Biogas Production from Anaerobic Digestion of Biodegradable Household Wastes

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Abstract

This study focuses on production of biogas as an alternative energy by using biodegradable wastes (BWs) in view of solving waste management at household level. The research was conducted on ARTI model compact biogas plant of 1 m^3 digester and 0.75 m^3 gasholder in focusing the management of daily collected biodegradable wastes (1-2 kg) produced from households. Both laboratory and field analyses were carried out. Methane content in biogas was determined by Biogas Analyzer Gas Board-3200P. Average maximum of about 235 l gas was recorded per day with corresponding to 65 min/day burning hour with the gas flame of energy value 1.55 MJ/h. According to the plant owners, the burning period of the gas was approximately 2 h/day during the spring and pre-monsoon seasons. The average gas production (per kg) from fresh waste materials was approximately 60 l. The use of high moisture containing cellulosic waste materials and incomplete digestion due to lower digester temperature were the major causes of lower gas yield. The proportion of methane exceeded by carbondioxide in the beginning but then after gradually methane exceeded carbondioxide and reached 56.43% on an average. Although fertilizer value in terms of NPK increased gradually but it remained below 1% except K, which was found to be 1.22%. Simple payback periods of 4.81, 7.57 and 7.20 years were found in kerosene, firewood, and LPG substitutions respectively.

Key words: alternative energy, biogas analyzer, compact biogas plant, methane, simple payback period

Introduction

Energy is one of the basic requirements of all living beings. The unsustainbility of conventional energy resources and their associated environmental pollutions made renewable energy the prime need of present time. It plays decisive role in the sustainable socio-economic development and improved quality of life. Energy consumption ratio of Nepal by fuel type's reveals still major proportion is of traditional fuels where as contribution of renewable energy is less than 1% (MoF, 2009). The production of green house gases (GHGs) owing to excessive use of conventional energy resources in the world is the major cause of global warming and climate change.

Biogas technology is the biochemical conversion technology of bio-energy conversion where decomposition or degradation of organic matter occurs in the absence of oxygen by microorganisms. Compact biogas plant is a new biogas technology. It is a floating drum biogas plant. The digester of the plant is simple water storage plastic tank of 1 m^3 and the gasholder of 0.75 m^3. Gasholder is placed upside down in the bigger one. The biodegradable wastes (BWs) are used as feeding materials. This plant is kept generally above the ground.

The increasing problem of BWs and their improper management is degrading the urban environment day by day. Restrictions of space, unavailability of cow dung or other animal manures in urban and semi urban areas as well as loss of resources as discarded materials compelling the people to seek alternative renewable energy resources. The main objective of the study is biogas production as an alternative energy from anaerobic digestion of biodegradable household wastes.

Study site

The study was carried out in Kathmandu valley at Tikathali of Lalitpur district. The valley lies at a mean elevation of about 1300 metre from the sea level. The climate is cool temperate or moderate with maximum temperature of 35 °C in April and minimum -3 °C in January. The temperature in general is 19 to 27 °C in summer and 2 to 20 °C in winter.

Methodology

Designing and fabrication of digester: The study was carried out in an ARTI model compact biogas plant of 1 m^3 capacity of water storage tank for digester where its upper part was removed to place the gasholder. The inlet pipe, which is a bit longer than the height of the digester tank, was fitted into near the bottom of digester and extended to its centre. Outlet pipe was fixed in the upper side of digester tank and drainage valve near its bottom. Gasholder of 0.75 m^3, which receives gas outlet pipe, was placed upside down in the digester tank (see Figure 1).

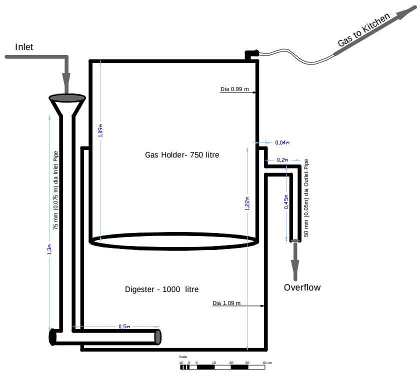

Fig. 1. Drawing of compact biogas plant installed during study

Initial feeding and checking of gas leakage: To begin with, the digester tank was loaded with about 60 kg cow dung as inoculum and was filled almost at the brim by water. Gas leakage was checked by submerging the gasholder halfway into the slurry up to 24 hours.

Collection, segregation, and chopping of feeding substances: All types of biodegradable solid wastes except very acidic and hardly decomposed were collected from household. They were sorted out, weighed, and chopped into smaller ones of size 10-20 mm to allow ease of bio-degradation and reduce choking problem. They were kept separately in small buckets for pre-fermentation up to a week. The plant was fed daily.

Laboratory analysis: The physico-chemical parameters such as NPK, pH, total solid, volatile solid and organic matter were determined at the laboratory of Central Department of Environmental Science, Tribhuvan University and at Agriculture Technology Centre, Pulchowk, Lalitpur by adopting the standard methods.

Measurement of biogas production: Total volume of gas produced was determined by measuring the height gained by gasholder on daily basis, as gas flow meter did not work properly due to low gas pressure.

Determination of methane content: The percentage of methane content and carbon dioxide was determined by Biogas Analyzer Gas Board-3200P.

Results and Discussion

Designing and fabrication of experimental bioreactor: There is no hard and fast rule for standard dimensions that should be maintained during the designing of the biogas plant. Unavailability of required volume and diameter of tanks for digester and gasholder to minimize the wider gap that exists between the digester and gasholder (rim), lesser amount of BWs production from household etc were some of the reasons regarding sizing of the biogas plant. The compact biogas plant of size ratio 1:0.75 was taken in focusing the management of 1-2 kg BWs produced from family size of 4-6 members of household per day. The fabrication of plant took approximately four hours for two persons who had the simple knowledge of plumbing.

Temperature: The temperature recorded inside the bioreactor during the study was found lower than optimum temperature for biogas production. The measurement was conducted in the morning office period hour. The study was carried out in the post monsoon and autumn seasons. The optimum range of temperature 32 to 37 °C may be quite impossible in hilly regions of Nepal like Kathmandu valley but more possibility is there in the Terai belt, where temperature is more favourable for gas production.

Biogas production: Relevant data on biogas production are given in Table 1 below

Table 1. Biogas production

Date of recording	Weeks	Daily average biogas yield (in litre)	Average burning period (in min)
2065/04/27-065/05/01	1st	124.24	10.33
2065/05/02-065/05/07	2nd	144.58	20.42
2065/05/08-065/05/14	3rd	136.68	16.50
2065/05/15-065/05/21	4th	147.93	22.08
2065/05/22-065/05/28	5th	196.03	45.93
2065/05/29-065/06/04	6th	188.83	42.36
2065/06/05-065/06/11	7th	172.07	34.05
2065/06/12-065/06/18	8th	198.43	47.12
2065/06/19-065/06/25	9th	199.03	47.42
2065/06/26-065/07/01	10th	206.25	51.50
2065/07/02-065/07/09	11th	211.32	53.51
2065/07/10-065/07/16	12th	234.82	65.16
2065/07/17-065/07/23	13th	214.21	54.94
2065/07/24-065/07/30	14th	184.50	40.21

The table 1 shows the low amount of biogas production corresponding to burning hour due to low pressure of gas in gasholder. Lower digester temperature, drastic fluctuations in day and night temperature, lack of maintenance of total solid, incomplete digestion and greater percentage of cellulose containing feeding materials may be some of the reasons for low gas yield.

The amount of biogas increased gradually along with increasing amount of feeding materials and digestion period. Average maximum of about 235 L/day was recorded with burning hour 65 min/day with gas flame of energy value 1.55 MJ/h. However, according to plant owners' approximately two hours per day burning period of gas was noted during spring and pre-monsoon season. The gas generation per kg fresh feeding materials depends upon the type and digestibility of feeding materials as well as digester temperature etc. The amount of gas production was found approximately 60 L/kg feeding waste materials. The higher cellulose and moisture containing waste materials such as vegetables and fruit wastes, lower digester temperature and improper digestion etc were some major limiting factors, which caused low gas yield per kg waste.

Methane content

Initially the percentage of methane was lower in comparison to carbon dioxide but thereafter the proportion of methane exceeded the percentage of carbon dioxide and reached 56.43% on an average and maximum 57.74%. However, this value is normal but the improper digestion as well as lower percentage of starchy and sugary feeding materials was some of the causes of low methane yield. Methane content depends upon the type and nature of feeding materials and digester temperature as well.

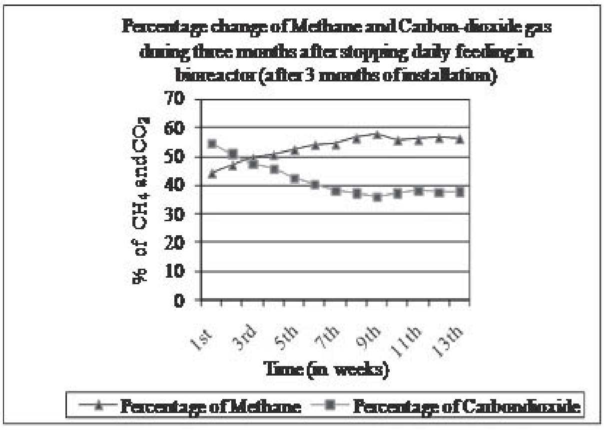

Fig. 2. Percentage of methane and carbon dioxide versus time in weeks

pH: The pH value of the slurry was found between 6 and 7 except in slurry-A during the study period, which is satisfactory range for biogas production. The higher value of pH in slurry-A may be due to formation of ammonia along with continuation of digestion process. The methane formation is also followed by slightly increase in pH of slurry.

Table 2. Physico-chemical analyses of raw materials and bio-slurry

S.N	Sample identification	pH	N%	P_2O_5%	K_2O%	OM%	TS%	C/N ratio	VS%
1	Raw waste material	5.18	1.75	0.028	0.44	68.115	13.29	22.57	75.57
2	Cow dung only	6.37	2.10	0.70	2.55	48.60	—-	13.00	—-
3	Slurry-A (2065/5/26)	8.09	0.02	0.06	3.24	3.24	0.37	94.00	41.10
4	Slurry-B (2065/08/30)	6.50	0.68	0.42	1.00	1.42	0.55	2.00	42.27
5	Slurry-C (2065/10/28)	6.55	0.70	0.40	1.22	1.45	0.115	2.00	53.33

Volatile solid: The volatile solid content in raw waste material was found 75.57%. The value was decreased outstandingly in slurry-A. Then after it was slightly increased along with further digestion process and finally it was found to be 53.53%. The decrease in volatile solid in former case may be due to over dilution.

C/N ratio: The carbon to nitrogen ratio of feeding waste materials was found within the range for optimum gas production. However, the value was high in bio-slurry-A, which was taken after one month of gas production. It indicates rapid drop off in percentage of nitrogen in the initial month of gas generation. Then after it was decreased drastically after three months and stabilized to an average of 2, which may be due to increased percentage of nitrogen and decrease in availability of carbon in bio-slurry along with increasing digestion process.

NPK: The NPK values were increased gradually in bio-slurry along with increasing digestion period but were found below 1% such as 0.70% and 0.42% in the case of nitrogen and phosphorus respectively except potassium, which was found to be 1.22%. Too much dilution, improper digestion, and lack of optimum retention time etc can be some causes of low NPK values.

Organic matter: The organic matter content in feeding raw materials was found 68.11% but this value was drastically decreased in slurry-A in first one month after gas generation. Then after the values were slightly decreased in later cases. Too much dilution of bio-slurry and increase in population of bacteria along with digestion period decreased the availability of organic matter in slurry may be the reasons for drastically decrease in organic matter content in the former case. Higher organic matter content in slurry makes the digestion process faster. The above result shows that the values were quite low for proper digestion of slurry.

Energy content

The calorific value, determined based on methane content in newly produced biogas was an average 20.20 MJ per cubic metre. Similarly, the average energy content in the produced biogas was found as 5.61 KWh_{th}/m^3 (Table 3). There is proportional relationship between methane content, calorific value and energy content in biogas. The higher the percentage of methane content in biogas, more the calorific value and greater its energy content. The methane content in biogas depends upon the type of feeding materials used and the degree of digestion process. Lower digester temperature resulting incomplete digestion of slurry and the use of high cellulose containing feeding materials instead of sugary and starchy substances may be some reasons of yielding low methane content.

Table 3. Energy content in biogas

Methane content (In %)	Calorific value (In MJ/m^3)	Energy content (In KWh_{th}/m^3)
Maximum 57.74	20.67	5.74
Average 56.43	20.20	5.61

Financial analysis

The financial analysis of the biogas plant showed the return of investment or simple payback period of 4.81, 7.57, and 7.20 years in kerosene, firewood and LPG substitutions respectively. The detail cost-benefit estimations are given in the tables below:

Table 4. Cost-benefit estimation of kerosene substitution in terms of biogas

Gas production/ day (in m^3)	Annual cost savings in kerosene@ 14.4/KWh_{th}	Carbon emission saved per year (in tonne)	Carbon trading benefits(in Rs)	Investment cost (in Rs)	Total cost savings in kerosene (in Rs)	Simple payback period (in year)
0.235	4,465	0.195	107	22,000	4,572	4.81

Table 5. Cost-benefit estimation of firewood substitution in terms of biogas

Gas production/ day (in m^3)	Annual cost savings in firewood @8.06/ KWh_{th}	Carbon emission saved per year(in tonne)	Carbon trading benefits(in Rs)	Investment cost (in Rs)	Total cost savings in firewood (in Rs)	Simple pay back period (in year)
0.235	2,495	0.751	411	22,000	2,886	7.57

Table 6. Cost-benefit estimation of LPG replacement in terms of biogas

Gas production/ day (in m^3)	Annual cost savings in LPG @9.66/KWh_{th}	Carbon emission saved per year (in tonne)	Carbon trading benefits (in Rs)	Investment cost(in Rs)	Total cost savings in LPG (in Rs)	Simple pay back period (in year)
0.235	2,988	0.118	65	22,000	3,065	7.20

The installation outlay of 1m^3 compact biogas plant was found approximately Rs. 22,000 during the study. It incorporates the cost of digester and gasholder, other necessary fitting materials and labour charge as well. The cost is relatively lower than the installation cost of 4m^3 GGC-2047 model biogas plants even including the donation of government on this plant.

Overall role in the conservation of Environment

The majority of wastes produced from household were comprised of BWs. Except non-biodegradable, very acidic, and hardly decomposed wastes; all types of BWs produced were used as feed materials in the bioreactor. It showed that such plant could be effective way for management of biodegradable domestic wastes at household level. The further study regarding improvement on its weaknesses and promotion could help in proper management of domestic biodegradable wastes in urban and semi urban areas of terai belt in decentralized manner.

Reduction in GHGs emission and global warming

The result of study shows that total biogas production from compact biogas plant was found about 235 L/ day or 0.235 m^3 which is less as cited in literature review. Based on the above value, then total gas production during one-year period is equals to about 85 m^3 or 477 KWh thermal energy. In terms of fuel wood, it saves 751 kg CO_2 eq/year emission, 195 kg CO_2 eq/year in the case of kerosene and similarly 118 kg CO_2 eq/year in LPG replacement. It would be meaningful to reduce emission of hundreds of tonnes of GHGs or carbon equivalent if installed large in number. It also helps to reduce the emission of methane gas especially from landfill sites indirectly. So, installation of such plants may play vital role to combat global warming by lowering the emission of GHGs.

Conservation on conventional energy resources

The quantity of conventional energy replaced in terms of cost is about 2.7 LPG cylinders/year or equivalent to a saving of approximately 38 kg LPG per year. As to kerosene, 83 L/year or 577 kg firewood/year would be saved if such plant could be installed. These values however seems small but the commercial scale of installation of such plants can help to diminish the use of non-renewable energy resources largely.

Energy production from discarded BWs is a recovery of energy. Revitalization of such wastes in the form of renewable energy not only helps to conserve the resources but these can also be used more appropriately. Therefore, the BWs could be new sources of alternative renewable energy further contributing to green energy revolution too.

Viability in future

This plant could be one of the alternatives of GGC 2047 model in those areas where there is no availability of cow dung or other animals' manure for feeding substances, problems of BWs and lack of wider space for installation. It would be a good option for lower and medium income families too. It needs further installation and study especially in urban and semi urban areas of terai belt of Nepal where average annual ambient temperature is relatively higher in compare to other geographical regions. Further research to increase working efficiency along with improvement of its weaknesses, would make it a good alternative biogas model in urban and semi urban areas of terai region and some extent in city areas of hilly region as well.

Some weaknesses of compact biogas plant

- The installation in shady places results low gas production.
- The plant is easily affected by rise and fall of ambient temperature as it remains above the ground.
- Choking problem may occur off and on during feeding if inlet pipe is not sufficiently large. Similarly, low gas pressure in gasholder results low gas flame.

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References

ARTI. 2008. *ARTI Biogas Plant: A compact digester for producing biogas from food waste*, viewed 12 March 2008, http://en.howtopedia.org/wiki/How_to_Build_the_ARTI_Compact_Biogas_Digester.

Aryal, S. and R.B. Singh. 2006. Studies on generation of biogas from cattle dung and grasses. In: *Preconference proceedings of first national conference on renewable energy technology for rural development* (October 12-14, 2006), Kathmandu. Center for Energy Studies, Institute of Engineering, Kathmandu, Pp. 71-79.

Dhakal, N.R. 2003. Use of vegetable and kitchen wastes as alternative feed stocks for biogas production. In: *Proceedings of international conference on renewable energy technology for rural development* (October 12-14, 2003), Kathmandu (Eds. J.N. Shrestha, T.R. Bajracharya, B. Vaidya & S. Pradhan). Center for Energy Studies, Institute of Engineering, Kathmandu, Pp. 114-121.

FAO/CMS. 1996. Food and Agricultural Organization of the United Nations, Support for Development of National biogas Programme (FAO/TCP/NEP/4451-T). *Biogas technology: a training manual for extension*. Consolidated Management Services Nepal (P) Ltd.

IDMAC. 2008. *Design, development and promotion of new compact biogas technology to recycle municipal solid waste for development of alternative options on recycling of solid waste*: *Report*, submitted to Solid Waste Management and Resource Mobilization Centre, Minsitry of Local Development, Nepal by Integrated Development and Management Center (IDMAC), Kathmandu, Nepal.

Karki, A.B., J.N. Shrestha, S. Bajgain and I. Sharma. 2009. *Biogas-as renewable source of energy in Nepal: theory and development*. 2nd ed, BSP-Nepal, Kathmandu, Nepal.

Mittal, K.M. 1996. *Biogas systems: principles and applications*. 1st ed, New Age International (P) Limited, Publishers, New Delhi, India.

MoF. 2009. *Economic survey*: *fiscal year 2008/09*: *Report*, Ministry of Finance, Kathmandu, Nepal.

NOC. 2008. *Selling price of Petroleum product based on Kathmandu (Inclusive VAT)*, viewed 18 August 2009, <http://www.nepaloil.com.np/main/>

Singh, R., A.B. Karki and J.N. Shrestha. 2009. Production of biogas from poultry waste in Kathmandu. In: *Proceedings of international conference on renewable energy technology for sustainable development* (November 12-14, 2009), Kathmandu (Eds. J.N. Shrestha, J.H. Eun & J. Shrestha). Nepal Solar Energy Society, Kathmandu, Pp. 136-141.

Voegeli, Y., C. Lohri, G. Kassenga, U. Baier and C. Zurbrugg. 2009. Technical and biological performance of the arti compact biogas plant for kitchen waste: a case study from Tanzania. In: *proceedings of twelfth international waste management and landfill symposium* (October 5-9, 2009), S.Margherita di Pula, Cagliari, Italy.

WCE. 2007. *Gasboard-3200P biogas analyzer manual*. Wuhan Cubic Electronics Co., Ltd, Hongshan district, Wuhan city, Hubei Province, China.