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Effect of substrate variation on biomethane production at pilot scale

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Abstract
Biomethane refers to the gas produced by the biological conversion of organic matter in the absence of oxygen. The direct benefits gained from biomethane is its use as an alternate and pollution free fuel. In the present study attempt has been made to design a small unit of biogas reactor so as to have a convenient model for determining the quantitative effect of substrate variation on the amount of gas produced in a biogas unit. The substrates chosen for biogas production were different types of waste products such as waste grain flour obtained during cleaning of flour mill, oil-seed coat powder, spent nutrient broth and paper pulp. The substrates were compared with respect to the amount of gas produced (water displacement technique), the amount of methane content of the gas produced (gas chromatography) and by the Carbon Nitrogen ratio (C:N). Grain Flour having minimum C:N ratio 27:1 and present in finely ground form showed maximum gas production of average 3.2L and had maximum percentage methane content (66.3 %).

Keywords: Biomethane, C:N ratio, Water displacement

Introduction
Organic waste such as dead plant and animal material, animal dung and kitchen waste can be converted into a gaseous fuel called biogas. Biogas can be generated from biogenic material and is a type of biofuel. It is produced by the anaerobic digestion or fermentation of biodegradable materials such as, manure, sewage, municipal waste, plant material, animal waste material, animal dung and kitchen waste. Biogas comprises primarily methane and carbon dioxide and may have small amounts of hydrogen sulphide and moisture [1]. Biogas is produced by the biological conversion of organic matter in the absence of oxygen.

For generating this biogas organic matter can be degraded anaerobically with the help of consortia of organisms inside a biodigester. A biodigester is a physical structure, commonly known as the biogas plant. Since various chemical and microbiological reactions take place in the biodigester, it is also known as bio-reactor or anaerobic reactor. The main function of this structure is to provide anaerobic condition within it. The biodigester should be air and water tight.[2]. Biogas digester unit may be designed as balloon type, floating drum type or fixed dome type[3]. The major parameters affecting methanogenic reactions in a digester are the C/N ratio, temperature, pH value, presence of volatile substance, biological oxygen demand (BOD), chemical oxygen demand $(COD)_2$ etc[4].

A parameter to determine the degradability of any substrate is its C:N ratio. For determining C:N ratio, Carbon content can be determined using total organic carbon in which all the carbon in the sample is converted to carbon dioxide, by combustion at very high temperature in presence of oxygen. The carbon content is then quantified gravimetrically[5]. Nitrogen can be estimated using Kjeldhal method, the Nitrogen present in organic form is digested with sulphuric acid containing catalyst (copper sulphate, mercuric oxide and Selenium powder) in the presence of sodium hydroxide, and converted to ammonium nitrogen. To this an indicator mixture of bromo cresol green and methyl red is added and is titrated against hydrochloric acid[6].

Materials and Methods
In the present study small unit of biogas reactor was designed so as to have a convenient model for determining the quantitative effect of substrate variation on the amount of gas produced in a biogas unit. The substrates chosen for biogas production were different types of waste products such as waste grain flour obtained during cleaning of flour mill, oil-seed coat powder, spent nutrient broth after growth of organisms in microbiology laboratory and paper pulp.

i. The Grain flour waste was flour obtained from flour mill which is generated during cleaning of the mill. It was in the form of fine powder which contains large amount of very fine stones and gravel and hence not used for consumption.
ii. Oil seed coat was a waste product obtained after removing the oil seeds of *Jatropha* from their kernels (seeds are used to obtain biodiesel). The seed coat was ground to form course powder.
iii. Waste paper that does not get recycled, such as the ones used as paper wipes used for various household purposes end up in garbage bins. The shredded papers were mixed in water and slurry was made.
iv. Nutrient broth which was used for growing microorganisms in a microbiology laboratory after the growth was autoclaved to kill the organisms is a waste that is thrown down the drain. This liquid waste was used after the auotoclaving was done.

The substrates were compared with respect to the amount of gas produced using water displacement technique [7]. The amount of methane content of the gas produced by anaerobic degradation of organic matter was determined using gas chromatography [8]. The values obtained were correlated to the Carbon Nitrogen ratio (C:N).
Slurry of cow dung was made by diluting 1Kg of cow dung with 20L tap water. 10L of this slurry was introduced into the unit through the inlet pipe. The units were kept at room temperature for 4 weeks. Gas from the dung slurry got captured into the inverted container which made the inverted container to rise. The risen gas was combusted through the Bunsen burner. Once the gas completely stopped getting produced the units were used for effect of substrate on gas production.

Estimation of gas volume by water displacement
The volume of gas generated was quantified by water displacement method [7] (Photoplate3)

1. The biogas unit in which gas was collected was connected to another similar unit containing water. This water unit was calibrated such that volume of gas collected could be determined.
2. The biogas unit was connected to the calibrated unit via rubber tubing such that when the inverted cylinder of the biogas unit was pushed down, the gas was transferred to the calibrated unit and the amount of gas collected in this unit could be determined by reading on the calibrated scale till the point the inverted cylinder rose in this unit.
3. After determining the amount of gas collected, the gas was ignited with the help of a Bunsen burner.

Substrate variation for studying the effect on gas formation

1. Once the gas produced due to the organic matter present in the cow dung was completely exhausted (30days), the biogas units were fed with different substrates. Substrates used were organic waste products generated during various processes.
2. The grain floor was in the form of fine powder 50g of which was added to 500ml tap water to make slurry and feed into the mini-bioreactor.
3. Oil seed coat powder was procured from Indian Biodiesel Corporation, Baramati. 50g of this coarse seed powder was added to 500ml tap water to make slurry and feed into the mini-bioreactor.
4. The paper pulp, 50 gram of finely shredded filter paper was soaked in 500ml tap water overnight and this slurry was feed into the mini-bioreactor.
5. The used autoclaved nutrient broth which is a waste from Microbiology laboratory was used as a substrate. 500ml of this broth was added to the mini-bioreactor.
6. The amount of gas produced was estimated using water displacement method as described before.
7. The C:N ratio of the substrates used was determined by estimating the total organic carbon content and nitrogen content. Nitrogen was estimated by Kjeldahl method and Carbon by Titrimetric method[5]. Carbon and Nitrogen estimation was done at Aashalini laboratory, Panvel.
8. The amount of gas produced was quantified for a period of 5 weeks for each of the substrates. The substrate was fed every 3 days and the amount of gas produced was also determined every three days. The average volume of gas produced was calculated using 10 readings.
9. The volume of gas produced was compared to the C:N ratio of the substrates Table 1.

Qualitative analysis of gas produced

1. The gas produced from the biogas units were also analyzed qualitatively for the content of methane and other gases. This was done by gas chromatographic analyses at Master Speciality Gases Pvt. Ltd, Rabale, Navi Mumbai. The manufacturer of the instrument was Netel India limited and the model was Analyte 2900. The column used was molecular sieve and the carrier gas was Argon[7]. The analyzer used was thermal conductivity analyzer.
2. The gas was transported to the analysis lab by collecting it into an air tight plastic urine bag Photoplate 2[9].

The substrate found to be most productive in terms of amount of gas produced and the methane content was determined. In this unit the amount of gas produced and its methane content (Gas chromatography) were estimated.

Results & Discussion

- Biogas unit was designed and was found to be suitable for collection and quantification of gas produced using water displacement method (Photoplate 2). The rising of the inverted container of the designed biogas unit occurred due to the synthesis of biogas by the organisms present in the dung on converting the organic nutrients under anaerobic conditions.
- Using various substrates the amount of gas produced was quantified and the substrate that led to production of maximum amount of biogas was determined.
- The amount of gas produced was quantified for each substrate after 3 days of addition of substrate and average amount of gas produced was determined using 10 readings of gas produced using each substrate (Table 1).
- Grain Flour having minimum C:N ratio 27:1 and present in finely ground form showed maximum gas production of average 3.2L.
- Paper pulp gave minimum gas production of 1.2L which

could be correlated to its high C:N ratio of 175:1 and the course nature of the paper pulp.

- The oil seed coat powder being course with C:N ratio 40:1 produced average of 1.4 L gas and Nutrient broth with C:N ratio 50:1 present as liquid produced average 2L gas.
- Each of the gas samples were also analyzed for percentage Methane content using Gas chromatography (Table 2).

The mini biogas reactor designed was a smaller replica of the ARTI model (Appropriate Rural Technology Institute)[10]. Liquid displacement,a common method of biogas collection[8] was used to quantify the volume of gas collected. The volume of gas collected was maximum when thw substrate used was Grain flour. Also gas produced using grain flour had maximum percentage methane content (66.3 %) followed oil-seed coat powder (48.4 %). The C:N ratio of Grain flour was minimum i.e. 27:1. A C:N ratio between 25:1 and 30:1 is found to be suitable for proper biogas production[11] .This shows that lower the C:N ratio and smaller the particle size of the substrate more and better is the biomethane production. Similar results have also been observed by Kuglarz and Morowiec in 2009, while comparing C:N ratio of substrates with methane production.

Tables and Figures

Table 1: Average gas production from each substrate

Sr. No	Substrate	C:N Ratio	Average amount of gas produced in 3 days (L)
1	Paper Pulp	175:1	1.1
2	Oil-seed coat powder	40:1	1.4
3	Nutrient Broth	50:1	2.0
4	Grain Flour	27:1	3.2

Table 2: Percentage Methane content of gas using various substrates

Sr. No	Substrate	Percent Methane Content
1	Paper Pulp	46.13
2	Oil-seed coat powder	48.4
3	Nutrient Broth	45.17
4	Grain Flour	66.3

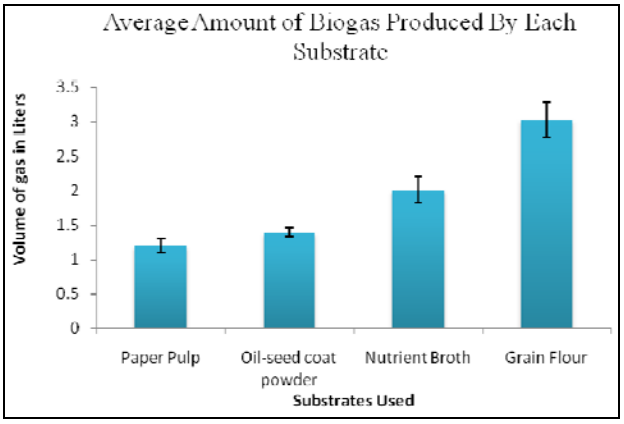


Fig 1: Average Amount of Biomethane produced by each substrate.

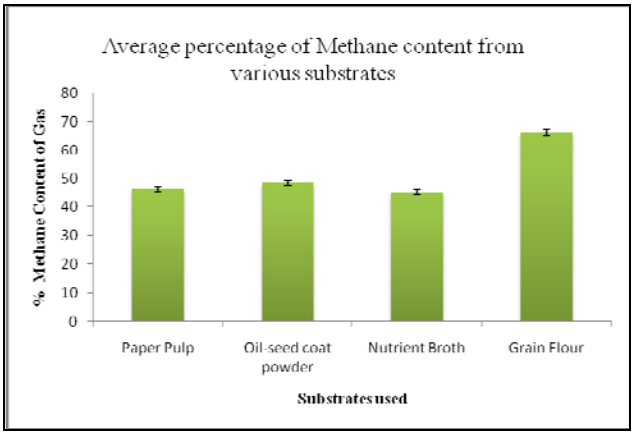


Fig 2: Average percentage of Methane content from various substrates

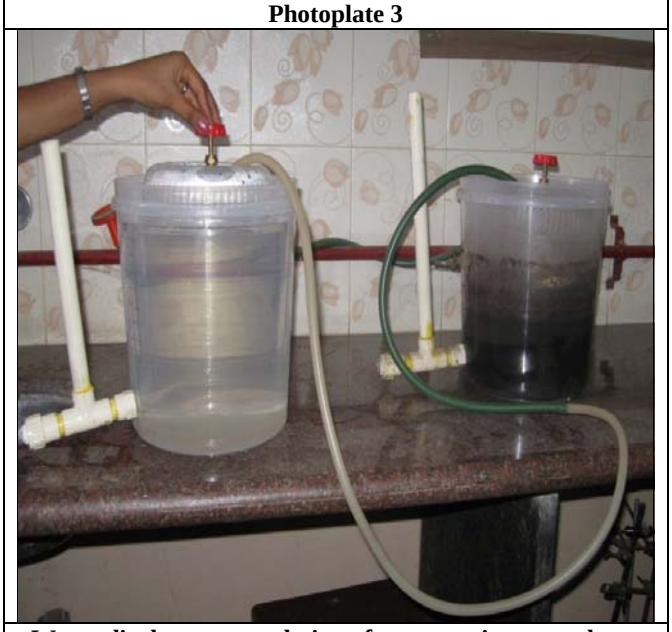
Photoplate 1

Mini Bio-reactor (floating dome type)

Photoplate 2

Collection of gas in Urine bag

Photoplate 3



Water displacement technique for measuring gas volume

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