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An experimental investigation into use of food waste for improved biogas production

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ABSTRACT

In this study food waste from a restaurant, chicken waste and waste flour are used as feedstock. Along with this, one new biogas unit model is used and compared with the existing one for various features. The outcomes are documented. Different decisive parameters were verified and got compared with those generated from conventional type of feed stock in various AD processes mentioned in different literature searched. With the individual effect all above influensive parameters, the relation between them is also verified which shown consistent results.

Introduction

Solar energy, wind energy, different thermal and hydro sources of energy, biogas are all renewable energy resources. But, biogas is distinct from other renewable energies because of its characteristics of using, controlling and collecting organic wastes and at the same time producing fertilizer for use in agricultural irrigation.

Biogas

Biogas is a renewable form of energy. Biogas is produced by bacteria through the bio-degradation of organic material under anaerobic conditions. Methanogens (methane producing bacteria) are last link in a chain of micro-organisms which degrade organic material and returns product of decomposition to the environment. Apart from the use of biogas for household cooking and lighting, it is claimed that systems can be built to provide power for small scale productive operations such as pumping of water, village service facilities like clinical refrigerators and small scale industry. Biogas consists mainly of methane and carbon dioxide, but it also contains several impurities. The composition of raw biogas is in general 50% – 75 % methane, 30 % – 45 % carbon dioxide and traces of other gases [1].

Principles for production of biogas

Organic substances exist in wide variety from living beings to dead organisms. Organic matters are composed of Carbon (C), combined with elements such as Hydrogen (H), Oxygen (O), Nitrogen (N), and Sulphur (S) to form variety of organic compounds such as carbohydrates, proteins & lipids.

There are two types of digestion process, Aerobic digestion and Anaerobic digestion. The digestion process occurring in presence of oxygen is called Aerobic digestion**.** It produces mixtures of gases having carbon dioxide (CO_2), one of the main responsible for global warming [5]. Composting is an aerobic process. The digestion process occurring without (absence) oxygen is called 'Anaerobic Digestion' which generates mixtures of gases. Anaerobic digestion is widely applied for treatment of organic wastes that are easily biodegradable and have relatively high moisture contents [7].

There are three distinct stages in an anaerobic process. Firstly, the hydrolysis, second phase is acidification and final stage is methanogenesis [2].

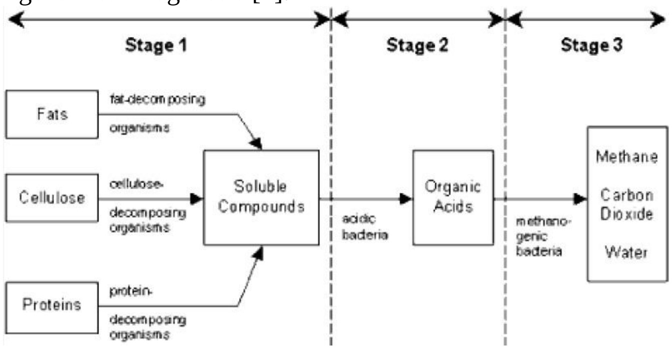

Figure 1. Stages in Anaerobic digestion

Parameters affecting the anaerobic digestion

The design and performance of anaerobic digestion processes are affected by many factors. Some of them are related to feedstock characteristics, reactor design and operation conditions. Factors that influence the anaerobic process are pH, temperature, composition of the food waste and loading rate [8]. Methane producing bacteria require a neutral to slightly alkaline environment (pH 6 to 8) in order to produce methane. Anaerobic micro-organisms are very sensitive to temperature. Operating temperature is the most important AD reactors because it is an essential condition for microbial consortia (combination of bacteria for associative action). Despite the fact that they can survive a wide range of temperature, bacteria has three range of temperature viz. Psychrophilic, mesophilic and thermophilic [6]. At present most of the systems are mesophilic because the thermophilic consume too much energy while psychrophilic meets many obstacles [4]. Mesophilic digesters have an operating temperature 10°C - 50°C and thermophilic digesters have an operating temperature 40°C - 70°C. The bio-mechanization potential of the waste depends on the

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concentration of the four main components: proteins, lipids, carbohydrates, and cellulose bio-chemical characteristics of these components. Organic loading rate is a measure of the biological conversion capacity of the AD determines the amount of feed stock as an input in the AD system [10]. Overloading of the system can results in low biogas yield. A biogas plant can become acidic and fail if it is over-fed, and this is a particular problem with a plant using highly digestible organic materials [3].

Methodology

New type of biogas unit

In this new unit the gas holder contains pockets where concrete blocks can be placed. Because of this provision enough weight can be added as per application requirement which allows the user to choose how much biogas pressure he wants. Because of unique stackable design all components can be easily transported at very modest cost. Roof top installation of this unit is possible. It also requires small space, only 7 feet diameter pit for a plant of 4m3. A pipe takes the biogas to the kitchen, where it is used with a biogas stove. The gas holder gradually rises as gas is produced, and sinks down again as the gas is used for cooking. Weights can be placed on the top of the gas holder to increase the gas pressure. Concrete weights can be put in pockets which will provide adequate pressure at burners. Additional pockets if gas is to be carried for long distance. Concrete weight in pockets increases gas pressure. Weight can be added as desired. This biogas plant is made from standard high-density polyethylene (HDPE). The larger tank acts as the digester and the smaller one is inverted and placed into it to serve as a gas-holder. The plant safely digests kitchen waste, food waste or waste flour from mills, thus reducing the problem of waste disposal [11].

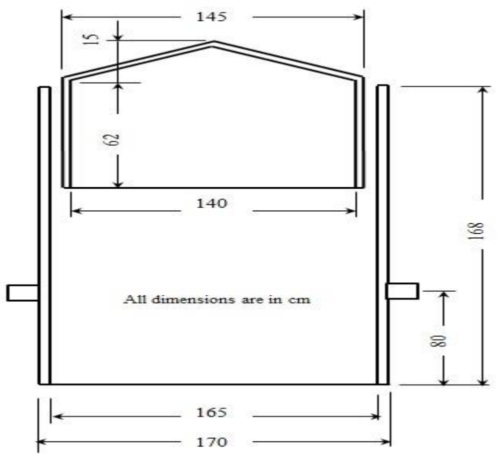


Figure 2. Significant dimensions of unit

New type offeed stock

The biogas plant was fed with a mixture of ratio of 6 kg/day food wasteand1 kg/day waste flour and 1 kg/d chicken waste for 8 weeks. The feeding rate of 5 kg per day was chosen because of suitability of plant and on the other hand it conforms to the reactor specifications. The rate of feeding of all substrates was increased from 6 to 17 kg/day. The purpose was to assess the effects of increasing substrate feeding rates on the performance of the digester [14].

Procedure (Monitoring Method)

During the start-up period, the biogas plant was inoculated with 60 kg of dried cow dung mixed with water and 60 liter effluent from an existing biogas plant. The homogenous mass was then poured into the digester [9]. Thereafter, the plant was left without further feeding for 20 days, to develop the culture inside the digester. All waste materials were chopped and mixed with water before they were fed to the digester. Mixing was achieved by putting the daily waste amount into bucket and adding water. To minimize the risk of blocking the inlet pipe, the feedstock was first stirred to best homogenize the slurry. In this study, the pre-treatment of food waste was only needed for the meat, fish and fruit pieces.

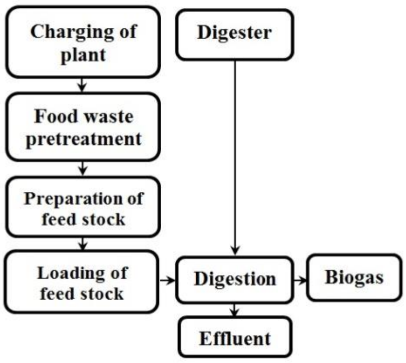


Figure 3. Process followed

They were cut up with a kitchen knife. Then put them into the chopper to make smaller size. The chicken waste also chopped in pieces from chicken center and stored flour waste in desired quantity is mixed with the food waste [12]. The feeding rate of 5 kg per day was chosen because of suitability of plant and on the other hand it conforms to the reactor specifications. The rate of feeding of all substrates was increased from 6 to 17 kg/day.

Plant Layout

The installation layout of plant is explained in detail in figure 4.The plants have a floating drum design and consist of a digester tank (b), a gasholder drum (a), a food waste inlet (d), an effluent outlet (e) and a biogas outlet (f).The digester tank (b) is made of high density polyethylene (HDPE) elements fitted together in an excavated pit. Thanks to a central guiding system (c), the biogas can be collected almost in its integrity by the gasholder which is anchored in the orthogonal barrier serves as a guide frame for the gasholder. Because the central guiding system (c) it moves straight and cannot tilt to the side. Weights (g) are kept on the gasholder to make it heavy and thus increase the gas pressure. The food waste inlet (d) and the effluent outlet (e) both consists a funnel pipe and a ‘T’ pipe respectively attached to digester. A valve on the gasholder enables to connect a pipe (f) which carries the biogas to the kitchen where the cooking can be done on a biogas stove [11].

Figure 4.Plant Layout

Observations

Further, the study is divided into following parts which mainly includes technical performance of plant (gas production and composition) and effluent quality (pH value and temperature).

After installation of the plant, the charging process was carried on for first 20 days then the food waste was loaded. Afterwards the plant was monitored and evaluated for eight weeks for below mentioned parameters.

Analysis of effluent

The effluent was collected while the feedstock was poured into the plant in order to check its pH value (measured in laboratory) and temperature (measured on site). On the day of measurement, the effluent was collected and the temperature is measured on site then it was packed in one bag and taken to the laboratory to measure its pH value. The thermometer used to measure the temperature of slurry is ELITE India having range 0 to 360ºC. While for measurement of pH value of effluent the instrument used is Systronics Digital pH meter 335.

Measurement of gas production

Measuring gas production on the plant in a floating-drum plant, the height difference of the gasholder is measured. To measure the gas production, scaling of the gasholder was done. The scaling was related to production rate of biogas by simple calculations [9].The difference between the scale on digester after removal of whole gas and occupation of gas before utilization is measured (figure 5) as Δh and further it gets multiplied with the area under the gas holder to have the value of gas production.

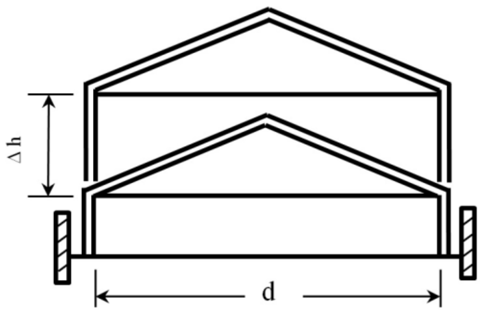


Figure 5. Height difference of gas holder

Sample Calculation for gas production,

Height difference observed (Δh) =7.8 cm =0.078m

Internal diameter of gas holder (d) =140 cm =1.4m

Area of gas accommodation, A $= (\pi/4) \times d^2$

$= (\pi/4) \times (1.4)^2 = 1.54 m^2$

As, $G_p = A \times \Delta h$

$= 1.54 \times 0.078 = 0.120 m^3$

As, $1 m^3$ =1000 litre

$0.120 m^3$ =120×1000litre =120 litre

∴ The gas production is 120 litre per day.

Measurement of gas composition

The rate of production of methane content is evaluated using gas chromatography analysis. The gas samples which are collected from the biogas plant are taken to the laboratory for determination of composition of biogas by using gas chromatography.

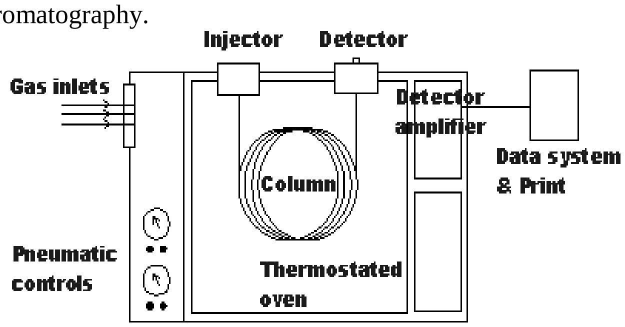


Figure 6. Height difference of gas holder

A gas chromatograph (GC) is a chemical analysis instrument for separating composition in a complex sample. The basic principle of GC is vaporizing the sample by injection into a heated system, eluted through a column by inert gaseous mobile phase and detected. Although not the only components analyzed, there were several readings of significance gathered from each data set like % CH_4, % CO_2, % N_2 etc. The results were printed directly to a dot matrix printer attached to GC and results were manually recorded and analyzed [13]. The instrument used for determining the gas composition is SHIMADZU Gas chromatograph (GC 2014).

Table 1. Observation Table

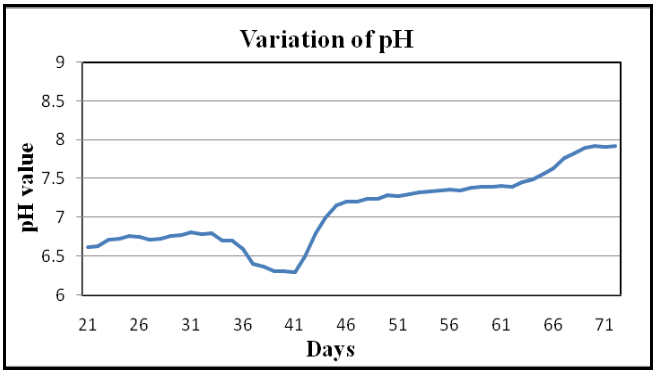
Day	*pH value*	*Temp. (ºC)*	*Gas prod. (lit/day)*	*Ch_4 (%)*	*CO_2 (%)*	*Day*	*pH value*	*Temp. (ºC)*	*Gas prod. (lit/day)*	*Ch_4 (%)*	*CO_2 (%)*
1	Charging Of Unit (From Day 1 to Day 20)					37	6.4	29	193	52	33
2						38	6.37	30	190	53	34
3						39	6.31	32	187	53	34
4						40	6.31	32	192	54	33
5						41	6.3	31	198	54	33
6						42	6.5	31	212	53	32
7						43	6.8	31	225	52	33
8						44	7	32	230	53	33
9						45	7.16	32	233	54	32
10						46	7.2	31	245	55	32
11						47	7.21	33	249	56	32
12						48	7.24	31	250	55	31
13						49	7.24	32	259	56	31
14						50	7.29	31	255	55	32
15						51	7.28	32	261	57	31
16						52	7.3	31	260	57	32
17						53	7.32	32	261	58	31
18						54	7.34	31	263	58	31
19						55	7.35	31	263	59	32
20						56	7.36	33	271	59	31
21	6.62	27	120	40	45	57	7.35	34	276	58	32
22	6.63	26	125	41	44	58	7.38	35	283	58	31
23	6.71	27	123	40	43	59	7.39	37	290	60	30
24	6.73	29	135	42	43	60	7.4	36	298	59	31
25	6.76	28	140	43	43	61	7.41	37	303	60	32
26	6.75	27	156	44	42	62	7.4	39	307	61	31
27	6.72	29	164	46	42	63	7.45	40	312	61	32
28	6.73	28	170	47	40	64	7.49	40	319	60	31
29	6.76	29	178	48	39	65	7.56	41	324	61	31
30	6.78	27	190	49	38	66	7.63	41	325	60	32
31	6.81	27	195	48	36	67	7.76	41	330	61	31
32	6.79	28	200	50	36	68	7.82	40	331	62	31
33	6.8	29	203	52	35	69	7.9	40	330	61	30
34	6.7	31	200	51	35	70	7.92	40	332	62	31
35	6.7	30	197	53	35	71	7.91	41	331	61	30
36	6.6	31	194	52	34	72	7.92	41	330	62	31

Results and discussion

While monitoring, the values of different parameters were considered from day 21 as from day 1 after installation to day 20, it was charging time of plant during which the bacteria culture fully develops. The block in observations (Table 1) indicates this period.

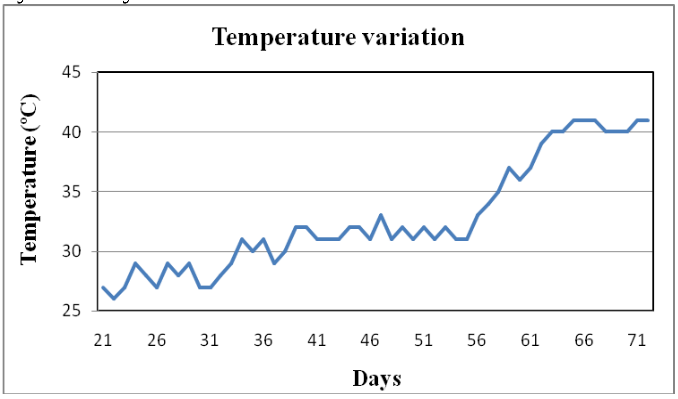
Variation of pH value

From the graph, it clearly shows that the pH is initially stable, then it fall and again it keeps rising. This is because during the initial stage hydrolysis was going on, then due to acidification the pH value falls and then again rises during Methanogens. The pH value at the start was found to be 6.62 to 6.8 and once the process of fermentation has stabilized it took maximum of 7.92.



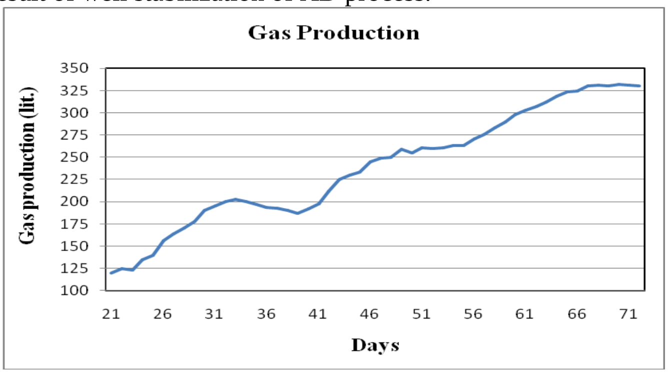
Temperature Variation

Graph clearly shows that initially, during stabilization phase from day 21 to day 56 the mesophilic stage was found during temperature 27°Cto33°C. From then onwards the temperature gets rises from 34°Cto41°C which is thermophilic stage during day 57 to day 72.



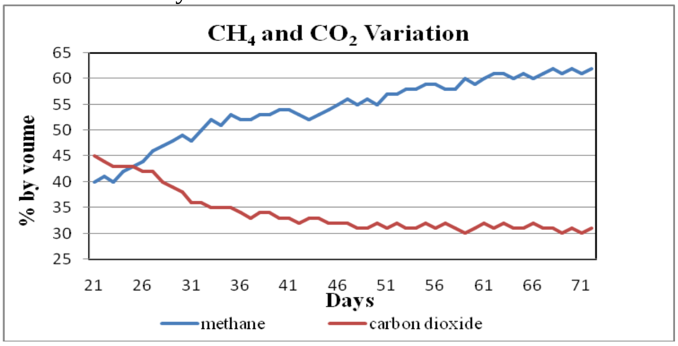
Gas production

From the graph it clearly shows that the biogas production has increased enormously in starting phase during day 21 to day 35 due to fully developed culture during charging period. The gas formation then stabilized somewhat during day 36 to 48, and then it again increased from that day onwards, which is the result of well stabilization of AD process.



Methane and carbon dioxide variation

The most significant feature is that Carbon dioxide represents 45% by volume of gas, whereas, methane seems to be 40%, at the first day of measurement. Composition of CO_2then gradually decreases and dropped to a value of 31% by volume for the last day of experiment. On the other hand, the percentage of methane sharply increases and picked to the value of 62% by volume in last day.



Conclusions

In this study, a new biogas unit and a new combination of feed stock was used which was a mixture of ratio of 6 kg/day food waste and 1 kg/day waste flour and 1 kg/day chicken waste. Different decisive parameters were verified and got compared with those generated from conventional type of feed stock in various AD processes.

Observations of technical performance of anaerobic digestion process

- The average pH value was 7.08 which shows that the anaerobic reaction process going on well. The minimum pH value was 6.62 and the maximum was 7.92 which is better when compared to literature data which were obtained using convention feed stock from wastes.
- Temperature showed greater impact on the overall process. The average temperature was 32ºC with minimum of 27ºC and maximum of 41ºC which shows mesophilic range within which the best growth of anaerobic degradation was achieved. This is consistent with the data obtained in literature.
- The amount of biogas production was affected by increase in temperature. The results have shown improved gas production as compared to existing unit. The highest gas production was 332 liters at highest temperature 41°C in digester. The average gas production was 243 liters with minimum of 120 liters and maximum of 332 liters. The gas production rate and pH value at two extreme point showed there was smooth propagation of biogas production which indicates the proper working of unit.
- The methane mean concentration in biogas was 54% with minimum concentration of 40% and maximum 62%. The average carbon dioxide concentration in biogas was 34% with minimum concentration of 31% and maximum concentration of45%.Initially the concentration of carbon dioxide was found more than methane. But later on as the loading rate was increased the methane content also increased. This is due to better hydraulic mixing in digester which reduced methane solubility in waste water. The results showed improved gas composition than that of literature survey.
- It was observed from the anaerobic phase that the performance of the unit was improved when the loading rate was increased. In terms of anaerobic digestibility the feed stock, it was shown that the fast loading rate seemed to digest better than the low loading rate in terms of gas production. The highest gas produced for the loading of 16 kg/day.

The advantages of new unit

- The operating of new type of biogas unit with several advantageous features is found very convenient.
- The pressure at burner was found quite maintained due to the concrete weights.
- The feeding process was very simple with no special skill was necessary.
- To avoid the moisture in the gas line the dripping was done on several points so that the water content can be discharged during the closing of gas valve.
- It was really easy to install the plant and the space required was very less.
- Due to material HDPE, the unit was very light to handle and transport.

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