IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

DEVELOPMENT OF PILOT SCALE ANAEROBIC DIGESTION SYSTEM FOR TREATMENT OF BIODEGRADABLE WASTES GENERATED IN GIRLS' POLYTECHNIC CAMPUS

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ABSTRACT

Waste is regarded as one of the major environmental issues facing the modern world. One of the specific goals of environmental preservation is effective waste management due to the growing amount of garbage produced as a result of human activities. The trash issue will be a big burden on the next generation if it is not adequately managed. This paper aims at designing a pilot plant anaerobic digestion system in the Girls' Polytechnic campus which is located in Guwahati, Assam considering the organic waste generated per day. An approach has been made to fabricate the prototype to fit into modern design for better efficiency. The pH and biogas volume was monitored daily to avoid failure of the system. The primary focus of this work is to provide a proper waste management system for the polytechnic campus which is to be done by converting waste to fuel by anaerobic digestion. Thus, the biogas generated will be used in the kitchen of the girls' hostel for cooking purpose.

Keywords: Anaerobic Digestion, Biogas, Digester, Floating Drum Type, Agitator.

Introduction:

Biogas is produced from all kinds of biological organic waste like animal manure and industrial waste, human manure, restaurant waste, etc. Such wastes become a major source of air and water pollution and responsible for 18% of the overall greenhouse gas and 64% of anthropogenic ammonia emissions [1]. With the aid of multiple anaerobic bacterial species, biogas is generated from organic wastes through anaerobic decomposition.

Anaerobic digestion is the process of breaking down complex organic molecules with the aid of microorganisms in the absence of oxygen. It is also known as the biological oxidation of biodegradable waste by microbes in anaerobic conditions. This product's final byproduct contains significant amounts of carbon dioxide and methane. Kitchen waste is an organic material having high calorific value and nutritive value to microbes, so the efficiency of methane production can be enhanced by several orders of magnitude [1]. As a biochemical process, anaerobic digestion mostly uses substrates high in organic matter, such as sludge, household waste, sewage, and waste from a cow feedstock. It offers a better alternative to conventional energy sources because it is renewable and creates little or no negative consequences, which has been recognized by several nations, including India. The majority of its applications are in fermentation technology and the control of waste.

Today, waste is regarded as one of the major environmental issues facing the modern world. One of the specific goals of environmental preservation is effective waste management due to the growing amount of garbage produced as a result of human activities. The trash issue will be a big burden on the next generation if it is not adequately managed. Garbage is separated into different categories depending on how it was formed. These categories include home or municipal waste, waste in public spaces, industrial waste, construction waste, agricultural waste, sediments and sludge from waste water, sewage septic tanks, and street drains. The municipal wastes are made up of various scrap that is produced as a byproduct in homes, institutions, stores, and shops. An approach has been made to solve the growing problem of waste in the girls' hostel at the Girls' Polytechnic campus, Guwahati, Assam in India. The geographical location of this institution is 26.183970° N latitude and 91.790340° E longitude.

MATERIALS AND METHODS

Characterization of food wastes:

200 gm of food waste was taken as sample and was tested to find out the parameters as shown in *table-1*. The food wastes were mainly used as the feedstock for the digester. As it can be seen the methane yield to be 47% of the sample waste therefore cow dung should be added initially to the digester as fertilizer.

Table-1 composition of food waste

PARAMETERS	RESULTS
Total Solid	182 mg/kg
Volatile Test	93 mg/kg
Carbon composition	58.2%
Hydrogen composition	2.06%
Nitrogen Composition	0.9%
Methane yield	47%

Characterization of biogas:

Biogas is produced by the methanogenic bacteria in the final stage of the anaerobic digestion process which is called methanogenesis. Biogas can be used for power generation and also can be used as fuel. The bio-geochemical carbon cycle plays an important role in natural biogas generation. In the composition of biogas methane, carbon dioxide, hydrogen sulfide, nitrogen, oxygen, ammonia, chlorinated organic matter, silanes, siloxanes, volatile phosphorous substances, and other volatile trace compounds are found [1].

Table-2 composition of Biogas [1]

Component (volume)	Concentration
Methane (CH_4)	55-60%
Carbon Dioxide (CO_2)	35-40%
Hydrogen Sulphide (H_2S)	2%
Water (H_2O)	2-7%
Ammonia (NH_3)	0-0.005%
Nitrogen (N_2)	0-2%
Oxygen (O_2)	0-2%
(H_2)	0-1%

Stages of Anaerobic Digestion

There are four stages in anaerobic digestion.

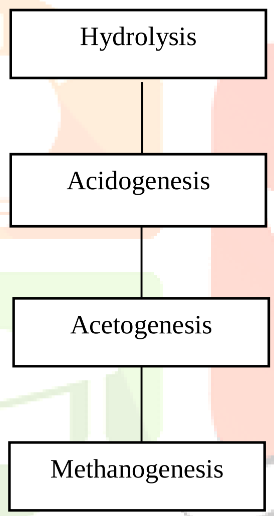

Fig-1 stages of anaerobic digestion process

HYDROLYSIS: It is the initial stage in the anaerobic digestion process. In the process of hydrolysis, hydrolytic bacteria are able to secrete extracellular enzymes that can convert carbohydrates, lipids, and proteins into sugars, long chain fatty acids (LCFAs), and amino acids, respectively [2]. Thus, the complex organic materials are broken down to basic monomers. It is a slow process.

Hydrolysis fraction of organic fraction is represented by the following reaction:

$C_6H_{10}O_4 + 2H_2O \rightarrow C_6H_{12}O_6 + 2H_2$ …. [3]

ACIDOGENESIS: In this stage further fermentation of the slurry into volatile fatty acid takes place. VFAs constitute a class of organic acids such as acetates, and larger organic acids such as propionate and butyrate, typically in a ratio varying from 75:15:10 to 40:40:20 [4].

ACETOGENESIS: Here, the volatile fatty acids break down the complex carbon compounds into simpler compounds i.e. formation of acidic acid takes place. This stage is known as acid forming bacteria stage. Acetogenesis is the process by which the higher volatile fatty acids and other intermediates are converted into acetate, with hydrogen also being produced [5].

METHANOGENESIS: Methanogenesis marks the final stage of anaerobic digestion, where accessible intermediates are consumed by methanogenic microorganisms to produce methane [6]. The methanogenic bacteria are very sensitive to oxygen due to which the pH of the system should not be acidic.

DESIGN AND FABRICATION

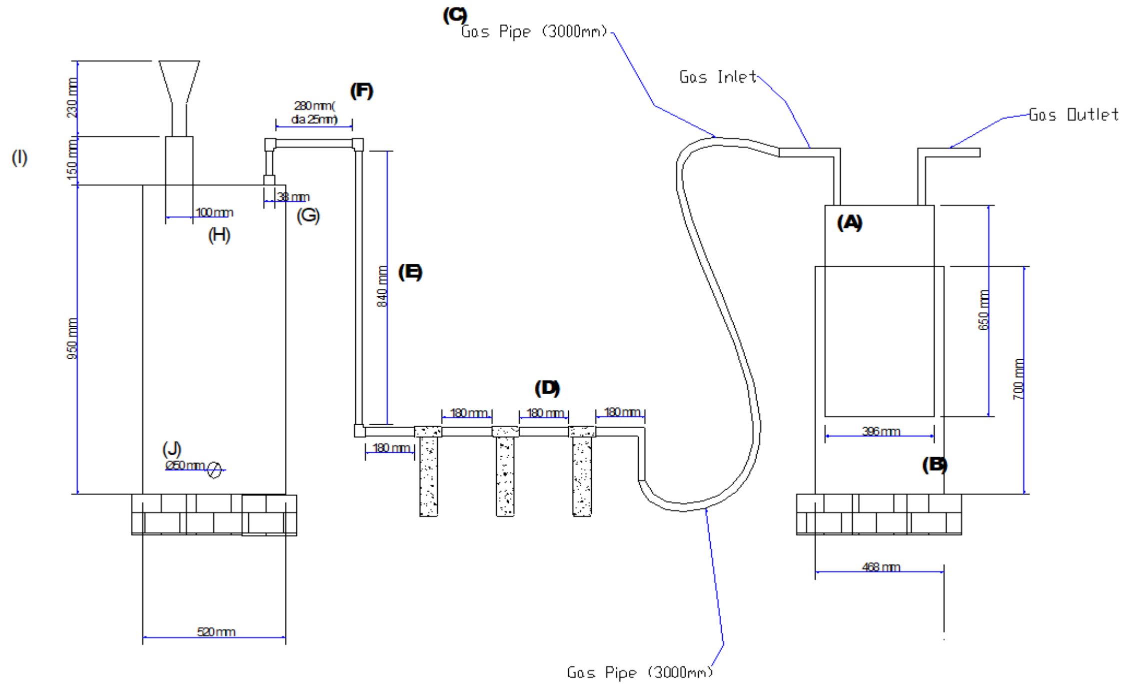

Fig-2 a schematic diagram of the pilot plant anaerobic digester plant.

Figure-2 represents a schematic diagram of the pilot plant anaerobic digestion which is prepared in AutoCAD.
Dimensions:

- A funnel is connected to the inlet PVC union pipe.

Diameter = 101.6 mm
Height = 230 mm

- G – Gas outlet pipe of diameter = 38mm

A valve or switch has also been provided for the gas outlet.

- H - Inlet PVC union: the wastes are fed into the digester through this union.

Diameter = 101.6mm
Height = 150mm
A valve is included in this inlet system for a proper airtight system.

- I - Digester tank: the solid wastes goes through the anaerobic digestion process in this tank of 200litre volume.

Diameter = 634 mm
Height = 950 mm
It is installed upon a pile of bricks of total 140 mm height.

- J – The outlet PVC union pipe of diameter = 50.88mm

It also has a valve to let the slurry pass out of the digester.

- F – connecting pipe of diameter = 254 mm

Length = 280 mm

- E – is also a PVC pipe of length = 840mm

Diameter = 2.54mm

- D – distance between each filter = 180mm
- C – gas pipe of 1.4 m length.
- B = The volume of the gas storage tank = 120 litre

Here 60% volume of the drum is filled with water. Thus, 72 litre of the drum is filled up with water.
Diameter = 468mm

Height = 700mm

- A – The 80 litre drum is placed inversely on the water in 120 litre drum.

Diameter = 396 mm

Height = 650 mm

In order to calculate the volume of the digester, we need two parameters which are the daily feedstock (in litre) and the retention time (RT). The organic matter used is coming from kitchen waste.

The time that the organic matter spends inside the digester is referred to as the retention time (RT). It may differ based on the digester being utilized as well as the climate of the area being investigated. The digester that we will be using in our study is a water storage tank and a floating drum for gas storage. For a digester in a tropical climate we can assume a good retention would be between 25-30 days. The design measurements were according to the construction manual [7].

$RT = \frac{25+30}{2}$

$= 27.5$ days

Daily feedstock is fed to the digester in the ratio 1:1 of kitchen waste and water.

Daily feedstock = (28 kg of waste + 28 kg of water) per day.

= 56 kg per day

Then the digester volume is equal to:

V_d = daily feedstock X retention time

= 56 litre per day X 27.5

=1540 litre

The digester we intend to construct must have a volume of 1540 litre. But due to lack of funds we decided to construct a 200 litre digester tank.

Therefore, Daily feedstock = (3.65 kg of waste + 3.65 kg of water) per day.

= 7.3 kg per day

The final digester volume:

V_d = daily feedstock X retention time

= 7.3 litre per day X 27.5 days

= 200.75 litre

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But daily feeding must be 2 % of the digester volume i.e. 2% of 200 litre = 4 litre.

Fig-3 image of the digester

Polyethylene water storage tank is chosen rather than constructing a digester out of bricks as it becomes time consuming and bears a high cost. The funnel is made of PVC pipe of 4-inch diameter which was cut into required length of 23 cm. The funnel is connected to the inlet PVC threaded union having a diameter of 4 inches. A valve is also fitted in the union to close and open the fed pipe. The inlet union is fitted on top of the digester tank with PVC adhesive glue. It was left to dry for about 1.5 hours. Outlet PVC threaded union: The outlet of the digester for slurry is made out of PVC same as the inlet union. It has a diameter of 3 inches. Also, here a valve is included in the outlet union design. With the help of a drilling machine and a hole saw of 3 inches blade, a 3-inch diameter hole is drilled in the water tank. After the insertion of the union, the PVC adhesive glue is applied to it and was kept for an hour or two.


Fig-4 PVC threaded union


Fig-5 slurry outlet

MOTOR CONNECTIONS

A motor of washing machine is installed on the top of the digester tank as shown in *figure-6*. It has a power of 70 Watts. A regulator and timer was also included in the connection since the speed has to be controlled or else the digester might explode at some point due to aggressive agitation.


Fig-6 motor


Fig-7 timer

The timer is installed with the help of the clock gear mechanism as shown *in figure-7*. The motor is connected to the shaft which is the threaded rod to which also the blades of the stirrer are associated with. It was run for 1 hour daily for stirring the slurry.

AGITATOR

The agitator/stirrer in digesters is installed vertically from the drum as shown in *figure-8*. The stirring blades were fabricated. The Aluminum blades have a total length of 400mm. A threaded screw rod of 12 mm diameter and 945 mm height is fitted inside the blade holes at the center; the screw rod is inserted vertically into the plane of the blades. This enables the openings for the agitator on the digester wall to be submerged in the slurry, thus, preventing the escape of the produced gas. The agitator or stirrer was incorporated into the biogas plant design to provide means of breaking scum produced on the surface of the slurry [8].

The agitator was made in parts that were assembled inside the digester for easy installation and removal [8]. The agitator or stirrer consists of two sets of blades fitted one above the other having a distance of 250 mm connected with a threaded screw rod attached to the motor. The lower end of the rod is connected to a wooden piece of a small platform. The wooden platform of **20 cm X 10 cm X 4 cm** is fitted to the lower part of the tank as shown in *figure-9* to prevent vortex formation of slurry during the stirring process.


Fig-8 stirrer


Fig-9 wooden platform for stirrer

Calculation of the stirrer blades

Density of cow dung slurry

= 1020 kg/m^3

TS = 20 to 27%

Volume of digester = 200 litre

$\frac{D}{T} = 0.4$…………………………… Equation (1)

D= diameter of stirrer

T= diameter of the digester

Total of four blades were fabricated, two blades at bottom and two blades at bottom.

Considering square geometry

Batch volume = $(3.14 * T^3)/4$……. Equation (2)

From equation 1, T = 634 mm

From equation 2, D = 253 mm

POWER OF MOTOR

Bulk velocity (V_c): The speed at which the vessel's bulk mass agitates or mixes after receiving momentum from the agitator has a significant impact on the reactions and workups carried out throughout routine manufacturing.

The scale of agitation:

- 1 – quite mild
- 2 – normal
- 3- vigorous
- 10 – violent

Considering scale of agitation 4,

$V_c = \frac{(4\times 6ft\times 12inches\times 2.54cm)}{100\times 60}$

$V_c = 0.12 m/s$

Pumping Rate

- Pumping rate (Q) = $(V_c * 3.14*T^2)/4$

= $0.038 m^3/s$

The values of flow number and power number can be found from *table-3* below.

Table-3 flow number and power number [9]

Agitator type	N_P	N_Q
45°C Pitched Blade Turbine (PBT)	1.27	0.79
Hydrofoil	0.30	0.56
Rushton	5.20	0.72
GL Retreat Blade	0.35	024
GL Curved Blade Turbine	1.44	0.54

We have two terms N_p and N_q which are power no. and flow no. respectively,

Here, from table-3 N_q can be considered = 0.79

To calculate N (rpm)

$N = \frac{Q}{Nq\times D3}$

N = 178 rpm

N_P depends upon agitation width/ diameter ratio and even on no. of blades used.

N_P = 1.27 from table-3.

Power (P) = $N_P \times density \times N^3 \times D^5$

$P = \frac{1.27\times 1020\times 178^3 \times 0.253^5}{60*60*60*1000}$

= 0.035 Kw

= 35 Watts

Assuming loading of 80%,

Motor power required = $\frac{0.035}{0.8}$ Motor power = 0.0437 kilo Watt = 43.7 Watt

GAS STORAGE

To store the biogas produced I have selected the floating drum type storage. The volume of gas stored is easily noticed by the position of the drum [10]. An 80-litre drum is selected to store gas, and the top head was cut with a hacksaw and placed upside down on a 120-litre drum filled with 72 litre of water. Inlet and outlet PVC pipes were connected to the bottom part of the storage drum. A gas cock is installed with the outlet pipe. The inlet (shown in *figure-10*) and outlet pipes were connected with LPG pipe as the position of the storage drum will be shifting up and down. The gas cock in the outlet pipe was turned on and the drum was placed until it reaches more than halfway into the 120-litre drum to allow for the escape of the trapped air through the gas tubing valve [11]. The main reason for the elimination of air from the gas holder is to minimize the risk of explosion [11]. The air is allowed, aids a combination of methane and oxygen which is an explosive mixture and can cause serious hazards when accidentally exposed to a spark or fire [11]. If the gas holder sinks in the drum even after shutting down the gas cock, then it is an indication of the joints leaking air. The joints should be tested with a soap-water solution; a leaking joint would produce a soap bubble. The arrangement of the floating drum-type biogas storage is shown in *figure-11*.

Fig-10 gas pipe

Fig-11 floating drum type gas storage

Fig-12 arrangement of the anaerobic digestion pilot plant

Three filters are also installed in order to purify the biogas. The three filters aim at removing Carbon Dioxide, moisture and Hydrogen Sulphide from the generated biogas. They are placed at the lower position. Finally, all the elements are assembled and the digester is colored black to absorb the maximum amount of sunlight.

ECONOMIC EVALUATION

<u>Calculation of energy payback time (EPT):</u>

Total cost of the prototype = ₹ 24,370

Cost of one LPG cylinder = ₹ 1100

Therefore, no. of cylinders in ₹ 24,370 $= \frac{24,370}{1100}$

$= 22$

Calorific value of LPG = 46 MJ/Kg = 46000 kJ/0.546 m^3

Mass of gas contained in one cylinder = 14.2 kg

Therefore, gas $= \frac{46000}{0.546} \times 22 \times 14.2 \times 0.546$

$= 14370.4$ MJ

Calorific value of Biogas = 20 MJ / m^3

Volume of biogas required equivalent of 22 cylinders $= \frac{14370.4}{20}\ m^3$

$= 718.52\ m^3$

Therefore, EPT $= \frac{volume\ of\ biogas\ required\ equivalent\ of\ 22\ cylinders}{volume\ of\ biogas\ produced\ per\ day}$

$= 3.2$ years.

Energy payback time is an important profitability indicator which is found to be 3.2 years for the prepared prototype. Sergio Juárez-Hernández and Alejandra Castro-González presented a work on the economic evaluation of prototype biogas plant fed by restaurant food waste [90]. *Table-4* below presents the profitability indicator of the prototype biogas plant by Sergio Juárez-Hernández and Alejandra Castro-González [12]. They designed a digester of 6 m^3 volume [12].

Table-4 prototype biogas plant- profitability indicators [12]

Indicator	Estimated (MXT)
Net present value, MXN	63,816
Payback period years	18

MXN: Mexican Peso

As it can be seen clearly from the table above that the payback period year is 18 years for a 6 m^3 digester volume. With an initial investment of ₹24,370 the current work requires only 3.2 years for the energy payback time which proves to be economically feasible over the work published by Sergio Juárez-Hernández and Alejandra Castro-González.

CONCLUSION

This paper describes the process to develop a prototype small-scale biogas plant that will be fueled by food waste produced on the campus of Girls' Polytechnic in the girls' hostel where 150 students reside. The hostel on average generates 5.75 kg per day of food waste. A quantitative approach has been made to operate a continuous stirring reactor tank to conduct the anaerobic digestion process aiming to operate the project at minimum investment. After the installation of the pilot plant shed was designed. The biggest challenge in this work was the proper operation of the digester. pH was checked daily to avoid failure of the system. Initially, the slurry was found to be acidic but on the 5th day lime solution was added to the system to control the pH. 1/4th of the volume of waste fed into the system on the fifth day which was 4.8 kg. After which the slurry started tending towards basic. The loading rate also plays a very important role in biogas formation. The variations in the pH graphs were also affected by the loading rate. Thus, the organic loading rate should be uniform. In the present work, the initial investment is ₹24,370 and only 3.2 years is the energy payback time which proves to be economically feasible to build a biogas plant at such a small rate. As biogas resources are renewable, the deployment of this technology would therefore be extremely advantageous to the hostel. This waste-to-wealth and waste-to-energy technology would enable affordable gas cooking without bearing additional costs for refueling with petroleum gas.

REFERENCES

1. Amar Kumar Das, Shovan Nandi, Amit Kumar Behera, July 2017," ***Experimental Study of Different Parameters Affecting Biogas Production from Kitchen Wastes in Floating Drum Digester and its Optimization"***, *International Journal of Latest Technology in Engineering*, Management & Applied Science (IJLTEMAS) 3rd Special Issue on Engineering and Technology, Volume VI, Issue VII, ISSN 2278-2540.

2. Li Y., Park S.Y., Zhu J., "***Solid-state anaerobic digestion for methane production from organic waste".*** Renew. Sustain. Energy Rev. 2011;15:821–826. doi: 10.1016/j.rser.2010.07.042.

3. Karena Ostrem Advisor: Prof. Nickolas J. Themeli, May 2004, ***"GREENING WASTE: ANAEROBIC DIGESTION FOR TREATING THE ORGANIC FRACTION OF MUNICIPAL SOLID WASTES",*** Corpus ID: 534512.

4. Bergman E.N. "***Energy contributions of volatile fatty acids from the gastrointestinal tract in various species".*** *Physiol. Rev.* 1990;**70**:567–590. doi: 10.1152/physrev.1990.70.2.567.

5. Hansen C.L., Cheong D.Y. "***Handbook of Farm, Dairy, and Food Machinery Engineering"***. Academic Press; Cambridge, MA, USA: 2013. Agricultural Waste Management in Food Processing.

6. Kiener A., Leisinger T. "***Oxygen sensitivity of methanogenic bacteria"***. Syst. Appl. Microbiol**.** 1983;**4**:305–312. doi: 10.1016/S0723-2020(83)80017-4.

7. J. ED. United States Forces-Afghanistan and A. Kabul, "***Biogas plant construction manual***", online available at https://policy.asiapacificenergy.org/sites/default/files/Biogas Plant Construction Manual.pdf.

8. Chisom Emmanuel Aralu, Daniel Eseoghene Karakitie, David Abimbola Fadare, December 2021, "***Construction of a pilot scale biogas digester at the University of Ibadan Dairy Farm",*** Abadina**,** Fuel Communications Volume 9**, 100033.**

9. Ajay Kumar Kalva, 13th May 2016, "**AGITATION SCALE-UP",** available online at pharmacalculations.com.

10. Osei-Marfo, M., Awuah, E., & de Vries, N. K. (2018). "***Biogas technology diffusion and shortfalls in the central and greater Accra regions of Ghana. Water Practice and Technology",*** 13(4), 932–946**.** doi:10.2166/wpt.2018.100.

11. ONONOGBO.C. NWUFO, O.C., NWAIWU C. F. and IGBOKWE, J. O (2015), "***AN INNOVATIVE APPROACH TO CONSTRUCTION ANDOPERATION OF BIODIGESTERS: A CONSDERATION OFFLOATING DRUM BIOGAS PLANT",*** TLEP International Journal of Mechanical Engineering Research, vol.-1, no.-3.

12. Sergio Juárez-Hernández, Alejandra Castro-González, 2015. **"*Design and Economic Evaluation of a Prototype Biogas Plant Fed by Restaurant Food Waste*",** INTERNATIONAL JOURNAL OF RENEWABLE ENERGY RESEARCH J.Hernández and C.González,Vol. 5, No. 4.