International Journal of Recent Trends in Engineering & Research
ISSN (ONLINE) : 2455 – 1457
IMPACT FACTOR : 4.101

Implementation of Custom Made Mini Biogas Plant Using Organic Waste

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Abstract—This paper is a complete report on the real-time implementation of a custom-made mini biogas plant for cooking and transport applications using organic waste formed in a college canteen. Biogas is a useful fuel for heating, generation of electricity and transport applications. The generation of solid and biodegradable waste is increasing day by day. These wastes are being dumped as landfills. If the wastes could be used to produce biogas, it would be a wealth out of waste. Therefore, considering the need for 'Reduce, Reuse and Recycle', the organic waste formed in a college canteen was used to produce biogas and the sludge is used as manure for the college garden. For the anaerobic decomposition by microorganisms, a digester was designed based on the amount of organic waste obtained and the space available to install the plant. For decomposition, a suitable temperature and pressure range is required. Circuitry with pressure, temperature and gas sensors were implemented to verify the parameters. After a period of one month, the gas generated in the digester was tested in a lab to measure its composition. The lab results ensured the biogas formation as the constituents of generated gas are methane, carbon dioxide (CO_2), Hydrogen Sulphide (H_2S) and oxygen. Content of methane was higher, which shows that the calorific value of the generated biogas is higher. Tests were conducted to check the effectiveness of produced biogas for heating application and operation of IC engines. The results prove that the generated biogas could be well used for heating and transport applications.

Keywords—*Anaerobic decomposition; biogas; digester; organic waste; substrate*

I. INTRODUCTION

In most urban and rural areas, kitchen waste is disposed of as landfill or just discarded, which causes public health hazards like malaria, cholera, typhoid, etc. Inadequate management of waste causes several adverse consequences: It not only leads to polluting surface and groundwater and further promotes the breeding of flies, mosquitoes, rats and other disease-bearing vectors. It emits unpleasant odor and methane, a significant greenhouse gas that contributes to global warming. Therefore, this so called waste could be utilized subsequently to substantiate the production of fuel.

Allocating this waste into biogas also means that higher efficiency and reduced cost of fuel is inherited. As organic waste is formed every day in a college canteen, means are found to convert this waste into usable fuel and hence the implementation of a biogas plant was planned. Organic waste is a combination of food and vegetable wastes. Food waste is generated from the remains or unconsumed food. Typically, vegetable waste is the accumulation of cutting and peeling of vegetables. These wastes can be decomposed by microorganisms and produce biogas and bio-fertilizer, which are resources for fuel generation and agriculture.

II. BY-PRODUCTS AND COMPOSITION OF BIOGAS

In a biogas plant, two primary by-products are methane and enriched compost matter. Methane has high calorific value and hence is an efficient fuel for heating. [1] - [3] Table 1 shows the composition of biogas and their calorific value.

Table 1. Major Composition of Biogas

Content (Avg %)	Calorific Value (Kj/Kg)
Methane (50-70%)	55.5
Carbon-di-oxide (30-40%)	30.2
Hydrogen sulfide (5%)	10

Kitchen waste consists of an organic material having high caloric value and highly nutritive added by microbes, and that is why several orders of magnitude could increase methane production. It means the size of the reactor and the cost of biogas production is reduced.

Compost manure acts as a fertilizer in the most economical and adequate texture and boosts agriculture.

Biogas plants may be seen only in few places at the present time but are capable of significant development in the future. Biogas is capable of replacing and turning the table round to reduce the import of oil and pollution. Thus, this could be anticipated to secure and work as the best alternative to a nation's persistent energy requirement.

III. METHODOLOGY

Based on the area provided for the installation of a biogas plant, it was decided to construct a floating dome type of biogas plant, as the efficiency of this type is also higher. The components of a biogas plant are

- Digester
- Floating dome
- Gas outlet pipe or biogas delivery tube
- Inlet pipe for substrate (organic waste)
- Outlet pipe for sludge (decomposed waste)
- Nozzles and Valves
- Measuring Instruments – pressure, temperature, and gas sensor.

3.1. WORKFLOW

The workflow planned to implement the biogas plant is given below.

- ➢ Analyze the availability of organic waste and area for plant installation
- ➢ Determine the size and design of the mentioned components.
- ➢ Determine the availability of the substrate.
- ➢ Develop or purchase the components as per the calculated dimensions.
- ➢ Install the Biogas plant.
- ➢ Add substrate into the digester.
- ➢ Close digester for a minimum period of one month to enable anaerobic decomposition and hence biogas production
- ➢ Test the produced gas for its composition and applications.

3.1.1. Availability of organic waste

In the college canteen, an average of 400 people utilize the service per day, and approximately 20 Kg of kitchen waste is generated per day. It is an ideal quantity of garbage to install a mini biogas plant near the college canteen kitchen.

3.1.2. Space available for biogas plant

The biogas plant was planned to be constructed inside a college next to its canteen. Hence the space available is limited and cannot be expanded. Therefore, to install the biogas plant within the area, measurements were meticulously determined to fit the plant and the digester's design. The measurements for the allocation of space for the digester are shown in figure-1.

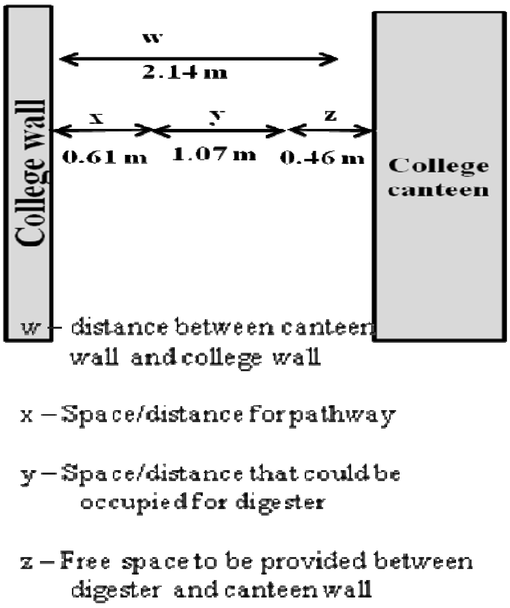

Figure-1. Space allocation for Biogas plant

3.2. PROPOSED MODEL OF PLANT LAYOUT

Based on the calculated amount of organic waste obtained per day from the canteen and the space available for installation of the plant, a model layout for a low-cost mini biogas plant was made, as shown in Figure-2.

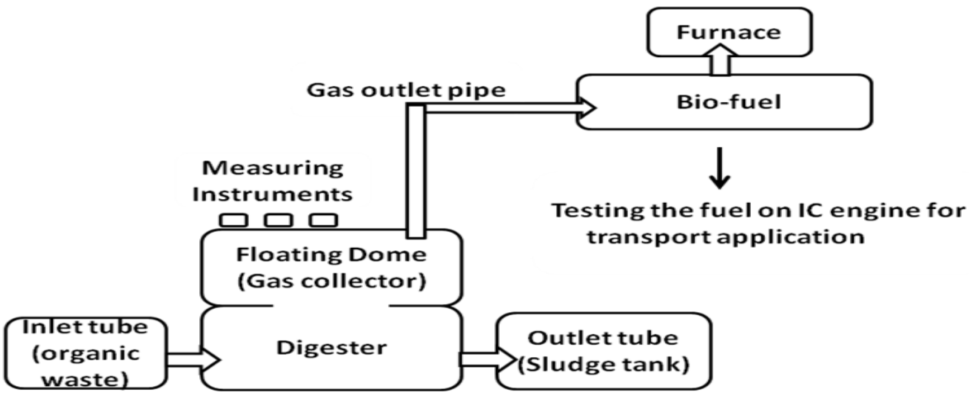

Figure-2. Layout of Mini Biogas plant

3.3. PROCESS FLOW CHART

The production of biogas involves a simple but efficient and less time-consuming process. The process is shown in Fig.3. The composition of biogas generated in the digester was determined to identify the effectiveness of the gas produced.

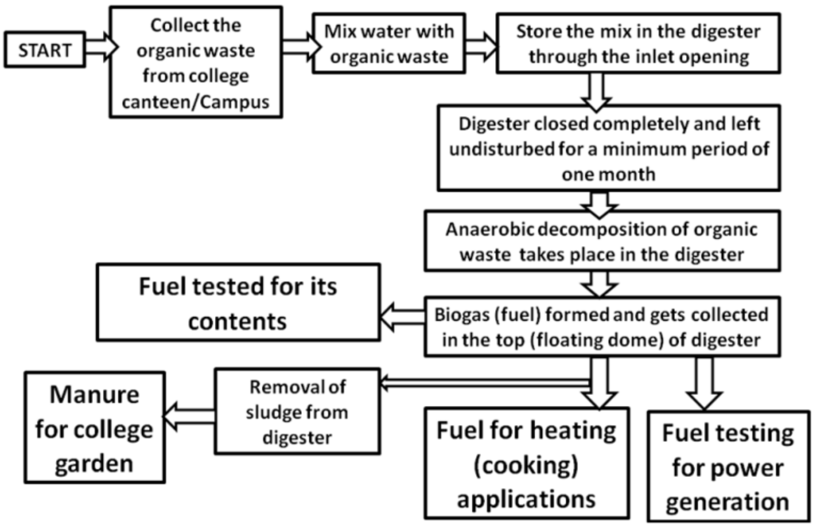

Figure-3. Process Flow Chart

IV. DESIGN OF COMPONENTS

The significant component in a biogas plant is the digester tank. It occupies more space. Hence, in addition to the substrate volume, the space available for plant installation should also be considered for the design of the digester.

4.1. DESIGN OF DIGESTER

There are various types of digesters available for implementing anaerobic decomposition. Depending on the technology, anaerobic digesters can typically handle between 2 to 13 percent total solids (TS), which would require dewatering the manure before digestion or only sending the higher strength wastes (i.e., high solid content) to the digester. A floating dome type digester was constructed due to its higher reliability and efficiency.

The digester size was calculated based on the time the substrate needs to remain in the digester for adequate digestion. The duration of time the substrate stays within the digester is known as the **Hydraulic Retention Time** (**HRT**). A minimum period [4] – [5] of 30 days is required for the production of biogas and the required pressure inside the digester for the biogas to be pushed out. Hence, HRT is fixed as 30 days.

The size of the digester i.e., the digester volume, $\mathbf{V_d}$ was determined [6] based on the chosen **HRT** and the daily substrate input quantity, $\mathbf{S_d}$. The substrate is a mixture of organic waste and water.

➢ QUANTITY OF SUBSTRATE

Initially, cow dung [2] was added along with kitchen waste to increase or kick start the anaerobic decomposition.

• Solid waste = Food waste + cow dung
= 20 kg + 10 kg
= 30 kg

• Substrate (waste + water)
• For liquid and solid waste, the water added should be 10% and 30%, respectively.
• Weight of substrate (S_d)
S_d = Solid waste + water
= 30 kg + 9 kg (since 30% of 30kg = 9 kg)
= 39 kg
= 0.039 m^3
Therefore,
Volume of the substrate, Vs = 0.039 m^3.

➢ **VOLUME OF DIGESTER**

$V_d = S_d$ in m^3 * HRT
Considering HRT as 30 days,
V_d = 0.039 * 30
= 1.17 m^3
For a substrate amount of 20 kg per day, the required volume of the digester is 1.17m^3. But, expecting future expansion and considering higher amount of waste from the whole campus, it is decided to fix a higher volume for the digester.
Therefore, $\mathbf{V_d = 2\ m^3}$

➢ **DIMENSIONS OF DIGESTER**

• Volume of the digester = (pi) r^2 h = 2 m^3
• Diameter of digester, d = 1.07 m
• Height of the tank, h = 2.22 m
• Circumference of the tank = 2 π r = 3.34 m
• Base surface Area = π r^2 = 0.899 m^2

➢ **FLOATING DOME**

The floating dome is a tank or pressure vessel provided on the top of the digester tank to collect the formed biogas. As the pressure increases due to the gradual formation of biogas, the floating dome starts to rise, thereby allowing gas accumulation**.** The gas storage drum is made up of PVC material, and the diameter of the tank is 0.9m.

➢ **SUBSTRATE INLET PIPE**

Inlet pipe is provided to feed the substrate into the digester. PVC pipe of the required diameter was selected for the purpose. Organic waste is led straight into the digester tank at a steep angle through the inlet pipe. The Inlet pipe diameter is about 25-30 cm.

➢ **NOZZLE AND VALVES**

A nozzle was designed to control the direction of the fluid's flow or characteristics (especially to increase velocity) as it exits (or enters) an enclosed chamber or pipe. Valves are provided near the nozzle for closing, opening and controlling the flow of fluid.

➢ **GAS OUTLET TUBE**

A gas outlet tube is a discharge tube which discharges bio-gas from the gas storage drum. The diameter of the gas tube is 3cm. It leads the bio-gas to the furnace. From the distance between the nozzle and the furnace, the length of the gas tube was determined as 3 m,. An outlet tube for gas is connected to the furnace for using the biogas for heating applications.

- **OUTLET PIPE FOR SLUDGE**

The outlet pipe is called a discharge tube, which is made up of PVC material. Sludge is a semi-solid by-product produced during biogas treatment. This sludge is used for agricultural applications. The sludge is stored in a tank, which is called a sludge tank. Sludge is the waste of the anaerobic process in the biogas plant. It consists of water, dry matter, nitrogen and potassium. The sludge is collected into a tank through an outlet tube and planned to be used as garden manure.

4.2. MEASURING INSTRUMENTS

Anaerobic decomposition of the substrate will occur with the proper availability of parameters like temperature and pressure inside the digester. These parameters play a vital role in the production of biogas effectively in a limited time. Table 2 shows the significance of digester parameters.

Table 2. Significance of digester parameters

Parameter	Significance
Digester Temperature (around 37°C)	The occurrence of anaerobic decomposition
The pressure created inside the digester	High enough to enable the breakdown of organic material and for the formed biogas to travel out of the digester tank.
Methane gas	It has a high calorific value, hence should be of higher percentage for efficient heating.
H_2S gas	Pollutant hence should be of low quantity.

Therefore, to measure the temperature and pressure inside the digester and detect gas leakage, appropriate circuitry is provided with sensors, controllers, and display units. Programs are coded and executed to accomplish the process of measurement. The display unit is placed on the top of the digester to show the reading. Table 3 presents the sensors used to measure the parameters.

Table 3. Sensors used for measurement

Parameter	Sensor Used	Purpose
Temperature	BMP180	To measure temperature and pressure inside the digester tank
Pressure		
Gas	MQ-5	To detect leakage of gas out of the digester.

The sensors are interfaced with the Arduino Uno controller to derive the measured parameters.

4.3. 3D MODELING OF COMPONENTS

A 3d model of the digester, floating dome, inlet and outlet pipes is designed based on the calculated dimensions to understand the construction and assembly of components. The software **Tinkercad** was used to develop the 3D model.

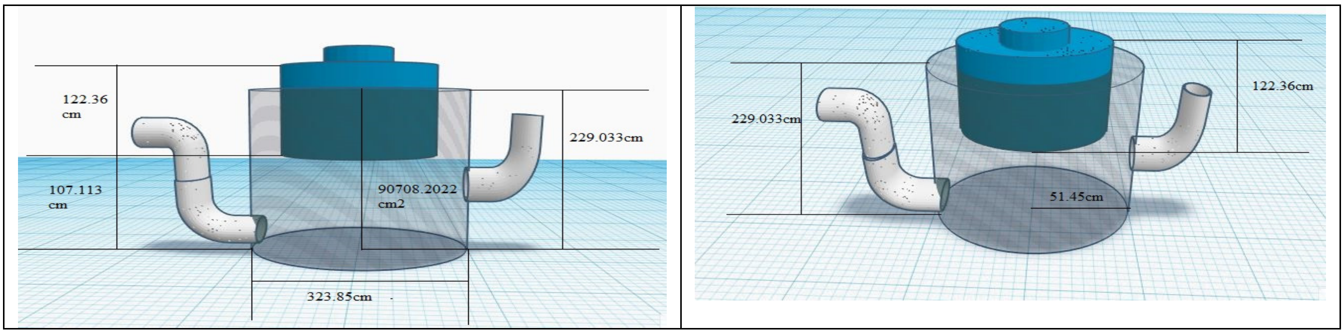

Figure-4. 3d model of digester using Tinkercad software

V. CONSTRUCTION OF PLANT

The components were developed for the calculated dimensions. The various parts are assembled. The digester tank is fitted with the inlet pipe, floating dome, outlet pipe and gas outlet tube, and installed in position in the space allotted for the biogas plant. The figure.5 shows the picture of the installed plant.

(A)

(B)

Figure-5. (A): Digester tank with a floating dome, inlet and outlet pipe (B): 1. Substrate inlet pipe 2. Digester tank 3. Nozzle and valves, 4. Floating dome 5. Gas outlet tube 6. The sludge outlet pipe 7. Pressure and Temperature sensors 8. Gas sensor

After installing the entire set up, the digester was loaded with the collected and measured quantity of substrate (waste + cow dung + water). The digester was closed entirely to favor the process of production of gas. The values of temperature and pressure readings are noted regularly. It is also evident from the gas sensor's reading that there is no leakage of gas. After a month, the gas outlet tube's valve was opened to check for the production of gas.

VI. TESTS AND RESULTS

6.1. MEASUREMENT OF PARAMETERS

The [5] temperature and pressure developed inside the digester are measured to verify the suitability for anaerobic decomposition by microorganisms. Table 4 presents the measured values of the significant parameters.

Table 4. The measured value of the required parameters

Parameter	Measured value	Desired value
Temperature	35 ^{o}C	37 ^{o}C (avg.)
Pressure	5 kPa	2.5～10kPa

The comparison of measured values with the desired values shows the availability of favorable conditions for the decomposition of organic waste.

6.2. TEST FOR BIOGAS COMPOSITION

The biogas comprises Methane, Carbon-di-oxide (CO2), Hydrogen Sulphide (H2S) and Oxygen. The calorific value of methane is higher. Hence, a higher percentage of methane in biogas would prove the effectiveness of the generated biogas. The biogas produced was stored in a gas storage bag and given to a 'private lab' to determine the gas's effectiveness. Table 5 shows the composition of produced gas as issued by the lab.

Table 5. Composition of produced Biogas

Parameter	Unit	Test value
Methane	%	45.1
CO_2	%	41.3
H_2S	ppm	0.6
O_2	%	5.5

The test results show a higher percentage of methane. This value is received after a minimum period of 30 days. Higher composition of methane could be achieved as the number of days increases. Hence it is evident that the produced biogas could be used for heating applications as the calorific value of methane is higher.

6.3. HEATING APPLICATION

The biogas generated in the digester was transmitted to a burner through the gas outlet tube and the distance between the digester nozzle and the burner is 3m; accordingly, tubing was arranged. Initially, when the gas output to the burner was checked after 20 days, firing could not be achieved as the pressure for gas flow from digester up to burner was not sufficient. Then, the output was checked for burning after 30 days, and the goal was achieved. The biogas resulted in a well-burning flame and served for 2.5 hours per day for cooking application.

6.4. TRANSPORT APPLICATION

Biogas is capable of operating IC engine [7]. Hence it could be considered a useful fuel for transport. The biogas generated in the digester is fed to an IC engine. For initial combustion, 2ml of petrol was added. The combustion process was successful, and the biofuel was supplied for the successful operation of IC engine. The IC engine used for testing the biogas as a biofuel was the Hero Honda Passion Plus, 97.2cc, single-cylinder, 4-stroke, air-cooled, wet multi-plate clutch, Digital CDI 8.8:1

compression ration OHC based engine with a bore and a stroke of 50 mm and 49.5mm respectively to give a maximum power of 7.37 bhp at 8000 rpm and a maximum torque of 7.95Nm at 5000 rpm.

It was ensured that IC engine could be operated using the biogas produced from the mini plant. Further, the test with the vehicle needs to be performed and analyzed.

6.5. MANURE FOR AGRICULTURE

The biogas plant consists of two parts. One is the production of biogas, and the other is the formation of fertilizer [8]. The decomposed waste from the digester tank is collected in the sludge tank. The sludge is rich in nutrients and hence is used as manure for the college garden. In the digester drum, only the organic matter breaks and produces biogas, and ultimately there is no loss of nutrients. Figure(7) shows the collection of sludge through the outlet pipe and its use as manure for the garden plants, respectively.

Figure-7. Collection of sludge through the outlet pipe (left picture); The sludge as manure for the garden plants (right picture)

VII. CONCLUSION

A mini biogas plant was successfully completed. The fixed targets of testing the produced biogas for heating and transport applications were performed, and the results are found to be effective. Therefore, the gap between demand and supply for energy sources can be reduced by converting biodegradable kitchen waste into biogas. It is a source of renewable green energy. The biogas can be used as cooking gas and also can be used as fuel for transport. The leftover sludge can be packed and used as manure and compost for agriculture forming. There is a need to investigate further the cost of economics and utility returns to establish the plant and run the unit for 365 days a year at the residential community level.

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