DESIGN OF NOVEL BIOCNG PRODUCTION PLANT USING MIXED AGROWASTE AS AN AFFORDABLE SOURCE OF GREEN HYDROGEN

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Abstract

Fossil fuels are inadequate to satisfy the demands of increasing energy consumption as the pace of industrialization and consumption is quite high. It is important to consider renewable and recyclable energy resources such as biogas, Biomethane and BioCNG. These raw to purified fuels have several advantages in terms of production costs as well as reduction in environmental pollutants. The management and handling of conventional fossil fuels is difficult compared to the renewable fuels. The current technology used for production of fuels is not found to be commercially viable or environmentally safe, so there is a need to focus on efficient techniques such as BioCNG. The BioCNG has many advantages such as half of the cost of gasoline and diesel, tailpipe emissions lower than fossil fuels, reduction in imports, and significant support to establish circular economy.

Researchers have synthesized BioCNG production mechanisms and many of them are commercialized which are based on cow dung, poultry liquor, kitchen waste and spent wash substrates. However, no significant work is done with mixed agro-waste as the substrate for digestion. This is the unique attempt presented herewith to address and tap the potential of usage of mixed agro-waste for BioCNG production which is available in India in ample quantity. The present work emphasizes on the production of BioCNG from various waste, especially from mixed agro-waste and highlights the significance of agro-waste in energy self-sufficiency of India

Keywords: *Energy, Renewable, Agrowaste, BioMethane, Energy Consumption, BioCNG*

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1.Introduction

An important method for treating organic waste is anaerobic digestion. The technology has been around for a while and has been routinely used on a limited basis to treat sewage and farm manure. Its commercial potential, however, has only recently been investigated. Recent developments have made it possible to produce renewable natural gas, a product with quality equivalent to natural gas and with a wide range of applications, whereas old technology resulted in the generation of biogas, a product with poor calorific value and few applications.[1]

Understanding the various technologies in-depth is crucial for potential investors in order to build a workable renewable natural gas plant. The many phases involved in anaerobic digestion and the technology available are described in detail in this research paper.[1][2]

2. Details of biogas plant and technology

2.1 Technology process description.

Anaerobic digestion, a process, is how biogas is made for use in industry. To create biogas and digestate, the procedure entails breaking down organic waste materials like animal waste, food waste, and industrial sludge. Later, the latter is prepared for use as fertilizer. An anaerobic digester, also known as a sealed, oxygen-free tank, is where the anaerobic digestion process takes place. Scrubbing, upgrading, and compression (200 bar pressure) procedures are applied to the produced biogas to create renewable natural gas (RNG).[2]

Anaerobic digestion process can be classified into different types based on the following parameters:

- Operating temperature
- Feedstock variation
- Wet (low-solids) and Dry (high-solids)
- Batch vs. continuous flow [2]

2.2 Types of processes by operating temperature

- Different goal temperature ranges can be used to operate digesters. Normal temperature ranges for mesophilic and thermophilic organisms are 30 to 38 C and 50 to 60 C, respectively. Different anaerobic bacteria communities flourish in various temperature ranges.[2]
- When more pathogen death is required, thermophilic anaerobic digestion (AD) is typically performed. Due to the lack of pollutants, the sludge produced at these temperatures can be applied directly to crops without prior treatment. The processing of feedstock using thermophilic digesters takes less time, but may be more expensive and challenging to operate.
- Although mesophilic digesters are more widely utilized and simpler to operate and maintain, they do not sufficiently eliminate pathogens to generate sludge of higher quality.[1][2]

2.3 Types of processes by feedstock variation

Some digesters are made to handle a certain kind of feedstock, while others are made to handle a variety of feedstock. Anaerobic digester growth is frequently fueled by co-digestion. Pre-processing before digestion is necessary for many feedstocks or can be advantageous (e.g., blending, screening, thermal conditioning, etc.) [2]

Anaerobic digestion process involves 4 steps:

1. Pre-processing of organic waste
2. Anaerobic digestion for the production of biogas
3. Biogas scrubbing and upgradation to renewable natural gas (RNG)
4. Treatment of digestate to produce manure [3]

3. Pre-processing of organic waste

The pre-processing step involves adding water to the solid organic waste after segregation in order to turn it into a slurry form. The organic waste is obtained from numerous feedstock sources, including commercial, industrial, and agricultural waste. The sort of trash will determine how much water has to be added. The amount of water needed for a 10 TPD plant using food waste as a feedstock is 1:0.5. (H_2O). This water could be recycled in vast quantities. The amount of additional fresh water required is modest if industrial organic waste water is one of the feedstocks being used (as part of a co-digestion plant).

When pre-processing agricultural waste, a further step is required in which the waste is chopped up and hydrolyzed to liberate the cellulose component for digestion by microorganisms. The agro waste is combined with other feedstock and placed in the hydrolysis or pre-digester tank after hydrolysis.[1][2][3]

4.Production of biogas by anaerobic digestion

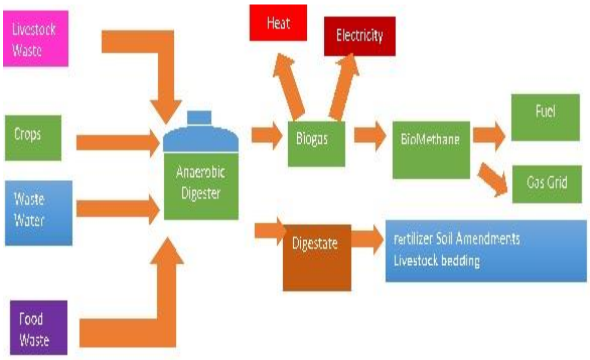


Fig 1: Specially designed Biogas production process by anaerobic digestion

4.1 Raw material and equipment used

The raw materials and equipment required for biogas production include:

- Biomethanation plant consisting of hydrolysis holding tanks, N2 dosing system, digester tanks, cooling tank, and sludge separator
- Agitator
- Sensors (Either electronic or pneumatic)
- SCADA connected panel system

4.2 Process description

- After the feedstock has undergone pre-processing, it is fed into the hydrolysis tank where it is allowed to undergo pre-digest for two to three days before being sent to the digester, where mesophilic or thermophilic organisms perform the digestion. By maintaining ideal conditions for variables like temperature and pH, the microorganisms can either be added separately or made to grow inside the digester.[3]
- The temperature in a range of 30-38˚C at atmospheric pressure for mesophilic organisms is maintained
- Continuous or intermittent sludge feeding and sludge withdrawal is done, with the feeding rate being 1.6 to 6.4 kg VS/m^3/day
- The digestion process to produce biogas takes place in four steps:
  1. Hydrolysis
  2. Acidogenesis
  3. Acetogenesis
  4. Methanogenesis

- The complex organic molecules undergo hydrolysis, which reduces them to simple sugars, amino acids, and fatty acids.
- By way of acidogenic (fermentation) bacteria, the residual components are further broken down. Along with other by-products such ammonia, carbon dioxide, and hydrogen sulphide, volatile fatty acids are produced.
- Simple molecules produced during the acidogenesis phase are further broken down by acetogens to produce mostly acetic acid, along with carbon dioxide and hydrogen, in the process of acetogenesis.[4]
- Methanogens utilize the byproducts of the earlier stages in the final phase to break them down into methane, carbon dioxide, and water.
- Methanogenesis takes place between pH 6.5 and pH 8, and it is sensitive to both high and low pHs.
- Unreacted materials get settled in the bottom of digester which is removed at intervals.
- Digestate, the product of anaerobic digestion, is also produced during the biogas production process. Use of this digestate as fertilizer.[3][4]

5. Production of Renewable Natural Gas (RNG) from biogas

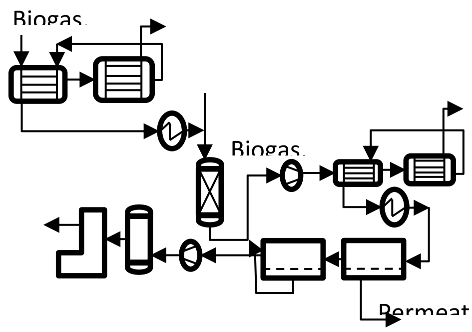


Fig 2: Flow diagram used in present study for upgradation of biogas to BioCNG

6. Biohydrogen

An easily biodegradable agro-resource is converted into biohydrogen, a renewable energy fuel. It is a source of renewable energy, and because each hydrogen molecule has a high enough energy, it may be burned as fuel. creates water as a result of combustion. The discovery and advancement of hydrogen technology has given rise to fresh optimism for the proliferation of renewable energy sources to stabilize the effects of global warming brought on by pollution from the burning of fossil fuels. Organic biodegradable substances that can be employed as a substrate during autotrophic conversion processes, where photosynthesis plays a crucial role, are necessary for the activities involved in the creation of biohydrogen. In such a situation, it is necessary to use specific organisms (algae, protists, and single-celled microorganisms) that can facilitate the direct conversion of the sun's energy to hydrogen.[5][6]

The complex series of actions that make up the biohydrogen production process are constrained by the heterogeneous nature of the substrate being used, regardless of whether or not it has a complex structure and inhibits microbial activity. This is supported by research on the pretreatment of corn stalks for biohydrogen production, which appears to boost yield in both acid and alkaline treatment, in comparison to other pretreated feedstock employed. [7][8]

7. Design of biogas plant

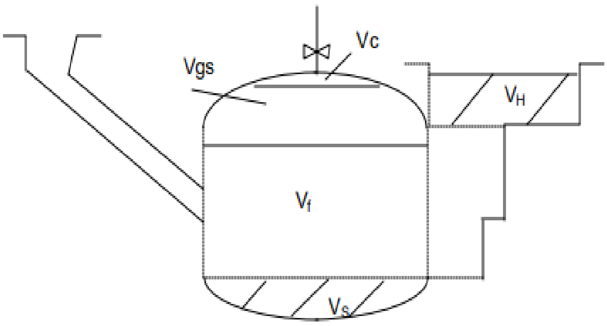


Fig 3: Cross section of a digester [9][10]

a) Volume of gas collecting chamber = V_C
b) Volume of gas storage chamber = V_{gs}
c) Volume of fermentation chamber = V_f
d) Volume of hydraulic chamber = V_H
e) Volume of sludge layer = V_S

Total volume of digester **V** = $V_C + V_{gs} + V_f + V_S$

7.1 Geometrical dimensions of the cylindrical shaped biogas digester body

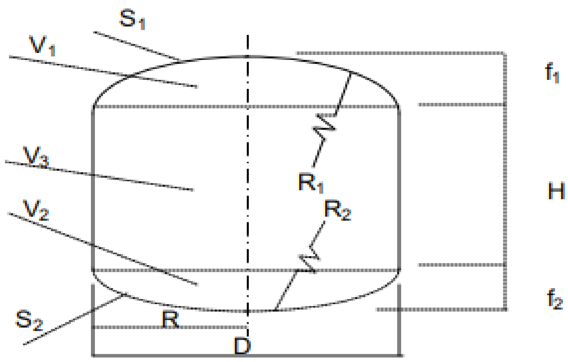


Fig 4: Dimensions of the biogas digester body

7.2 Assumptions [11][12]

For volume	**For geometrical dimensions**
$V_C \leq 5\%$ V $V_S \leq 15\%$ V $V_{gs} + V_f = 80\%$ V $V_{gs} = V_H$ $V_{gs} = 0.5(V_{gs} + V_f + V_S)$ K Where K=Gas production rate per m^3 digester volume per day. For Bangladesh K = 0.4 m^3/m^3d. [14]	D= 1.3078 X $V^{1/3}$ $V_1 = 0.0827 D^3$ $V_2 = 0.05011 D^3$ $V_3 = 0.3142 D^3$ $R_1 = 0.725$ D $R_2 = 1.0625$ D $f_1 = D/5$ $f_2 = D/8$ $S_1 = 0.911 D^2$ $S_2 = 0.8345 D^2$

7.3 Volume calculation of digester and hydraulic chamber

Volume calculation of digester chamber [15]

Given: 60kg of biomass per day

Sr. No.	**Variable**	**Values**		
		60 kg/day	**500 kg/day**	**10000 kg/day**
1	V	6 m^3	50 m^3	1000 m^3
2	D	2.40 m	4.82 m	13.8 m
3	H	1 m	2 m	5.52 m
4	R1	1.74 m	3.5 m	10.005 m
5	R2	2.55 m	5.12 m	14.662 m
6	f1	0.480 m	0.964 m	2.76 m
7	f2	0.30 m	0.6025 m	1.725 m

Temp. = 30°C (average)

Solution:[16]

Let Hydraulic Retention Time (HRT) = 40 days (for temp. 30°C)

Total discharge = 10 kg X 6 = 60 Kg/day

TS of fresh discharge = 60 kg X 0.16 = 9.6 Kg

In 8% concentration of TS (To make favorable condition)

8Kg. Solid = 100 Kg. Influent

1Kg. Solid = 100/8 Kg influent

9.6 Kg. Solid = 100 X 9.6/8 =120 Kg. Influent

Total influent required = 120 Kg.

Water to be added to make the discharge 8% concentration of TS

=120 Kg – 60 Kg = 60 Kg.[17]

Working volume of digester = $V_{gs} + V_f$

$V_{gs} + V_f$ = Q.HRT

= 120 Kg/day X 40 days

= 4800 kg

= 4.8 m^3

From geometrical assumptions

$V_{gs} + V_f = 0.80$ V

Or V = 4.8/0.8 = 6.0 m^3

& D= 1.3078 X $V^{1/3}$= 2.376 m = 2.4m

Again

$V_3 = (3.14 \times D^2 \times H)/4$

(Putting $V_3 = 0.3142\ D^3$)

Or, H = $(4 \times 0.3142 \times D^3)/(3.14 \times D^2)$ = 0.96 m

Say H = 1.00 m

Now we find from assumption as we know the value of 'D' & 'H' [8][9]

f_1= D/5 = 2.40/5 = 0.480m

f_2= D/8 = 0.30 m

R_1= 0.725 D = 1.74m

R_2= 1.0625 D = 2.55 m

$V_1 = 0.0827\ D^3 = 1.143\ m^3$

$V_C = 0.05V = 0.3\ m^3$

Now the dimension of digester chamber is known & drawn below[18][19]

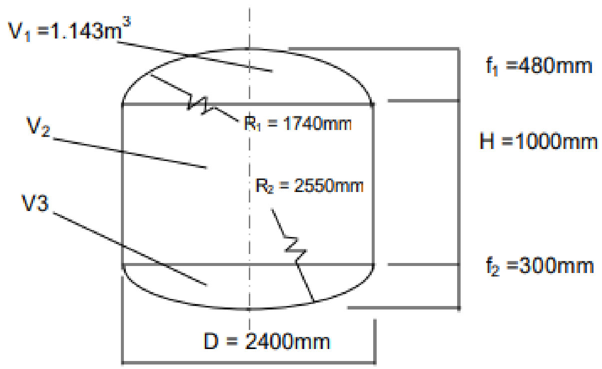


Fig 5: Dimensions of digester chamber

Now we know the dimension of the hydraulic chamber. Moreover, keeping h = 800 mm, we can choose or re-arrange the dimension considering availability of site and construction suitability. For most suitable dimensions we can select the drawing for 60 Kg cow dung per day as raw material [19]

8. Results and discussion

Table 1: Pilot design calculations

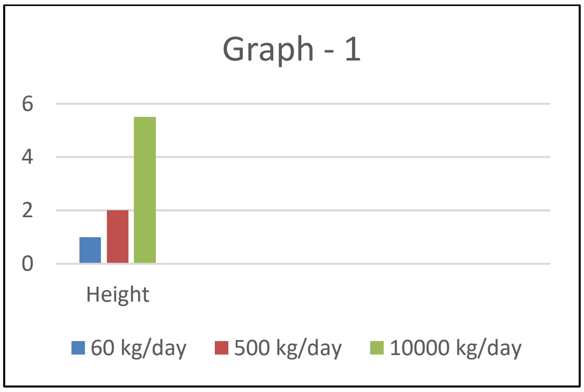


Fig 6: Scale up design for higher productivity

Table 2 : Variation of intrinsic volumes for different sized bio digesters

Sr. No.	Variable	Digester size D_H		
		2.85 m	**4.19 m**	**18.21 m**
1	VC	0.3 m^3	2.5 m^3	50 m^3
2	Vgs	1.344 m^3	13 m^3	224 m^3
3	V	1.644 m^3	15.5 m^3	274 m^3

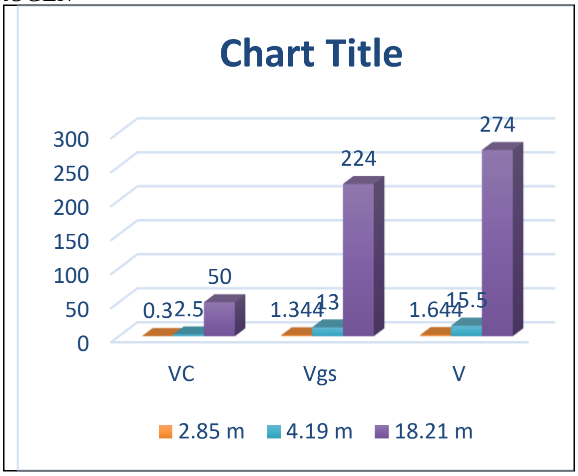
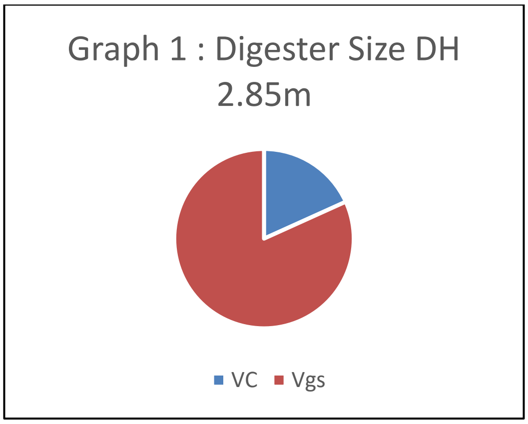
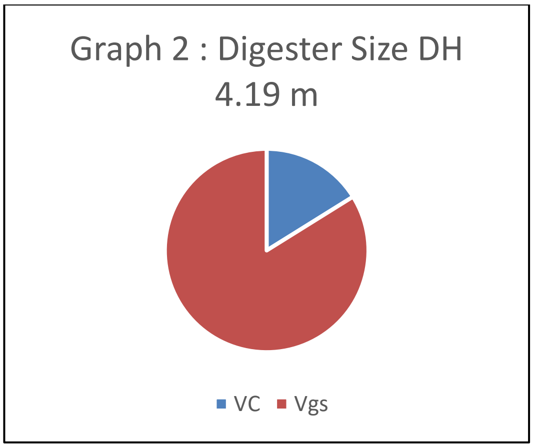


Fig 7: High rise in Vgs proving effectiveness of the present research





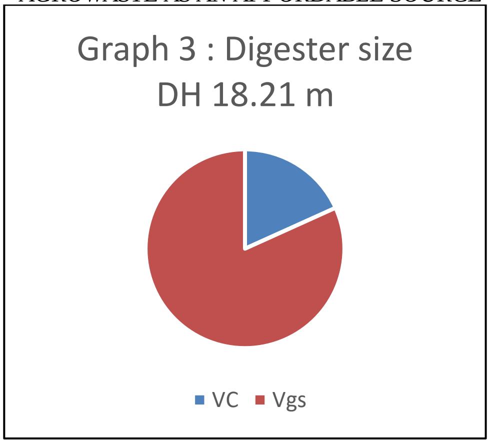


Fig 8: Variations in digester size with collecting gas and storage gas volumes

9. Conclusions

In addition to electricity, direct firing and Green Hydrogen generation are other promising applications of the renewable bio natural gas. Many urban local bodies in India have installed many biogas plants in both the rural and urban areas based on cow dung. Fossil fuels will soon be phased out in favor of biogas as a fuel source. With this, the greenhouse effect and global warming will both decline in the upcoming years. Awareness and education will undoubtedly continue to be the most effective approaches to promote the usage of biogas as we move into the twenty-first century. Many such researches have been observed and studied in India recently including biomass-based gasifiers and crude oil based systems. [20-23].

This research article is essentially on using mixed agrowaste for producing high yield second generation bio CNG. The increased yield and enhanced design for that production is discussed in this article. It is found that the mixed agrowaste biodigesters need special designs rather than using conventional cow dung-based plants. The product analysis with pilot scale studies on such biodigesters seems interesting to work upon and shall be the future study work.

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