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Biomethanation of Water Hyacinth, Poultry Litter, Cow Manure and Primary Sludge: A Comparative Analysis

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Abstract

Facing energy crisis and climate change, the world is in need of a green, efficient, carbon-neutral energy source to replace fossil fuels. Biogas, produced by biomethanation of organic materials, contributes to sustainable, reliable and renewable energy. There is potential for biogas production from animal manure, energy crops and industrial wastes not only because the wastes themselves can be treated to minimize the environmental impact, but also for biofuel methane, which holds promise for the future. In the present study biomethanation of fresh water hyacinth, dry water hyacinth, poultry litter, cow manure and primary sludge were studied in a series of laboratory experiments using 250 ml biodigesters with 7% total solids and 60 days retention time. The digester fed with poultry litter produced highest biogas of 0.39 liters/g VS followed by the digester fed with primary sludge (0.28 liters/g VS).

Key words: Biomethanation, biogas, water hyacinth, poultry litter, cow manure, primary sludge.

Introduction

In the current scenario both energy crisis and change in climate are key issues all over the world. There will be severe scarcity of energy in the next few decades. It is predicted that the crude oil and natural gas may last for another six to seven decades. The use of fossil fuels as primary energy source has lead to global climate change, environmental degradation and human health problems[1]. Global climate change will inevitably lead to drought, flooding, increases in hurricanes and tornadoes and possibly widespread crop failures and global warming[2-3]. Security of energy supply, especially sustainable energy and reduction of CO_2 emission are priorities on agenda worldwide. Biogas is regarded as carbon neutral fuel, as CO_2 released during combustion of the biogas is utilized by plants for photosynthesis to create organic biomass[4]. Therefore biogas is environmental friendly and is one of the most efficient and effective options among the various other alternative sources of renewable energy. Biogas is produced by biomethanation process and the effluent from the process is rich in essential nutrients which can also be utilized as fertilizer. Biogas can be produced from variety of substrates, such as animal manure, energy crops, industrial wastes etc. Biogas production is a sustainable solution to treat waste and the cost of the waste treatment is low[5]. Biomethanation is the degradation of organic materials by microorganisms in the absence of oxygen. It is a multi-step biological process where the organic carbon is mainly converted to carbon dioxide and methane[6]. The process can be divided into four steps: hydrolysis, acidogenesis, acetogenesis and methanogenesis. Figure 1 shows the pathway of the process.

Hydrolysis is the first step in biomethanation where complex organic matters, such as carbohydrates, proteins and lipids are hydrolyzed into soluble organic molecules such as sugars, amino acids and fatty acids by extracellular enzyme, i.e. cellulase, amylase, protease or lipase[7]. In the second step acidogenesis or acidification, the soluble organic molecules from hydrolysis are utilized by fermentative bacteria or anaerobic oxidizers to produce volatile fatty acids (acetic acid, propionic acid and butyric acid), alcohols, aldehydes and gases like CO_2, H_2 and NH_3. In the third step acetogenesis, the products of the acidification are converted into acetic acids, hydrogen, and carbon dioxide by acetogenic bacteria. Finally in methanogenesis step, acetate and H_2/CO_2 are converted to CH_4 and CO_2 by methanogenic archaea. In the present study biomethanation of various organic wastes like water hyacinth[8], poultry litter, cow manure and primary sludge were studied and comparative analysis was done on biogas yield.

Material and Methods

Sample collection: Water hyacinth used for the study was obtained from silver lake at HBR layout (Bangalore, Karnataka, India). Thickened primary sludge was collected from primary clarifier from Vrishabhavathi sewage treatment plant at Vrishabhavathi valley, Nayandanahalli (Bangalore, Karnataka, India). Overnight, fresh poultry litter was collected from J M J Chicken Center (Bangalore, Karnataka). Fresh cow dung was collected from Dodla dairy (Bangalore, Karnataka).

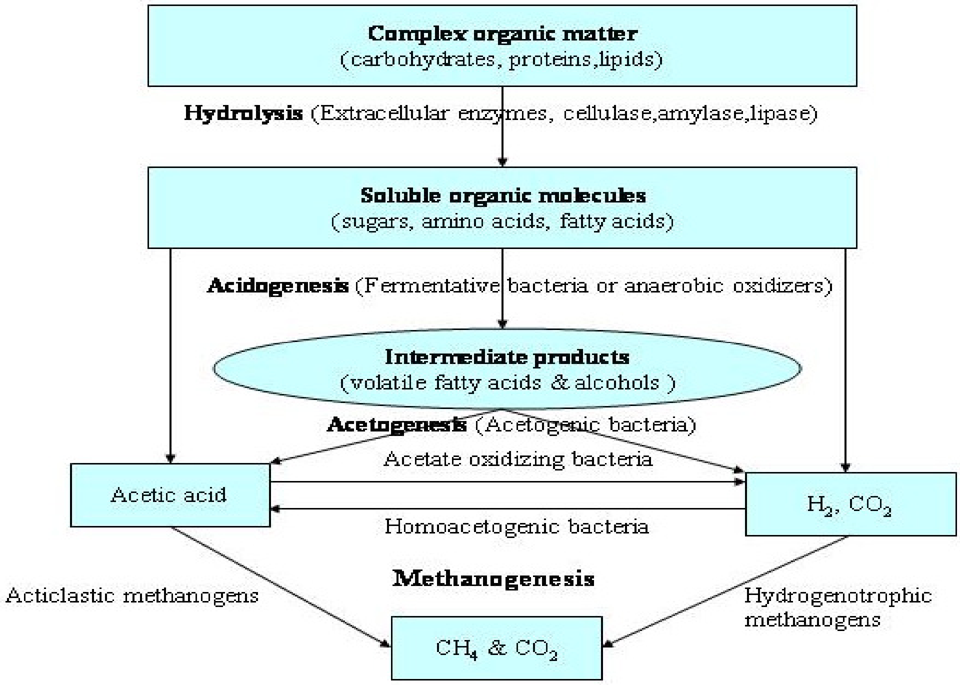

Figure-1
Pathway of biomethanation process

Sample analysis: Water hyacinth, poultry litter, cow manure and primary sludge were analyzed for the following parameters

1. pH measurement: pH measurement was monitored using a glass electrode pH meter (Systronics)
2. Total solids (TS) and total volatile solids (VS) standard methods[9]: TS were determined at 104 ^{0}C to constant weight and VS were measured by the loss on ignition of the dried sample at 550 ^{0}C.
3. Biogas collection and composition: Biogas produced by anaerobic digestion was collected by water displacement method. The composition of the gas was measured using a gas chromatograph (CHEMITO)

Biomethanation unit: Biomethanation unit consists of a temperature controlled thermo bath which is maintained at 35^{0}C and has a battery of biodigesters. Each biodigester is connected to a graduated gas collector by means of a connecting tube. A stand holds all the gas collectors. Biogas evolved is collected by downward water displacement.

Preparation of fermentation slurries: Biomethanation of fresh water hyacinth (FWH), dry water hyacinth (DWH), poultry litter (PL), cow manure (CM) and primary sludge (PS) were studied in a series of laboratory experiments using 250 ml biodigesters with 7% total solids. Fresh water hyacinth leaves on collection were chopped and ground to fine paste. This paste was used to prepare fermentation slurry FWH (41.44 g. water hyacinth and 58.56 g. water). Fresh water hyacinth leaves were chopped to small sizes of about 2 cm allowed to dry under the sun for a period of 7 days, after which they were dried in an oven at 60^{0}C for 6 hours. This oven-dried water hyacinth was then ground to fine powder[10]. Moisture free powder was used to prepare fermentation slurry DWH (7 g. water hyacinth and 93 g. water). Other substrates poultry litter, cow manure and primary sludge were homogenized previously before fermentation slurries PL (33 g. poultry litter and 67 g. water), CM (32.82 g. cow manure and 67.18 g. water) and PS (45.66 g. primary sludge and 54.34 g water) were prepared. Biomethanation of these digesters were carried out in duplication with a retention time of 60 days in the mesophilic range (30-40^{o}C). Cumulative biogas production, slurry temperatures were monitored throughout the study.

Results and Discussion

Solids and pH analysis: Total solids (TS) are the sum of suspended solids and dissolved solids. TS analyses and pH are important for assessing anaerobic digester efficiencies. Total solids analysis was done using standard methods while pH was measured using pH meter (Systronics). The total solids are composed of two components, volatile solids (VS) and fixed solids. The volatile solids are organic portion of total solids that biodegrade anaerobically. Total solids and volatile solids are calculated as given bellow.

TS, % = $\frac{(A-B)}{(D-B)}\times 100$ and VS, % = $\frac{(A-C)}{(A-B)}\times 100$

Biomethanation potential of digesters: Biomethanation of all the digesters were carried out in the mesophilic range (30-40°C) with a retention time of 60 days. The cumulative biogas productions with time for all the digesters are presented in given in table 2, while profiles of cumulative biogas yield are shown in figure 2.

Where

A Weight of dish + dried sample at 103°C to 105°C (grams)

B Weight of dish (grams)

C Weight of dish + sample after ignition at 550°C (grams)

D Weight of dish + wet sample (grams)

Table 1 gives the solid analysis and pH data of water hyacinth, poultry litter, primary sludge and cow manure.

Table-1
Solid analysis and pH data

Material	% TS	% VS	pH
Water hyacinth	16.89	82.85	6.4
Poultry litter	21.21	83.47	7.1
Primary sludge	15.33	51.84	6.8
Cow manure	21.33	72.47	6.3

Table-2
Biogas production from all digesters

Digester → Time ↓(days)	FWH (liters/g VS)	DWH (liters/g VS)	PL (liters/g VS)	CM (liters/g VS)	PS (liters/g VS)
0	0	0	0	0	0
5	0	0.006	0.010	0.005	0.01
10	0.001	0.011	0.025	0.010	0.02
15	0.005	0.016	0.110	0.040	0.05
20	0.006	0.022	0.190	0.070	0.08
25	0.008	0.035	0.250	0.100	0.12
30	0.008	0.051	0.310	0.140	0.17
35	0.008	0.096	0.340	0.170	0.21
40	0.008	0.170	0.360	0.190	0.24
45	0.008	0.220	0.370	0.210	0.26
50	0.008	0.230	0.380	0.220	0.27
55	0.008	0.235	0.390	0.230	0.28
60	0.008	0.240	0.390	0.230	0.28

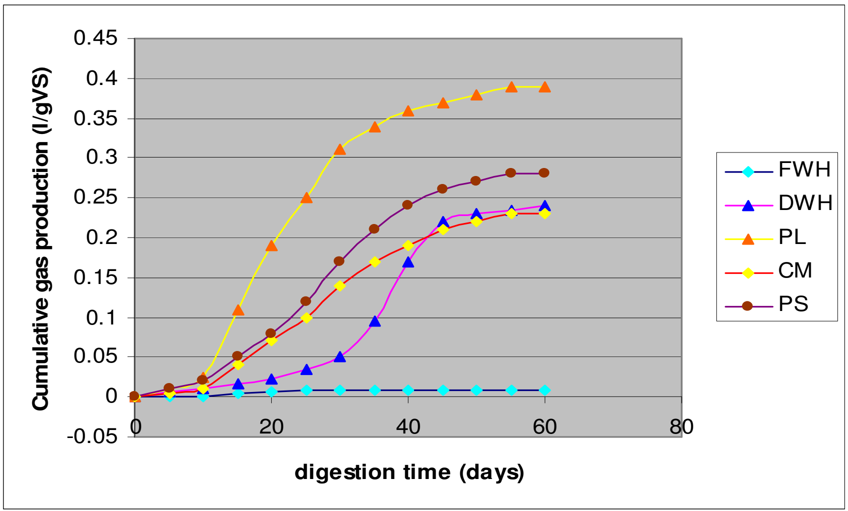

Figure- 2
Biomethanation potential of different digesters

The specific biogas productions shown in figure 2 shows biogas production tend to obey sigmoid function (S curve) for all digesters except FWH. Biogas production was slow at the beginning and the end period of observation. This is predicted due to the biogas production in batch condition directly corresponds to specific growth of methanogenic bacteria in the biodigester[11].

Observation can be made from figure 2, that digesters PL and PS had the shortest onset of gas evolution of 1 day while other digesters CM, DWH and FWH had 3, 5 and 10 days respectively. Digesters PL, PS and CM had very short lag period and produced flammable gas much earlier in comparison with DWH, which had a long lag period of 20 days and produced flammable biogas after 22 days. This clearly indicates that digester WHB does not have essential microbes for early evolution of gas and necessitates enriched seeding (inoculums) to enhance biomethanation. The total amount of gas produced at the end of detention period was highest for digester PL (0.39 liters/g VS), This could be because poultry litter is rich in nutrients and contains adequate amount of carbon, oxygen, hydrogen, nitrogen, phosphorous, potassium, calcium, magnesium and a number of trace elements which are very essential for the growth of anaerobic bacterium[12]. This could have optimized syntrophic interaction between acetogens and methanogens which is the most critical step in the biomethanation process[13].

Digesters PS, DWH and CM produced 0.28, 0.24 and 0.23 liters/gVS respectively, while digester FWH produced 0.008 liters/gVS. The poor performance of FWH could be because of lack of water in the fermentation slurry. Water content is one of very important parameter affecting biomethanation of plant wastes. There are two main reasons (a). Water makes possible the movement and growth of bacteria facilitating the dissolution and transport of nutrient; and (b) water reduces the limitation of mass transfer of non homogenous or particulate substrate[14].

The results also show that digester with dried water hyacinth (DWH) produced slightly more biogas as compared to digester with cow manure (CM). This indicates the fact that substrates for methanogenic bacteria are readily available in water hyacinth. However, the time period for attaining the maximum production rate is longer (about 45 – 55 days) for water hyacinth as compared to cow manure (35 – 45 days). This is due to the fact that bacteria needed for biogas production in the case of water hyacinth takes a longer time period to grow whereas in ruminants waste such as cow manure pathogens are already present and bacterial growth takes a little time for biogas production.

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Conclusion

Among all the substrates of the study, poultry litter (PL) produced the highest biogas with better rate as it contains more nutrients and nitrogen compared to cow manure, primary sludge and water hyacinth[15]. Unlike most plant wastes studied so far, the present study has revealed that water hyacinth is a very good biogas producer but requires enrichment with inoculum and minimal pre-treatment of drying and grinding to enhance the biogas yield. The use of enriched and pretreated water hyacinth for biogas generation therefore, will be a good energy source for those residing in the coastal areas, which face the menace of clogging of waterways by the weed.

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