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Effect of Pretreatment on the Biogas Production from Energy Plant Using Batch Reactor

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Abstract

The proposed study aims at biogas potential estimation of sugar beet using different total solid concentration and pretreatment methods. The effect of alkali (Sodium hydroxide), acid (Hydrochloric acid) and mechanical (particle size reduction) pretreatment of sugar beet over un-pretreated substrate have been investigated for the potential of biogas production using biphasic continuous bio digester–TEAM (TERI's Enhanced Acidification and Methanation) process (50 kg/day capacity) developed by TERI+. The estimation of biogas potential of sugar beet has also been studied in single phase batch digester (2 L capacity) using three different Total Solids (TS) concentration *viz.* 5%, 7.5% and 10%. However the effect of particle size reduction was also studied in two phase digester. The biogas yield from single phase batch digester fed with 5% TS, 7.5% TS, 10% TS, were recorded as 44 m^3/ton, 58 m^3/ton, 57 m^3/ton of substrate fed respectively whereas the yield from un-pretreated, Hcl (6%; v/v) pretreated and NaOH (1%; w/v) pretreated sugar beet are, 72 m^3/ton, 60 m^3/ton and 61 m^3/ton respectively. The biogas yield from mechanically pulverized is estimated to be 90 m^3/ton which is 25% more than not pretreated substrate that too in Total Hydraulic Time (HRT) of less than six days.

Keywords: Biogas; TEAM process; Biphasic digester; Pretreatment

Introduction

Exhaustive usage of fossil fuel has compelled the human society to look for alternate sources of renewable energy for sustainable growth. Animal wastes are generally used as source of clean energy. However, the availability of these substrates is one of the major problems hindering the successful operation of biogas plants [1,2]. Hence there is a need for identification of alternate feedstock and agro residues which can be used for biogas production and to meet the energy demand. The two most important parameters in the selection of particular plant feed stocks are the economic considerations and the yield of methane [3]. Sugar beet is considered to be an important energy crops for biogas production because of the high organic content. Additionally, it contains a high fraction of degradable components. Moreover, sugar beets can be stored and used for the whole year. Another advantage of sugar beets is the low dry matter which makes it easily conveyable and hence the possibility of easy feeding. Several studies have been reported on the use of wastewater and solid wastes from sugar beet processing namely sugar beet pulp for generation of biogas. During the process of extraction of sugar from sugar beets, approximately 25% of sugar beet processed is generated in the form of spent pulp which is a rich source of energy [4]. Sugar beet pulp consists mainly of cellulose, hemicellulose and pectin making it suitable for biological degradation and thus biogas production [5]. Weiland reported a methane yield of 0.3 m^3 methane per kg Volatile Solid (VS) for two-stage systems under mesophilic conditions and HRT of 13 days with maceration (80% of solids were less than 0.63 mm) of beet pulp [6]. The average methane yield from thermophilic leach-bed digester was 0.336 m^3 CH_4 at STP (kg VS)$^{-1}$ [7]. The methane yield for two-stage processes was about 350 L methane per kg VS which is equivalent to 94.5 m^3 of methane per ton of waste assuming TS of 30% and VS of 90% [8,9]. In this study, various methods of treatment of the sugar beet have been studied for the maximum production of biogas. For these studies, a biphasic bio digester developed by TERI-TEAM process was also used. TEAM is a tailor made product for treatment of different types of organic wastes including fibrous crop wastes, which are difficult to be digested in conventional systems. It fully eliminates the operational problems like scum formation and requirement of preparation of homogeneous slurry for digestion.

Materials and Methods

The methodology and protocols used for assessing the biomethanation potential and characteristics of the waste are described as below.

Material

The feedstock-whole plant of sugar beet (leaves and tuber) was used for the study. Sample of sugar beet plants were collected from the fields in Rajasthan, India. Sugar beet was first analyzed for its characteristics-pH, TS, VS, ash content, organic carbon and Kjeldahl's nitrogen.

Experimental set up

Biogas potential estimation using different total solids concentration in single phase digester (batch set up): Sugar beet plant (root and leaves) was chopped into small pieces. Three sets of mesophilic batch experiments in 2 L glass reactors (Figure 1). Were conducted at different initial concentrations of 5% TS, 7.5% TS and 10% TS. The sugar beet was cut into pieces and amount of 285 g (for 5% TS), 428 g (for 7.5% TS) and 571 g (for 10% TS) were put into reactor for experiment. Cattle dung slurry was used as an inoculum of methanogen. These reactors were housed in a wooden box fitted with heat convector and temperature controller. The temperature was maintained at 37°C. The experiments were monitored for biogas generation, pH, COD, TS, VS, total sugar on daily basis. Batch reactors were operated for approximately 6 weeks.

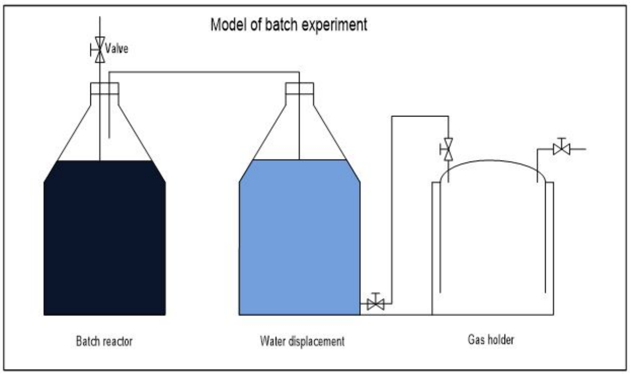

Figure 1: Model for batch experiments for anaerobic treatment of sugar beet.

Effect of chemical and mechanical pretreatment on biogas production using two phase digester (TEAM digester): Chemical and mechanical pretreatment studies were carried out in TEAM digester having the capacity of 50 kg/day. So 50 kg of sugar beet was used for each of the run from 4 to 7. Sugar beet plant chopped into small pieces (25-50 mm) were first soaked in 1% (w/v) NaOH, and 6% (v/v) HCl for overnight.

The soaked material was then transferred to acidification reactor of the TEAM and 100 L water was added so as to maintain the ratio of waste to water as 1:2. Run 6 were made with not pretreated sugar beet sample so that the net effect of pretreatment could be analyzed.

These experiments were then allowed to undergo acidification process for a period of seven days. The liquid samples (leachate) from each experiments were analyzed for chemical oxygen demand, pH, total sugar and reducing sugar. The leachate obtained after seven days of acidification process was fed into a digester for biogas production continuously at retention time of 40 days. For run 7 (mechanical pretreatment) sugar beet plant was pulverized to reduced particle size (> 95% was 5 mm). Experimental setups at a glance are shown in Table 1.

Experiment	Protocol	Experimental run
Total solids variation (batch digester)	5% TS concentration of Sugar beet+inoculum	Run 1
	7.5% TS concentration of Sugar beet+inoculum	Run 2
	10% TS concentration of Sugar beet+inoculum	Run 3
Chemical pretreatment (TEAM digester)	Sugar beet soaked in sodium hydroxide solution (1% w/v)+water (1:2 ratio)	Run 4
	Sugar beet soaked in hydrochloric acid solution (6 % v/v)+water (1:2 ratio)	Run 5
Mechanical pretreatment (TEAM digester)	Sugar beet+water (1:2 ratio)	Run 6
	Pulverized sugar beet+water (1:2 ratio)	Run 7

Table 1: Description of different Experiment.

Analytical methods

Samples were regularly drawn from the batch reactors and acidification reactor of TEAM digester, and were measured to determine pH, Chemical Oxygen Demand (COD), total sugar, volatile solids, Volatile Fatty Acids (VFAs). The pH of the samples was assessed digitally using a calibrated Beckman glass electrode pH meter (Orion Research Incorporated, USA).

Moisture content and total solids in substrate were determined according to ASTM standards D3172-3173. The oven-dried sample after total solids estimation at 110°C was further analyzed for VS and ash content at 550°C. Nitrogen present in the sample is estimated by Kjeldahl's method. The daily gas production was measured through water displacement method.

COD analysis: COD was determined using a COD digester (Spectra Lab 2017) as per standard method APHA. Most of the organic matter is destroyed when boiled with a mixture of potassium dichromate and sulphuric acid producing carbon dioxide and water. A sample was refluxed with a known amount of potassium dichromate in sulphuric acid medium and the excess of dichromate is titrated against ferrous ammonium sulphate. The amount of dichromate consumed is proportional to the oxygen required to oxidize the organic matter.

VFA analysis: The gas liquid chromatography (NUCON, India, and series 5700) fitted with a Flame Ionization Detector (FID) was used for VFAs (acetic, propionic and butyric acids) analysis. A glass chromosorb-101 column of 6 m length and 3 mm diameter was used. Temperature at injector port, column and detector were maintained at 230°C, 200°C and 240°C respectively. The nitrogen gas was used as a carrier gas at a flow rate of 30 mL/min. A mixture of hydrogen and Zero air used to sustain the flame in the detector. Standard plots were obtained using a standard solution of VFAs.

Results and Discussion

The results of sugar beet characterization are indicated in Table 2.

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Parameter	Unit	Values
pH	-	6.92
Moisture	%	64.78
Total solids	%	35.22
Volatile solids	% of TS	95.57
Ash Content	% of VS	66.88
Calorific value	MJ/Kg	15.62
Total organic carbon	% of TS	39.24
Total Kjeldahl's nitrogen	% of TS	0.336

Table 2: Characteristics of Sugar beet.

Results of experimental runs conducted in batch reactors at different total solids concentration

The analysis showed a significant drop in pH in all the sets which may be due to formation of volatile fatty acids. Hence pH of the slurry was controlled at 7.0 by alkali. After 15 days, increase in pH of the slurry was observed. The profile of pH and biogas production during the anaerobic digestion of different TS batches is shown in Figure 2.

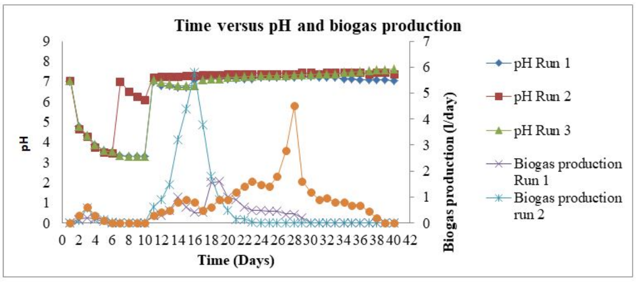

Figure 2: Profile of pH and biogas gas production with different TS experiments.

Comparison of biogas gas production at different initial TS concentrations indicate a higher production at initial stage for a concentration of 7.5% TS. However, biogas gas production was low in the initial stage for run 3, which increased subsequently. Total gas production was 12.5, 24.8 and 32.4 for run 1, 2 and 3 respectively that corresponds to biogas yield of 44, 58 and 57 m^3/ton of substrate in an incubation period of 40 days. After 40 days, there no gas formation was observed in either of the reactor, hence experiments were dismantled and digested samples were analyzed for TS, VS, COD and total sugar. The reduction in TS and VS was found higher in run 3 and lowest in run 2. The initial and final concentration of TS, VS, total sugar and COD are indicated in Table 3.

Parameter	Run 1				Run 2				Run 3			
	Total solids (%)	Volatile solids (in % of TS)	Total sugar (g/L)	COD (g/L)	Total solids (%)	Volatile solids (in % of TS)	Total sugar (g/L)	COD (g/L)	Total solids (%)	Volatile solids (in % of TS)	Total sugar (g/L)	COD (g/L)
Initial	8	91.2	13.87	49.6	10.5	92.25	15.08	66.4	13	93.4	25.73	100
Final	6.03	68.22	1.65	23.2	7.75	64.46	2.63	31.2	8.45	63.48	3.66	62.4
Reduction (in %)	24.63	25.2	88.07	53.23	26.19	30.12	82.52	53.01	35	32.03	85.78	40

Table 3: TS, VS, total sugar and COD reduction in different Batch experiments.

Total sugar reduction in case of run 1 is observed to be higher, in the tune of 88.07%, than that of run 2 and 3 but the biogas yield for run 1 is least amongst all the three experiments. The biogas yield in terms of m^3/kg sugar reduced is least for run 1 (1.02) and maximum for run 2 (3.87).

This may be attributed to the reason that the available sugar in case of run 1 might have been consumed for metabolic growth of microbes while in case of run 3 excess sugar leading to high organic load of 100 kg COD/m^3/day must have suppressed the metabolic activity of the microbes and hence leading to inefficient conversion of sugars into biogas. Thus it may be concluded that for anaerobic digestion of sugar beet plan in batch type reactor, the TS concentration may be maintained at 7.5%.

Results of effect of chemical pretreatment on biogas production using two phase digester (TEAM digester)

The profile of COD in the extract obtained under different pre-treatment conditions is shown in Table 4. A maximum COD of 60.4 g/L was achieved in 5 days for run 6. In order to estimate the maximum possible extraction, the residue left after the removal of concentrated extract on seventh day was further subjected to extraction with same volume of fresh water. The extraction was allowed to take place up to fifth day as we have observed that in the first extraction the maximum extraction had been achieved on day fifth which is confirmed by COD. This resulted in additional COD of 19.8 g/L for not retreated sample while for acid and alkali pretreated sample, the COD is 13.1 g/L and 12.4 g/L respectively. Hence it is evident that there was not much effect in the concentration of COD due to the pre-treatment being carried in two phase system.

Time (days)	Alkali pretreated (run 4)		Acid pretreated (run 5)		Un- pretreated (run 6)	
	COD (g/L)	pH	COD (g/L)	pH	COD (g/L)	pH
1	39.2	4.54	45.6	1.31	44	3.87
2	44	3.78	47.2	1.42	48.8	3.5
3	47.2	3.63	50.4	1.44	52.4	3.38
4	53.6	3.62	51.2	1.46	56	3.28
5	55.2	3.6	51.2	1.48	60.4	3.27
6	54.6	3.61	52	1.51	59.9	3.23
7	55.6	3.57	53.4	1.54	60.2	3.22
Re-extraction with fresh water on day 5	12.4	3.95	13.1	3.1	19.8	4.1

Table 4: Chemical oxygen demand and pH concentration of leachate samples from TEAM digester.

The change in COD concentration was also confirmed by the profile of VFA. The concentration of VFA is shown in Table 5. The result of VFA shows that there is absence of acetic acid formation in case of not pretreated and alkali pretreated samples whereas in case on acid pretreated sample it very low (0.19 g/L). The absence or very low concentration of propionic acid is an ideal condition for biogas generation as propionic acid inhibits the biogas production. The ideal ratio of Propionic to Acetic ratio (P/A) is about 1.4 [10]. In all the cases, the P/A ratio is under limit that also validates the suitability of the substrate for biomethanation.

Time (days)	Un-pretreated sample			Alkali pretreated sample			Acid pretreated sample		
	Acetic acid (g/L)	Propionic acid (g/L)	Butyric acid (g/L)	Acetic acid (g/L)	Propionic acid (g/L)	Butyric acid (g/L)	Acetic acid (g/L)	Propionic acid (g/L)	Butyric acid (g/L)
1	2.74	0	0.25	0.63	0	0	0.52	0.044	0.54
2	3.42	0	0.31	0.84	0	0	0.64	0.052	0.41
3	4.21	0	0.48	1.46	0	0.025	0.78	0.078	0.39
4	4.55	0	0.54	1.21	0	0.031	0.97	0.082	0.38
5	4.5	0	0.61	2.21	0	0.036	0.96	0.096	0.21
6	4.78	0	0.64	5.43	0	0.039	1.21	0.1	0.22
7	4.89	0	0.7	5.44	0	0.41	1.35	0.19	0.14

Table 5: VFA in un-pretreated, Alkali and Acid pretreated TEAM pretreated samples.

Results of Effect of mechanical pretreatment on biogas production using two phase digester: The mechanically pulverized sugar beet sample was tested in the acidification reactor (run 7) for the potential of extraction of the organic content into water. The ratio of pulverized sugar beet to water (w:v) was kept as 1:2. The maximum COD of the extract was observed to be 100 g/L within a minimum Hydraulic Retention Time (HRT) of four days. With a 90% of COD reduction in methanation reactor, and a gas yield of 0.5 m^3/kg COD removed [11], the gas yield works out to be 90 m^3/ton of sugar beet.

Comparison of gas yield

Gas productions in different experiments were compared for assessing the optimum conditions and the maximum biogas generation potential from sugar beet (whole plant). Figure 3, indicates the biogas yield from different experiments.

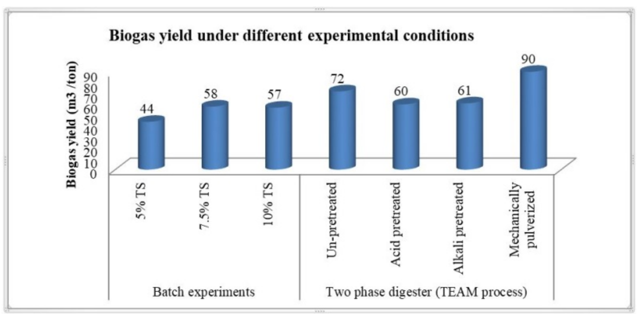

Figure 3: Sugar beet biogas yield (m^3/ton) under different experimental conditions.

Cost benefit analysis

According to the analysis carried out using some economic indicators resultant that the investment profitability from small scale to large scale plant tends to decreasing. The analysis also showed that the plant unit cost and operation cost are reduced drastically by 85% and 92% respectively from lowest plant size (100 kg) to highest plant size (10000 kg) (Figure 4).

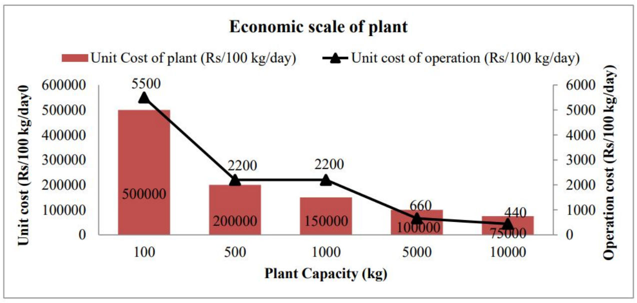

Figure 4: The economic scale of plant.

Conclusion

Maximum gas yield from batch digestion carried out with 7.5% TS of sugar beet is 58 m^3/ton of feed stock. Degradation of the not pretreated sugar beet in TEAM digester resulted in a high strength leachate. COD of the leachate attained a cumulative value of 80.2 g/L within five days. However the COD of the leachate obtained from mechanically pulverized sugar beet is 100 g/L in four days. The extraction of the organic content in the form of high strength leachate from mechanically pulverized feedstock appears to be promising option for the treatment of sugar beet. As compared to the other pre-treatment methods, the gas yield from pulverized feedstock in a high rate anaerobic digester is 90 m^3/ton of feedstock. The positive aspect associated with the pretreatment process is considerable reduction in the residence time of 4.75 days (4 days for acidification process and 18 hours for methanation process) compared to batch digestion and other models of continuous digestion. However, further studies are essential for optimizing other design parameters.

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