CHAPTER 3

METHODOLOGY

3.1 BIOGAS PLANT

A biogas plant using mess food waste, such as leftovers from cafeterias or dining halls, is an effective solution for managing organic waste while generating renewable energy. In this setup, food scraps are collected and fed into an anaerobic digester, where bacteria break down the organic material in the absence of oxygen, producing biogas—a mixture primarily of methane and carbon dioxide. This biogas can then be used for cooking, heating, or generating electricity, offering a clean, renewable energy source that reduces reliance on fossil fuels. The digestion process also produces a nutrient-rich by-product called digestate, which serves as an organic fertilizer, supporting sustainable agriculture by replacing chemical fertilizers. Mess food waste is well-suited for biogas production due to its high moisture and nutrient content, which accelerates microbial activity and enhances biogas yield. Pre-treatment may be needed to remove contaminants, and stirring mechanisms are often incorporated in the digester to ensure efficient breakdown of the food waste. In addition to reducing landfill waste and associated greenhouse gas emissions, such biogas plants provide institutions like universities, hospitals, and large dining facilities with an eco-friendly way to repurpose waste while achieving energy self-sufficiency and lowering waste disposal costs.

3.2 BIOGAS PLANT SET UP

A biogas setup for college mess food waste with an integrated water tank in the digester tank enhances the efficiency and stability of the biogas production process, particularly in environments with variable temperatures. In this system, food waste from the college dining hall is collected, pre-processed, and fed into an insulated anaerobic digester, where a surrounding water jacket maintains an optimal temperature range for microbial activity. This water jacket, or integrated water tank, functions as a thermal buffer, using heated water to regulate the digester's internal temperature and ensure a consistent environment for anaerobic digestion, which is essential for high biogas yield. The biogas produced, primarily methane, can be stored and utilized for cooking, heating, or powering campus facilities, offering a renewable energy source that lowers the college's energy costs and reduces reliance on fossil fuels. Additionally, the system produces a nutrient-rich by-product, digestate, which can be used as an organic fertilizer for campus grounds or shared with local farms, supporting sustainable land use. By maintaining a stable temperature in the digester, the water-jacketed design enhances the plant's efficiency and year-round operation, making it ideal for colder climates. This setup not only reduces waste management costs and environmental impact but also serves as a live educational tool for students interested in renewable energy and sustainable practices, reinforcing the college's commitment to eco-friendly initiatives.

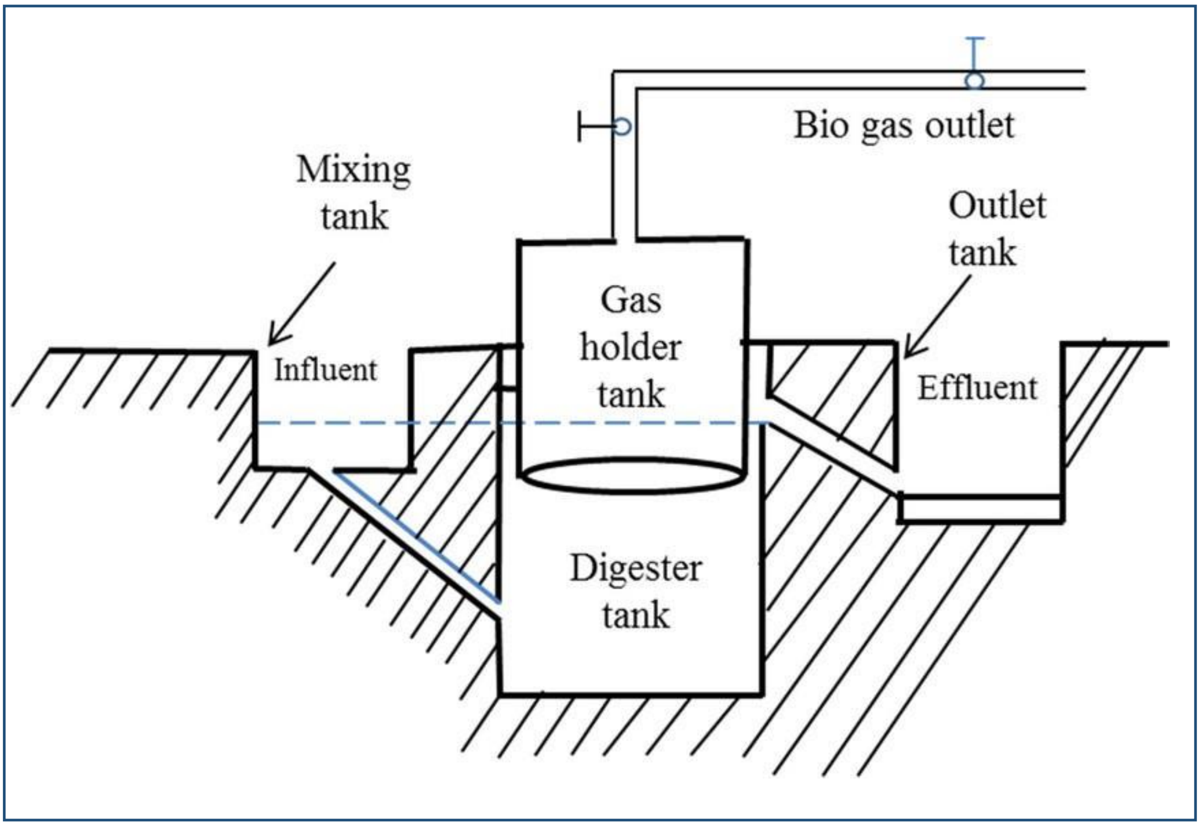

Figure 3.1 Experimental setup of Biogas plant

3.3 SITE DESCRIPTION AND FOOD WASTE CHARECTERICTS

The site for the biogas plant must be meticulously chosen to ensure it is in close proximity to the primary sources of food waste, such as canteens, restaurants, and food processing facilities. This strategic location not only minimizes transportation costs but also streamlines the collection process, making it more efficient and environmentally friendly. The designated area should provide ample space to accommodate the digester tank, a water jacket for temperature control, and all necessary auxiliary systems, such as feedstock storage, digestate handling, and gas storage units. Additionally, the site must comply with local environmental regulations and safety standards to mitigate any potential negative impacts on the surrounding community. The local climate plays a crucial role in the design of the biogas plant; particularly, the water jacket system must be engineered to maintain optimal digestion temperatures ranging from 35 to 40°C, which is especially important in colder regions where ambient temperatures can hinder the anaerobic digestion process. The food waste that will be processed in the digester typically consists of a diverse mix of carbohydrates, proteins, fats, and fibers, which are essential for microbial activity. This waste is characterized by a high moisture content, often between 70% and 90%, which facilitates the formation of a slurry that is conducive to efficient digestion. Managing the organic loading rate (OLR) is vital to prevent the digester from being overloaded, which can lead to inefficiencies and process disruptions. Ideally, the OLR should be balanced with an appropriate carbon-tonitrogen (C/N) ratio, typically between 20 and 30:1, to optimize biogas production while minimizing the risk of ammonia toxicity. Furthermore, the pH level of food waste is generally acidic, which necessitates the incorporation of buffering agents to maintain the optimal pH range of 6.8 to 7.2 for anaerobic bacteria activity. To enhance the overall efficiency of the digestion process, pre-treatment processes to reduce the particle size of the food waste are recommended. Smaller particle sizes increase the surface area available for microbial action, thereby maximizing biogas yields within the water-jacketed digester system. This comprehensive approach ensures the biogas plant operates effectively and sustainably, contributing to waste reduction and renewable energy generation.

2.4 SELECTION OF CONSTRUCTION SITE

Selection of construction sites are mainly governed by the following factors:

- The site should facilitate easy construction works.
- The selected site should be such that the construction cost is minimized
- The selected site should ensure easy operation and maintenance activities like feeding of plant, use of main gas valve, composing and use of slurry, checking of gas leakage, draining condensed water from pipeline etc.
- The site should guarantee plant safety.
- To make plant easier to operate and avoid wastage of raw materials, especially the dung/swine manure, plant must be as close as possible to the cattle shed.
- The site should be in slightly higher elevation than the surrounding. This helps in avoiding water logging. This also ensures free flow of slurry from overflow outlet to the composting pit.
- For effective functioning of bio-digesters, right temperature (20-35°C) has to be maintained inside the digester. Therefore it is better to avoid damp and cool place – Sunny site is preferable.
- To mix dung and water or flush swine manure to the digester, considerable quantity of water is required. If water source is far, the burden of fetching water becomes more.
- The well or ground water source should be at least 10 meter away from the biodigester especially the slurry pit to avoid the ground water pollution.
- If longer gas pipe is used the cost will be increased as the conveyance system becomes costly. Furthermore, longer pipeline increases the risk of gas leakage. The main gas valve which is fitted just above the gas holder

should be opened and closed before and after the use of biogas. Therefore the plant should be as near to the point of application as possible.

- The site should be at sufficient distance from trees to avoid damage of bio-digester from roots.
- Type of soil should have enough bearing capacity to avoid the possibility of sinking of structure.

2.4.1 Location of biogas plant

A biogas plant should not be located further than 5 meters from the field. The digester chamber must be in an open area and should not be near any water source or natural water as animal excrement may seep into underground water. The plant should also be situated on a slope and not on the low land to avoid the danger of floods. The excess manure from expansion chamber should flow into the farmer's field or the storage tank and not into natural water bodies such as rivers to avoid the risk of pollution.

2.5 MATERIALS AND METHODS OF CONSTRUCTION

If the materials used in the plant construction such as cement, sand, aggregate etc. are not of good quality, the quality of the plant will be poor even if the design and workmanship are excellent. A brief description regarding the specifications for some of the construction materials is provided below to assist with selection of the best quality materials.

Cement

Cement should be high quality Portland cement from a brand with a good reputation. It must be fresh, free from lumps and stored in dry place. Bags of cement should not be stacked directly on the floor or against the walls. Wooden planks have to be placed on the floor to protect cement from dampness. Cement bags should be stalked at least 20 cm away from any walls.

Sand

Sand should be clean and not contain soil or other material; dirty sand will have a very early negative effect to the structure. Coarse and granular sand are suitable for concreting work, however fine sand should be used for plastering works. River/lake sand is well graded hence preferred. Avoid dusty sand.

Gravel/Ballast

The size of gravel should neither be very big nor very small and should be clean, hard and angular in shape. If dirty should be cleaned first before use and the maximum size of gravel should be ¾" or ¼ the slab thickness. Gravel should be clean, hard and of angular shape. If it is dirty, it has to be washed properly before use.

Water

Water is mainly required for making the cement mortar for masonry works, concreting works and plastering. It is also used to soak bricks before using. Besides, it is required for cleaning or washing construction materials if they are dirty. The water from ponds or cannel may be dirty so it is better not to use it. Dirty water will have an adverse effect on the strength of structure. Water from water tap or well or any other sources that supply clean water has to be used.

Bricks

Brick plays a very important role in construction of biodigesters. Bricks should be of high quality, usually the best quality available in the local market. The bricks should be well burnt, straight, regular in shape, sizes and should not have cracks or broken parts. High quality bricks make a clear metallic sound when hitting them to each other. Such bricks should be able to bear a pressure of 120 kg per square centimeter. Before use, bricks must be soaked for few minutes in clean water. Wet brick will not absorb water from the mortar which is needed for setting properly.

Mild steel bars

MS bars are used to construct the covers of outlet tank and water drain chamber. It should meet the engineering standard generally adopted. For plants of 4, 6 and 8 cum, MS rods of 8 mm diameter and for plant of 10 cum capacity 10 mm diameter is recommended. MS bar should be free from heavy rust.

Mixing Device

This device is used to prepare good quality water-dung solution in the inlet tank when cattle dung is used as feeding material. Usually for household biogas digesters, vertical mixing devices are installed. The device should be of good quality, as per the design, and the mixing blades have to be well galvanized. The blade should be properly aligned for the effective mixing.

2.5.1 Plant layout

Construction works of biodigester starts with the process of layout works. This is the activity carried out to mark the dimensions of plant in the ground to start the digging work. For this purpose, first a small peg has to be stuck in the ground at the centre spot of the digester. Then the following steps should be followed:

- Level the ground and determine the centre line of the digester, outlet tank and inlet pit

- Decide the reference level. It is better to assume the leveled ground level as the reference level. The top of the dome (outer) should exactly be in this level.

- Select the outer radius of the pit (digester diameter plus wall thickness plus space for a footing projection of at least 10 cm) and mark it in the rope or chord.

- Insert a stick or wooden peg in the leveled ground at the centre of the proposed digester pit. With the help of this pole and chord prepared earlier, make a circle, which indicates the area to dig.

- From the centre point where the central line meets with the perimeter line, draw a tangent and measure a length equal to half of the breadth of outlet plus wall thickness (for outlet chamber) and half of the size of manhole (30cm) plus wall thickness for manhole, on either side of this tangent. Mark the manhole ensuring that the inner size is 60 cm x 60 cm.

- Draw horizontal parallel lines from the points in either side in the tangent, which will meet the dome. From the centre point where the central line meets with the perimeter line, measure the length of outlet plus wall thickness to decide the outer dimension of outlet.

- Use coloured powder to mark the dimensions.

- Decide the location of slurry pits while laying out plant digester and outlet.

2.5.2 Digging of Pit

After completion of lay-out work, the work for digging of pit has to be started. Tools like, crow-bar, picks, spade, shovel and basket should be available at the site. The following points have to be followed to dig the pit.

- Digging should be done as per the dimensions fixed during layout

- As far as practical the cutting in ground should be vertical

- If the water table is high and digging to the required depth is difficult, a deeper pit has to be constructed near the digester pit. Water accumulated in the digester pit has to be drain to this pit through underground pipes. Water should be pumped from this pit.

- Once the depth of digging is equal to the dimension, the work of leveling and ramming the base has to be done. The pit bottom must be leveled and the earth must be untouched

- Ensure that the excavated earth is deposited at least 2 m away from the pit in each side to ease the construction works.

- Be careful to avoid accident while digging near the sides as soil may collapse.
- Dig the foundation for the manhole (first step of outlet tank) along with the foundation for digester as per the dimensions in the drawing during the layout.

2.6 METHODOLOGY

Designing a biogas plant with a water jacket in the digester tank involves a few crucial steps, particularly aimed at optimizing the temperature for bacterial activity to maximize gas production. Here’s a suggested methodology:

1. Define Objectives and Scope

- **Objective:** To design a biogas plant that integrates a water jacket to maintain optimal temperature within the digester tank, thus enhancing methane production.
- **Scope:** Determine the type of waste (e.g., agricultural, animal, or food waste) and the plant's capacity (e.g., small-scale for a household or large-scale for a farm or community).

2. Site Selection and Analysis

- **Climate and Temperature:** Understand the local climate to assess heating needs. A water jacket is beneficial in regions with low ambient temperatures, as it stabilizes the digester’s internal temperature.
- **Space Requirements:** Allocate enough space for the digester, water jacket, and ancillary equipment like pumps and heat exchangers (if required).
- **Accessibility:** Ensure easy access for waste input, gas output, and maintenance.

3. Design Specifications

- **Digester Volume Calculation:**

Calculate daily feedstock input and retention time based on waste type and digestion rate.

Volume = Daily Feedstock Input × Retention Time.

- **Water Jacket Sizing:**

Decide on the thickness of the water jacket, considering the need to cover as much of the digester surface as possible for uniform heating.

Calculate the volume of water needed for the jacket, ensuring it’s sufficient to maintain the required temperature.

- **Thermal Insulation:**

Choose appropriate insulating material to minimize heat loss from both the water jacket and digester walls.

4. Material Selection

- **Digester and Jacket Materials:** Use corrosion-resistant materials like stainless steel or HDPE for durability and thermal stability.
- **Insulation Material:** Use polyurethane foam or similar materials with high thermal resistance.

5. Heating Mechanism

- **Water Circulation System:**

Design a closed-loop water circulation system connected to the water jacket. Use a pump to circulate water, and incorporate a temperature control system (e.g., thermostats) to maintain consistent water temperature.

- **Heat Source:**

Depending on the available resources, heat the water using a solar heater, electric heater, or waste heat recovery system. Include a heat exchanger to transfer heat from the source to the water jacket efficiently.

6. Control System

- **Temperature Monitoring:**

Install temperature sensors inside the digester and water jacket to monitor and regulate the digester's internal temperature.

- **Automatic Controls:**

Integrate a feedback loop to control the heating system based on the digester's temperature requirements. Set up an alarm for temperatures outside the optimal range.

7. Structural and Piping Design

- **Inlet and Outlet Piping:**

Design inlet and outlet systems to allow easy feeding of organic waste and removal of digested slurry, minimizing contamination or gas leakage.

- **Gas Collection System:**

Install piping from the top of the digester to collect biogas and channel it to a storage or utilization system (e.g., gas stove or generator).

- **Safety Valves:**

Include safety relief valves in both the water jacket and digester tank to handle pressure fluctuations and avoid damage.

8. Testing and Commissioning

- Test the biogas plant to ensure all components function as expected. Monitor temperature stability, gas production rate, and quality over a few weeks.
- Adjust temperature control settings and water jacket flow rate as needed to optimize performance.

9. Operation and Maintenance

- **Regular Monitoring:**
  Track digester temperature, pH, and gas production rates.
- **Maintenance:**

Inspect pumps, pipes, and heating components regularly for any leaks, blockages, or wear.

This methodology provides a framework for designing a biogas plant with a water-jacketed digester that optimally maintains digester temperature for efficient biogas production.