ISABB Journal of Food and Agriculture Science Vol. 1(3), pp. 44-48, December 2011
Available online at http://www.isabb.academicjournals.org/JFAS
ISSN 1937-3244©2011Academic Journals

Full Length Research Paper

Study on renewable biogas energy production from cladodes of *Opuntia ficus indica*

Elias Jigar[1]*, Hameed Sulaiman[2] and Araya Asfaw[2] and Abraham Bairu[3]

[1]Samara University, College of Dry land Agriculture, Afar Region, Ethiopia.
[2]Addis Ababa University, Environmental Science Program, Addis Ababa, Ethiopia.
[3]Tigray Science and Technology Agency, Mekelle, Tigray Region, Ethiopia.

Accepted 18 October, 2011

In this study, Cladodes, which is a plate like section of *Opuntia ficus indica*, were characterized for their physical properties, total solids (TS) and volatile solides (VS) and they were assessed in five combinations with or without cow dung for their suitability to biogas production in 2.8 L triplicate batch digesters. The highest total biogas yields were obtained from T_5 (75% Cow dung: 25% Cladodes combination) as 14.183 L followed by T_1 (cow dung alone) as 13.670 L (0 .022 m^3/kg) and the lowest was from T_2 (Cladodes alone) as 6.176 L. The percentage of methane gas obtained from the experiment for treatments T_1, T_2, T_3 (50% cow dung: 50% cladodes), T4 (25% cow dung: 75% Cladodes) and T_5 were 66.33, 53.16, 63.84, 52.1 and 69% respectively. Among all treatments, T_5 was found to produce high methane percent of the biogas. Treatments (T_1 and T_5) that have a C:N ratio within the range of 20 to 30 were found to perform better in biogas yield and methane production than those that are not. Statistical test showed that the biogas and methane content of the gas produced by T_5 vary significantly at 0.05 level except with T_1 and T_3 which means the biogas and methane content of the gas produced by T_1 and T_3 were comparable with that of T_5. The experimental findings further showed that the composition of methane for all treatments were within the range of 50 to 70%. The finding further revealed the suitability of the substrate as a supplement feedstock with the conventional cow dung for biogas production and if suitable materials for co-digestion, such as manure, are not available, Cladodes can be digested alone.

Key words: Biogas, percentage of methane, co-digestion, Cladodes, cow dung.

INTRODUCTION

Nowadays, both energy crisis and climate change are key issues all over the world. Several factors have led to the search for alternative sources of energy from renewable sources. These include the ever-increasing consumption of nonrenewable fossil fuels, the harmful ecological aspects of directly using cow dung and wood as fuel, and inadequate rural electrification (Garg et al., 1980). According to recent research and future predict-tions, the crude oil will run out within 40 to 70 years, and natural gas will be finished within 50 years (Courtney and Dorman, 2003). Global average temperature is predicted to increase 1.4 to 5.8°C by year 2100 and continue to rise long after that (Dow and Downing, 2006). Several investigations point out that this will lead to drought, flooding, increase in hurricanes and tornadoes and possibly widespread crop failures (Sen, 2009; Mills, 2009). Global warming is now widely accepted that it

*Corresponding author. E-mail: eliasjig@yahoo.com or eliasjig@gmail.com.

is caused by the rapidly increasing concentrations of greenhouse gas (CO_2 and others) in the atmosphere, which is emitted mainly by the combustion of fossil fuels containing carbon like coal, oil, and natural gas (Jaynes, 2010). Security of energy supply, especially sustainable energy, and reduction of CO_2 emission are priorities on agenda worldwide. The use of biogas and biomass as an energy source is regarded as CO_2 neutral, because the CO_2 released during combustion of the biogas is the same CO_2 that the plant have assimilated during photosynthesis to create organic biomass (Jorgensen, 2009).

The anaerobic digestion of biomass requires less capital investment per unit production cost compared to other renewable energy sources, such as hydro, solar and wind energy (Rao et al., 2010). Apart from this, the effluent from the biogas process supplies nutrients which can also be utilized as fertilizer (Vasudeo, 2005). Cattle dung has been used as the major feed material for anaerobic digesters which is not likely to have significant impact. This calls for widening the scope of this technology by tapping other organic materials like energy crops. Using spineless cacti as an energy crop is offering serious perspectives to countries prone to drought and relying on imports for their energy consumption (Tarisse, 2008). The main objective of this paper is to evaluate the possibility of methane production from cladodes of *Opuntia ficus indica* through anaerobic digestion on the sample collected from *O. ficus indica* producing communities.

MATERIALS AND METHODS

Feedstock (inputs)

The substrates used as feed stock materials for the generation of biogas in the laboratory were samples of Cladodes (flat green, plate-like sections of *O. ficus-indica* called cladodes (pads) and cow dung and different combinations of substrate with cow dung were set as different treatments. The Cladodes were found from *O. ficus-indica* producing community in Raya azebo district (Southern Tigray) whereas the required quantity of dung was obtained from a private farm (Yeha Biofarm) in Addis Ababa. Cladodes were cut manually into small pieces and used for digestion (physical pre-treatment, particle size reduction) as reported by Badger et al. (1979).

Methods to determine physical-chemical properties of the feedstock

Total solids (TS) and volatile solids (VS)

The total solid (TS) and volatile solids (VS) were estimated using the oven at 105°C for 24 h and furnace at 650°C for 3 h, respectively.

C: N ratio

The carbon content of the feed stock is measured by considering the volatile solids content that was expressed as a percentage and the total carbon content was obtained from volatile solids data using an empirical equation as reported by Haug (1993) and Badger et al. (1979):

$$\boldsymbol{Carbon}(\%) = \frac{\boldsymbol{VS}(\%)}{\mathbf{1.8}} \quad (1)$$

Hence, the carbon to nitrogen ratio for each treatment is calculated by dividing the % carbon with % nitrogen.

Batch digestion

The amount of TS in the bottle is fixed at 100 g and for the purpose of this research a set of 15 batch reactors were used as digesters. Each digester contains cow dung: cladodes proportions and aimed at investigating the efficiency of Cladodes in biogas production. The treatment combinations were as follows: T_1; 100:0, T_2; 0:100, T_3; 50:50, T_4; 25:75, and T_5; 75:25, cow dung: Cladodes on a weight percent weight basis. The water content for each sample was determined using the recommendation for better biogas production as reported by Ituen et al. (2007), that is, a total solid (TS) of 8% in the fermentation slurry.

Measuring yield and quality of biogas

The gas production is measured by water displacement method whereas the quality, which is the percentage of methane from the biogas, is estimated by the displacement of sodium hydroxide, with a process held one next to the other. The gas volume produced in the anaerobic reactor was captured in a bottle filled with water, which was kept under pressure. When a gas bubble entered the bottle with water, the gas replaced the water, which was then forced out of the bottle into an empty bottle. The volume of water in the measuring cylinder thus resembled the gas production in the reactor. The displaced water is collected and then using a measuring cylinder its volume would be calculated. The displaced water indicates the total volume of biogas produced. Note that the gas coming out of the digester is stored in the displaced bottle.

Adding back the displaced water to the displacement bottle would push out the biogas stored before; and passing it through 5% NaOH solution. The CO_2 from the biogas would be retained in the solution whereas the methane would displace its equivalent volume of NaOH. Collecting the displaced solution and measuring its volume using a measuring cylinder would give the volume of methane from the produced biogas (Veeken and Hamelers, 1999). Hence, it would be possible to estimate the percentage of methane in the biogas, using the following simple equation.

$$\boldsymbol{CH_4}(\%) = \frac{\boldsymbol{displaced\ NaOH}}{\boldsymbol{displaced\ water}} \times \mathbf{100} \quad (2)$$

Regular follow up of a digester pH was made since the starting time.

Table 1. Carbon to nitrogen ratio of the five treatments.

Treatments	Carbon content (%)	Nitrogen content (%)	C/N ratio
T_1	44	1.83	24
T_2	43	0.86	50
T_3	44	1.30	34
T_4	43	1.10	39
T_5	44	1.60	28

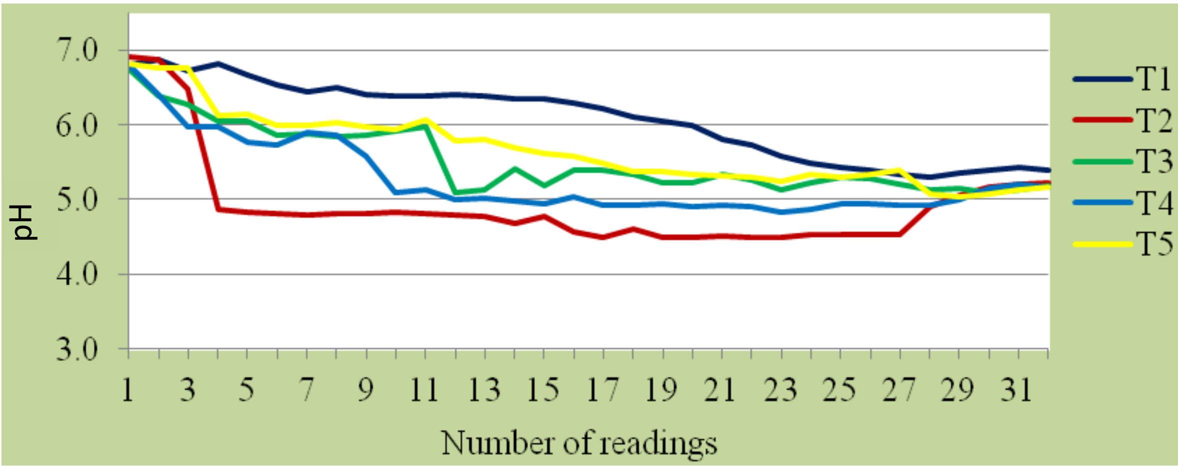

Figure 1. pH reading of the digester throughout the fermentation process.

RESULTS AND DISCUSSION

Characterization of feed stocks

In this study, the total solid contents of Cladodes were 14% out of the total solid, the volatile solid were 78%. This shows that a large fraction of the Cladodes is biodegradable. This implies that Cladodes can serve as an important feedstock for biogas production. Similarly the total solid content of fresh cow dung was 16% while its volatile solid content was 79%. The carbon content of the feed stock was obtained from volatile solids data (% carbon=%VS/1.8) as reported by Haug (1993).

For example the VS of cow dung were 79%, using the aforestated formula, the total Carbon in percent was found to be 44%. In this regard, the Carbon and Nitrogen content for each treatment is calculated according to the proportion of the feed material in each treatment, finally their Carbon to Nitrogen ratio was obtained by dividing the % Carbon with % Nitrogen. The C/N ratios of the five different combinations of Cladodes and cow dung as feedstock for biogas are given in Table 1. The Carbon to Nitrogen ratio obtained from the T_1=24:1, T_5=28:1were in agreement with the optimum C: N ratio 20 to 30 as stated by Marchaim (1992). On the contrary, the Carbon to Nitrogen ratio of T_2 and T_4 is beyond the optimum C:N value. For example, the C:N ratio of Cladodes alone is about 48 which is greater than as it should always be kept below 43 as stated by Stephanopoulos (2007). This shows that Cladodes biomass is highly organic having less nitrogen, therefore it might need feed stock supplements which are rich in nitrogen.

The pH value of digester

pH is one of the indication factors of inhibition in anaerobic reactors. Therefore, the pH of each digester's substrate was recorded in two days interval on a regular basis. The initial pH of each input mixture in digester was 6.79, 6.91, 6.75, 6.76 and 6.81 for the digester labeled as T_1, T_2, T_3, T_4 and T_5 respectively. So this result was in agreement to a pH range of input mixture in the digester between 6.25 and 7.50, which is suitable for most methanogenic bacteria to function as reported by Mahanta et al. (2004). The given line graph (Figure 1) illustrates information on triplicate average pH values of different treatments for 32 reading numbers at two days

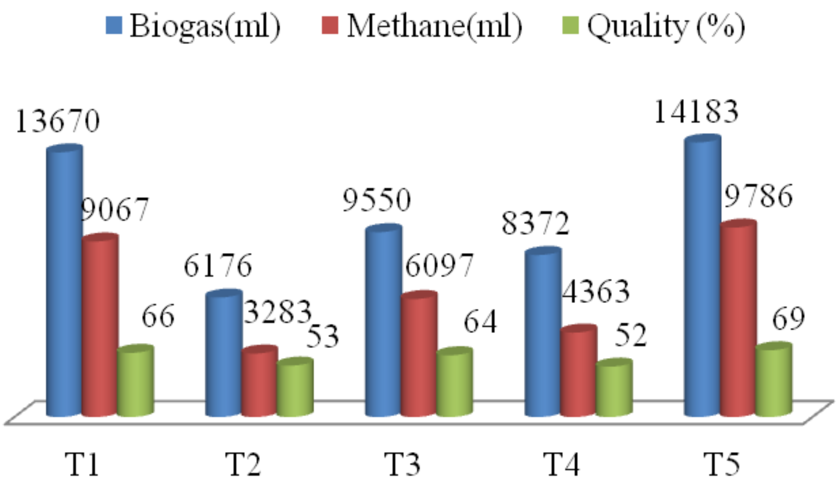

Figure 2. Amount of biogas and methane produced from the five treatments.

interval. Overall, the pH of all treatments decreased from the beginning to the end of fermentation process.

However, treatments containing Cladodes in any proportion to the cow dung went down to acidity and remain relatively at a lower pH than cow dung alone. Moreover, the pH of all digesters except T_1 decreases sharply to acidity in few days. It is generally agreed that at the initial stages of the overall process of biogas production, acid forming bacteria produce volatile fatty acids (VFA) resulting in declining pH and diminishing growth of methanogenic bacteria. That is, a low pH value inactivated microorganisms responsible for biogas production. In this regard, the pH of all the digesters was not in the range of optimal level 6.7 to 7.4 suitable for most methanogenic bacteria to function for biogas production as described by Verma (2002).

Amount and composition of biogas produced

The total biogas from each treatment was measured until it stopped to produce any more gas. The total water displaced expressed in terms of biogas and NaOH displaced expressed by methane content is shown in Figure 1. It can be seen from Figure 2 that a relatively high volume of total biogas production was recorded in the T_5 with 75% of cow dung. The volume of biogas produced increases when the amount of cow dung mixed with Cladodes increases from 25 to 75% whereas it decreases to some extent when the Cladodes was mixed with 25% cow dung. Moreover, the optimum proportion of Cladodes with cow dung for best biogas production was found to be 1:3 ratio, which means 25% of Cladodes mixed with 75% of CD (Figure 2). The percentage of methane in the biogas was estimated using the following simple equation.

$$CH_4(\%) = \frac{displaced\ NaOH}{displaced\ water} \times 100 \quad (2)$$

As shown in Figure 2, the percentage of methane for T_1,T_2 ,T_3,T_4 and T_5 were 66, 53, 64, 52 and 69% respectively. Value of the percentage of methane in this experiment is almost similar to the value (40 to 80) suggested by Stewart et al. (1984). Results further indicate that T_5 was found to produce methane rich biogas with 9786 ml: the next is T_1 by providing 9067 ml followed by T_3 with 6097 ml. Again, the lower performance is from digester T_2 and T_4 by an amount of 3283 and 4363 ml respectively. Treatment five (T_5) stands first in terms of quality of the biogas that is the proportion of methane from the produced biogas (69%). Treatment one (T_1) and Treatment three (T_3) follows 2nd and 3rd by 66 and 64% respectively, while treatment (T_2) is the least in the quality of biogas.

To sum up, T_5 has the best performance relative to other digesters of treatments because it gives highest amount of biogas with quality. The other treatments such as T_1, T_3 and T_4 were comparable with the typical quality of biogas from animal manure mostly from 50% to 60 % as reported by Marchaim (1992). Statistical test for the mean difference of dependable variable biogas and methane content of the gas produced by T_5 vary significantly at 0.05 level except with T_1 and T_3 which means the biogas and methane content of the gas produced by T_1 and T_3 were comparable with that of T_5.

Conclusions

In this study, out of the five treatments the optimum gas production was obtained in the 75 CD:25% Cladodes ratio which clearly indicates that Cladodes as a substrate can be used as good supplement with cow dung and can be recommended that 75:25% ratio should effectively be tried in pilote scale trails and further at commercial scale productions. Cladodes biomass is highly organic having less nitrogen, therefore it might need feed stocks which are rich in nitrogen if used as substrate for biogas production. The result also showed that the pH of the digesters throughout the retention time was under acidic condition. In this regard, the pH of all the digesters of treatments were not in the range of optimal level 6.7 to 7.4, suitable for most methanogenic bacteria to function for biogas production.

Finally, the quality of the biogas either from Cladodes alone or with combination of cow dung also were beyond 50% or were within the range of quality biogas. Again from the laboratory result, the volatile solid content of the Cladodes substrate was 78% of the TS. This shows that a large fraction of the Cladodes is biodegradable. This implies that Cladodes can serve as an important feedstock for biogas production. Biogas and methane production from T_1 (100%CD), T_3 (50%CD: 50%CL) and T_5 (75%CD: 25%CL) were not statistically significant at 0.5 level. Co-digestion of cow dung and Cladodes biomass is therefore, one way of addressing the problem of lack of enough feedstock for biogas production. If suitable materials for co-digestion, such as manure, are not available; Cladodes can be digested alone and is a good opportunity for poor people who have not access to cow dung.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the Horn of Africa Regional Environment Centre of Addis Ababa University for the financial support.

REFERENCES

Garg HP, Pande PC, Pareek OP(1980). Designing a suitable biogaasplant for India. Appropriate Technol., 7: 29-31.
Courtney B, Dorman D (2003). World Wide Fossil Fuels. Chemistry Department of Louisiana State University.
Dow K, Downing T (2006). The Atlas of Climate Change: Mapping The World's Greatest Challenge. Los Angeles: University of California Press.
Sen Z (2009).Global warming threat on water resources and environment: a review. Environ. Geol., 57, 321-329.
Mills DMMA (2009). Climate change, Extreme Weather Events, and US Health Impacts: What Can We Say? J. Occupational Environ. Med., 51(10): 26-32.
Jaynes D (2010).Global Warming: Mythes and Realities. Social Sciences, SOC, pp. 461-11.
Jorgensen PJ (2009).Biogas: Green Energy.2nd edition. PlanEnergi and Researcher for a Day, Faculty of Agricultural Sciences, Aarhus University.
Rao PV, Baral SS, Dey R, Mutnuri S (2010).Biogas generation potential by anaerobic digestion for sustainable energy development in India. Renew. Sustain. Energy Rev., 14: 2086-2094.
Vasudeo G (2005). Biogas Manure (BgM): a viable input in sustainable agriculture an integrated approach. International Seminar on Biogas Technology for Poverty Reduction and Sustainable Development, Beijing, China.
Tarisse A (2008). Natural gas consumption of Turkey and the strategic use of drought tolerant energy crops for biogas production. ESE-IER-Lyon III University.
Badger CM, Bogue MJ, Stewart DJ(1979). Biogas production from crops and organic wastes. New Zeland Journal of Science , 22:11-20.
Haug RT(1993). The practical handbook of compost engineering . Florida: Lewis Publisher, 717 pp.
Ituen EE, John NM, Bassey BE (2007). Biogas production from organic waste in Akwa Ibom State of Nigeria. Appropriate Technologies for Environmental Protection in the Developing World. Ghana: ERTEP.
Veeken A, Hamelers B (1999). Effect of temperature on hydrlysis rates of selected biowaste components. Biores. Technol. , 69:249-254.
Fulford D (1988). Running a biogas programme, a handbook. London: Intermidiate Technology Publications, p. 34.
Marchaim U (1992). Biogas processes for sustainable development. Rome: FAO.
Stephanopoulos (2007). Challenges in engineering microbes for biofuels production. Sci., 315(581): 801-804.
Mahanta P, Dewan A, Saha UK, Kalita P(2004). Influence of Temperature and total solid concentration on the gas production rate of biogas digester. J. Energy Southern Afr., 15(4):112-117.
Verma s (2002). Anaerobic digestion of biodegradable organics in. MSW.
Stewart DJ, Bogue MJ, Badger DM (1984). "Biogas production from crops and organic wastes". New Zealand J. Sci., 27(3): 285-294.