CHAPTER THREE

Plant Design

3.1 Design of Fixed Dome Type Digester

A biogas digester is essentially a chemical reactor in which there is a reactant flow and a product flow, the rate of gas production is dependant not only on microbial growth rate but also on the effectiveness of dispersion of the solid, liquid and gas phases and on the residence time distribution within the reactor.

The term 'dispersion' of different states of matter is related to the extent of mixing taking place in the digester. For example, continuous stirring leads to a high degree of dispersion which is known to increase gas production. The fact that all the feed material may not 'reside' in the digester for the same time leads to the concept of residence time distribution. If the feed is divided into N smaller portions, some portions might stay longer in the digester than the other portions. The residence time distribution is dependent upon the geometry of the digester, the degree of mixing etc. all these factors give rise to several design options. Conventional and established methods of designing of fixed dome type plants are presented below.

The principal parameter which determines the cost of the digester is its volume (V), which includes of the active digester volume (V_s) and the gas storage space. [2]

The active digester volume (V_s) is the volume occupied by the biomass in the digester and is calculated as:-

$$V_s(m^3) = \text{daily biomass feed } (m^3/day) \times HRT(days) \qquad (3.1)$$

HRT ≡ hydraulic retention time in days.
Dilution ratio= 1:1 (cattle dung: water), or water can added up to 8-10% TS (Total Solid).

The total volume of gas storage space provided is usually equal to the volume of gas generated in 24 hours under normal operating condition.

3.1.1 Biomass Movement in a Fixed Dome Type Digester

The digester consists of a cylindrical brick walled pit with inlet and outlet tanks (Figure 3.1). When the gas pressure is equal to atmospheric pressure (no gas can be withdrawn for use under this condition), the biomass level in the digester is equal to that in the inlet and outlet chambers as shown in figure 3.1.
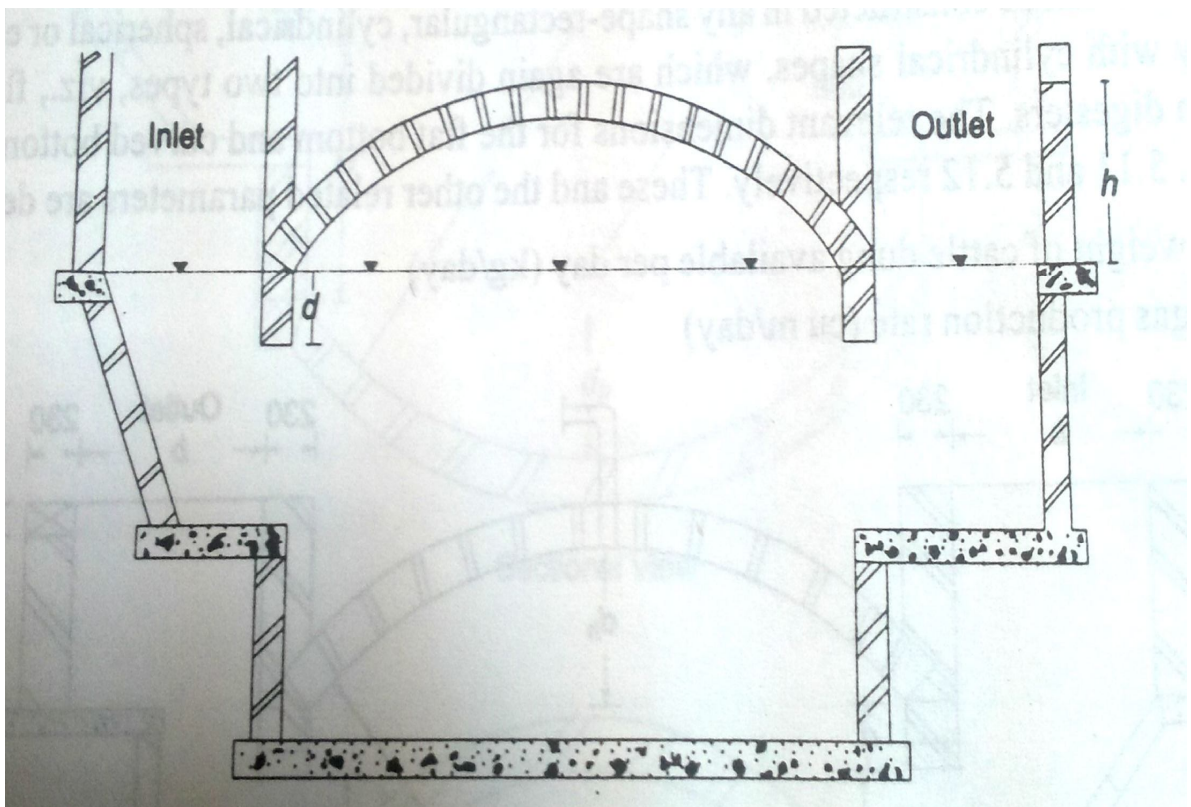

Figure 3.1 Biomass Level after Complete Withdrawal of Gas

The gas evolving from the surface of the biomass accumulates in the space above and gets compressed. As the compressed gas pushes down the biomass level in the digester, the biomass level in the inlet and outlet chambers raises to a point such that the pressure of the gas is balanced by the pressure of the water column in the inlet and outlet chambers. When the storage space is completely filled with gas, the biomass level inside the digester is pushed to the lowest position and the biomass level in the inlet and outlet chamber rises to the highest position as shown in figure 3.2. The volume of the biomass in excess of the active digester volume is pushed out through an opening in the outlet chamber. Thus under ideal operating conditions, the volume of biomass flowing out as fertilizer of the digester in a day would exactly be equal to the volume of the daily feeding. If gas is not withdrawn for use even after reaching the position indicated in figure 3.2, the excess gas generated will bubble out through the inlet and outlet openings.
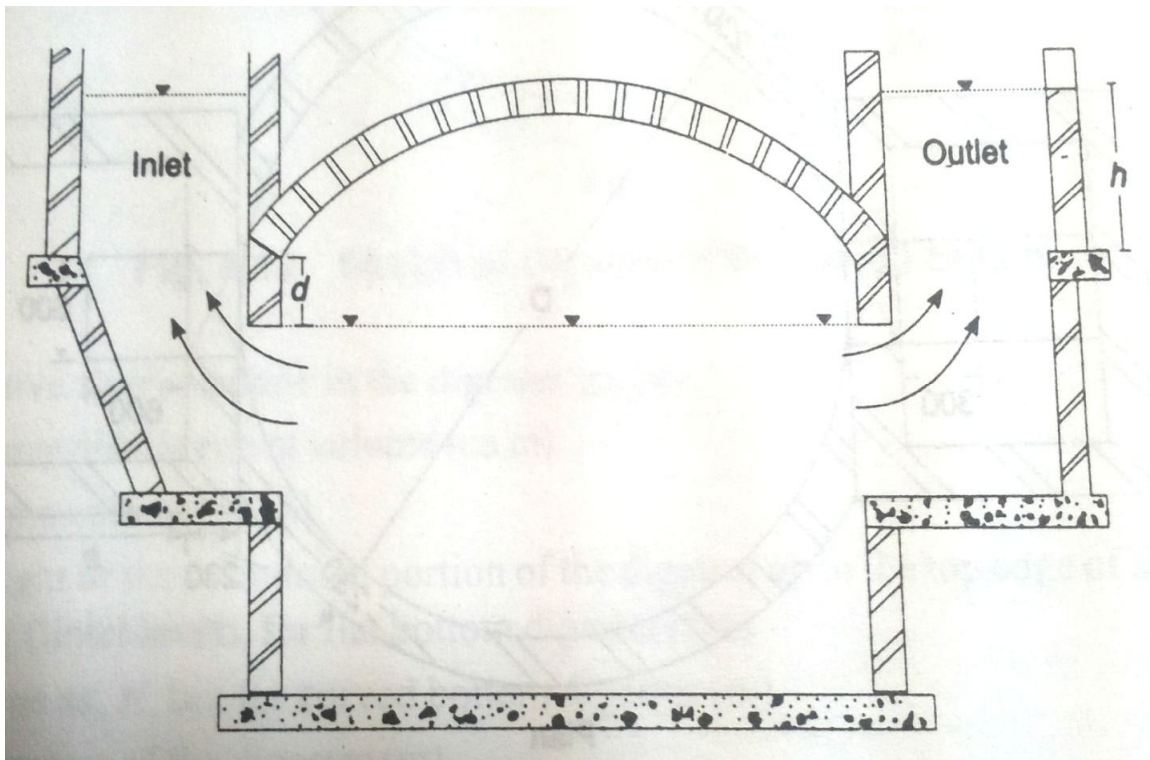

Figure 3.2 Biomass Level with Storage Full of Gas

3.1.2 Design Calculations

Fixed dome digester can be constructed in many shapes (rectangular, cylindrical, spherical, or ellipsoidal. We will calculate the design equations for only cylindrical shape which are divided into two types, flat bottom, and curved bottom digesters. The relevant dimensions for the flat bottom and curved bottom digester are shown in Figure. 3.3 and 3.4 respectively.
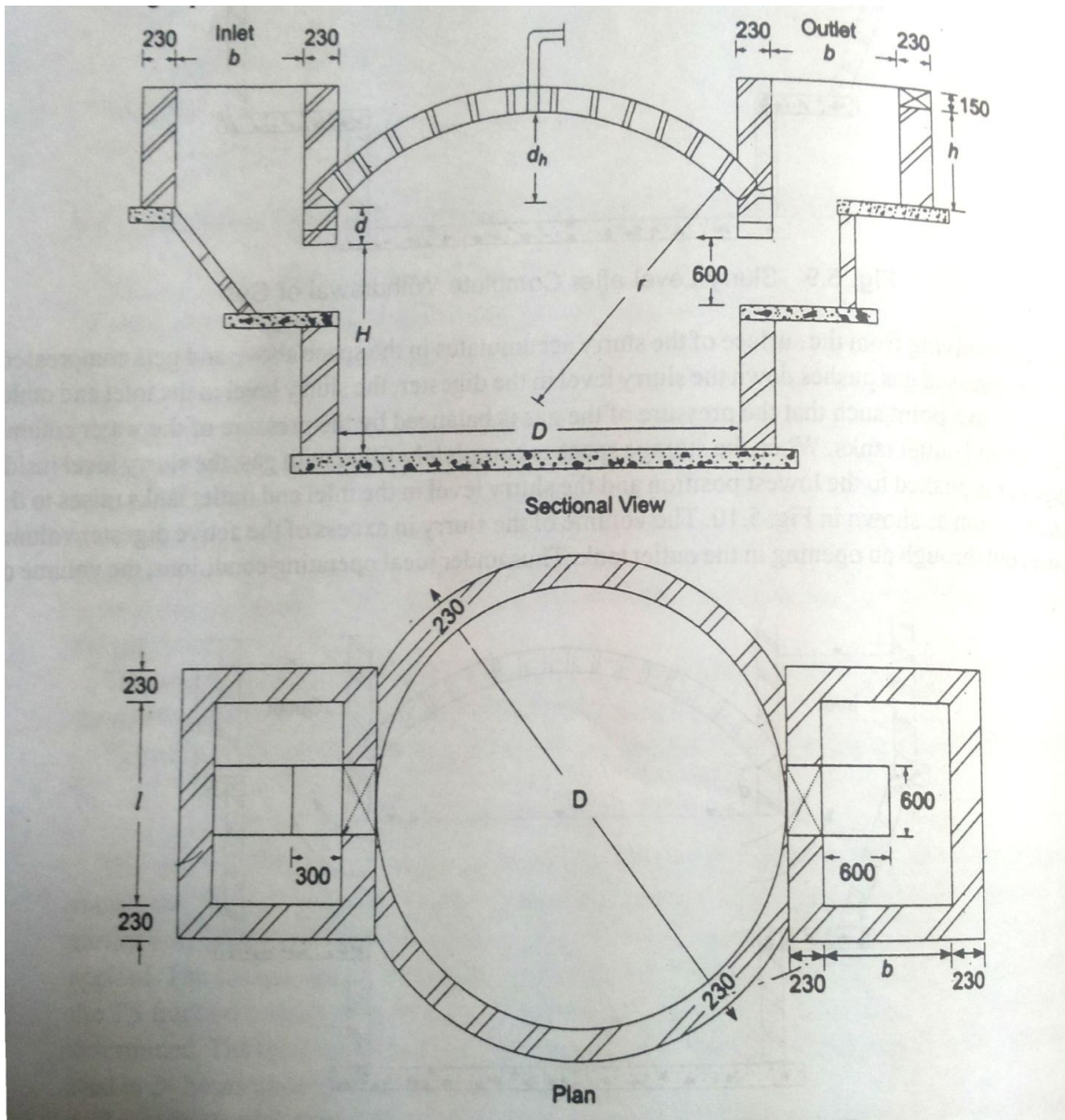

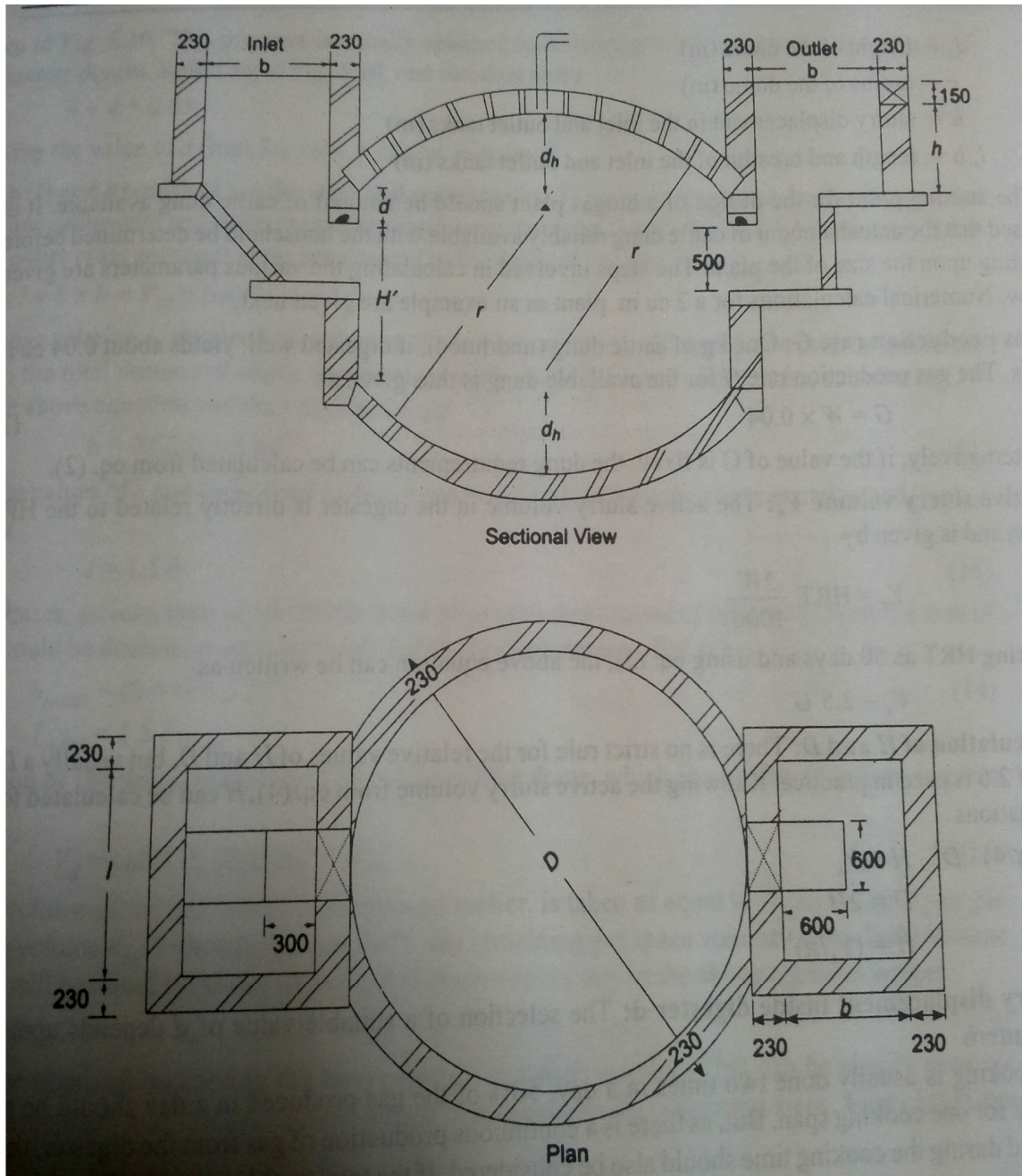**Figure 3.3 Sketch of Flat Bottom Digester**

Figure 3.4 Sketch of Curved Bottom Digester

D=diameter of the digester (m).

H=height of the cylindrical portion of the digester up to the top edge of the inlet/outlet opening (lintel level), for flat bottom digester (m).

H^1=same as, H, but for curved bottom digester (m).

d_h=height of the dome (m).

d=Slurry displacement inside digester.

h=Slurry displacement in the inlet and outlet chambers.

r=radius of the dome (m).

l=length of the inlet and outlet chambers (m).

b=breadth of the inlet and outlet chambers (m).

V_s=active slurry (biomass) volume in the digester (m^3).

V_{sd}=slurry displacement volume (m^3).

V_d=dome volume (m^3).

W=weight of cattle dung available per day (kg/day).

G=gas production rate (m^3/day).

The starting point for the design of a biogas plant should be amount of cattle dung (biomass) available. The steps involved in calculating the various parameters are given below.

- **Gas production rate(G):** One kg of cattle dung (undiluted), if digested well, yields about 0.04m^3 of gas. the gas production rate(G) for the available dung is given as

$$G= W \times 0.o4 \tag{3.2}$$

  Alternatively, if the value of G is fixed, the dung requirements can be calculated from equation (3.2).

- **Active slurry volume V_S:** The active slurry volume in the digester is directly related to the HRT(hydraulic retention time in days) chosen and is given by

$$V_S = HRT \times (2W/1000) \tag{3.3}$$

  Taking HRT as 50 days and using equation (3.2), the above equation can be written as

$$V_S = 2.5G \tag{3.4}$$

- **Calculation of (H) and (D):** There is no strict rule for the relative values of (H) and (D), but usually a (D/H) ratio of 2.0 is used in practice. knowing the active slurry volume from equation (3.4), (H) can be calculated from the equations

$$(\pi/4).D^2.H = V_s \qquad (3.5)$$

$$D = 2H \qquad (3.6)$$

$$H = (V_s/\pi)^{1/3} \qquad (3.7)$$

- **Slurry displacement inside digester (d):** The selection of a suitable value of (d) depends upon gas usage 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. But, as there is a continuous production of gas from the digester, the gas generated during the cooking time should also be considered. If the total cooking time is about 3 hours, the variable gas storage volume (V_{sd}) is obtained from the equation

$$(3/24).G + V_{sd} = 0.5G \qquad (3.8)$$

This after simplification leads to

$$V_{sd} = 0.375G \approx 0.4G$$

(d) is then obtained as

$$(\pi/4)D^2 d = V_{sd} = 0.4G \qquad (3.9)$$

Using equation (3.4) & (3.5), we get

$$d = (H/2.5) \times 0.4 = 0.16\ H \qquad (3.10)$$

- **Slurry displacement in the inlet and outlet chambers (h):** The maximum pressure attained by the gas is equal to the pressure of the water (slurry) column above the lowest slurry level in the inlet/outlet chambers as shown in Figure 3.2. This pressure is usually selected to be 0.85 m water gauge as a safe limit for brick/concrete domes. Referring to Figure 3.2 we can write

$$h + d = 0.85 \qquad (3.11)$$

Knowing the value of (d) from equation (3.10), (h) can be calculated.

- **Length (l) and breadth (b) of the inlet and outlet chambers:** There is no restriction on the shape of the cross section of the inlet and outlet chambers, but usually a rectangular shape with (l=0.5b) is selected. If the inlet and outlet cross sectional areas are selected to be identical , we get

$$2 \times l \times b \times h = V_{sd} = 0.4 \, G$$

The above relation is obtained by equating the volume of slurry displaced downwards inside the digester to the total volume of slurry displaced upwards in the inlet and outlet tanks, substituting (l=1.5 b) in the above equation and rearranging, we get

$$b = (0.2 \, G/1.5 \, h)^{1/2} \qquad (3.12)$$

Using the values of (h) and (G) obtained earlier, (b) can be calculated from the above equation and (l) is then obtained as

$$l = 1.5 \, b \qquad (3.13)$$

In some cases, an inlet pipe of 15-20 cm diameter is provided instead of inlet chamber. Then the area of the outlet should be doubled to accommodate the slurry displacement. For this

$$b_{outlet} = (0.4 \, G \,/1.5 \, h)^{1/2} \qquad (3.14)$$

$$l_{outlet} = 1.5 \, b_{outlet}$$

- **Calculation of the dome height (d_h) :** the volume of the dome, which is a section of sphere, is given by

$$V_d = (\pi/6) \, d_h . [\, 3(D/2)^2 + d^2_h] \qquad (3.15)$$

The total volume of the gas space, as mentioned earlier, is taken as equal to (G). As the slurry or gas displacement volume (V_d) is already fixed as (0.4 G), the remaining gas space volume, which is

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the volume of the dome, will be equal to (G-0.4 G) or (0.6 G). Substituting this in the above equation we get

$$0.6\ G = (\pi/6)\ d_h\ .[\ 3(D/2)^2 + d^2_h\ ] \tag{3.16}$$

(d_h) has to be obtained by solving the above equation; which is cubic. This can be simply done by iteration. An algebraic solution also exists, which is obtained by the following steps. First obtain the parameters

$$p = 0.75\ D^2 \tag{3.17}$$
$$q = -0.6(\pi/6)\ G \tag{3.18}$$
$$R = (p/3)^3 + (q/2)^2 \tag{3.19}$$
$$A = [(-q/2) + \sqrt{R}\ ]^{1/3} \tag{3.20}$$
$$B = [(-q/2) + \sqrt{R}\ ]^{1/3} \tag{3.21}$$

Then (d_h) is given by

$$d_h = A + B \tag{3.22}$$

- **Radius of the dome (r):** the dome radius is obtained by the equation
$$r = [\ (d/2)^2 + d^2_h\ ]/\ 2\ d_h \tag{3.23}$$

- **Calculation for (H^1) for curved bottom digesters:** For digester with curved bottom, the bottom portion is identical to the dome. (H^1) is then obtained from the equation
$$(\pi/4)\ .\ D^2\ H^1 + 0.6\ G$$
  Or by simplifying
$$H^1 = (H/2.5) \times 1.9 \tag{3.24}$$

- **Other dimensions:** The size of the inlet and outlet openings (these openings also called 'boxes' connect the inlet /outlet chambers to the digester) in the digester are normally 0.6m×0.6m for digesters of any capacity. This size is selected so that a man can go inside the digester during the construction period.

The wall are 230mm thick (full brick) and the walls of the inlet and outlet boxes are 115mm thick (half brick). For curved bottoms, two brick layers are provided, the lower layer being 115mm thick and the upper layer 75mm thick. Concreting should be 100mm thick.

3.1.3 Case Study: Cow Farm at Assalaya Sugar Factory

Number of cows at the farm = 80 cow. [1]

Dung (biomass) production per day (one cow produce 12 kg/day) =
$$W = 12 \times 80 = \underline{960 \text{ kg/day}}.$$

Gas production rate (G) =
$$G = W \times 0.04 = 960 \times 0.04 = \underline{38.4 \text{ m}^3\text{/day}}.$$

Active slurry volume(V_s) =
$$V_s = 2.5 \times G = 2.5 \times 38.4 = \underline{96 \text{ m}^3}.$$

Height of the cylindrical portion of the digester up to the top edge of the inlet/outlet opening (lintel level), for flat bottom digester (H) =
$$H = (V_s/\pi)^{1/3} = (96/\pi)^{1/3} = \underline{3.13 \text{ m}}.$$

Diameter of the digester (D) =
$$D = 2 \times H = 2 \times 3.13 = \underline{6.26 \text{ m}}.$$

Slurry displacement inside digester (d) =
$$d = (H/2.5) \times 0.4 = (3.13/2.5) \times 0.4 = \underline{0.50 \text{ m}}.$$

Slurry displacement in the inlet and outlet chambers (h) =
$$h = 0.85 - d = 0.85 - 0.50 = \underline{0.35 \text{ m}}.$$

Breadth of the inlet and outlet chambers (b) =
$$b = (0.2 \times G/1.5h)^{1/2}$$
$$= (0.2 \times 38.4/1.5 \times 0.35)^{1/2} = \underline{3.82 \text{ m}}.$$

Length of the inlet and outlet chambers (l) =
$$l = 1.5 \times b = 1.5 \times 3.82 = \underline{5.74 \text{m}}.$$

Calculation of the dome height (d_h):
$$p = 0.75 D^2$$

$$= 0.75 \times (6.26)^2$$

$$= 29.39$$

$$q = -0.6 \times (6/\pi) \times G$$

$$= -0.6 \times (6/\pi) \times 38.4$$

$$= -44.00$$

$$R = (p/3)^3 + (q/2)^2$$

$$= (29.39/3)^3 + (-44.00)^2$$

$$= 2876.23$$

$$\sqrt{R} = 53.63$$

$$A = [(-q/2) + \sqrt{R}\,]^{1/3}$$

$$= [(44.00/2) + 53.63]^{1/3}$$

$$= 4.23$$

$$B = [(-q/2) - \sqrt{R}\,]^{1/3}$$

$$= [(44.00/2) - 53.63]^{1/3}$$

$$= -3.16$$

$$d_h = A + B$$

$$= 4.23 - 3.16 = \underline{1.07 \text{ m.}}$$

Radius of the dome(r) =

$$r = [\,(D/2)^2 + d^2{}_h]\,/\,2 \times d_h$$

$$= [\,(6.26/2)^2 + (1.07)^2\,]\,/\,(2 \times 1.07)$$

$$= \underline{5.11 \text{ m.}}$$

The suitable design parameters are listed below:-

Gas production rate (G) = 38.4 m^3/day.

Active slurry volume(Vs) = 96 m^3 .

Height of the cylindrical portion of the digester up to the top edge of the inlet/outlet opening (lintel level), for flat bottom digester (H) = 3.13 m.

Diameter of the digester (D) = 6.26 m.

Slurry displacement inside digester (d) = 0.50 m.

Slurry displacement in the inlet and outlet chambers (h) = 0.35 m.

Breadth of the inlet and outlet chambers (b) = 3.82 m.

Length of the inlet and outlet chambers (l) = 5.74m.

The dome height (d_h) = 1.07 m.

Radius of the dome(r) = 5.11 m.

3.1.4 Material Estimation for the Plant

It's essential to make correct material estimates in order to have correct cost estimates and to avoid wastage.

3.1.4.1 Concreting

Concreting is required at the digester bottom; at the base of inlet and outlet chambers etc. these foundations are usually 0.1m thick. The total volume of concreting is found as follows:-

First: concreting at the bottom of digester

At the bottom of digester = $(\pi/4)$ × [D + 2 (digester wall thickness) + 0.2]^2 × 0.1

The digester wall thickness = 0.23m.

D = 6.26 m

Volume of concreting required for the bottom =

$$(\pi/4) × [6.26 + 0.46 + 0.2]^2 × 0.1 = \underline{3.76\ m^3}$$

Second: concreting at the inlet and outlet box

The base of the inlet box is rectangular, with dimensions of 0.75m × 1.00m and that of the outlet box is almost square, with dimensions 1.05m × 1.00m. these dimensions are fixed for any size of the plant .

The volume of concreting required =

$$(0.75 × 1.00 × 0.1) + (1.05 × 1.00 × 0.1) = \underline{0.18\ m^3}$$

Third: concreting at the inlet and out let chambers

The base of the inlet and outlet chambers has rectangular shape with dimensions

$$= (I + 0.46 + 0.2) \times (b + 0.46 + 0.2)$$

The volume of concreting required =

$$2 \times (I + 0.46 + 0.2) \times (b + 0.46 + 0.2) \times 0.1$$
$$= 2 \times (5.74 + 0.46 + 0.2) \times (3.82 + 0.46 + 0.2) \times 0.1 = 5.73 \text{ m}^3$$

The base of the inlet and outlet chambers is, however, not completely concreted. The volume to be subtracted is

$$- [(0.6 \times 0.6 \times 0.1) + (b \times 0.6 \times 0.1)]$$
$$= - [(0.6 \times 0.6 \times 0.1) + (3.82 \times 0.6 \times 0.1)] = - 0.27 \text{ m}^3$$

The volume of concreting required = 5.73 - 0.27 = <u>5.46 m³</u>

Fourth: volume of the concrete for lentils

The volume of the concrete for lentils = $2 \times 0.9 \times 0.23 \times 0.1 =$ <u>0.04 m³</u>

Fifth: volume of concrete for cover slabs for the inlet and outlet chambers

The volume of concrete for cover slabs for the inlet and outlet chambers =

$$2 \times (I + 0.46) \times (b + 0.46) \times 0.075$$
$$= 2 \times (5.74 + 0.46) \times (3.82 + 0.46) \times 0.075 = \underline{3.98 \text{ m}^3}$$

Sixth: total volume of concrete

The total volume of concrete is obtained by summing up all the above quantities

$$= 3.76 + 0.18 + 5.46 + 0.04 + 3.98 = \underline{13.42 \text{ m}^3}$$

The reinforced cement concrete is mixed in the proportion of 1:2:4 (cement: sand: stone ballast).

The materials needed for 1m^3 of concreting are :-

Cement: 0.22 m^3 (6.6 bags) ; for 13.42 m^3 of concreting we need 2.95 m^3 (88.5 bags) of cement.

Sand (coarse): 0.44m^3 ; for 13.42 m^3 of concreting we need 5.90m^3 of sand .

Stone ballast (25mm): 0.88 m^3 ; for 13.42 m^3 of concreting we need 11.81 m^3 of stone .

Steel (8mm): 40kg ; for 13.42 m^3 of concreting we need 536.80 kg of steel.

Binding wire: 0.10 kg ; for 13.42 m^3 of concreting we need 1.34 kg of wire.

3.1.4.2 Brickwork

The brickwork for digester wall and inlet/outlet chambers is 0.23 m thick and bonded with 1:5 (cement: sand) cement mortar.

First: digester wall:

Volume of brickwork needed = $(\pi/4)[(D+ 0.46)^2 - D^2] \times (H + D)$
$= (\pi/4)[(6.26+ 0.46)^2 - (6.26)^2] \times (3.13 + 6.26)$
$= 44.03$ m^3

Deductions for inlet/outlet openings = $2 \times (0.6 \times 0.23 \times 0.6) = 0.17$ m^3
Deductions for lintels = $2 \times (0.9 \times 0.23 \times 0.1) = 0.04$ m^3
Total volume of brickwork needed for digester wall = 44.03 - 0.17 - 0.04
$= 43.82$ m^3

The materials needed for 1m^3 of the above brickwork are:-

Bricks (0.23 m × 0.115 m × 0.075 m): 500 Numbers; for 43.82 m^3 = 21910 bricks .

Cement: 0.05 m^3 (1.5 bags) ; for 43.82 m^3 = 2.19 m^3 (65.7 bags).

Sand (coarse): 0.25 m^3 ; for 43.82 m^3 = 10.96 m^3

Second: inlet/outlet chambers:

Volume of brickwork needed for inlet/outlet chambers

$$= 4 \times (l + b + 0.46) \times 0.23 \times (h + 0.15)$$
$$= 4 \times (5.74 + 3.82 + 0.46) \times 0.23 \times (0.35 + 0.15)$$
$$= 4.61 \text{ m}^3$$

The materials needed for 1m^3 of the above brickwork are:-

Bricks (0.23 m × 0.115 m × 0.075 m): 500 Numbers; for 4.61 m^3 = 2305 bricks.

Cement: 0.05 m^3 (1.5 bags) ; for 4.61 m^3 = 0.23 m^3 (6.9 bags).

Sand (coarse): 0.25 m^3 ; for 4.61 m^3 = 1.15 m^3

Third: inlet/outlet boxes:-

The side walls of the inlet and outlet boxes are half brick walls bonded with CM 1: 5. The height of the walls is equal to (0.6 + d - 0.1) m the area of these walls are given below:

Inlet box side walls = $2 \times \dfrac{0.4 + (b + 0.1)}{2} \times (0.6 + d - 0.1)$

$$= 2 \times \dfrac{0.4 + (3.82 + 0.1)}{2} \times (0.6 + 0.50 - 0.1) = 4.32 \text{ m}^2$$

Inlet box sloping wall = $[(b - 0.3)^2 + (0.6 + d - 0.1)^2]^{1/2} \times 0.6$

$$= [(3.82 - 0.3)^2 + (0.6 + 0.50 - 0.1)^2]^{1/2} \times 0.6 = \underline{2.20 \text{ m}^2}$$

Outlet box $= 2 \times 0.7 \times (0.6 + d - 0.1)$

$$= 2 \times 0.7 \times (0.6 + 0.50 - 0.1) = \underline{1.40 \text{ m}^2}$$

Side walls $= 1 \times 0.6 \times (0.6 + d - 0.1)$

$$= 1 \times 0.6 \times (0.6 + 0.50 - 0.1) = \underline{0.60 \text{ m}^2}$$

Total area $= 4.32 + 2.20 + 1.40 + 0.60 = \underline{8.52 \text{ m}^2}$

The materials needed for 10 m^2 area are:-
Bricks: 500 Numbers.
Cement: 0.05 m^3 (1.5 bags).
Sand (coarse): 0.25 m^3.

So, for area 8.52 m^2 we need:-
Bricks: <u>426 Numbers.</u>
Cement: <u>0.04 m^3</u> <u>(1.3 bags).</u>
Sand (coarse): <u>0.21 m^3</u>

Forth: bricks for dome construction:-

Dome is constructed using first class brick bonded with CM 1 : 2
Area of dome $= 2 \times \pi \times (r + 0.05) \times (d_h + 0.05)$

$$= 2 \times \pi \times (5.11 + 0.05) \times (1.07 + 0.05) = \underline{36.31 \text{ m}^2}$$

One layer around the dome along with the first ring $= \pi \times D \times 0.1$

$$= \pi \times 6.26 \times 0.1 =$$

<u>1.97 m^2</u>

Total area $= 36.31 + 1.97 = \underline{38.28 \text{ m}^2}$

Material requirements for 10 m^2 are:

Bricks: 370 Numbers.

Cement: 0.05 m^3 (1.5 bags).

Sand (coarse): 0.11 m^3.

So, for area 38.28 m^2 we need:-

Bricks: 1417 Numbers.

Cement: 0.19 m^3 (5.7 bags).

Sand (coarse): 0.42 m^3

Fifth: brick tiles for dome:-

The total area of brick tile = 2 × π (r + 0.17) × (d$_h$ + 0.17)

$$= 2 × \pi (5.11 + 0.17) × (1.07 + 0.17) = \underline{41.14 \text{ m}^2}$$

Material requirements for 10 m^2 are:

Tiles: 370 Numbers.

Cement: 0.1 m^3 (3.0 bags).

Sand: 0.04 m^3.

So, for area 41.14 m^2 we need:-

Tiles: 1522 Numbers.

Cement: 0.41 m^3 (12.4 bags).

Sand: 0.16 m^3

3.1.4.3 Plastering and Filling

First: CM 1 : 2 for filling:-

In the canal between dome and side wall:

For the first ring = π × (D + 0.23) × 0.1 × 0.1

$$= \pi \times (6.26 + 0.23) \times 0.1 \times 0.1 = \underline{0.20 \text{ m}^3}$$

In the corners of the dome $= \pi \times D \times [(0.025)^2 / 2]$
$$= \pi \times 6.26 \times [(0.025)^2 / 2] = \underline{0.006 \text{ m}^3}$$
Total volume $= 0.20 + 0.006 = \underline{0.206 \text{ m}^3}$

<u>Material requirements for one m^3</u> <u>are:</u>
Cement: 0.42 m^3 (12.6 bags).
Sand (fine): 0.84 m^3.

So, for volume 0.206 m^3 we need:-
Cement: <u>0.087 m^3</u> <u>(2.6 bags).</u>
Sand (fine): <u>0.17 m^3</u>

<u>Second: Plastering with CM 1 : 2 (12mm):-</u>

For dome inside $= 2 \times \pi \times r \times d_h$
$$= 2 \times \pi \times 5.11 \times 1.07 = \underline{34.35 \text{ m}^2}$$
For side walls in the gas storage $= \pi \times D \times d$
$$= \pi \times 6.26 \times 0.50 = \underline{9.83 \text{ m}^2}$$
Total area $= 34.35 + 9.83 = \underline{44.18 \text{ m}^2}$

<u>Material requirements for 10 m^2</u> <u>are:</u>
Cement: 0.06 m^3 (1.8 bags).
Sand (fine): 0.12 m^3.

So, for area 44.18 m^2 we need:-
Cement: <u>0.27 m^3</u> <u>(7.95 bags).</u>
Sand (fine): <u>0.53 m^3</u>

Third: Neat cement plaster:-

For dome inside $= 2 \times \pi \times r \times d_h$

$\qquad = 2 \times \pi \times 5.11 \times 1.07 = \underline{34.35 \ m^2}$

For side wall in the gas storage $= \pi \times D \times d$

$\qquad\qquad = \pi \times 6.26 \times 0.50 = \underline{9.83 \ m^2}$

Total area $= 34.35 + 9.83 = \underline{44.18 \ m^2}$

Material requirements for $10 \ m^2$ are:
Cement: $0.022 \ m^3$ (0.6 bags).

So, for area $44.18 \ m^2$ we need:-
Cement: $\underline{0.097 \ m^3}$ $\underline{(2.6 \ bags).}$

Fourth: Plastering with CM 1 : 5 (12 mm):-

Digester inside wall $= \pi \times D \times H$

$\qquad\qquad = \pi \times 6.26 \times 3.13 = \underline{61.56 \ m^2}$

Digester bottom $= (\pi/4) \times D^2$

$\qquad\qquad = (\pi/4) \times (6.26)^2 = \underline{30.78 \ m^2}$

Lintel bottom $= 2 \times 0.6 \times 0.23 = \underline{0.28 \ m^2}$

Digester outside $= \pi \times (D + 0.46) \times 0.3$

$\qquad\qquad = \pi \times (6.26 + 0.46) \times 0.3 = \underline{6.33 \ m^2}$

Over and below brick tiles $= 2 \times \pi \times (r + 0.15) \times (d_h + 0.15)$

$$= 2 \times \pi \times (5.11 + 0.15) \times (1.07 + 0.15) = \underline{40.32 m^2}$$

Inlet box side walls = $(0.3 + b) \times (0.6 + d)$
$$= (0.3 + 3.82) \times (0.6 + 0.50) = \underline{4.53 \ m^2}$$

Inlet box sloping wall = $[(b - 0.3)^2 + (d + 0.6)^2]^{1/2} \times 0.6$
$$= [(3.82 - 0.3)^2 + (0.50 + 0.6)^2]^{1/2} \times 0.6 = \underline{2.21 \ m^2}$$

Inlet box bottom = $0.53 \times 0.6 = \underline{0.32 \ m^2}$

Outlet box side walls = $3 \times 0.6 \times (d + 0.6)$
$$= 3 \times 0.6 \times (0.50 + 0.6) = \underline{1.98 \ m^2}$$

Outlet box bottom = $0.83 \times 0.6 = \underline{0.498 \ m^2}$

Inlet & outlet chambers inside = $2 \times 2 \ (l + b) \times (h + 0.15)$
$$= 2 \times 2 \ (5.74 + 3.82) \times (0.35 + 0.15) = \underline{19.12 \ m^2}$$

Inlet & outlet chambers outside = $2 \times (l + b + 0.92) \times 0.3$
$$= 2 \times (5.74 + 3.82 + 0.92) \times 0.3 = \underline{6.29 \ m^2}$$

Inlet & outlet chambers top & bottom = $2 \times [(l + 0.46) \times (b + 0.46)]$
$$= 2 \times [(5.74 + 0.46) \times (3.82 + 0.46)]$$
$$= \underline{53.07 \ m^2}$$

Total area = 61.56 + 30.78 + 0.28 + 6.33 + 40.32 + 4.53 + 2.21+ 0.32 +
1.98 + 0.498 + 19.12 + 6.29 + 53.07
$$= \underline{227.29 \ m^2}$$

Deductions:

Inlet chamber bottom = b × 0.6

$$= 3.82 \times 0.6 = \underline{2.29 \text{ m}^2}$$

Outlet chamber bottom = 0.6 × 0.6

$$= \underline{0.36 \text{ m}^2}$$

Total deductions = 2.29 + 0.36

$$= \underline{2.65 \text{ m}^2}$$

Then, total area = 227.29 - 2.65 = $\underline{224.64 \text{ m}^2}$

Material requirements for 10 m^2 are:
Cement: 0.04 m^3 (1.2 bags).
Sand: 0.18 m^3.

So, for area 224.64 m^2 we need:-
Cement: 0.898 m^3 (26.96 bags).
Sand: 4.04 m^3.

Fifth: Miscellaneous:-

Steel rings around the base of the dome = 2 × π × (D + 0.5)

$$= 2 \times \pi \times (6.26 + 0.5) = \underline{42.47 \text{ m}}$$

Chicken wire mesh = 2 × π × (r + 0.1) × (d$_h$ + 0.1) × 1.25

$$= 2 \times \pi \times (5.11 + 0.1) \times (1.07 + 0.1) \times 1.25 = \underline{47.88 \text{ m}^2}$$

GI pipe for gas outlet = $\underline{0.45 \text{ m}}$

Bamboos or (S) hooks for dome construction = <u>7 – 8 Numbers</u>

Material for scaffolding, measuring tape, rope nails etc.