CHARACTERISATION OF FRUIT AND VEGETABLE WASTE FOR MAXIMIZING THE BIOGAS YIELD

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ABSTRACT

Biogas, as a renewable energy source, is gaining importance in today's era of global warming and depleting sources of fossil fuels. Biogas is produced by anaerobic digestion (digestion in the absence of oxygen) of organic material which can be available from various wastes such as agro industrial waste, urban and rural wastes, human and animal waste and aquatic plants.

This study deals particularly with characterisation of fruit and vegetable waste. The characterization of fruit and vegetable waste included cabbage leaves, potato skin, banana skin, waste tomato, cauliflower leaves, lady finger remains, cucumber skin, spinach remains, watermelon skin, sweet lemon skin, mango skin, orange skin, onion skin, carrot skin, cluster beans remains. Characterisation was carried out by following the APHA standards. The characterization of fruit and vegetable waste includes determination of Total solids, Volatile solids and C/N ratio. This characterisation of fruit and vegetable waste can help in determination of possible combination of easily available market waste which will yield C/N ratio of 25.

C/N ratio of 25 is considered optimum for anaerobic digestion. Because if the C/N ratio is very high, gas production will be low. On the other hand, if the C/N ratio is very low,it will result into pH value higher than 8.5which will start showing toxic effect on methanogenic microbes.

Keywords: C:N, CS, CFL, IFL and BP

I. INTRODUCTION

Developing alternative energy source to replace traditional fossil fuel has recently become more and more attractive due to the high energy demand, the limited resource of fossil fuel, and environmental concerns as well as a strategy to survive post-fossil fuel economy period. Biogas is generated through the process of anaerobic digestion in which the microorganisms degrade the organic material in the absence of oxygen. Conventionally anaerobic digestion has mainly been associated with treatment of animal (pig, cattle, poultry) manure and sewage sludge from aerobic treatment plants. As stated earlier the increased environmental concerns accompanied by the demand for new waste management strategies and renewable energy has broadened the field of applications for anaerobic digestion. Hence organic matter available from agro industrial waste, urban and rural wastes, human and animal waste and aquatic plants have been used for generation of biogas. Typically, biogas consists of a mixture of various gases as shown in Table 1.1

Table 1.1: Composition of Biogas[1]

Compound	Composition (%)
Methane	50-60
Carbon dioxide Carbon dioxide	30-45
Hydrogen	5-10
Nitrogen	0.5-7
Hydrogen sulphide and Oxygen	Traces

Biogas can be used directly in gas burning appliances for heating, cooking, lighting, refrigeration and as a fuel for internal combustion engines having a compression ratio of 8:1 or higher. Its calorific value (mainly due to methane) is the most important parameter which makes it an attractive alternative fuel source. The physical and chemical properties of methane in biogas are given in Table 1.2.

Table 1.2: Physical and Chemical Properties of Methane Chemical formula[2]

Chemical formula	CH_4
Boiling point at 760 mm	-161.49 °C
Freezing point at 760 mm	-182.46 °C
Critical pressure	47.363 kg/cm^2
Critical temperature	-82.5 °C
Specific volume at 15.5 °C and 760 mm	1.47 l/gm
Calorific value at 15.5 °C and 760 mm	38,130.71 kJ/m^3
Air required for combustion m3/ m3 of CH_4	9.53
Ignition temperature	650 °C

Based on the methane yield, organic material can be generally grouped into three classes each having its own characteristic methane yield as shown in Table 1.2. Most wastes have a combination of these classes. Hence for the achievement of a good biogas yield, the composition of the feed material is very crucial.

Table 1.3: Maximum Gas Yields and Theoretical Methane Content[3]

Substrate	Biogas (Nm^3/t TS)	CH_4 (%)	CO_2 (%)
Carbohydrate	790-800	50	50
Raw protein	700	70-71	29-30
Raw fat	1200-1250	67-68	32-33
Lignin	0	0	0

Producing energy from biogas is largely CO_2-neutral, i.e. the CO_2 released by burning biogas was previously removed from the atmosphere during the generation of biomass through photosynthesis. This is the most important contribution of biogas technology to environmental protection as compared to fossil energy sources.

The collection of methane from the fermentation of manure also reduces emissions which would have otherwise escaped from raw liquid manure thereby resulting in far more damages to the climate than CO_2 (GWP of methane is 25). Moreover, fermentation reduces the development of odor during liquid manure storage and spreading since the odor contained in the liquid manure are broken down and neutralized during the fermentation process. In addition, fermentation improves the quality of manure as pathogens and weed seeds are killed and acts as a nutrients for plants which can act as a substitute for inorganic fertilizers.

In India, extension of floating dome type biogas plants began in 1962, by Khadi and Village Industries Commission. The National Project on Biogas Development (NPBD) was launched by Government of India in 1982, which accelerated the pace of implementation. It gained momentum with the establishment of the Department of Non-Conventional Energy Sources (DNES, now MNES), in1982. Popular and approved models of biogas plants which were promoted under the programme include (i) floating gasholder type, popularly known as "Indian or Khadi and Village Industries Commission (KVIC) Model" and (ii) fixed dome type, commonly known as "Deenbandhu Model". In addition, low cost fixed dome digesters made of alternate construction materials, namely pre-fabricated ferro-cement or reinforced cement and also in situ built ferro-cement are being promoted. During the year 2007-08, biogas plants and components made of High Density Polyethylene (HDPE) have been introduced. In India, the population of cattle and buffalo is over 240 million heads, which yields about 1000 million tonnes of cattle waste annually. Assuming that 75% of the total cattle waste is available, for Bio-gas production and keeping in view the ownership pattern of livestock, on a rough calculation there is a potential for setting up 16 to 22 million small (1 m^3) bio-gas units in the country [4]. Still only 4 million plants are installed up to 2008[5]. A major social and health aspect of biogas is its potential to reduce the drudgery of collecting firewood and likelihood of chronic diseases because of using firewood as a cooking fuel especially for women and children while serving as an excellent waste disposal system. The power generation potential from urban solid waste in India is huge as about 30 million T/yr of solid waste is generated from household and commercial activities every year. Table 1.4 shows the estimated quantities of different wastes from urban and industrial sectors in the country produced every year. The energy recovery potential from this waste is given in Table 1.5 and its status is given in Table 1.6.

Table 1.4: Different Categories of Urban, Municipal and Industrial Wastes and Their Quantities[6]

Wastes	Estimated Quantity
Municipal solid waste	30 MT/yr
Municipal liquid waste	12000 MT/yr
Food and fruit processing waste	4.5 MT/yr
Paper and pulp industry waste	1.6x103 m^3/d
Press mud	9 MT/yr

Table 1.5: Energy Recovery Potential of Different Wastes[6]

Source	Potential (MWe)
MSW	900
Food and fruit processing waste	40
Press mud	220
MLW	100
Pulp and paper, dairy, tannery etc	140
Distilleries	300

Table 1.6: Power Generation Potential of Urban and Industrial Wastes (MWe) [6]

Sources	**Urban and industrial waste**
Potential	1700
Achieved Upto Dec. 2000	15.20
Mar.2003	25.8

According to India Agricultural Research Data Book 2004, the losses in fruits and vegetables are to the tune of 30 per cent. Estimated production of fruits and vegetables in India is 150 million tonnes, out of that 50 million tonnes waste generates per annum[7] .The pile up of this putrefying mass at various places becomes a breeding ground for disease and pests.

These wastes constitute a source of nuisance in municipal landfills because of their high biodegradability. Disposal of this waste in low lying areas has the potential to pollute nearby waterways. Disposal in landfills costs the producer, fills the landfill sooner and adds water to the landfill, potentially adding to leachate quantities. Composting of this material provides the soil conditioner but waste product is typically greater than 85% moisture and has high sugar content which aids in biomass bacterial growth, but little humus formation. Decomposition of each metric ton of solid waste could potentially release 50-110 m^3 of CO_2 and 90-140 m3 of CH_4[7]. One way of solving the problem is to make use of this waste for, production of biogas which could be suitably utilized in the surrounding areas and the digested slurry as organic manure.

Objective of the study was to determine physical and chemical characteristics of fruit and vegetable waste. It helps to best optimize the feed rate of waste into the digesters and therefore optimize the output of methane.

Characterization of fruit and vegetable waste included determination of Total solids, Volatile solids and C/N ratio.

Outline of the paper is as mentioned here. Heading 1 gives the introduction. Heading 2 deals with literature review which consist of understanding the effect of various process parameters (temperature, pH, organic loading rate, etc) and certain enhancement techniques such as (co-digestion, inoculum proportion, mixing etc). Heading 3 is materials and methods which gives procedure followed for characterization of the market waste.Heading 4 deals with the results.

II. LITERATURE REVIEW

2.1 Operational Details of Biogas Plants

Process parameters which have bearing on the performance of the biogas digester are discussed below. These parameters are biogas digester configuration, HRT, OLR, pH and buffering capacity, mixing, temperature, co-digestion, addition of various types of additives and monitoring of these parameters.

2.1.1 Mixing

Mixing is carried out to ensure efficient transfer of organic material for the active microbial biomass, to release gas bubbles trapped in the medium and to prevent sedimentation of denser particulate material. Mixing does not always take place continuously; it is often intermittent. To prevent the need for moving parts within the reactor, the recirculation of biogas through the bottom of the reactor or hydraulic mixing by recirculation of the digestate with a pump can be used to achieve adequate mixing.

A certain degree of mixing is necessary for making the substrate available to the bacteria, but excessive mixing can reduce biogas production. It is reported that low speed mixing can withstand against the disturbance of shock loading than did high speed mixing conditions and resulted in improved performance and also stabilized a continuously- mixed unstable digester [8]. Gollakota and Meher [9] found that at higher organic loading rate and temperature, biogas yield was increased by 38% because of stirring. Excessive agitation reduces the rate of oxidation of fatty acids which can lead to digester instability.

Extracellular polymeric substances (EPS) are a combination of proteins and carbohydrates which are responsible for the formation of granules [10]. Measurement of EPS can be indicative of the state of granule formation in a digester. It has been shown with the anaerobic digestion of cattle manure that an increase in mixing decreased the amount of extracellular polymeric substances. This suggests that minimal mixing produces larger anaerobic granules as greater quantities of EPS are required to maintain their structure [11].

2.1.2 Temperature

Anaerobic digestion can take place at psychrophilic temperatures below 20 ºC [12] but most reactors operate at either mesophilic temperatures or thermophilic temperatures, with optimum temperature at 35 ºC and 55 ºC, respectively. The structures of the active microbial communities at the two temperatures are different. A change from mesophilic to thermophilic temperatures (or vice versa) can result in a sharp decrease in biogas production until the necessary populations have increased in number. Even small changes in temperature, from 35 ºC to 30 ºC and from 30 ºC to 32 ºC have been shown to reduce biogas production rate[13].

Studies of both mesophilic and thermophilic digesters have conflicting results, the anaerobic digestion of combined olive mill and abattoir waste water at 37 ºC and 55 ºC and found that the thermophilic reactor produced a higher COD removal and biogas yield than the mesophilic reactor, and could sustain this at a high organic loading rate.

During batch digestion of vegetable waste and wood chips, more rapid degradation of fatty acids was found at 55 ºC than at 38 ºC, and also 95% of the methane yield was attained after 11 days under thermophilic conditions compared to 27 days under mesophilic conditions[14]. It has also been shown that the net energy output from 18 liter thermophilic digesters was 427 kJ/day higher than that produced by mesophilic digesters, but when compared two-stage digesters of mesophilic–mesophilic, mesophilic–thermophilic, and thermophilic–thermophilic configurations treating potato waste, found that the methane yield was higher in the mesophilic second stage than the thermophilic second stage, but the thermophilic second-stage reactors could manage a shorter retention time. There is also evidence that mesophilic temperature digesters have improved degradation rates when compared with thermophilic digesters. For instance, experiments with proteinaceous wastewater using 2.8 liter UASB laboratory scale reactors under mesophilic (37 ºC) and thermophilic (55 ºC) conditions showed that the mesophilic reactor removed about 84% of COD whereas the thermophilic reactor removed only 69–83 % [15].

2.2 Ph and Buffering Capacity

The ideal pH range for anaerobic digestion is very narrow: pH 6.8–7.2. The growth rate of methanogens is greatly reduced below pH 6.6 [16], whereas an excessively alkaline pH can lead to disintegration of microbial granules and subsequent failure of the process [17]. Although the optimal pH of methanogenesis is around pH 7.0, the optimum pH of hydrolysis and acidogenesis has been reported as being between pH 5.5 and 6.5 respectively [18]. Veeken and Kalyuzhnyi [19]found that pH is the primary process variable in controlling the hydrolysis rate of the anaerobic solid state fermentation process. This is an important reason why the hydrolysis/acidification and acetogenesis/methanogenesis processes are separated in two-stage processes.

Buffer capacity is often referred to as alkalinity in anaerobic digestion, which is the equilibrium of carbon dioxide and bicarbonate ions that provides resistance to significant and rapid changes in pH, and the buffering capacity is therefore proportional to the concentration of bicarbonate. Buffer capacity is a more reliable method of measuring digester imbalance than direct measurements of pH, as an accumulation of short chain fatty acids will reduce the buffering capacity significantly before the pH decreases. Increasing a low buffer capacity is achieved by reducing the organic loading rate, although a more rapid approach is the addition of strong bases or carbonate salts to remove carbon dioxide from the gas space and convert it to bicarbonate, or alternatively bicarbonate can be added directly [20]. Direct bicarbonate addition is more accurate as converting carbon dioxide to bicarbonate will require a time lag for gas equilibrium to occur which could result in over-dosing. It has also been demonstrated by Gunaseelan [21] and Ward [11] that the inoculum-to-feed ratio can be modified to maintain a constant pH.

2.2.1 Co-Digestion

It is generally found that during anaerobic digestion microorganisms utilize carbon 25–30 times faster than nitrogen. Thus to meet this requirement; microbes need a 20–30:1 ratio of C to N with the largest percentage of the carbon being readily degradable.

Co-digestion of feedstocks is done for achieving this required carbon-to-nitrogen (C: N) ratio. Feedstocks vary widely in their C:N ratios, and some reactors are affected more than others by non ideal ratios, e.g. sewage sludge has a C:N ratio of approximately 9:1, human waste is high in nitrogen, 6:1 and agricultural residues have C/N ratio above 40. Indeed, it is reported that the two-stage reactor can deal successfully with biomass having C: N ratios less than 20.

Callaghan and Wase [22] state that FVW has low nitrogen and phosphorous content hence can be successfully used as a co- digestate with CS. Demirci and Demirer [23]state that the higher nitrogen content of poultry wastes makes them difficult substrate for anaerobic digestion as it results in a range of problems: process inhibition, decreased COD removal efficiency, reduced biogas production, malodor and a poor biogas quality as stated by Strik and Holubar [24]. Lahdheb and Romdan [25] found that maximum biogas was produced from the co-digestion of FVW with AW than WAS and FW respectively. Murkute and Ramakant[26] found that, maximum gas production was obtained at 30% of the mustard cake with CS. Saev and Koumanova [27] found that mixture of cow dung and wasted tomato at the proportion of (80:20) can be used successfully for generation of biogas.

The co-digestion of cattle manure with MSW has also been shown to enhance methane production, also the co-digestion of sewage sludge with agricultural wastes or MSW has shown improvement in the methane production. Co-digestion of a low C: N ratio feedstock with a high C: N ratio feedstock such as biomass is beneficial as it adjusts the C: N ratio closer to ideality[11].

2.3 Organic Loading Rate (Olr)

Gas production rate is highly dependent on loading rate. Methane yield was found to increase with reduction in loading rate. In an another study carried out on a 100 m^3 biogas plant operating on manure, when OLR was varied from 346 kg VS/day to 1030 kg VS/day, gas yield increased from 67 to 202 m^3/day. There is an optimum feed rate for a particular size of plant, which will produce maximum gas and beyond which further increase in the quantity of substrate will not proportionately produce more gas. A lab-scale digester operating at different OLRs produced a maximum yield of 0.36 m3/kg VS at an OLR of 2.91 kg VS/ m^3/day. Based on pilot plant studies (1 m^3 capacity), maximum gas yield was observed for a loading rate of 24 kg dung/m^3 digester/day but percent reduction of VS was only 2/3rd of that with low loading rate [11].

Particle size can affect the rate of anaerobic digestion as it affects the availability of a substrate (i.e. the surface area) to hydrolyzing enzymes, and this is particularly true with plant fibers: it is reported that fiber degradation and methane yield improve with decreasing particle size from 100 mm to 2 mm. Maceration of manure to reduce the size of recalcitrant fibers was found to increase biogas potential by 16% with a fiber size of 2 mm, and a 20% increase in biogas potential was observed with a fiber size of 0.35 mm; no significant difference was found with fiber sizes of 5–20 mm [11]. Sharma and Mishra [28] found that particle size of 0.088 mm for feedstock ML, CFL, IFL and BP produced, 16.9, 18.2, 10.9 and 50.2% respectively more biogas than the digesters run at the largest particle sizes of the respective feed stocks.

2.3.1 Seeding

Digested material from an established reactor or ruminant manure is often used to seed a new reactor, for reducing the start-up time. Many reactors use methods of inoculating the fresh material with either digested material or the liquid fraction from the reactor, thus reducing washout of microorganisms. The microbial populations available in rumen fluid have been used as a seeding material in anaerobic digestion, often to increase the production of fatty acids from lignocellulosic feedstocks. A higher reduction in biological oxygen demand (BOD) was reported when swine waste was anaerobically digested with both a commercial seeding material and one derived from chicken manure at 5 ml/l. Treatment of manure with the hemicellulose degrading bacterium B4 gave an increase in methane potential of 30% [11].

2.3.2 Monitoring

Monitoring of anaerobic digestion is difficult and a complex, multi-variate process with few reliable on-line (i.e. those that monitor the process constantly) sensors for the measurement of important parameters. Even some of the basic measurement parameters can be difficult to obtain reliably over extended time periods as the sensor devices can become blocked or obscured. Many anaerobic digesters have variable feedstock sources, which can cause fluctuations in the chemical composition of the reactor. As a result of poor monitoring systems, most

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anaerobic digesters are currently run at a less-than-optimum loading rate to prevent instability occurring in the digester. This instability is often a result of inhibition of methanogens by excess fatty acids. It is therefore important to maintain a balance between fatty acids and the buffering capacity of the system.

Measurement of parameters can take place in either of the two phases:

- Liquid phase: It includes volatile fatty acids, pH, alkalinity (buffering capacity), COD, and dissolved hydrogen.
- Gas phase: It includes total gas production rate, gas composition, and also the individual production rates of methane, carbon dioxide, hydrogen sulphide, and hydrogen.

III. MATERIALS AND METHODS

3.1 Characterization of Fruit and Vegetable Waste

Characterization of fruit and vegetable waste involves determination of total solids, volatile solids and C, H, N, S, O analysis. These tests were carried out as per the APHA standard. The detailed description of the procedure is given below.

Table 3.2: Methods for Characterization of Fruit and Vegetable Waste

Parameter	Reference No	Reference
Total solids (TS)	2540B	Standard methods for the examination of water and wastewater, 17th edition, 1989.
Volatile solids (VS)	2540E	Standard methods for the examination of water and wastewater, 17th edition, 1989.
C, H, N, S and O Analysis	Model- FLASH EA 1112 series	

IV. RESULTS AND DISCUSSION

There is lack of basic information of C/N ratio of fruit and vegetable waste for Indian conditions. Characterization carried out will be helpful in arriving at various possibilities of combinations of FVW as per the seasonal and location availability.

Table 4.1: Analysis of Total Solids, Volatile Solids, Moisture Content and CHNSO of Fruit and Vegetable Waste

Substrate	TS (%)	VS (%)	Moisture content (%)	C	N	H	S	O	C/N ratio	C/N from literature
Cabbage leaves	13.27	88	86.73	40.18	3.11	5.06	0.00	0.00	12.91	392.00
Potato skin	21.34	93.08	93.08	39.86	1.34	5.86	0.00	0.00	29.79	29.27
Banana skin	10.87	79.99	89.13	42.20	0.51	5.50	0.00	36.29	83.06	102.62
Waste tomato	4.85	78.69	94.13	41.59	1.58	6.02	0.00	45.65	26.32	368.00
Cauliflower Leaves	17.79	81.48	80.21	37.34	5.68	5.01	0.35	39.24	6.57	-

Lady finger remains	13.86	90.63	86.14	37.56	0.79	5.08	0.00	45.61	47.61	-
Cucumber skin	12.3	93.63	88	41.58	3.10	5.43	0.00	38.86	13.40	-
Spinach remains	10.08	76.33	89.92	40.07	3.12	5.10	0.00	35.14	12.83	-
Watermelon skin	6.93	87.5	93.06	38.75	1.33	5.02	0.00	0.00	29.07	-
Sweet lemon Skin	44.98	-	45.02	42.39	0.21	5.57	0.00	45.03	202.82	-
Onion skin	11.73	-	88.27	43.57	.45	4.85	0.00	42.39	6.83	212.00
Carrot skin	9.03	-	-	42.10	0.18	5.68	0.00	45.10	230.06	219.00
Cluster beans (Gawar) remains	17	-	-	39.60	2.90	5.49	0.00	0.00	13.64	-
Mango Skin	-	-	-	41.09	5.92	0.00	0.00	0.00	6.94	-
Orange skin	-	-	-	46.44	0.40	6.00	0.00	43.16	115.82	212.00

Note: Repeatability test is not done.

The C/N ratio between 20 to 30, is considered optimum for anaerobic digestion. If the C/N ratio is very high, the nitrogen will be consumed rapidly by methanogens for meeting their protein requirements and will no longer react on the left over carbon content of the material. As a result, gas production will be low. On the other hand, if the C/N ratio is very low, nitrogen will be liberated and accumulated in the form of ammonia (NH_4). NH_4 will increase the pH value of the contents in the digester. A pH higher than 8.5 will start showing toxic effect on methanogenic microbes.

V. CONCLUSION

Characterisation of 15 vegetable and fruit waste (11 vegetable and 4 fruits) were carried out for total solids, volatile solids and C/N ratio. The C/N ratio varied in the range from 230 to 6.5. Total solids varied in the range from 5 % to44% and volatile solids from 80 % to 90%. This information of total solids, volatile solids and C/N ratio can be useful to maintain the C/N ratio and total solids in the biogas reactor. Alsothe detailed review on parameters important for improving the biogas yield is discussed.

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KEYWORDS

C:N: Carbon to Nitrogen ration

CS: Cattle Slurry

CFL: Cauliflower leaves

IFL: IpomoeaFistulosa Leaves

BP: Banana Peels