

CHAPTER-5

**EXPERIMENTAL SET UP AND PLANT
LAYOUT**

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5.1 EXPERIMENTAL SET UP AND PROCEDURE

In the experimental study kitchen waste mainly food and vegetable waste is used. The maximum amount of waste is 5 kg for laboratory set up.

Considering the feeding system to the digester two setup arranged

- (i) Semi- batch digestion system.
- (ii) Continuous digestion system.

5.1.1 Semi- batch digestion system

The study has been conducted by using a high-density polyurethane-tapered vessel as a bioreactor and it has been placed inside the thermostatically controlled bath where any temperature in between -5 to 60° C can be maintained as shown in the fig. no. 5.1.1

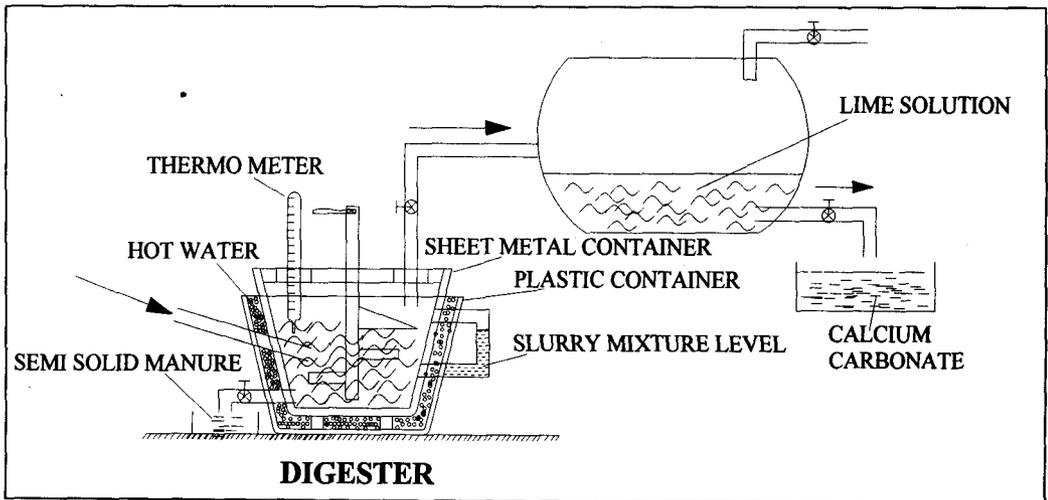


Fig. No.5.1.1 Semi- batch Digestion System



Photograph of Mixing Machine Fig. no.5.1.1 (b)

A stirrer has been placed from the top of the digester and it has been operated by a 0.25 H.P. electric motor. The gas outlet pipeline from the top of the reactor has been connected to a water displacement system for the gas collection. Subsequently the gas sample has been analyzed using Orsat apparatus and gas chromatograph.

Operational Procedure

At first a mixture of dried, specific sized vegetable waste and water has been prepared in the separate mixing tank as shown in fig. No.5.1.1 (a)

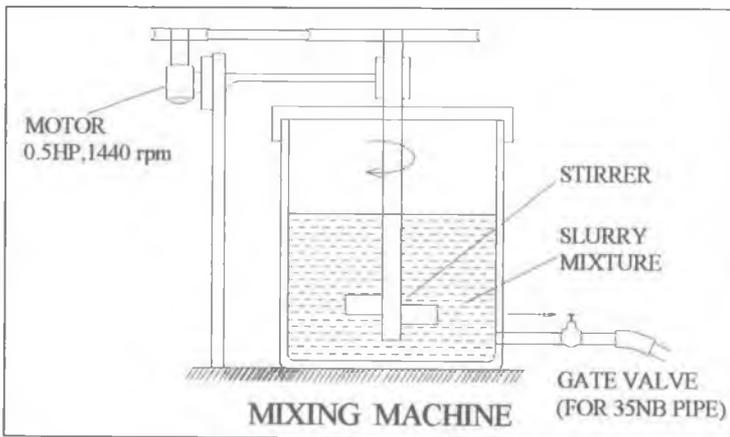


Fig.no.5.1.1 (a)

A slurry of definite concentration is prepared and same is fed to the digester. The digester is sealed from the top by a rubber wound cover in order to obtain the anaerobic condition inside the digester.

The composition of the gaseous products and its volume has been determined after each 24 hours and it has been continued till gas output drops to below 25 c.c. The change of pH of the slurry with time has also been recorded. Arrangement for periodical agitation of the slurry in the digester for almost half an hour at interval of 12 hours has been made. Gas has been collected through displacement of water mixed with 2% glycerol solution to prevent the absorption of CO₂ in water. Gas composition, has been checked through Orsat apparatus. Finding the difference of volume of CO₂ from the total volume of makes estimation of methane gas-produced. During experiment pH value of slurry mixture has been maintained in-between 6.8 to 7.0 automatically by auto pH controller as shown in the fig.5.3.

5.1.2 Continuous Digestion System

After segregation of dried vegetable waste it is fed to the vibrating screen in order to obtain the required sizes of particles and larger sizes of waste are to be shredded by a cutting machine. The feedstock containing a definite sized particle has been mixed with equal amount of water in the mixing unit before feeding to the digester, so that suitable solid liquid ratio needed for biomethanation is obtained. The experimental arrangement has been shown in the fig. no 5.1.1(a).

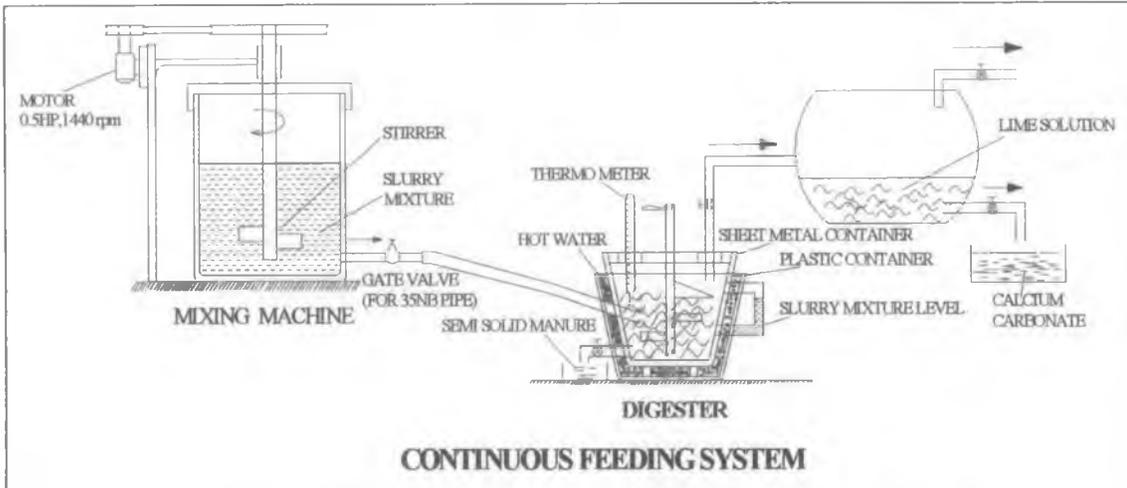


Fig. No. 5.1.2 Continuous Digestion System



Fig. No.5.1.2. (a) Photograph of Digester shown

With this arrangement thus concentration of the mixture is being known.

Two stage digester

As explained earlier the biomethanation process involves two different stages viz, acidogenesis and methanogenesis. Conventionally the two phases are allowed to be carried out in one digester. It is however possible to have the two reactions to take place in separate digester. Thus separating the two phases, allowing flexibility of operation and thereby improve digestion of the total mass. Maintenance of the plant is also convenient.

In the first reactor, the reaction rate is limited by the rate of hydrolysis of cellulose; in the second by the rate of microbial growth. The two-reactor process allows to increase the rate of hydrolysis.

For methanogenesis, the optimum growth rate of microbes is achieved by designing the reactor to provide a longer biomass retention time with high cell densities (also known as fixed film reaction, where the microbes responsible for conversion of the organic matter are attached to an inert medium such as rocks, plastic materials in the reactor). With this arrangement, complete digestion is achieved during less period of retention time.

Several experiments have been carried out with various feedstock received from kitchen feeding the bioreactor having the total volume of 10 liters in a continuous manner. The set up is shown in fig. No.5.1.2 With this arrangement slurry of definite concentration is prepared and fed to the digester. pH value of the slurry in the digester has been checked continuously and the same is maintained in the range 6.8 to 7.2 for optimum gas generation from the digester. Digester temperature is controlled by circulation of hot water in to the jacket around the digester to study the effect of temperature variation on gas yield. Gas yield at an interval of 24 hours interval has been recorded. Gas collection has been done by downward displacement of water. To prevent carbon dioxide absorption by water, 2% glycerol added to water so as to get record of total gas produced from the setup. The digester is fitted with a motor driven stirrer from the top for proper agitation. pH value in side the digester monitored continuously to maintain the value in the range 6.8 to 7.2.

Operational Procedure

Prepared sample of known slurry concentration and particle size has been fed to the digester with constant loading rate. When the system has been stabilized, the retention time and temperature of digestion has been recorded. Again by changing the digestion temperature with constant loading rate and constant particle size, the production of gas has been measured. Gas composition, mainly methane and carbon

dioxide has been checked through Orsat apparatus. Finding the difference of volume of CO₂ from the total volume of gas produced makes estimation of methane. As a check volumetric analysis has also been carried out using gas chromatograph.

5.2 DESIGN OF PROPOSED DIGESTER FOR ANAEROBIC DIGESTION

A biogas digester is essentially a chemical reactor which is linked to both inflow and outflow channels. Rate of gas production is dependant not only on microbial growth rate but also on the effectiveness of dispersion of solid, liquid and gas flows and on the retention time of the slurry mixture inside the digester. The digester has two-fold function i.e., accommodating digestible material as well as storage of gas.

Digester design is of utmost importance to get optimum gas output and for that the following points are to be kept in view:

- (i) Optimum gas yield
- (ii) Biodegradability of feed stock
- (iii) Retention time
- (iv) Slurry temperature inside the digester
- (v) Loading of digester
- (vi) C/N ratio

The digester is composed of a tapered cylindrical shell wall with dome as shown in the fig. no.5.2.1. The upper part of the digester is fully covered by a top cover so that it will be a perfect seal to maintain anaerobic condition.

The digester is to be fitted with motorized stirrer from the top and also a jacket for circulation of hot water for temperature control. The temperature of the slurry is maintained in the mesophilic condition.

In the experiments two-phase digestion technique has been proposed for separating the acid and methane forming phases as it has several advantages. It has been observed that the duration of acid phase is in the range of 4-6 days depending on the type of feed materials. The slurry from acid phase is immediately fed to the adjoining reactor for

methanogenic bacterial reactions. Thus, the methane-producing bacteria can work continuously without any acidic effect on them.

5.2.1 Design Calculation for Fixed Dome Type Digester

The design is based on the following data:

Assuming:

Active slurry volume V_s in cu.m.

Hydraulic retention time, (HRT) as 30 days

Total quantity to be fed to the digester = 100kg. + 100 kg. (Solid +water)

To increase the rate of hydrolysis and to facilitate maintenance work, provision for two nos. of digesters has been made.

Hence actual quantity to be fed to the each digester = $200/2 = 100$ kg.

Density of slurry mixture = 1090 kg. / cu. m.(by lab. measurement)

Volume of the digester = $200/1090 = 0.183486$ cu.m. ≈ 0.184 cu.m.

Required slurry volume, V_s of digester considering 30 days retention time, $V_s = 0.184 \times 30 = 5.5$ cu.m.

Actual volume of the digester V_d , considering 10 % over loading,

$V_d = 5.5 \times 1.1 = 6.06$ cu.m. -----(i)

Calculation of diameter, D and height, H of the digester

Considering the ratio D/H is 1.0,

Knowing the actual (active) slurry volume, V_d from equation (i), height of the digester can be calculated as follows:

$$V_d = (\pi/ 4) \times D^2 \times H$$

Since, $D = H$

$$D^3 = V_d / 0.785 \text{ i.e. } D = H = 2 \text{ m}$$

Diameter of the digester, $D = 2$ m and Height of the digester, $H = 2$ m

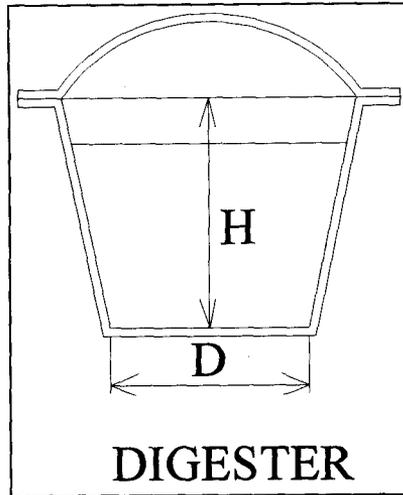


Fig. No. 5.2.1

5.2. 2 Design of gasholder

Gas production rate:

1 kg of waste (undiluted) yields about 0.04 cu m of gas.

The gas production rate, G for the available waste is thus

$$G = W \times 0.04 \text{cu.m. /day,}$$

Where, W = available waste from the kitchen per day i.e. 200 kg

Thus, total quantity of gas produced per day= $200 \times 0.04 = 8 \text{cu.m}$

Considering 6 hours cooking per day basis in the kitchen,

Considering 10% over loading,

$$\text{Volume of gasholder required} = (1-6/24) \times 1.1 \times 8 = 6.6 \text{ cu.m.}$$

From the above, it can be said that the capacity of the proposed plant is 8 cu. m. i.e. the plant shall be able to produce 8 cu.m. of gas per day on continuous basis.

In this case, it has been considered that the gasholder is common for both the digesters and the connecting tubes from both the digesters are being attached to the gasholder as shown in the fig. no.5.2.2

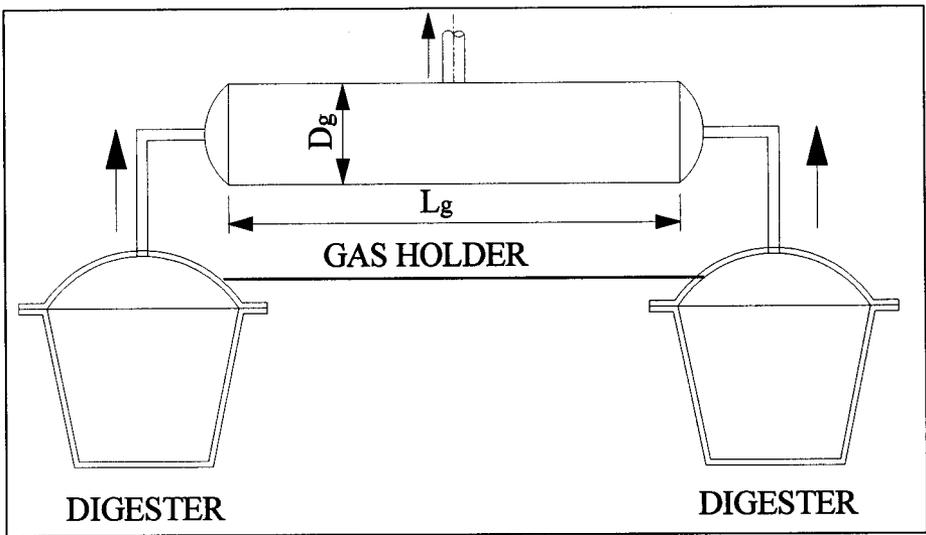


Fig. No. 5.2.2 Gasholder

The gasholder is placed horizontally to avoid to large static head inside the gasholder

Thus, considering diameter/depth ratio is 1:2, ($D_g : L_g$)

We get, $(\pi/4) \times D_g^2 \times L_g = 6.6$ where D_g and L_g are the diameter and length of the gasholder respectively.

Therefore, $D_g = 1.6134$ m. and $L_g = 3.226$ m.

Let us consider, Diameter of the gasholder, $L_g = 3.2$ m. and

Length, $D_g = 1.6$ m.

5.2.3 Slurry displacement volume inside the digester

Slurry displacement volume depends on the gas consumption pattern. As cooking is usually done two times in a day, 50% of the gas produced in a day should be made available for one cooking span. Since there is a continuous production of gas from the digester, the gas generated during cooking time is also considered while designing the digester. If the total time of cooking is about 6 hours per day., the variable slurry displacement volume, V_{sd} is obtained from the following equation

$V_{sd} = (6/24) \times 0.5 G$, where, G = total volume of gas produced per day
i.e. 8 cu.m.

Or, $V_{sd} = 1.0$ cu.m.

From the above equation, the value of slurry displacement height, h_{sl} as $= (\pi/ 4) \times D^2 \times h_{sl} = V_{sd}$, where, D is the diameter of the digester or, $h_{sl} = (\pi/ 4) \times 2^2 \times h_{sl} = 1.0$ m.

From the above, we get, slurry displacement height, $h_{sl} = 0.32$ m

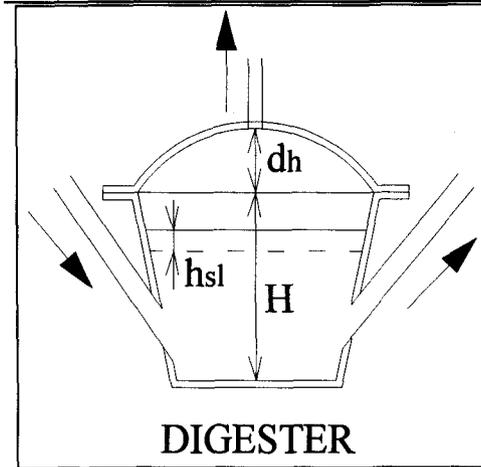


Fig. No. 5.2.3 Slurry Displacement height (h_{sl})

Slurry movement in the digester

At the starting time no gas can be withdrawn from the digester when pressure inside the digester is atmospheric. The slurry level at the inlet and outlet tanks will be as shown in the figure no. 5.2.3. When gas accumulates in the space above than slurry level, the slurry in the digester get compressed and pushed down, as a result slurry level in the inlet and outlet tank raises to a point such that the pressure of the generated gas is balanced by the pressure of the slurry column in the inlet and outlet tank.

Thus under ideal operating conditions, the volume of slurry flowing out from the digester in a day would be exactly equal to the volume of the daily input slurry.

In the proposed design, cylindrical shape of bioreactor having flat bottom has been considered. The relevant dimensions of the digester with other related parameters are as given below:

W = weight of the vegetable waste available per day (Kg / day) from canteen

G = gas production rate (cu m/ day)

V_s = active slurry volume in the digester (cu m)

V_{sd} = slurry displacement volume (cu m)

V_d = dome volume (cu m)

H = height of the cylindrical portion of the digester

h_{sl} = slurry displacement height(m)

D = diameter of the digester (m)

D_h = height of the dome

R_d = radius of the dome

5.2.4 Calculation of the Dome Height (d_h)

The volume of the dome, which is a section of a sphere, is given by

$$V_{sd} = (\pi/6) d_h [3(D/2)^2 + d_h^2] \text{-----eq. No. (5)}$$

Where, V_{sd} = slurry displacement volume

d_h = dome height

D = diameter of the digester

The total volume of the gas space in each digester, as mentioned earlier, is taken as equal to G/2, since we have considered two no. of digesters. As the slurry or gas displacement volume V_{sd} is already found out as 1.0, the remaining gas space volume will be the volume of the dome.

The value of d_h to be evaluated by solving the cubic equation (5). It can be easily done by iteration or by analytical method. The value of d_h is found to be 0.30895 m from the above cubic equation (5)

Let us take Dome height, d_h = 0.35 m

5.2.4 Radius of the Dome (R_d)

Dome radius can be obtained by the equation

$$R_d = (D/2)^2 + d_h^2 / 2d_h$$

$$\text{Or, } R_d = 2/2 + (0.35)^2 / 2 \times 0.35 = 1.607 \text{ m} = 1.61 \text{ m}$$

Considering, R_d = 1.61 m.

5.3 AUTO CONTROL OF pH OF SLURRY MIXTURE

In order to maintain the required pH value for slurry mixture inside the digester in the range of 6.8 - 7.2, it is necessary to maintain this range to enable the anaerobic digestion.

In view of the above a microprocessor (8050 core) based control system has been proposed to control the pH in the specified range as mentioned above. There are two chambers one containing the slaked lime solution and the other the acetic acid (CH_3COOH) solution which have been incorporated in the system and are controlled by the solenoid valves attached to it and these valves are controlled by the microprocessor unit as shown in the figure 5.3.

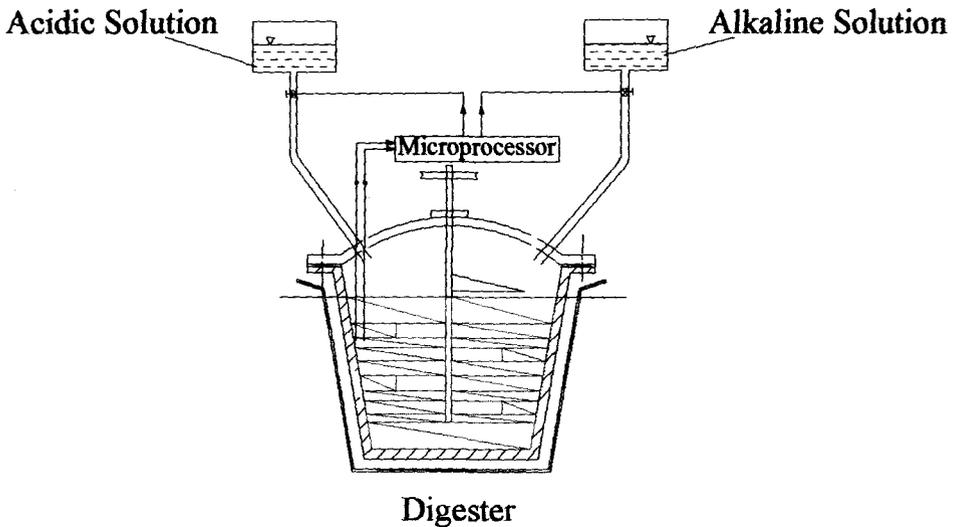


Fig. No.: 5.3 Auto control of pH of slurry mixture

A pH sensor is dipped inside the slurry. The sensor will detect the pH value of the slurry material and convert the same into an equivalent voltage. The voltage is calibrated according to the pH of slurry material.

5.4 Weighing Device for Maintaining Solid – Liquid ratio

One of the prerequisites of good digestion is proper maintenance of solid and liquid ratio of the slurry mixture in the digester.

To maintain the required ratio of solid and liquid, an auto control device has been incorporated in the process. In this process a motorized stirrer is inserted in the digester. The motor will take more current when the density of the slurry mixture is high. The motor input current is tapped by using current- transformer and fed to the micro controller system. The amount of current will depend on the ratio of the solid to liquid in the digester with proper calibration by measuring the input current to the motor; the solid- liquid ratio can be evaluated. Now, the micro controller system controls the solid-liquid ratio by measuring the input current to the motor when the valves are open for a specified time interval. For example, if the ratio is greater than the required ratio it means less quantity of water mixed during the preparation of slurry mixture, then solenoid valve connected to the water line will open for a particular time until solid and liquid ratio maintained at desired level. Again in reverse case when solid- liquid ratio is less than the required one, in that case the solenoid valve connected to the solid tank will open until the solid-liquid ratio brings back to the required value. The arrangement of all these equipment including stirring system inside the digester is shown in the fig. no. 5.4.

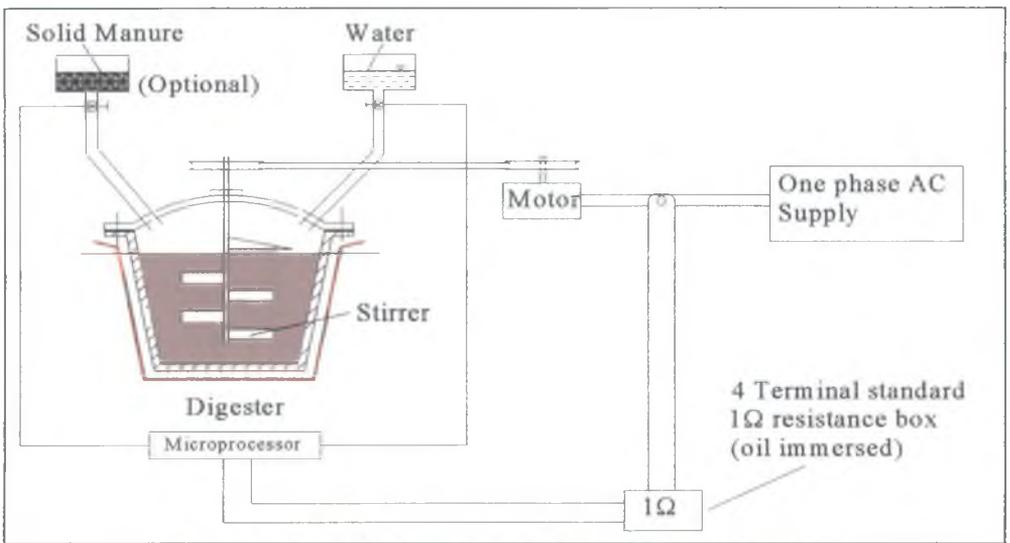


Fig. No. 5.4 Auto control of solid- liquid ratio

5.5 DRIVE MECHANISM OF SCUM BREAKER

A flap having 0.9 times of inside radius of the digester tank is welded with the rotating shaft of stirrer so that flap can rotate while stirring the slurry mixture twice or thrice a day. The flap is designed in such a way that the same can move vertically up and down according to level of the slurry and is shown in adjoining fig. no.5.5

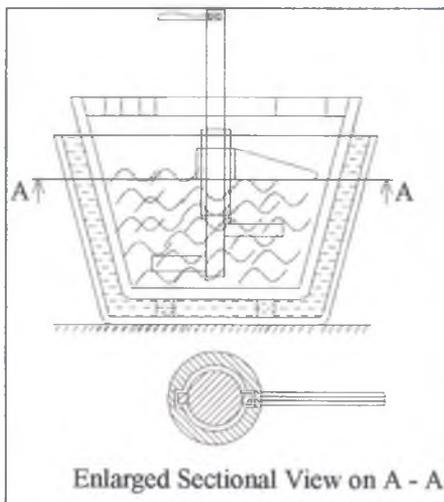


Fig. No. 5.5 Scum Breaker



Fig. No. 5.5(a) Photograph of Scum breaker

Thus generated scum in the top layer of slurry will break as soon as the flap rotates which will facilitate gas exit. The flap is fitted with the boss of the rotating shaft with the help of a grub screw.

5.6 SPECIFICATION OF EQUIPMENT AND INSTRUMENTS

5.6.1 DIGITAL pH METER WITH AUTO TEMPERATURE COMPENSATION

Make: EI Products, India Model: 111E/ 101E

pH range : 0 to 14

Accuracy: pH : + 0.01 Ph

Temperature range: 0 to 100 C

5.6.2 ORSAT APPARATUS

Make: Bhattacharya &Co, Kolkata

5.6.3 Shredding Machine (Motorized)

Make: Manufactured at Institutes Workshop

Blade Diameter: 180 mm

Motor Specification: Single phase, 0.25 hp, and @1430 r.p.m.

5.6.4 Laboratory Test Sieve

Make: S.C.Dey & Co., Kolkata

Motor: Single phase, 1h.p. and 1430 r.p.m.

5.6.5 Precision Balance

Make: Bombay Tools Supplying Agency, Kolkata

Accuracy: 1 gm.



Fig, No. 5.6.5 Photograph of Precision Balance

5.6.6 Weighing Machine:

Range: Up to 2 Kg

Make: S.C. Dey & Co., Kolkata, India

Accuracy: 10 gms



Fig. No. 5.6.6 Photograph of Weighing Machine

5.6.7 Bomb Calorie Meter

Make: S. C. Dey & Co.Pvt. Ltd, Kolkata, India

Type :Vertical cylinder, differential digital temperature gauge

Power: 120/220 Volts, 70 Watt.

5.6.8 Air Oven

Make: S. C. Dey & Co.Pvt. Ltd, Kolkata, India

Temperature Range: 0 to 250 C

5.5.9 Muffle Furnace

Make: Dey Brothers, Kolkata

Temperature Range: 0 to 1200^o C

5.5.10 Willey Mill

Make: S. C. Dey & Co.Pvt. Ltd. Kolkata, India

Sl. No.: 11R 00105.

Model No. F183

Power: 2.4 Watt, 2.4 amps. @ 1440 r.p.m.

5.6.11 Elemental (CHN) Analyzer

Measured at Central Laboratory of West Bengal Pollution Control Board, Kolkata

5.6.12 Filter Pres

Make: Oriental Machinery (1923) Pvt. Ltd., Kolkata

Capacity: 2 Lit.

Fig, no. 5.12 (a):

5.6.13 Mixing Machine

Make: Oriental Machinery (1923) Pvt. Ltd., Kolkata, India

Capacity: 2 Lit

Motor Capacity: 0.5 h.p., Single phase ,1440 r.p.m.

Shown in Fig. no. 5.1.1 (a)

5.6.14.Grinding Machine

Make Oriental Machinery (1923) Pvt Ltd. Kolkata, India

Motor Capacity: 0.5 h.p, Single phase, 1440 r.p.m.

5.5.15 Gauge Glass for detecting slurry level

A gauge glass is fitted to the digester wall in order to detect the slurry level inside the digester.

5.6.16 Pressure Gauge

A pressure gauge is fitted on the top of the spherical cover of digester to observe the gas pressure inside the digester.

This has been shown in fig. no.5.12 (d)

Make: Essab India Ltd.

Range: 1 bar to 7 bar

5.7 METHODS AND PREPARATION OF SOLUTIONS USED IN ORSAT APPARATUS

5.7.1 Preparation of Solutions used for ORSAT APPARATUS for gas analysis.

Different chemical solutions have been used for absorption of different components of the produced gas in the Orsat apparatus [233]. The methods of preparation of different solutions are given below:

5.7.1.1 Potassium Hydroxide Solution (KOH):

This is prepared by dissolving 500 gms of Stick Potassium Hydroxide in 500 ml of distilled water and stored in a stopper bottle.

Alkaline Pyrogallol Solution

The alkaline pyrogallol solution has been prepared by dissolving 25 grams of pyrogallic acid in 500 ml of caustic potash solution as prepared for carbon dioxide absorption.

5.7.1.2 Ammoniacal cuprous Chloride Solution

The solution has been prepared by the addition of 275 grams of ammonium chloride in 1000ml. of distilled water. Sufficient quantity of liquor ammonia is then added just to dissolve the solids.

Quantity of liquor ammonia in this 1000ml of solution would be such so as to just dissolve the solids, and solution, when correctly prepared, should smell only faintly of ammonia.

Absorbents used:

- (1). For CO₂ absorption, Potassium hydroxide, (KOH) solution
- (2) For Oxygen, (O), absorption Alkaline pyrogallol solution

(3) For Carbon monoxide, (CO), absorption Ammonia cal cuprous chloride solution

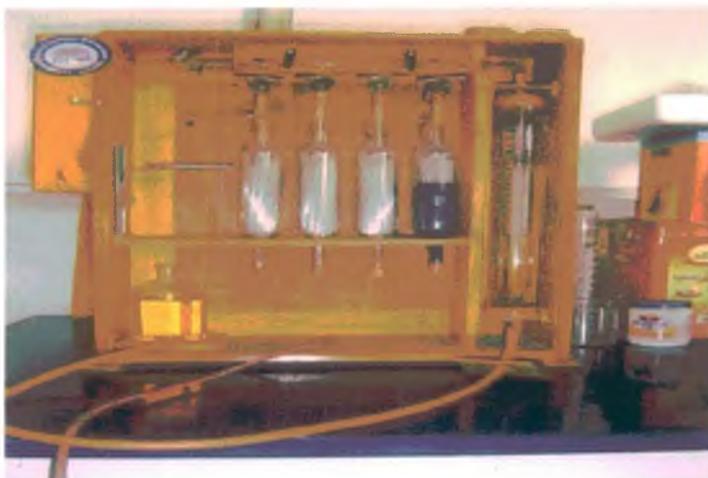


Fig. No. 5.7.1.2 Photograph of Orsat apparatus

5.8 ANALYSIS OF BIOGAS USING GAS CHROMATOGRAPH

Produced biogas has been initially analyzed by Orsat apparatus where mainly carbon dioxide has been detected and remaining gas has been considered to be methane. To conduct the confirmatory test of methane presence in the biogas gas liquid chromatograph is used.

5.8.1 Operational procedure

5.8.1.1 Detectors

Thermal conductivity detector (TCD) has been used. Detector temperature has been maintained at 80-85° C during the operation.

5.8.1.2 Column

Porapak Qs has been used as column for the separation of methane, carbon dioxide and ammonia gas. The column temperature has been maintained at 60°c- 65°c.

5.8.1.3 Oven

The oven temperature has been maintained at 55- 60°C.

5.8.1.4 Injection

0.1 to 0.2 micro liter samples has been injected through auto sampler. The temperature of the injection port has been maintained at 65-70° C.

5.8.1.5 Carrier gas and its flow rate

Hydrogen has been used as carrier gas. The flow rate of the carrier gas has been maintained at 30ml/ min.

5.8.2 Operational Procedure

Product gas from the digester has been collected into a gas-collecting unit. The collected gas has been transferred into a tedler bag, which is directly connected with the injection port through auto gas sampler device. 6 feet Porapak Qs column having 1/8-inch diameter has been connected in between injection port and detector. Gas chromatography has been switched on and the flow rate of carrier gas, the temperature of oven, detector and injection port have been fixed up at 30ml/ min, 65° C, 65° C and 60° C respectively. The gas sample has been injected through injection port. Response of the detector has directly recorded in PC through winchrom software where carbon dioxide, methane and ammonia have been separated individually by three different peaks.

5.9 RAW MATERIALS AND CHEMICALS USED

5.9.1 The materials used in the present investigative work have been listed with their sources in table no.5.9.1

Table No. 5.9.1

Sl. No.	Materials	Source
01.	Vegetable waste	College canteen
02.	Water hyacinth	Inside college pond
03.	Cow dung	Local market
04.	Flowers	Local cremation ground
05.	Cooked flesh and meat	Institute canteen
06.	Hydrochloric acid (HCl)	International Chemicals Calcutta, India
07.	Ammonia solution	Bhattacharya & Co. Kolkata
08.	Potassium Hydroxide (KOH) Pallets	Bhattacharya & Co. Kolkata
09.	Cuprous Chloride (Cu Cl ₂)	Bhattacharya & Co. Kolkata
10.	Pyrogallol (C ₆ H ₆ O ₃)	Bhattacharya & Co. Kolkata
11.	Ferric Chloride	Bhattacharya & Co. Kolkata
12.	Calcium Chloride	Bhattacharya & Co. Kolkata
13.	Glass Wool	Bhattacharya & Co. Kolkata
14.	Magnesium Sulfate	Bhattacharya & Co. Kolkata
15.	Ferric Chloride	Bhattacharya & Co. Kolkata
16.	Potassium Iodide	Bhattacharya & Co. Kolkata
17.	Calcium Hydroxide in dust form	Bhattacharya & Co. Kolkata
18.	Silica Gel	Bhattacharya & Co. Kolkata
19.	Manganese Sulfate (MnSO ₄)	Bhattacharya & Co. Kolkata
20.	Sodium Iodide (Na I)	Bhattacharya & Co. Kolkata
21.	Sulfuric acid (H ₂ SO ₄)	Bhattacharya & Co. Kolkata
22.	Potassium dichromate(K ₂ Cr ₂ O ₇)	Bhattacharya & Co. Kolkata

5.10 CHARECTERIZATION OF KITCHEN WASTE

5.10.1 Proximate analysis

Proximate analysis determines the moisture, fixed carbon, volatile matter and ash content of a material of interest. The sample has been ground to pass 72 meshes British Standard Test Sieve before any step of characterization process has been taken. The moisture, volatile matter and ash content of biomass sample have been determined by standard methods as recommended by the Fuel Research Board of UK and the British Standards Institutions, and the fixed carbon has been determined by difference.

5.10.1.1 Determination of moisture content

Apparatus required: Oven, Petridish with cover, Desiccators, Weight box and Balance.

Procedure:

Approximately 5gms of finely powdered air-dry biomass sample has been weighed in a petridish provided with a well-fitted cover. The area of the petridish should be such that the weight of the sample per sq cm does not exceeding 0.3 gms. The uncovered sample has been heated for about an hour at a temperature of 105- 110°C in an air oven. Then the sample has been taken from the oven with the cover in it and cooled in a desiccator's over calcium chloride or sulphuric acid and weighed along with the cover. The heating has been continued at the specified temperature till the wt. of the sample reaches a constant value. Then the moisture content has been determined by calculating the loss in wt by a percentage.

Calculations:

Wt of the petridish with cover = W1

Wt of the petridish with cover and biomass sample = W2

Wt of biomass sample taken = W2 - W1 = W3

Wt of petridish with cover plus biomass after the completion of heating = W4

Loss in weight = $W_2 - W_4$

Percent moisture content in the biomass sample taken = $\frac{[(W_2 - W_4) / W_3] \times 100}{}$

5.10.1.2 Determination of volatile matter

Apparatus required: Muffle furnace, crucible with lid, tongs, stopwatch, desiccators, wt. box and balance.

Procedure:

One gram of finely powdered air-dried sample has been weighed in a silica crucible. The sample has been sprayed in uniform layer by slight tapping of the crucible on the table.

The lid has been fitted and the crucible has been transferred to a muffle furnace which has been maintained at a temperature of $925^\circ\text{C} + 25^\circ\text{C}$ and the door of the furnace has been properly closed.

The sample has been kept in the furnace for exactly 7 minutes and the crucible has been removed and placed on a cold iron plate to ensure rapid cooling.

The crucible, while still warm, has been transferred to desiccators and than weighed when it has been cold.

The loss in weight has been calculated to a percentage of the biomass taken. The percentage of moisture has been deducted and the final result has been reported as percent volatile matter content.

Calculations:

Wt of crucible with lid = W_1

Wt of crucible with lid + biomass sample = W_2

Wt of biomass sample taken = $W_2 - W_1 = W_3$

Wt of crucible with lid + residue after heating for 7 minutes = W_4

Loss in weight = $W_2 - W_4$

Loss in weight to a percentage = $(W_2 - W_4) / W_3 \times 100 = W_5$

Percentage of volatile matter content in the biomass sample taken = $W_5 - \% \text{ moisture content}$

5.10.1.3 Determination of ash

Apparatus required: Muffle furnace, crucible with lid, tongs, stopwatch, desiccators, wt. box and balance.

Procedure:

About 1 gm of finely powdered air-dry sample has been weighed in a silica crucible and placed in a muffle furnace at room temperature without lid.

The sample has been heated to 400°C to 450°C in 30 minutes for duration of 30 minutes. Then the incineration has been completed by heating for one hour at a temperature of 775°C (+ 25°C).

When heating has been completed, the crucible with the residue has been placed on a cold iron plate for rapid cooling and when it is still warm; it has been placed in desiccators and weighed when it has become cold. It has been desirable to cover the crucible with a lid before it has been placed into the desiccators since rush of air sometimes might cause light ash to be blown away when it has been opened.

If incomplete combustion has been suspected, the incineration should be repeated until the weight is constant.

The residue remaining after heating has been calculated to a percentage on the sample taken to report the ash content.

Calculations:

$$\text{Wt of crucible} = W_1$$

$$\text{Wt of crucible biomass} = W_2$$

$$\text{Wt of biomass sample taken} = W_2 - W_1 = W_3$$

$$\text{Wt of crucible with the residue after the completion of heating} = W_4$$

$$\text{Wt of the residue} = W_4 - W_1$$

$$\text{: Percent of ash content in the biomass sample taken} = (W_4 - W_1) / W_3 \times 100$$

5.10.1.4 Determination of fixed carbon

It has been calculated to a percentage by subtracting moisture content, volatile matter and ash from 100.

5.10.2 Determination of C, H and N

C H N analyzer of the given sample of biomass has determined C, H and N at West Bengal Pollution Control Board, Kolkata, India.

5.10.3 Determination of Calorific value of Biogas

The higher heating value of oven-dried biomass sample has been determined in a bomb calorimeter according to ASTM D2075-77. The lower heating value is calculated by subtracting the heat of condensation of water vapour. The water vapour content has been known from the hydrogen content, determined from the ultimate analysis, which after combustion forms water. The determination of lower heating value is more of a calculated procedure than experimental. The calorific value of biomass has been determined in a bomb calorimeter at constant volume under precisely defined condition. These conditions must be adhered to since any alteration will cause a change in the determined calorific value.

A sample of biomass ground to pass a 72-mesh B.S. sieve has been burnt in oxygen in a bomb calorimeter of known heat capacity. The heat release has been obtained from the corrected temperature rise of water in the calorimeter vessel. Deduction have been made for:

- i. The constant heat gain due to heat release by the cotton thread and the firing wire.
- ii. The difference between the heats of formation of H_2SO_4 and SO_2 .
- iii. The heat of formation of Nitric acid.

But in practice, the following correction has been made after the experiment is over:

- i) Cooling correction
- ii) Thermometric correction

- iii) Correction for source of constant heat gain by cotton thread and firing wire
- iv) Correction for acid formed.

5.10.4 Results of Analysis of Kitchen Waste

5.10.4.1 Proximate Analysis (air dried basis)

Moisture: 15.24 %

Volatile Matter: 53.77 %

Ash: 15.85%

Fixed Carbon: 15.14 %

Gas has been collected into a gas-collecting unit. The collected gas has been transferred into a tedler bag, which is directly connected with the injection port through auto gas sampler device. 6 feet Porapak Qs column having 1/8/-inch diameter has been connected between injection port and detector. Gas chromatography has been switched on and the flow rate of carrier gas, the temperatures of oven, detector and injection port have been fixed up at 30ml/ min, 65°C, 65°C and 60°C are respectively. The gas sample has been injected through injection port. Response of the detector has directly recorded in PC through winchrom software where carbon dioxide, methane and ammonia have been separated individually by three different peaks.

5.10.4.2 Elementary Composition (air dried basis)

Carbon (C) : 36.52 %

Nitrogen (N) : 2.62 %

Hydrogen (H) : 5.12 %

C/N ratio : 13.94

5.10.4.3 Particle Size

Equivalent diameter of the vegetable waste is

- i) 1.80×10^{-3} m
- ii) 1.50×10^{-3} m
- iii) 1.10×10^{-3} m
- iv) 7.50×10^{-4} m

5.10.4.4 Calorific Value

2055 cal/gm

5.11 Determination of Mean Particle Sizes

It is very much essential to do the size reduction of the feedstock. Since the feedstocks are too tenacious or too resilient and hence it is very difficult to be broken either by compression or by impact. To achieve this a device for shearing/ shredding of the feedstock is being designed as shown in fig. No.5.11 (a)

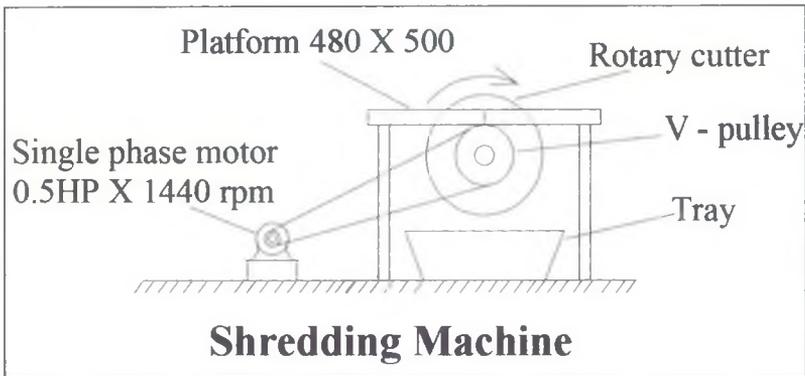


Fig. No. 5.11 (a)



Fig. no. 5.11 (b) Photograph of Shredding machine

Shredding Machine

In this machine a rotary cutter powered by an electric motor is fitted on the spindle to cut the feed stick in desired sizes. After shearing the feedstocks it is further fed to the grinder in order to achieve the required sizes of feedstocks as shown in the fig. No.5.11 (b)

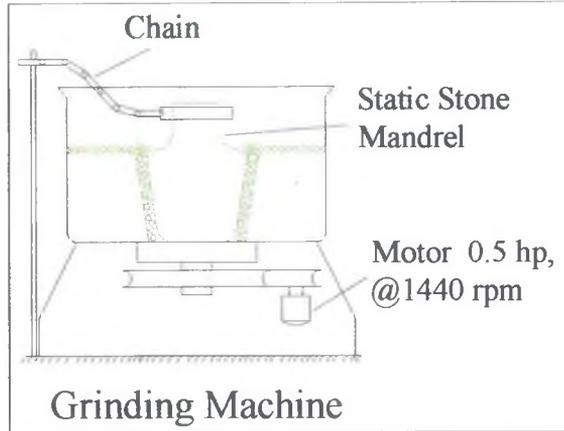


Fig.no.5.11 (b) Grinding Machine



Fig. No.5.11 (c) Photograph of grinding machine

The mean particle size for each run has been determined from the total fictitious area.

For this, the product from the crushing unit has been first weighed and then screened through a set of standard sieves as shown in the fig.no.5.11(c)

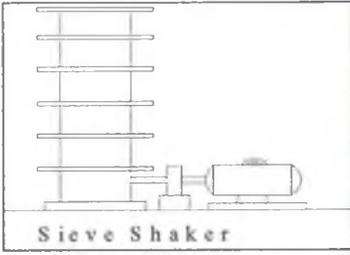


Fig. No. 5.11 (e) & Fig. No. 5.11 (f) Photograph of Sieve shaker

5.11.1 Methods of Calculation of mean Particle Size

Let us assume that each particle is a perfect cube with a linear dimension D and its surface area is A_1

Then its surface area, $A_1 = 6D^2$ and volume, $V_1 = D^3$.

Knowing that the particle sizes are not exactly cube, it has been assumed, on the average, their areas and volumes are proportional to the areas and volumes of the cubes of the same screen size.

Therefore, we can write, $A_1 = a D^2$ ----- (i)

and , $V_1 = b D^3$ ----- (ii), where , a and b are constants for a given waste material.

We have considered D is the average screen size and the materials are passed through it.

Let us consider no. of particles is N for the uniform size fraction and total weight is W .

$$\text{Or, } W = N \times [V_1 \times \rho],$$

Or, $N = W / [V_1 \times \rho]$, V_1 is volume of each particle and ρ is the density of the feed material.

$$\text{Or, } N = W / b \rho \times D^3 = W / c \cdot D^3, \text{----- (iii)}$$

Where, c is a constant and equal to $b \cdot \rho$

Let, total area for all the particles passed through the same fraction of screen is,

$$A = N \cdot A_1 = W / c D^3 \times a D^2 = (a/c) \times W / D \text{----- (iv)}$$

Now, considering the total fictitious surface area for all the particles in the product is A ,

$$\text{Therefore, } A = (a/c) \times W / D$$

Let us consider, D_m is the mean particle size in a total weight W , for all the particles, then, $W = A \cdot D_m \times \rho$

Or, $W = [(a/c) \times W/D] \cdot D_m \times \rho$, where, $A = (a/c) W/D$

Or, $D_m = W / A \times \rho$

From the above equations, (i), (ii), (iii) and (iv), we can find the value for D_m .

The mean particle size of the feed material has been determined by the method as described above and four different particle sizes have considered for anaerobic digestion.

5.12 PROPOSED PLANT LAYOUT INCLUDING MATERIAL HANDLING SYSTEM

In the propose plant layout we have considered four sections of the total processing unit such as:

- (a) Preparation of desired feedstock
- (b) Generation of Biogas
- (c) Up gradation of biogas
- (d) Separation of water and slurry mixture

The machinery are shown in the modular form in the fig nos.5.12 (c), 5.12(d), 5.12(e) and 5.12 (f).

All these machinery selected for processing of 200 kg. of waste available daily from kitchen. Design and detail engineering of various machinery like digester, gasholder are being mentioned in the previous sections. All these selected machinery shall be suitable for optimum utilization of the waste, purification of the generated gas, recycle of the used water after proper filtration and to obtain the retaining manure from the digester. The remaining solid manure after digestion will be taken out from the reactor and the same will be pressed by a filter press in order to separate the semi-solid manure and water. Detail of the filter is shown in the following fig. 5.12(a)

BLOCK DIAGRAM OF BIOGAS PLANT (HARI NARAYAN MODEL)

A block diagram showing all the equipment considered for the proposed plant for anaerobic digestion of kitchen waste has been shown in fig. no. 5.12(g)

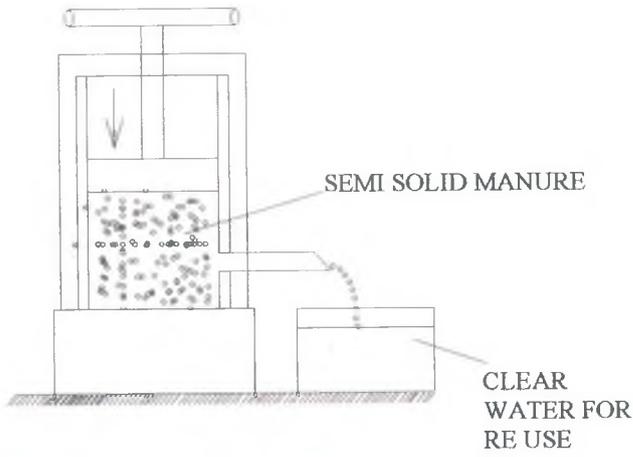


Fig.no.5.12 (a) Filter Press



Fig. no. 5.12 (b) Photograph of Filter press

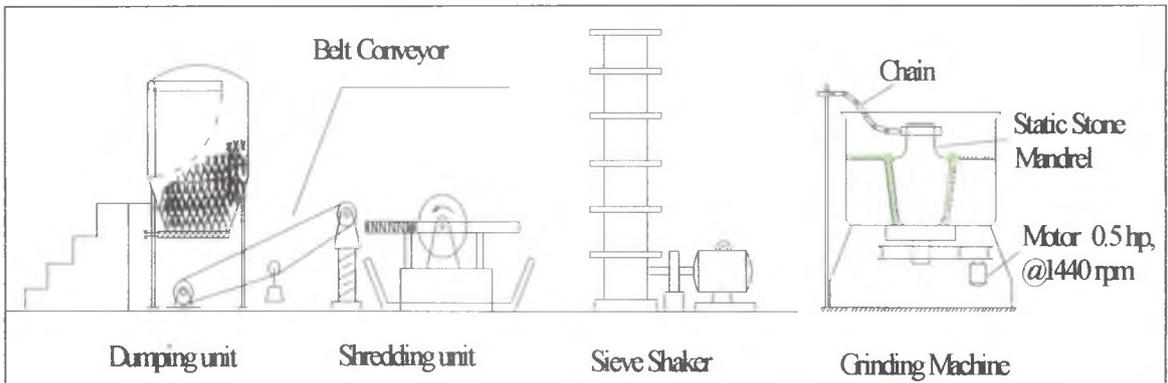


Fig. No. 5.12 (c) Feed Stock Preparation

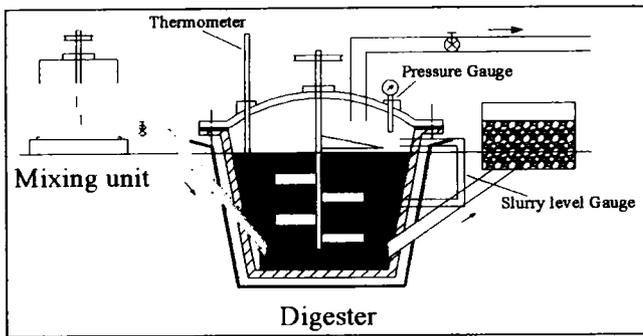


Fig. No. 5.12 (d) Generation of Biogas by Anaerobic Digestion Process

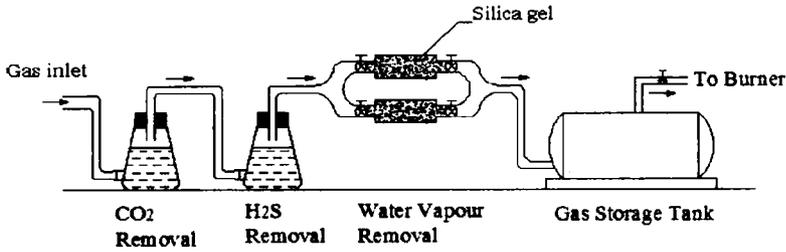


Fig. No. 5.12(e) Up Gradation of Biogas

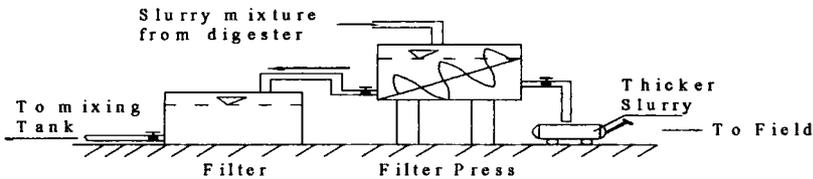


Fig. No. 5.12 (f) Dewatering of Slurry

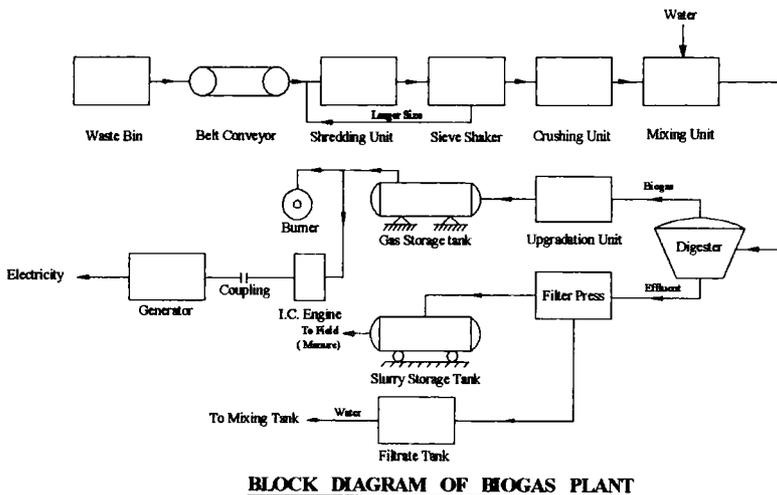


Fig. No. 5.12 (g) Block Diagram

Fig.No.5.12 Proposed Plant Layout (HARI NARAYAN MODEL)

5.13 Maintenance of Biogas Plants

The biogas plants require periodic maintenance to function properly. For example, the gasholders must be painted every two years with chlorinated rubber black paint or with any anti-rust paint to prevent corrosion. The selected material should be designed to be rust free i.e. it should be primed with non-corrosive primer followed by two coats of chlorinated rubber paint.

In addition, sand and mud tend to settle at the bottom of the digester in spite of efforts to keep the charge free of sand. The daily operation and maintenance activities of the operators should be simpler and routine by means of a flow chart and a problem- cause with remedies chart.

The proper training should be imparted to the users so that the technical awareness in respect of operating the plant to be increased.

5.14 Plant Location

It is proposed to install the biogas plant with the consideration of certain aspects as mentioned below: -

- (i) The biogas unit should be placed at a short distance from the kitchen and a safe distance from the cattle shed if any.

The short distance will minimize pressure drop in the pipelines connected in between the gasholder and the users end.

- (ii) There should be no trees close to the biogas unit. This is to avoid mechanical damage caused by roots, but also to avoid shedding from trees.

- (iii) The biogas unit should be placed in such a way that mechanical damage caused by cattle can be avoided.

- (iv) Due to the risk of leakage of liquids from the unit, it should not be placed near any wells

The space requirement depends on the size of the unit.