organic materials is a difficult task that requires further treatments to ensure absolute degradation and thereby biogas production.

Recently, co-digestion of organic materials is an imperative practice introduced to improve biogas production from complex materials too. In the course of co-digestion, diverse organic materials are allowed to digest in the same digester. Improved methane/biogas, highly nutritive biofertillizer, better degradability and cost effectiveness are the major significance coupled with co-digestion experiments. Since, few trials as evidenced that co-digestion of agricultural and industrial wastes with animal manure improved biogas yield than while they using individually for the purpose [5].

During biogas production, microorganisms convert various components of feedstock into methane, carbon dioxide, hydrogen sulfide, nitrogen and ammonia, under anaerobic circumstance. Generally, carbon, nitrogen, oxygen and hydrogen are the abundant elements by which composed whole organic materials. The elemental composition in each material varies with the metabolic processes take place in its native state. Moreover, carbon/nitrogen (C/N) ratio of feedstock is an adequate measure that desires the rate of microbial degradation of substrate and total methane production. The increased nitrogen uptake by methanogens and accumulation of ammonia during methanogenesis are the major problems linked with increased and decreased C/N ratio, as explored in earlier [6]. The pleasing methane production can be obtainable by employing the feedstock with an optimum C/N ratio in the range of 15-35. However, it is crucial to ensure optimum C/N ratio in feedstock prior to anaerobic digestion, in course to pledge process stability and thereby finest gas production. Higher carbon content of animal manure and nitrogen content of agricultural or domestic wastes could influence the characteristics of biogas in larger extent [3]. Therefore advance research is needed in this area to explore proficient feedstock mixtures through optimization of the C/N ratio to accomplish absolute biogas production. With these concepts, the present study had framed to analyze the biogas production potential of diverse substrates along with cow dung through co-digestion, in order to explore the potential substrate mixture for feasible biogas production in the meantime. Such kinds of approaches are also obligatory for mounting the availability of substrate throughout the year to account large-scale production of biogas in a sustainable manner.

MATERIALS AND METHODS

Collection of substrates

Organic substrates such as cow dung, poultry waste, fruit-vegetable waste, agricultural waste, municipal solid waste and kitchen waste were obtained around Tiruchegode, Namakkal (Dt), Tamil Nadu. Approximately 250g of each sample was collected for co-digestion purpose. All fresh substrates were collected ascetically in sterile polyteen bags and then directly brought to the Laboratory of Vivekanandha College, Namakkal, Tamil Nadu; where the further studies has been carried out.

Feedstock preparation

Based on the typical C/N ratio obtained for each substrate, cow dung was mixed with apposite ratio for co-digestion. Since the co-digestion mixtures or feedstock has been obtained by organic wastes and cow dung in the range of 10g : 10g for poultry waste, kitchen waste and fruit-vegetable waste whereas 13.35g : 6.65g for agricultural waste and municipal solid waste. A total solid content of the substrate mixture was maintained as lower range (8%) by adding 250ml of distilled water and was then stirred well to assure homogeneous mixing.

Experimental setup and co-digestion

For biogas production, five laboratory scale batch digesters were used in the present study. Each setup contains three flasks, where the first two flasks were sealed with rubber cork. Each flask is connected to the next flask through a connecting tube. Water displacement method was used in this study to quantify the rate of biogas production. The initial flask serves as the anaerobic digester that possesses a total volume of 500ml. The second flask possesses an exact volume of 250 ml, which was filled with acidified brine solution to avoid the dissolution of biogas in water. The acidified brine solution was obtained by the addition of few drops of concentrated sulfuric acid in supersaturated sodium chloride solution [5]. While the third flask with a volume of 250 ml, was kept as empty to carry displaced water during biogas production. The substrate mixture has been added to $3/4^{th}$ volume of the specific digester and then allowed for digestion under room temperature for 30 days. During the digestion period, all the samples in the digesters were agitated twice per day to achieve feasible degradation.

Analytical methods

Biogas production has been quantified by every 3 days time intervals, through measuring the water displaced into the third flask from second flask due to the displacement of biogas produced from the digester to second flask [7,8]. Substrate characterization was also carried out to examine the rate of degradation of various chemical components. Since the initial and final (0^{th} & 30^{th} day) samples from the digesters were collected and then evaluated for total solids, volatile solids, carbon, nitrogen, lignin and cellulose content [9,10]. The common parameters such as pH and temperature of fresh substrate mixture and digested slurry were examined through the digital pH meter and thermometer.

Biogas produced at varied time intervals (0th, 7th, 14th, 21st & 30th day) were collected from each digester through syringe collection method, and characterization of biogas has also been performed by using a gas analyzer to explore the concentration of methane present in it [4].

RESULTS

Feedstock feasibility and mixing

Various organic materials preferred in this study such as cow dung, poultry waste, fruit-vegetable waste, agricultural waste, municipal solid waste and kitchen waste showed respective C/N ratio. Based on the C/N ratio, the selected substrates were mixed with cow dung and are represented in the table 1. The materials those possess highest C/N ratio like agricultural waste and municipal solid waste were mixed with cow dung in the ratio 1:2 while the mixing ratio of poultry waste, fruit-vegetable waste and kitchen waste were 1:1.

Quantification of biogas

The digester set-up was satisfactory for carrying digestion process at anaerobic condition (Figure 1). During 30 days of digestion period, the water displacement has been initiated from the 3rd day in the fruit-vegetable waste and kitchen waste treated digester. Whilst the water displacement has been initiated at 6th day in poultry waste, and 12th day in municipal solid waste and agricultural waste treated digester. However, the highest water displacement of 171ml was achieved at 27th day in the digester possess a substrate mixture of poultry waste and cow dung. Followed by, kitchen waste-cow dung (144ml) and fruit-vegetable waste-cow dung (136ml) showed considerable gas production. Municipal solid waste-cow dung and agricultural waste-cow dung showed relatively lower biogas production of 129ml and 124ml at 30th day. Interestingly, fruit-vegetable waste-cow dung provided utmost production at 24th day itself. Nevertheless, the production rate of fruit-vegetable waste-cow dung was not promising in contrast to poultry waste-cow dung and kitchen waste-cow dung, where the highest production rate was observed at 27th day (Table 2).

Fig: 1 Laboratory scale digester set-up

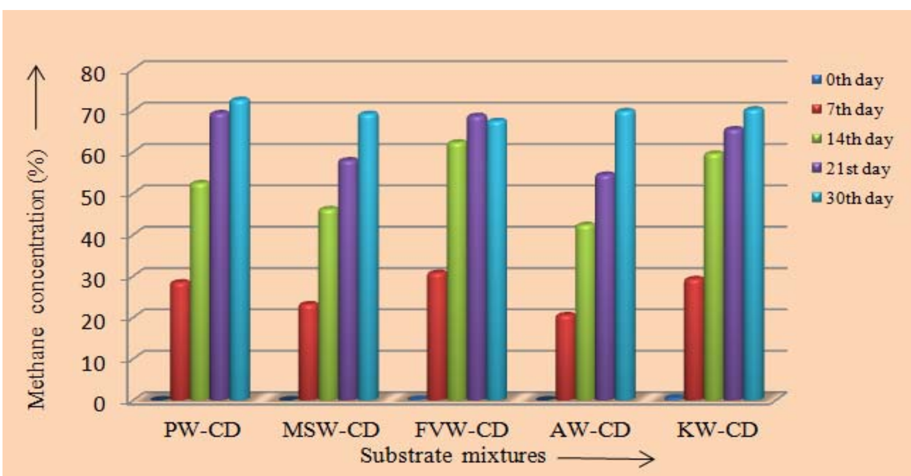

Fig: 2 Characterization of biogas

PW-CD (poultry waste-cow dung), MSW-CD (municipal solid waste- cow dung), FVW-CD (fruit-vegetable waste-cow dung), AW-CD (agricultural waste- cow dung), KW-CD (kitchen waste- cow dung)

Table 1: Carbon/Nitrogen ratio and mixing ratio of substrates

Substrates	C/N ratio	Mixing ratio with cow dung
Cow dung	19	-
Poultry waste	14	1:1
Municipal solid waste	45	1:2
Fruit-vegetable waste	17	1:1
Agricultural waste	52	1:2
Kitchen waste	24	1:1

Table 2: Quantification of biogas through water displacement

Time period	PW-CD	MSW-CD	FVW-CD	AW-CD	KW-CD
0^{th} day	-	-	-	-	-
3^{rd} day	-	-	2ml	-	-
6^{th} day	3ml	-	5ml	-	6ml
9^{th} day	5ml	2ml	9ml	3ml	10ml
12^{th} day	20ml	12ml	32ml	9ml	26ml
15^{th} day	107ml	44ml	80ml	30ml	103ml
18^{th} day	120ml	65ml	122ml	45ml	112ml
21^{st} day	125ml	82ml	127ml	85ml	120ml
24^{th} day	156ml	93ml	**136ml**	96ml	124ml
27^{th} day	**171ml**	126ml	132ml	116ml	**154ml**
30^{th} day	168ml	**129ml**	126ml	**124ml**	127ml

Physico-chemical parameters during digestion

The common environmental parameters such as pH and temperature were showed variations on time during anaerobic digestion. The initial and final pH shows that there was an increase of pH at the 30th day in the course of all the five trials. The higher pH of 8.1 and lower pH of 6.5 was observed at 30^{th} day in poultry waste- cow dung and fruit-vegetable waste-cow dung, respectively. There were slight changes in temperature obtained in the final period. However, all the systems tend to run at mesophillic temperature ranges. The comparatively highest temperature of 42.5^{0}C was observed in poultry waste-cow dung mixture, whilst the lowest temperature of 38.6^{0} C was observed in municipal solid waste-cow dung at 30^{th} day (Table 3).

Analysis of biochemical compounds

The biochemical composition of the substrate mixture during the digestion period shows that there was a gradual decrease in biochemical characteristics such as total solids, volatile solids, organic carbon, cellulose and lignin content from 0^{th} day to 30^{th} day. However, the organic nitrogen content was subsequently increased during the digestion process. Considerable solid removal has been achieved in all the substrate mixtures, which was supported by the reduced rate of cellulose, lignin and carbon (Table 4). The higher solid removal was observed in fruit-vegetable waste- cow dung mixture and the lower solid removal was accomplished in municipal solid waste-cow dung and agricultural waste-cow dung mixture. Although, the present study revealed that the system with low solid content of 8% was satisfactory for biogas production in greater extent.

Table 3: Physical parameters during biogas production

Substrate mixture	pH		Temperature	
	0^{th} day	30^{th} day	0^{th} day	30^{th} day
PW-CD	7.8	8.1	34.2	42.5
MSW-CD	7.1	7.9	33.8	38.6
FVW-CD	4.1	6.5	35.3	39.8
AW-CD	6.6	7.6	32.1	43.3
KW-CD	6.9	7.5	33.5	40.8

Table 4: Chemical characterization of fresh and digested slurry

Parameters	PW-CD		MSW-CD		FVW-CD		AW-CD		KW-CD	
	0^{th}	30^{th}	0^{th}	30^{th}	0^{th}	30^{th}	0^{th}	30^{th}	0^{th}	30^{th}
TS (%)	91.8	18.7	92.2	20.5	88.3	10.0	93.1	33.4	85.4	12.5
VS(%)	79.6	12.5	69.8	6.2	80.6	4.5	74.2	26.3	78.2	7.6
Carbon(%)	34.2	20.2	44.3	26.5	42.5	16.5	46.1	26.6	23.6	12.5
Nitrogen (%)	2.1	5.6	1.4	3.2	2.3	2.9	1.3	3.8	1.1	1.6
Cellulose(%)	30.5	8.2	35.4	12.8	20.2	4.5	42.2	22.8	33.2	14.3
Lignin(%)	16.3	10.2	14.5	7.9	8.5	1.0	22.7	15.9	12.2	7.3

Characterization of biogas

The characterization of biogas at different time intervals revealed that poultry waste- cow dung mixture produced biogas with highest methane content of 72.6% at 30^{th} day, than that of produced from other four trials. Followed by kitchen waste-cow dung (70.3%), agricultural waste-cow dung (69.9%) and municipal solid waste-cow dung mixture (69.2%) showed highest methane production at 30^{th} day. Whilst the fruit-vegetable waste-cow dung mixture furnished the most biogas production of 68.7% at 21^{st} day, which was relatively lower than the methane content obtained among the other trials (Figure 2). Moreover, the present study found out that poultry waste-cow dung (1:1) is the potential substrate mixture for obtaining favorable biogas production with high quantity and quality.

DISCUSSION

Usually, animal manure and vegetable wastes were on track for biogas production in ancient years, whilst agro-industrial wastes and municipal solid waste are being the major attraction for extensive biogas production at current scenario due to its high nutrient content. However, the complexity of such kind of materials resists microbial degradation and a lower methane content of 55-60% was observed in most of the cases [11,12]. However, the bioenergetic property of biomass is differing from each other and the relevance of a feedstock is allied with certain criterion such as substrate nature, availability and C/N ratio. Since the present study performed co-digestion of selected substrates such as poultry waste, municipal solid waste, fruit-vegetable waste, agricultural waste and kitchen waste with cow dung to accomplish optimum C/N balance for enhancing biogas production [13]. Comprehensively, the socioeconomic impacts of each material were taken as account to consider these substrates to neutralize its negative impact [1,3].

In due course of the digestion period, there was a gradual increase in the rate of water displaced that revealed the sequent production of biogas in each digester. Extensive displacement has been occurred in all the digesters whereas the poultry waste- cow dung (1:1) produced more biogas (171 ml) at 27^{th} day, which was promisingly comparable to the earlier reports where the highest production was obtained after 30-45 days. A study by Iyagba explored that cumulative biogas production of 161.5 ml was achieved from rice husk: cow dung (1:1) at 38^{th} day of digestion [5]. Similarly 161.5ml of cumulative biogas production has been occurred from the digestion mixture containing boiled rice chaff and cow dung in the ratio 1:1 [14]. Moreover, the co-digestion of complex substrates with ruminant manure was recognized as the promising prospect for enhancing biogas yield with decreasing hydraulic retention time since manures would provide adequate microorganisms to hydrolyze complex lignocellulosic materials [11]. Although, those earlier publications are concurrent with the present study that co-digestion assists the enhancement of biogas production from various substrates by the temporal means.

The parameters such as pH and temperature of digested slurry were increased in contrast to that of initial day. This increase in pH is due to the releasing of ammonia by methanogens during methanogenesis [3,15]. However, the increase of pH up to 8.5 is recognized as favorable pH range, whilst highly basic pH may cause process unsteadiness due to the accumulation of ammonia [16]. Similarly, lower pH (<5.0) would drastically affect methanogenesis by the accumulation of volatile fatty acids. Hence the final pH range of 6.5-8.1 showed stable biogas production, in the present study. Conversely, earlier studies reported that mesophillic temperature ranges (20.7-40^{0}C) are adequate for the degradation of typical organic wastes [17,18]. Moreover, the significance of the present study is that the highest production was observed at 27^{th} day in the mesophilic temperature. This result was promisingly comparable to the highest production rate observed in thermophilic temperature ranges.

Moreover, the current study revealed that maximum solid removal has been accomplished by co-digestion of various organic materials with cow manure. Generally, manures are prosperous with carbon content compared to agro-industrial wastes, while the nitrogen content is relatively lower in manures. Since manures produced high quantity of biogas with low methane concentration, whilst agro-industrial wastes like paper waste produced biogas with low quantity but high quality.

While the he co-digestion of cow dung and paper waste increases the quantity and quality of biogas extensively [2,19]. Likewise, the higher solid removal was obtained in this study due to the maintenance of sufficient total solid (8%) and volatile solid content through co-digestion. These results are also supported by the earlier experiment that showed a total solid content of about 7-8% was significant for a considerable rise in biogas production than high solid content [20]. The significant reduction of volatile solid has been achieved in poultry waste- cow dung, fruit-vegetable waste- cow dung and kitchen waste- cow dung. Even the biogas production efficiency was higher in poultry waste-cow dung, as evidenced by the highest quantity of water displaced during anaerobic digestion. The present study was also supported by earlier publications that revealed the presence of higher volatile solid content (75-93%) and simpler, highly nutritive nature of cow dung and poultry waste feasible for microbial degradation [14,21,22]. Concurrently, an average methane production of 64-69% was observed from cow dung and 65-70% was observed from poultry waste. However the recognized production rate was lower than that of compared to the present study where the highest methane content of 72.6% was observed at 30th day through co-digestion of poultry waste and cow dung [2,4,12]. This study also accomplished the prediction reported in the earlier reports that co-digestion of organic wastes with manure would be an interesting option for biogas production in the meanwhile.

CONCLUSION

The quantitative analysis of biogas production from five different substrate mixtures shows that the water displacement has been gradually increased from 0th day to 30th day, which implement the production of biogas in respective digester. The highest water displacement of 171 ml has been obtained from the poultry waste-cow dung mixture at 27th day. Conversely, maximum total solid and volatile solid removal was accomplished in all the five substrate mixtures through co-digestion, which was promising than the solid removal obtained by treating the substrates individually. The increased temperature and pH of 30th day revealed that appropriate degradation occurred throughout the process. Biogas characterization shows that highest methane concentration of 72.6% was achieved from poultry waste-cow dung (1:1) mixture in contrast to other four trials. However, this study concluded that poultry waste-cow dung is the potential substrate mixture, and hence this can be used for effective biogas production in the meantime. The present study also proved that co-digestion of various substrates with an optimum C/N ratio enhances biogas production quantitatively as well as qualitatively, which offers further advancements in biogas production technology through co-digestion in course to commercialize biogas in future.

ACKNOWLEDGEMENTS

The first author (Divya. D) acknowledges the financial assistance from the INSPIRE Programme Division, DST, Government of India, for conducting this research work. The authors are grateful to Dr. M. Karunanithi, Chairman, Vivekanandha College of Arts & Sciences for Women, for providing infrastructure for the present research.

REFERENCES

[1] Okonko, I.O., Adeola, O.T., Aloysius, F.E., Damiola, A.O., Adewale, O.A. 2009. Utilization of food wastes for sustainable development. Electronic Journal of Environmental Agricultural and Food Chemistry, 8(4), pp. 263-286.

[2] Bagudo, B.U., Garba, B., Dangoggo, S.M., Hassan, L.G. 2011. The qualitative evaluation of biogas samples generated from selected organic wastes. Archives of Applied Science Research, 3(5), pp. 549-555.

[3] Divya, D., Gopinath, L.R., Merlin Christy, P. 2015. A review on current aspects and diverse prospects for enhancing biogas production in sustainable means. Renewable and Sustainable Energy Reviews, 42, pp. 690-699.

[4] Merlin Christy, P., Gopinath, L.R., Divya, D. 2014. Microbial dynamics during anaerobic digestion of cow dung. International Journal of Plant Animal and Environmental Sciences, 4(4), pp. 86-94.

[5] Iyagba, E.T., Mangibo, I.A., Muhammad, Y.S. 2009. The study of cow dung as co-substrate with rice husk in biogas production. Scientific Research and Essay, 4(9), pp. 861-866.

[6] Naik, L., Gebreegziabher, Z., Tumwesige, V., Balana, B., Mwirigi, J., Austin, G. 2014. Factors determining the stability and productivity of small scale anaerobic digesters. Biomass and Bioenergy, http://dx.doi.org/10.1016/j.biombioe.2014.01.055, Article in press.

[7] Momoh, O.L.Y., Nwaogazie, I.L. 2008. Effect of waste paper on biogas production from co-digestion of cow dung and water hyacinth in batch reactors. Journal of Applied Science and Environmental management, 124, pp. 95-98.

[8] Itodo, I.N., Lucas, E.B., Kucha, E.I. 1992. The effect of media materials and its quality on biogas yield. Nigerian Journal of Renewable Energy, 3(1.2), pp. 36-44.

[9] AOAC. 2000. Official methods of analysis, 7th Edition, Association of official analytical chemists, Maryland, USA.

[10] Chellapandi, P. 2007. Biogas Technology, Laboratory manual in industrial biotechnology. Pointer publishers, Jaipur 302 003 (Raj), India. ISBN 978-81-7132-488-0, pp: 192-207.

[11] Ward, A.J., Hobbs, P.J., Holliman, P.J., Jones, D.L. 2008. Optimization of the anaerobic digestion of agricultural resources. Bioresource Technology, 99, pp. 7928-7940.

[12] Banik, S. 2004. Jute caddis- A new substrate for biogas production. Journal of Scientific and Industrial Research, 63, pp. 747-751.

[13] Sidik, U.H., Razali, F.B., Alwi, S.R.W., Maigari, F. 2013. Biogas production throygh co-digestion of palm oil mill effluent with cow manure. Nigerian Journal of Basic and Applied Science, 21(1), pp. 79-84.

[14] Vivekanandan, S., Kamraj, G. 2011. The study of biogas production from rice chaff (karukka) as co-substrate with cow dung. Indian Journal of Science and Technology, 4(6), pp. 657-659.

[15] Schlegel, M., Kanswohl, N., Rossel, D., Sakalauskas, A. 2008. Essential technical parameters for effective biogas production. Agronomy Research , 6(Special issue), pp. 341-348.

[16] Ilaboya, I.R., Asekhame, F.F., Ezugwu, M.O., Erameh, A.A., Omofuma, F.E. 2010. Studies on biogas generation from agricultural waste; Analysis of the effects of alkaline on gas generation. World Applied Sciences Journal, 9(5), pp. 537-545.

[17] Ezekoye, V.A. 2009. Studies on the influence of rice on husk on biomethanation: 1. Optimal condition for digestion and the domestic use of stored biogas. Pacific Journal of Science and Technology, 10(2), pp. 889-897.

[18] Uzodinma, E.O.U., Ofoefule, A.U. 2009. Biogas production from blends of field grass (*Panicum maximum*) with some animal wastes. International Journal of Physical Sciences, 4(2), pp. 091-095.

[19] Ofoefule, A.U., Nwankwo, J.I., Ibeto, C.N. 2010. Biogas production from paper waste and its blend with cow dung. Advances in Applied Science Research, 1(2), pp. 1-8.

[20] Islam, M., Salam, B., Mohajan, A. 2009. Generation of biogas from anaerobic digestion of vegetable waste. Proceedings of the International Conference on Mechanical Engineering, ICME09-TH-19, Dhaka, Bangladesh.

[21] Dhanya, M.S., Gupta, N., Joshi, H.C., Lata. 2009. Biogas potentiality of agro-wastes jatropha fruit coat. International Journal of Civil and Environmental Engineering, 1(3), pp. 136-140.

[22] Kelleher, B.P., Leahy, J.J., Henihan, A.M., O'Dwyer, T.F., Sutton, D., Leahy, M.J. 2002. Advances in poultry litter disposal technology- a review. Bioresource Technology, 83, pp. 27-36.

INTERNATIONAL JOURNAL OF
PLANT, ANIMAL AND ENVIRONMENTAL SCIENCES

ISSN 2231-4490

International Journal of
Plant, Animal and Environmental Sciences