TOPIC NINE

DESIGN CONCEPT AND OTHER PARAMETERS OF BIOGAS PLANT

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9.1 INTRODUCTION

Biogas plant can be defined as a physical structure where methane gas (i.e. biogas) is produced by anaerobic digestion of organic matter. In the literature it is also commonly known as a bio-digester, bio-reactor or anaerobic reactor. In principle a biogas plant should have three essential components as follows:

- **Digestion chamber**

Anaerobic reaction takes place in the digestion chamber. Since such reaction can occur only in the absence of air (oxygen), this chamber needs to be airtight.

Inlet

The input required for gas production (i.e., organic matter such as slurry) is fed into the digestion chamber via the inlet.

Outlet

Once digested, the effluent is removed via the outlet. The outlet level is always lower than the inlet level to ensure one way flow of the digested slurry (effluent).

9.2 PLANT TYPES

Although, various types of biogas plants have been developed, there are only three practical models of biogas plant in the Nepalese context. These are briefly discussed below.

9.2.1 Floating Drum Digester

Experiment in biogas technology in India began in the late 1930's. In 1956 Jasu Bhai J. Patel developed a design of floating drum biogas plant popularly known as Gobar Gas Plant. In 1962, the Khadi Village Industries Commission (KVIC) of India approved Patel's design and this model soon gained popularity in India as well as the sub-continent. This KVIC design is presented in **Figure 9.1.**

In the KVIC design, the digester chamber is made of brick masonry in cement mortar. A mild steel drum is placed on top of the digester chamber to store the gas produced. Thus, there are two separate structures for gas production and collection. With the introduction of the fixed dome Chinese model plant, the floating drum plants became obsolete due to comparatively high investment and maintenance cost along with other design weaknesses. For example, the mild steel drum corrodes and needs to be replaced within 5-10 years. Similarly, the drum has to be well anchored to prevent it from overtopping due to high gas pressure.

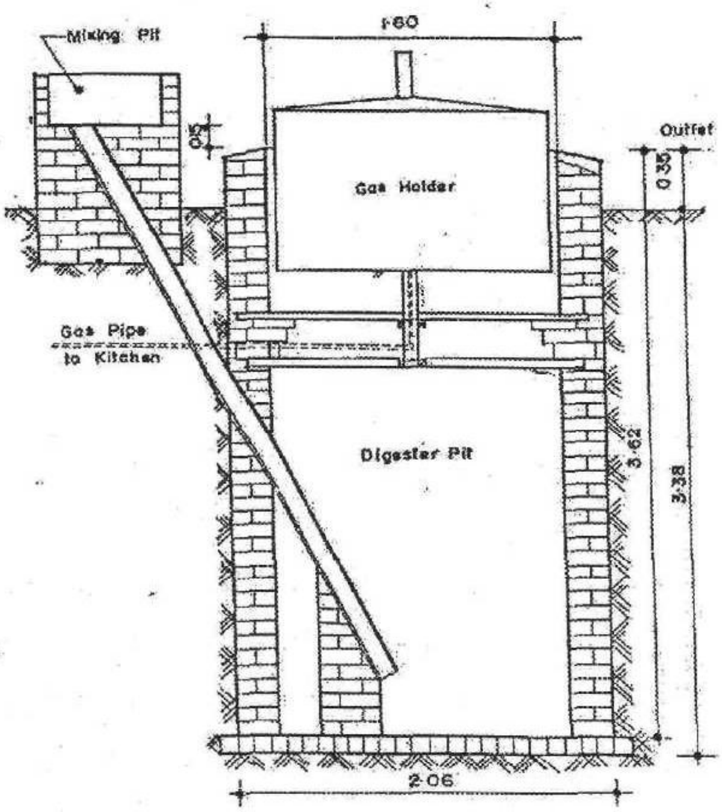


Figure 9.1: KVIC Floating Gas Holder System

9.2.2 Fixed Dome Digester

Fixed dome Chinese model biogas plant (also called drumless digester) was experimented in China as early as the mid 1930's. It consists of an underground brick masonry compartment (digestion chamber) with a concrete dome on the top for gas storage. Thus, in this design the digestion chamber and the gas storage dome are combined as one unit. This design eliminates the use of costlier mild steel gasholder. The life of a fixed dome type plant is longer (20 to 50 years) compared to KVIC plant. Based on the principles of fixed dome model from China, Gobar Gas and Agricultural Equipment Development Company (GGC) has developed a design commonly known as the GGC model. The GGC model biogas plant ARE presented in Figures 9.2 and Figure 9.3. Note that in both the GGC and Chinese models biogas the plant size corresponds to the actual volume. For example a GGC model "8 m^3 biogas plant" has a volume of about 8 m^3.

The plant measurements of the GGC model biogas plant for various plants size are presented in **Table 9.1** (corresponding to the **Figure 9.2**).

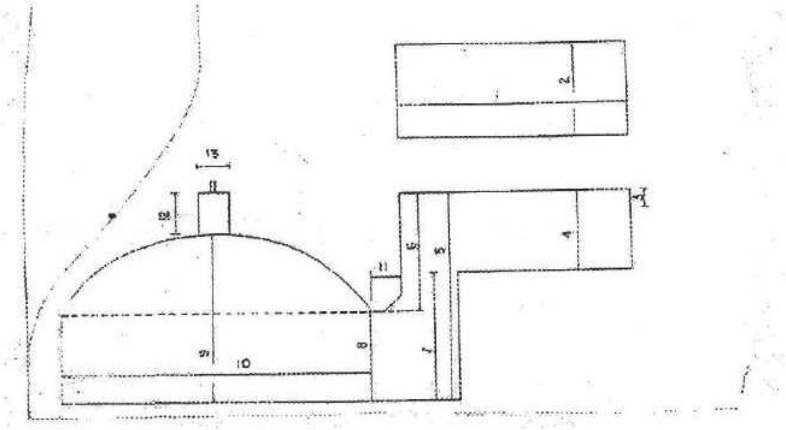


Figure 9.2: Dimensions of GGC model biogas plant (to be read in conjunction with Table 9.1)

Table 9.1
Plant Dimensions for 4m^3 - 20 m^3 GGC Biogas Plants

S.N.	Description Plant Size	Unit						
		m^3	4	6	8	10	15	20
1	Outlet length	cm^3	140	150	170	180	248	264
2	Outlet width	cm^3	120	120	130	125	125	176
3	Base overflow - top outlet	cm^3	15	15	15	15	15	15
4	Floor outlet - top outlet	cm^3	65	75	80	83	99	101
5	Floor Digester - top outlet	cm^3	177	191	207	207	231	238
6	Top manhole - top outlet	cm^3	91	99	102	113	116	123
7	Floor manhole - floor outlet	cm^3	112	116	127	124	132	137
8	Floor digester - top manhole	cm^3	86	92	105	94	115	115
9	Floor digester - top dome	cm^3	151	160	175	171	193	203
10	Diameter of digester wall	cm^3	204	244	270	308	350	398
11	Digester wall to outlet wall	cm^3	23	26	26	26	26	29
12	Turret Height	cm^3	50	50	50	50	50	50
13	Turret diameter	cm^3	36	36	36	36	36	36
14	Min. support for gas pipe	cm^3	12	12	12	12	12	12
15	Gas pipe to outlet	cm^3	125	148	161	180	201	228
16	Top outlet to top gas pipe	cm^3	51	46	45	41	39	42
17	Top manhole - floor outlet	cm^3	26	24	22	30	17	22
18	Dome height	cm^3	65	68	70	77	78	88
19	Dome radius	cm^3	102	122	135	154	175	199
20	Outlet volume	m^3	0.84	1.08	1.44	1.55	2.6	4.00
21	Dome volume	m^3	1.21	1.75	2.18	3.11	4.00	5.83
22	Volume of digester	m^3	2.81	4.30	6.01	7.00	11.10	14.30

Note. Measurements based on Handbook of Gobargas plant construction, BSP

In the GGC model, the dome volume is about 30% of the total plant volume. In the Chinese model, the dome volume is about 60% (double of GGC model). However, note that in the Chinese model part of the dome is also used as the digestion chamber and therefore the gas storage volume is close to 30% (as in the GGC model).

9.2.3 Deenbandhu Model

In an effort to bring down the investment cost of the fixed dome plant, the Deenbandhu (Hindi translation, "friend of the poor") model was put forth in 1984 by the Action for Food Production (AFPRO), New Delhi. Although, the Deenbandhu plant is also based on the fixed dome model the dome structure is constructed of brick masonry instead of concrete. Also, it has a concave bottom where as the GGC model has a horizontal bottom. A typical design of the Deenbandhu model is presented in Figure 9.4.

In India this model proved 30% cheaper than the Chinese fixed dome model of comparative size. However, in Nepal preliminary studies carried out by BSP did not find any significant difference between the investment cost of GGC and the Deenbandhu design of comparative size. This can be attributed to higher labour cost (and highly skilled masons) required to accurately construct the dome out of brick in cement masonry. Note that unlike the GGC model, the Deenbandhu plants are quoted in terms of the volume of biogas that can be produced in a day. For example a 2 m^3 Deenbandhu plant refers to the plant size which can produce 2 m^3 of gas in a day.

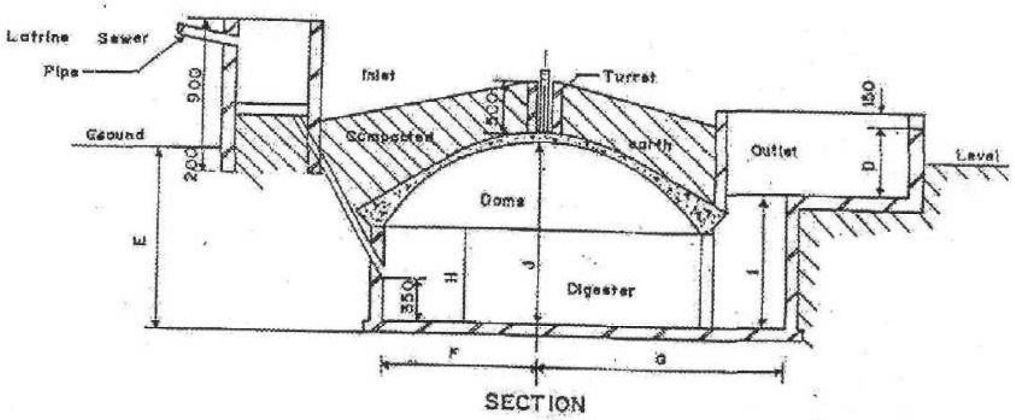


Figure 9.3: GGC Concrete Model Biogas Plant

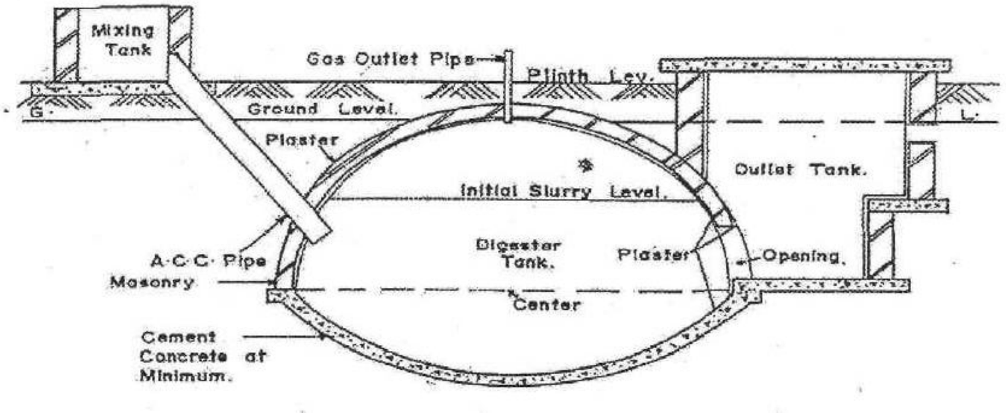


Figure 9.4: Deenbhandhu Biogas Plant (3 m^3 Gas Production/Day)

9.2.4 Other Designs

In addition to the 3 designs discussed above, there are also other designs which are suitable for specific conditions. These designs are briefly described below.

- **Bag Digester**

This design was developed in Taiwan in 1960s. It consists of a long cylinder PVC (plastic) cylinder as can be seen in **Figure 9.5.** This type of digester was developed to replace bricks/stone masonry or mild steel. This type of digester was also tested by GGC in Nepal in 1986. The study concluded that bag digester could be successful only if PVC bags are easily available.

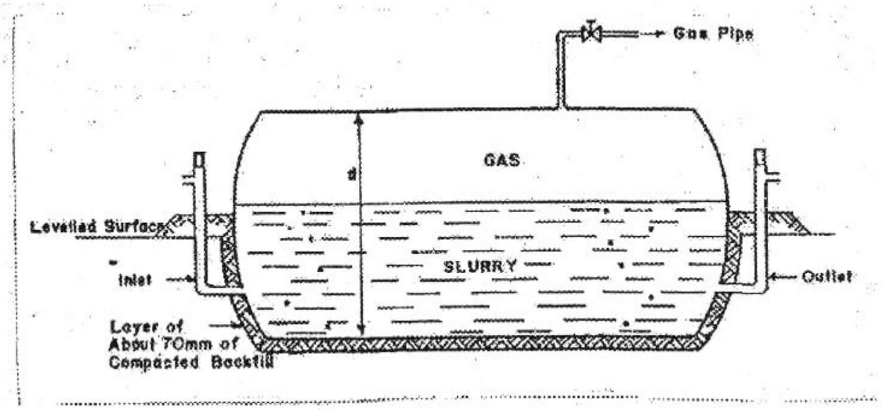


Figure 9.5: Bag Digester

- **Plug Flow Digester**

The plug flow design is similar to the bag digester. It consists of a concrete lined (or an impermeable member) trench that is considerably larger than the width or the depth. The reactor is covered with a flexible gasholder, concrete or galvanized iron (GI) sheet. The Plug flow digester is shown in **Figure 9.6.**

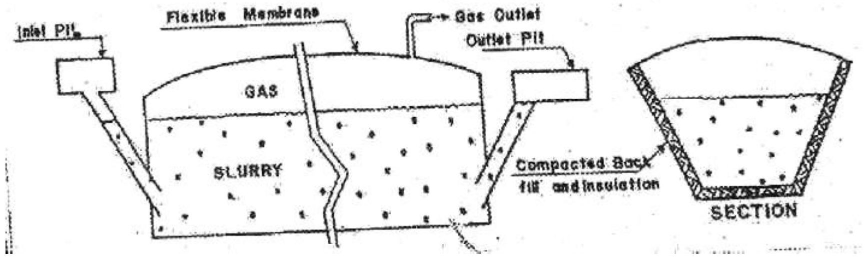


Figure 9.6: Plug Flow Digester

- **Anaerobic Filter**

The anaerobic filter was developed in 1950's to use relatively dilute and soluble waste water with low level of suspended solids. It is often used to in the treatment process of sewer waste system that is combined with storm drainage in the developed countries. This is one of the earliest and simplest type of design developed to reduce reactor volume. Different types of non-biodegradable materials have been used as the packing media for anaerobic filter reactors such as stones, plastic, coral etc. The methane forming bacteria form a film on the large surface of the media and are not carried out of the digester with the effluent. For this reason these reactors are also known as "fixed film" or "retained film" digesters. Figure 9.7 presents a sketch of this type of digester.

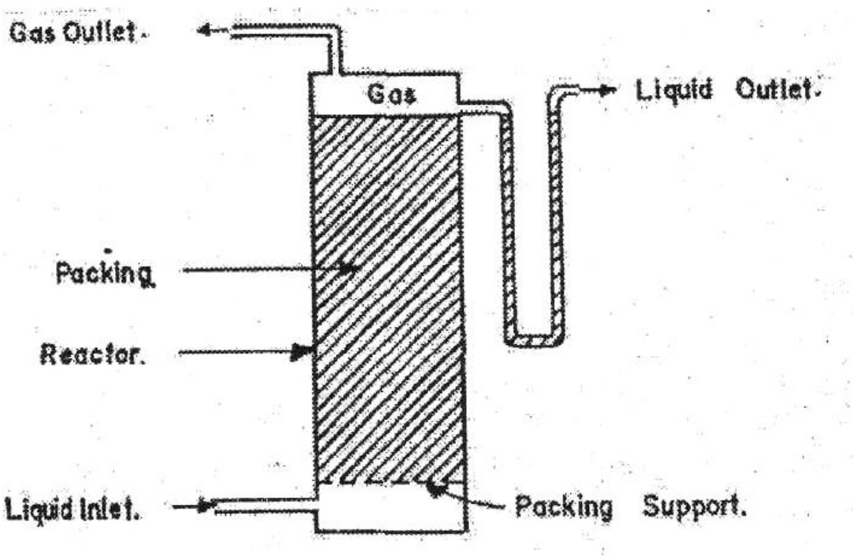


Figure 9.7: Anaerobic Filter

- **Upflow Anaerobic Sludge Blanket (USAB)**

The USAB design was developed in the 1980s in The Netherlands. It is similar to the anaerobic filter in that it involves a high concentration of immobilized bacteria in the reactor. However,, the USAB reactors contain no packing medium, instead, the methane forming bacteria are concentrated in the dense granules of sludge blanket which covers the lower part of the reactor. The inflow is fed from the bottom of the reactor and biogas is produced while the liquid flows up through the sludge blanket. These types of reactors are often used in Europe to treat sewer and industrial waste that are dilute. A sketch of the USAB design is presented in **Figure 9.8.**

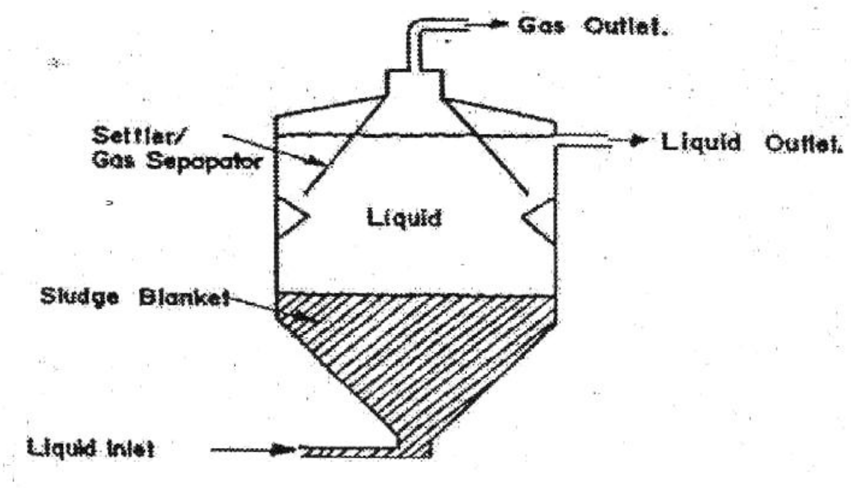


Figure 9.8: Anaerobic Filter

9.3 SITE SELECTION

Once the decision is made to install a biogas plant at the household level, a careful selection of the best site for the plant must be made. The factors which influence the decision, are:

- Close to the location where gas will be consumed (i.e. Kitchen) - gas pipes are expensive;
- Close to the supply of input materials (i.e., cow shed) -to save carrying efforts;
- Close to the place where the effluent can be stored (e.g., compost pits) - so that the effluent can flow into the storage pit without any handling;
- Not too close to sources of water such as wells-to prevent contamination, say 10 to 15 m away. However, note that if the water source is too far, it will take more time and effort to prepare the slurry;
- Not too close to trees/bamboos -to prevent damage to the structures from the roots of these plants;
- At location where the ground water table is low - ease of construction, to prevent seepage; and
- Suitable foundation condition.

At any particular site it may not be possible to fulfill all of the above criteria. However, efforts should be made to meet as many criteria as possible such that the cost is lowered and the operation becomes less cumbersome.

9.4 DESIGN PARAMETERS FOR SIZING OF BIOGAS PLANTS

Relevant design parameters required for sizing a biogas plant are summarized in **Table 9.2** (and explained afterwards).

Table 9.2
Design Parameters for Sizing of a Biogas Plant

S.N.	Parameter	Value
1	C/N Ratio	20-30
2	PH	6-7
3	Digestion temperature	20-35
4	Retention time (HRT)	40-100 days
5	Biogas energy content	6 kWh/m^3
6	I cow yield	9- 15 kg dung/day
7	Gas production per kg of cow dung	0.023-0.04 m^3
8	Gas production per kg of pig dung	0.04-0.059
9	Gas production per kg of chicken dung	0.065-0.116
10	Gas production per kg of Human excreta	0.020-0.028
11	Gas requirement for cooking	0.2 - 0.3 $m^{3/}$person
12	Gas requirement for lighting 1 lamp	0.1 -0.15m^3/hr

C/N Ratio: As discussed in the earlier topic, this is the ratio of carbon to nitrogen present in organic matter. Gas production is optimum when C/N ratio of the input is between 20 - 30. C/N ratio of cow/buffalo dung is about 25 and hence ideal for biogas production. Similarly, C/N ratios of some other inputs are presented below in **Table 9.3.**

Table 9.3
C/N Ratio of some Organic Materials

S.N.	Raw Materials	C/N Ratio
1	Duck dung	8
2	Chicken dung	10
3	Goat dung	12
4	Pig dung	18
5	Sheep dung	19
6	Cow/buffalo dung	25
7	Elephant dung	43
8	Human excreta dung	8
9	Water hyacinth	25
10	Straw (maize) dung	60
11	Straw (rice) dung	70
12	Saw Dust dung	Above 200

As will be discussed later, C/N ratio can be brought within the optimum range by mixing different inputs (in certain ratios).

PH: pH is the measure of acidity/alkalinity of the input. A pH value of 7 is neutral, pH less than 7 is acidic and higher than 7 is alkaline. Optimum gas production occurs when the pH value of the input is 6 - 7.

Digestion temperature: Optimum gas production occurs at 35°C. Below 20°C the gas production is significantly reduced. Hence, this technology in its simple form is not viable in clod climates. If the ambient temperature is 10°C or lower, gas production stops. Even a sudden fall of temperature by 2 to 3°C affects gas production. Insulation of the digester helps to increase gas production in the cold climates.

Retention time: This is also known as hydraulic retention time. The retention time is defined as the average time that a given quantity of input remains in the digester. This is calculated by dividing the total volume of digester by the volume of inputs added daily.

The retention time is also a function of the type of input and the ambient temperature. For cow/buffalo dung input, a retention time of 70 days in the hills and 55 days in the Tarai (warmer climate) is recommended. These loading rates translate into 7.5 kg of cow dung per m^3 plant size per day in Tarai and 6 in the hills. These loading rates for various plant sizes are recommended in **Table 9.4.**

Table 9.4
Loading Rate for various Plant Size

Plant Size (m^3)	Daily Loading Rate (kg)	
	Hills	Tarai
4	24	30
6	36	45
8	48	60
10	60	75
15	90	110
20	120	150

Since human excreta contain more pathogens (disease vectors) than most domestic animal dung, 90 - 100 days retention time is recommended when this is used as input.

Other parameters presented in **Table 9.2** are self-explanatory.

9.5 EXAMPLES OF SIZING BIOGAS PLANTS

Some examples of sizing of biogas plants (using the above parameters) are given below:

- **Example 5.1**

Calculate the amount of cow dung required to generate 1 m^3 of gas per day. Solution:

From Table 9.2: 1 kg of cow dung produces 0.023 - 0.04 m^3 of gas
Average value = (0.023 + 0.04)/2 = 0.032 m^3

– Or 0.032 m^3 of gas is produce from 1 kg of dung
– to produce 1 m^3 of gas: 1/0.032 kg of dung is required **= 31.3 kg of dung**

- **Example 5.2**

What is the appropriate plant size required in Example 5.1?

From Table 9.4: for loading rate of 31 kg of dung, the required plant size is 4 m^3 if the plant is located in Tarai (30 kg) and 6 m^3 (36) for hills

- **Example 5.3**

How many cows will the farmer need in the above examples (i.e. to produce 1 m^3 of gas)?

Solution:

From Table 9.2: 1 cow yields 9 - 15 kg of dung per gay (depending on whether it is stall fed or grazed)

- Average value: (9 + 15)/2 = 12 kg/day assuming animals are partly grazed and partly stall-fed
- to produce 31.3 kg of dung he will need 31.3/12 = 2.6 → **3 cows**

In practice, a farmer has a fixed number of animals and wants to find out the plant size required and the gas produced to meet his energy demand. Also, farmers are advised to weigh the dung produced daily a few times to determine the appropriate plant size.

- **Example 5.4**

Suppose a farmer has:

cows each producing about 10 kg/day of dung
2 buffaloes, each producing 16 kg/day of dung

Can he meet the energy demand to cook for a family of 6 and light one Iampfor4 hours per day?

Solution:

- Total dung available: 2x10 + 3x16= 68 kg/day
- 68 kg/day of dung produces: 0.032 m^3/kg x 68 kg/day = 2.2 $m^3$of gas/day
- From Table 4.3, he will need a plant size of 8 m^3 to 10 m^3
- Gas required for cooking: Table 3.1: 0.25 m^3/person (average)
- Fora family of 6: cooking requirements = 6x0.25 = 1.5 m^3
- Gas required for lighting: Table 4.1: 0.125 m^3 (average)
- Lighting requirements: 4 x 0.125 = 0.5 m^3
- Total gas requirement = 1.5 + 0.5 = **2 m^3 /day**

Since his gas requirement (2 m^3/day) is slightly less than his gas production rate (2.2 m^3/day), yes, he can meet his energy demand.

- **Example 5.5**

Optimizing C/N ratio:

Note that as discussed earlier C/N ratio of human excreta is about 8 and that of rice straw is 73. Also, optimum gas production occurs when the C/N ratio is between 20 and 30. Therefore, for 1 kg of human excreta, how much rice straw should be mixed?

Solution:

Aim for a C/N ratio of 25 (average):

1[kg] x 8[CN] + R[kg] x 73[CN] = (1 + R)[kg] x 25[CN}

(where R is the weight of rice straw in kg)

OR, 8 + 73R = (1+R)x25

48R= 17

R= 0.35 kg

Therefore for each kg of human excreta 0.35 kg (350 gm) of rice straw should be mixed).

- **Example 5.6**

Suppose a farmer has:

20 pigs each producing about 3 kg/day of dung
2 cows each producing 10 kg/day of dung

He has to cook for a household of 7 and he wants 3 lights, each for 4 hours per day? He has plenty of water. Does he have enough input to meet these energy demands and what plant should he choose?

Solution:

Potential gas production

– Pig dung available: 20 x 3 = 60 kg/day
– Gas available from pig dung 60 kg/day x 0.05 m^3/kg = 3.0 m^3/day (Table 4.1)
– Cow dung available 2 **x** 10 = 20 kg/day
– Gas available from cow dung20 kg/day x 0.032 m^3/kg = 0.64 m^3/day
– **Total gas available 3.0 + 0.64 = 3.64 m^3/day**
– **Total dung available 60 + 20 = 80 kg**

Gas requirements

– Lighting: 3 (lights) x 4 hr/day x 0.125 m^3/hr= 1.5 m^3Vday
– Cooking: 7 (persons) x 0.25 m^3/person per day = 1.75 m^3/day
– **Total gas requirement: 1.5+ 1.75 = 3.25 m^3/day**

Since the-potential gas production is slightly higher than the requirements, yes the farmer has enough inputs to meet the energy demand.

Plant size required:

From Table 4.3 for 80 kg inputs/day he will need 10 m^3 plant in Tarai (slightly overfed) and 15 m^3 (underfed) in Hills

9.6 DESIGN AND CONSTRUCTION ASPECTS

9.6.1 Construction Details

Some construction details of GGC model biogas plants are as follows:

- The digester wall is constructed of either brick or stone masonry depending on the local availability of these materials. In case of brick masonry, the wall thickness is 12 cm and the mortar consists of 1:4 (i.e., 1 part cement and 4 parts sand). Then, a 10 nun thick plaster is applied (1:3) on the internal surface. If stone masonry is used, the wall thickness is 23 cm and 1:6 mortar is used. Similarly a 10 thick plaster (1:3) is applied on the internal surface. These plaster are applied to ensure that the structure is water tight; and

- The dome is constructed out of plain cement concrete at 1:3:3 ratio (i.e. 1 part cement, 3 part sand and 3 part gravel). Once the dome is cured (it is kept moist for 7 days using jute bags), a 10 mm thick plaster (1:1) is applied on the internal surface. Then another 5 mm thick plaster (1:1) is applied. Further, a first coat of emulsion colour (1.5:20 emulsion to cement ratio) followed by a 1:2 ratio second coat are also applied in the internal surface of the dome. These plaster and colour coats are applied to ensure that the dome is airtight.

9.6.2 Volume Calculations for Chinese and Deenbandhu Models

The dimensions for the GGC model have been specified for all plant sizes (4 - 20 m^3) for ease of construction as can be seen in Table 2.1. Furthermore, for each plant size, the outlet, dome and digester volumes are given. The volume of the plant is approximately equal to the dome plus digester volume.

The volumes of the Chinese and the Deenbandhu models are based on the following equations (corresponding to Figure 6.1):

- **Volume of the Dome**

  $V_1 = \Pi f_1(D^2/8 + fi^2/6)$
  where: f_1 is the height of the dome and D is the diameter.

- **Volume of the Middle Cylindrical Section of the Digester**

$V_2 = \Pi[\{(D+D_1)/2\}^2/4]\ (0.5)$
Where D_1 is the diameter of the concave bottom

- **Volume of the Concave Bottom**

$V_3 = \Pi f_2(D_1^2/8 + f_2^2/6)$
Where f_2 is the height of the concave bottom

A quick check for the 10 m^3 Chinese plant (see **Figure 9.6)** is presented below:

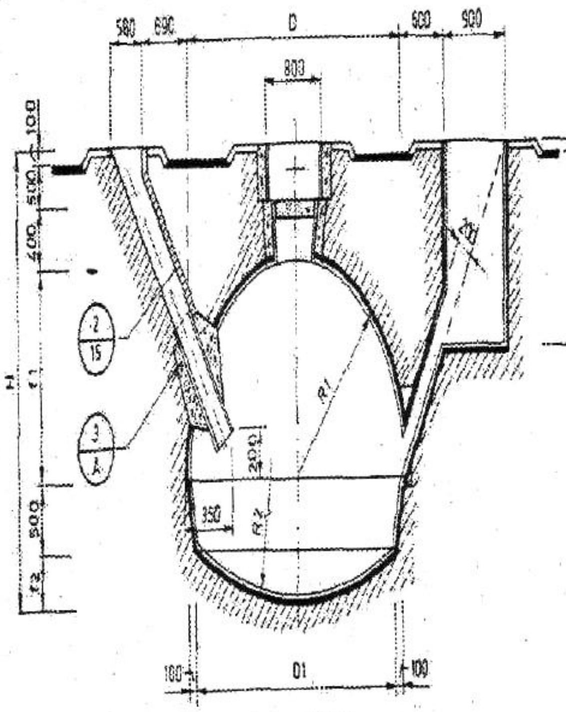
$V_1 = \Pi f_1(D^2/8 + f_1^2/6) = m.45(2.9^2/8 + 1.45^2/6) = 6.39$

$V_2 = \Pi\ [\{(D + D_1)/2\}^2/4]\ (0.5) = \Pi[\{(2.9 + 2.7)/2\}^2/4]\ (0.5) = 3.08$

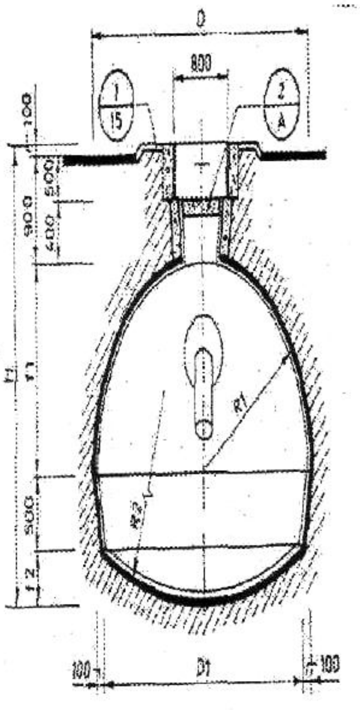
$V_3 = \Pi f_2\,(D_1^2/8 + f_2^2/6) = \Pi 0.034(2.7^2/8 + 0.034^2/6) = 0.10$

Total volume = $V_1 + V_2 + V_3 = 9.57m^3 \simeq 10m^3$

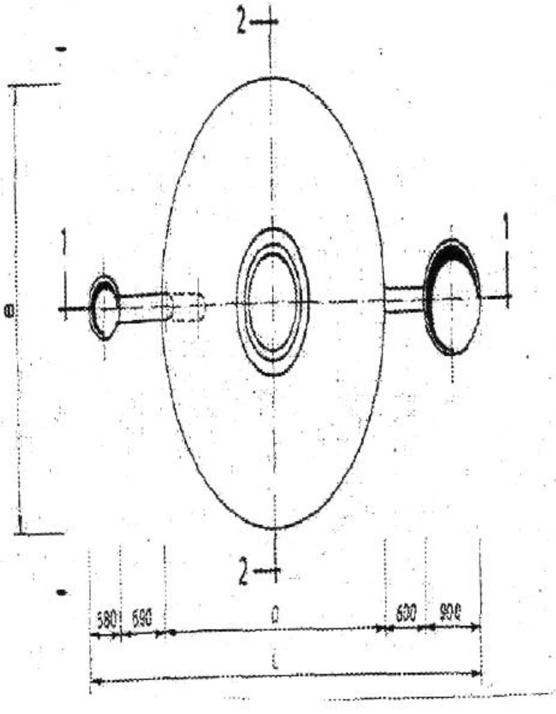
Similarly, the 6, 8 and 12 m^3 plants' volume can be verified using the above equations.



1-1 section



2-2 section



m^3	L	B	H	R_1	f_1	D	D_1	R_2	f_2
6	5270	2500	3040	1250	1250	2500	2300	2440	290
8	5470	2700	3160	1350	1350	2700	2500	2550	310
10	5670	2900	3290	1450	1450	2900	2700	2850	340
12	5870	3100	3410	1550	1550	3100	2900	3100	360

notes: 1. inlet pipe 1000 mm in length, see detail 3.

2. the opening for moveable cover and the connections of inlet's and outlet's lower openings are of #100 concrete.

9.6.3 Structural Design Aspect

The principles behind the design of the fixed dome biogas plant are outlined below:

- **The Concrete Dome**

Structurally a concrete/masonry dome is strong In compression (due to arch action) and weak in tension Hence, this structure should always be in compression, i.e. the load (force) acting on the outside surface of the dome should be higher than the force generated due to gas pressure in the inside surface.

The internal pressure (from the built up of biogas) in the concrete dome can be 0.1 to 0.15 bar This translates to 1000 kg/m^2 to 1500 kg /m^2 of pressure. Therefore compacted earth is placed-over the dome as a precautionary measure. Note that 50 cm of compacted earth provides about 900 - 1000 kg/cm2 and the balance can be easily met by the weight of the dome. The various loads on the dome are schematically shown below:

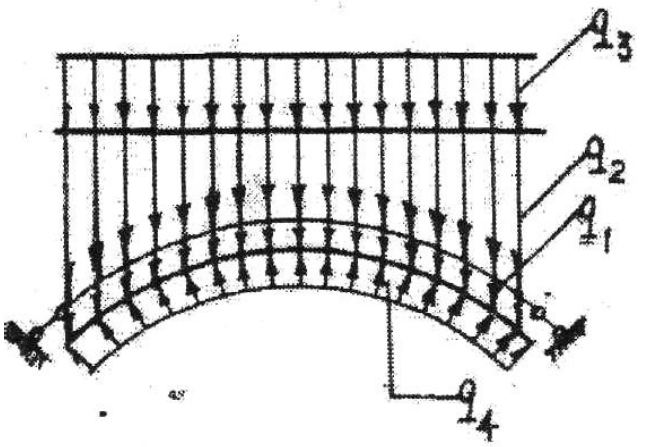


Figure 9.10: Loads Acting on the Concrete Dome

q_1 = dead load, i.e. weight of the dome
q_2 = load due to the compacted earth

- **The Digester Wall**

The loads acting on the digester wall are as follows:

– Earth pressure acting on the outside surface:

The resultant force is as follows:
$F_1 = (\gamma_{earth} h^2)/2$ where:
γ_{earth} is the unit weight of earth = 1800 kg/m3 when the soil is partially saturated and h is the hieght of the digester wall.

– Slurry pressure acting on the inside surface:

The resultant force is as follows:

$F_2=(\gamma_{slurry}h^2)/2$ where:

γ_{slurry} is the unit weight of slurry = 1500 kg/m^3 (approximate; since unit weight of water is 1000 kg/m3 and the partially digested slurry may add 50% weight) and h is the height of the digester wall.

Note that the critical condition occurs when the digester is empty. In this case the counter balance force provided by the slurry is absent. The forces and pressure diagram for both cases are presented in the sketch below:

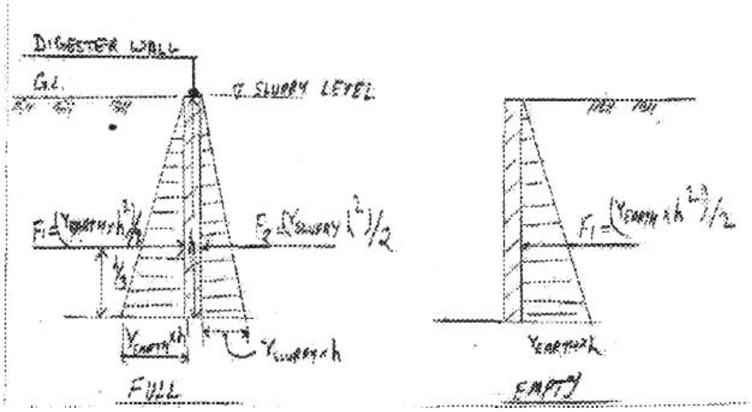


Figure 9.11: Forces and Pressure Acting on the Digester Wall

Note that for both cases (digester full and empty), the earth pressure is higher which ensure that the digester wall is in compression. Similar to the dome the circular cement masonry digester is strong in compression and weak in tension. Hence, the entire fixed dome biogas plant is buried (i.e., it is not only to save space). Also note that the largest biogas plant design (GGC model) is limited to 20 m^3. Biogas plants larger than 20 m^3 will require thicker dome an3 wall sections verified by a detailed design.