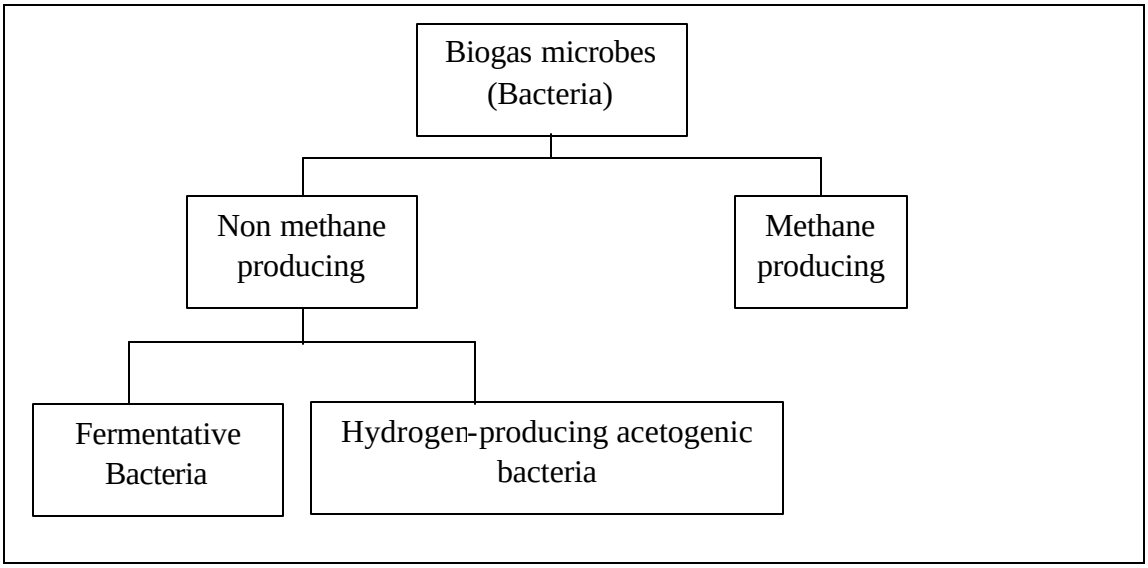
DESIGN OF BIOGAS PLANT

1.1 Introduction:

Biogas can be obtained from any organic materials after anaerobic fermentation by three main phases.

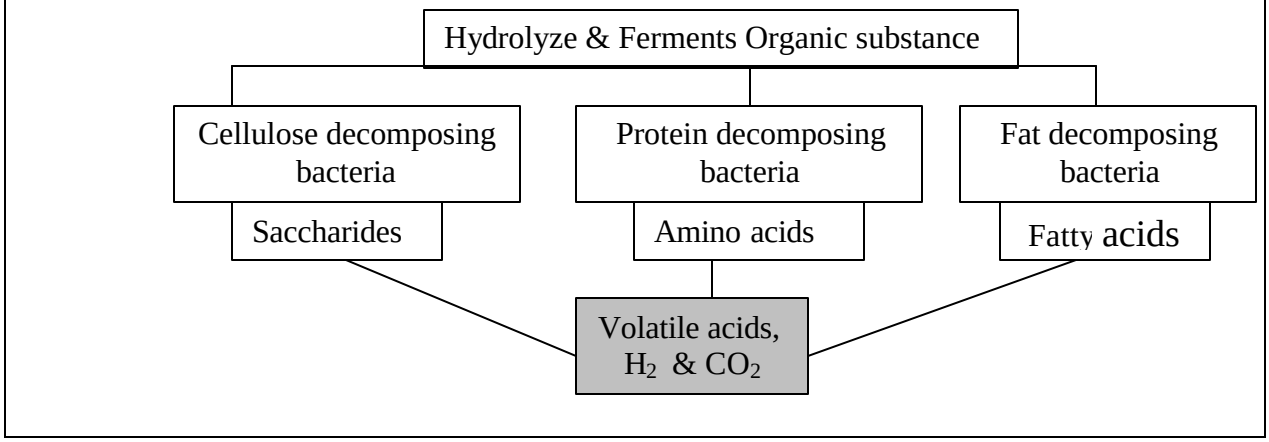
1.2 Mechanism of biogas fermentation:

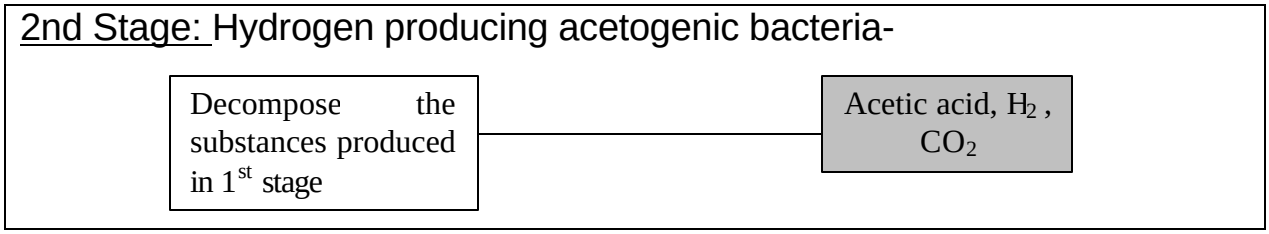
A) Groups of Biogas microbes-

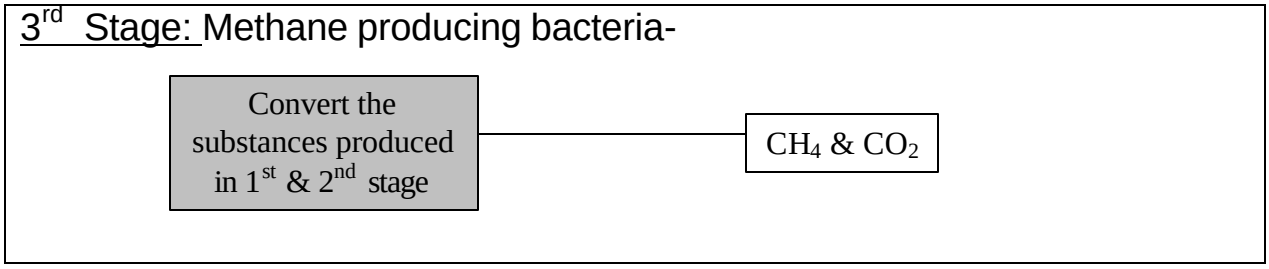


B) Groups of microbes involved in the 3 stages of biogas fermentation-

1st stage: Fermentative bacteria-







1.3 Design perameter:

A) Selection of materials :

B) Total solid (TS) contains calculations of organic materials Organic materials-

Solid part : Total solid contained in a certain amount of materials is usually used as the material unit to indicate the biogas- producing rate of the materials. Most favourable TS value desired is 08%

Liquid part : As per Annexure-I

C) Favourable temperature, P^H value & C/N ratio for good fermentation-

Temperature: Mesophilic; 20° c to 35° c (Annexure-II).
P^H value : Neutral P^H and ranges 6.8 to 7.2
C/N ration : Ranges from 20:1 to 30:1 (Annexure- VI)

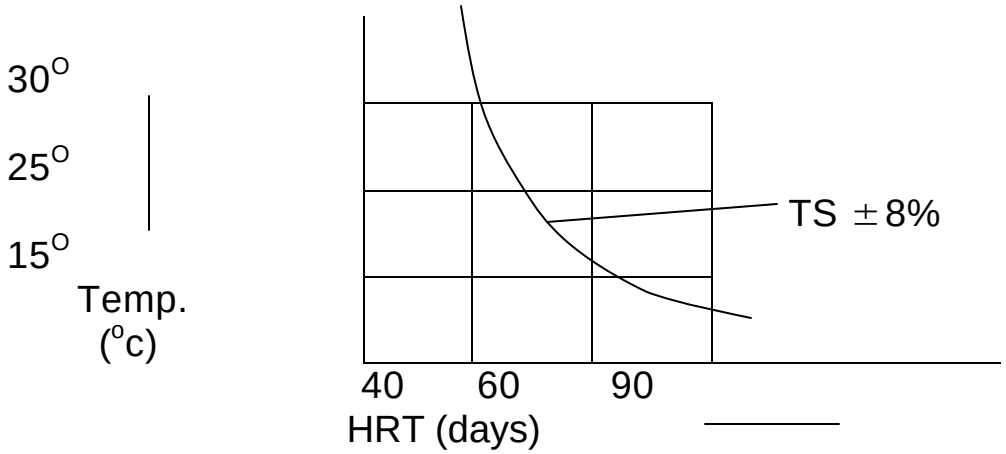
D) Table showing discharge per day, TS value of fresh discharge and water to be added to make favorable TS condition-

Kinds	Body weight (kg)	Discharge per day (kg)	TS value of fresh discharge (% by wt.)	Water to be added with fresh discharge to make the TS value 8% (kg)
Human	50	0.5	20	0.75
Cow	200	10	16	10
Chicken	1.5	0.1	20	0.15
Pig	50	5	20	7.5

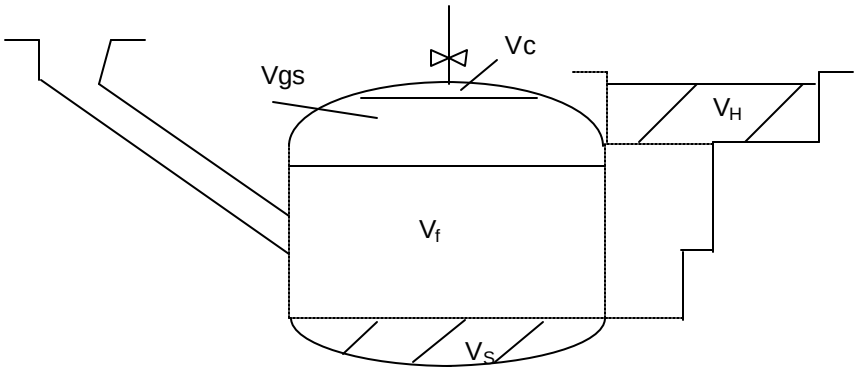
E) Hydraulic retention time (HRT)-

For Mesophilic digestion where temp. varies from 20^{o} c to 35^{o} C and HRT is greater than 20 days.

1.4 Relationship between temperature, HRT & TS value of 8% :



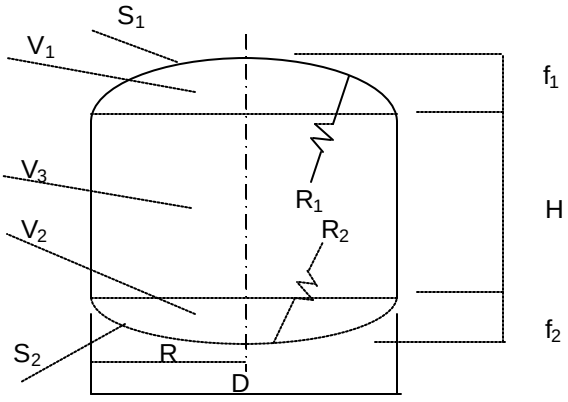
1.5 Cross-section of a digester:



a) Volume of gas collecting chamber = Vc
b) Volume of gas storage chamber = Vgs
c) Volume of fermentation chamber = V_f
d) Volume of hydraulic chamber = V_H
e) Volume of sludge layer = Vs

Total volume of digester **V** =Vc+Vgs+V_f+Vs

1.6 Geometrical dimensions of the cylindrical shaped biogas digester body:



1.7 Assumptions:

For volume	For geometrical dimensions
$Vc \leq 5\%\ V$ $Vs \leq 15\%\ V$ $Vgs + V_f = 80\%\ V$ $Vgs = V_H$ $Vgs = 0.5\ (Vgs + V_f + Vs)\ K$ Where K = Gas production rate per m^3 digester volume per day. For Bangladesh K = 0.4 m^3/m^3d.	$D=1.3078 \times V^{1/3}$ $V_1=0.0827\ D^3$ $V_2 = 0.05011\ D^3$ $V_3 = 0.3142\ D^3$ $R_1= 0.725\ D$ $R_2= 1.0625\ D$ $f_1 = D/5$ $f_2 = D/8$ $S_1 = 0.911\ D^2$ $S_2 = 0.8345\ D^2$

1.8 Volume calculation of digester and hydraulic chamber:

A)Volume calculation of digester chamber-

Given : 6 cows of body weight 200 Kg each.
Temp. = 30^OC (average)

Sol^n:

Let HRT = 40 days (for temp. 30^O C)
Total discharge = 10 kg X 6 = 60 Kg/day
TS of fresh discharge = 60 kg X 0.16 = 9.6 Kg.

In 8% concentration of TS (To make favourable condition)
8 Kg. Solid = 100 Kg. Influnt
1 Kg. Solid = 100 / 8 Kg influent
9.6 Kg Solid = 100 x 9.6/ 8 = 120 Kg. Influent.
Total influent required = 120 Kg.

Water to be added to make the discharge 8% concentration of TS
=120 Kg - 60 Kg. = 60 Kg.
Working volume of digester = $Vgs + V_f$

Vgs + Vf = Q.HRT

= 120 Kg/day X 40 days

= 4800 Kg. (1000 Kg = 1 m^3) = 4.8 m^3.

From geometrical assumptions:

Vgs + V_f = 0.80 V

Or V= 4.8/0.8 = 6.0 m^3. (Putting value Vgs + Vf = 4.8 m^3)

& D = 1.3078 $V^{1/3}$ = 2.376 m ≅ 2.40 m.

Again

$$V_3 = \frac{3.14 \times D^2 \times H}{4}$$

(Putting V_3=0.3142D^3)

$$Or, H = \frac{4 \times 0.3142 \times D^3}{3.14 \times D^2} = 0.96m$$

Say H = 1.00m

Now we find from assumption as we know the value of 'D' & 'H'

f_1 = D/5 = 2.40 /5 = 0.480 m

f_2 = D/8 = 0.30m

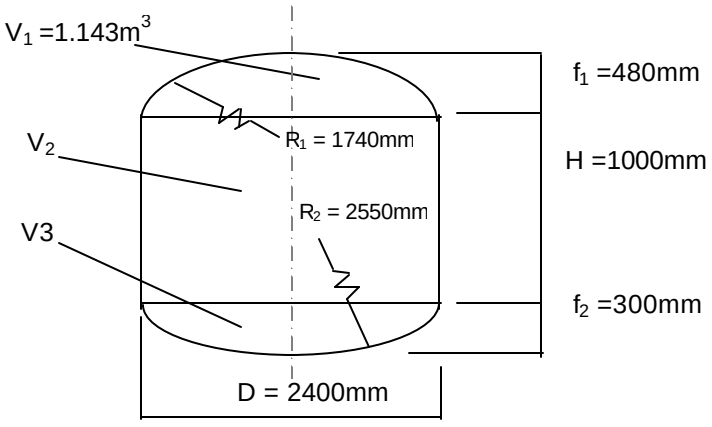
R_1 = 0.725 D = 1.74 m

R_2 = 1.0625 D = 2.55 m

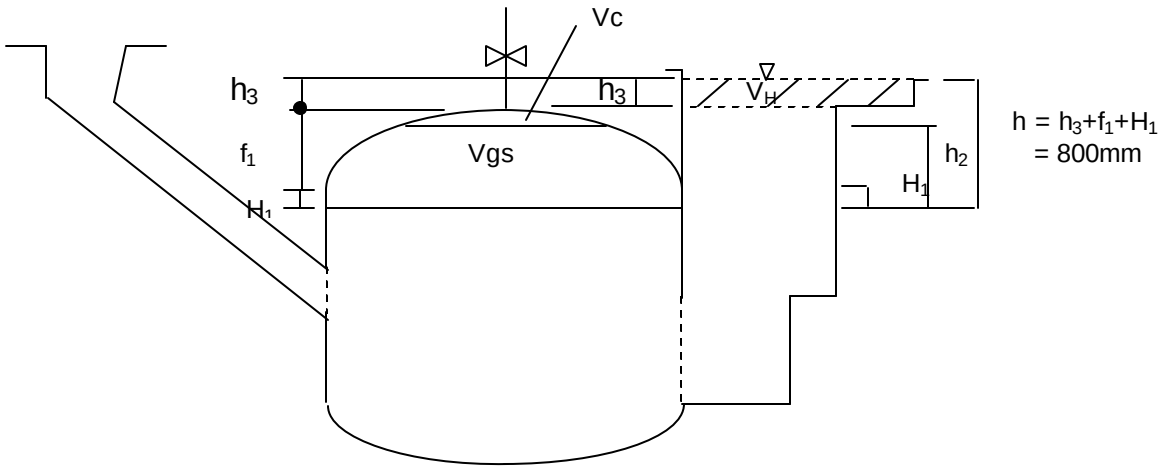
V_1 = 0.0827 D^3 = 1.143 m^3

Vc = 0.05V = 0.3 m^3

Now the dimension of digester chamber is kown & drawn below-



B) Volume calculation of hydraulic chamber-



From assumptions:

Vc = 0.05 V = 0.3 m^3

Vgs = 0.50 x (Vgs + V_f + Vs) x K (Where K = Gas production rate per m^3digeste vol./day)

= 0.5 x 5.7x 0.4 =1.14 m^3 ---------- **(A)**

Again,

Vgs = 50% of daily gas yield

= 0.5 x TS x gas producing rate per Kg TS

= 0.5 x (60 kg x 0.16) x 0.28 m^3/kg TS (See Annex- III)

= 1.344 m^3 ---------- (**B)**

From **A & B let Vgs = 1.344** m^3**.**

Vc + Vgs = 0.3 m^3 +1.344 m^3 = 1.644 m^3

Again V_1 = [{(Vc + Vgs) - {$\pi D^2 H_1$}/4]

= [1.644 - {3.14 x $(2.4)^2$ x H_1}/4]

Or, H_1 = 0.110m

We have fixed **h** = 800 mm water volume (I mm = 10 N/ m^2)

$h = h_3 + f_1 + H_1$

Or, h_3 = 0.210m.

Again we know that

$Vgs = V_H$

Or, 1.344 m^3= 3.14 x $(D_H)^2$ x h_3/4

Or, D_H = 2.85m

Now we know the dimension of hydraulic chamber. Moreover keeping h = 800 mm, we can choose or re-arrange the dimension considering availability of site and construction suitability. For most suitable dimensions we can select the drawing of Annexure- IX for 60 Kg cow dung per day as raw material.

Note: For ready reference 4 family type Biogas plant's drawing is shown(standared dimension's) in Annexure-VIII, Annexure-IX, Annexure-X & Annexure-X1 where 40 Kg, 60Kg, 80Kg and 100Kg cow dung is considered as raw marterial per day respectively. If bigger size plant is required ,it can be designed keeping all safety considerations in design and construction.

Annexure- 1

TABLE-1: THE TOTAL SOLID CONTENT OF COMMON FERMENTATION MATERIALS IN RURALAREAS (APPROXIMATELY)

Materials	Dry matter content (%)	Water content (%)
Dry rice straw	83	17
Dry wheat straw	82	18
Corn stalks	80	20
Green grass	24	76
Human excrement	20	80
Pig excrement	18	82
Cattle excrement	17	83
Human Urine	0.4	99.6
Pig Urine	0.4	99.6
Cattle Urine	0.6	99.4

Annexure-II

TABLE-2: BIOGAS-PRODUCING RATES OF SOME COMMON FERMENTATION MATERIALS ATDIFFERENT TEMPERATURES (m^3/Kg TS)

Materials	Medium temperature (35^o C)	Ordinary temperature (8^o ~ 25^o C)
Pig manure	0.45	0.25 ~ 0.30
Cattle dung	0.30	0.20 ~ 0.25
Human wastes	0.43	0.25 ~ 0.30
Rice straw	0.40	0.20 ~ 0.25

Wheat straw	0.45	0.20 ~ 0.25
Green grass	0.44	0.20 ~ 0.25

Experimental conditions:- The fermentation period of the excrement materials lasts 60 days and that of the stalk type lasts 90 days. The fermentation material concentration (total solid content) is 6%.

Annexure- III

TABLE-3: BIOGAS PRODUCING RATES OF SOME FERMENTATION MATERIALS AND THEIR MAIN CHEMICAL COMPONENTS.

Materials and their main components	Yield of Biogas m^3/kg TS	Methane content (%)
Animal barnyard manure	0.260 ~ 0.280	50 ~ 60
Pig manure	0.561	
Horse droppings	0.200 ~ 0.300	
Green grass	0.630	70
Flax straw	0.359	
Wheat straw	0.432	59
Leaves	0.210 ~ 0.294	58
Sludge	0.640	50
Brewery liquid waste	0.300 ~ 0.600	58
Carbohydrate	0.750	49
Liquid	1.440	72
Protein	0.980	50

Annexure- IV

TABLE-4 BIOGAS- PRODUCING RATES OF SEVERAL SUBSTANCES

Material	YpCMDV (m^3/m^3d)	YpKgM (m^3/KgTS)	Amount of biogas produced in a period of time (as a % of the total yield)			
			0 ~15 (d)	15 ~ 45 (d)	45 ~ 75(d)	75 ~ 13 (d)

Water Hyacinth	0.40	0.16	83	17	0	0
Alligator Weed	0.38	0.20	23	45	32	0
Water Lettuces	0.40	0.20	23	62	15	0
Cattle Dung	0.20	0.12	11	33.8	20.9	34.3
Pig Manure	0.30	0.22	19.6	31.8	25.5	23.1
Human Wastes	0.53	0.31	45	22	27.3	5.7
Dry Grass	0.20	0.21	13	11	43	33
Rice Straw	0.35	0.23	09	50	16	25

Note: - The fermenting temperature is 30^{o}C. It is batch-fed fermentation. YpCMDV refers to the average yield of biogas per cubic meter of the digester volume during the period of normal fermentation (m^3/ m^3d) YpkgM refers to the yield of biogas per kilogram of the fermentation material (m^3/kg TS)

Annexure-V

TABLE-5 : THE SPEED OF BIOGAS PRODUCTION WITH COMMON FERMENTATION MATERIALS.

Speed	Amount of biogas produced in a period of time (expressed as a percentage of the total yield of biogas)								Biogas Producing rate
Time(d)	10	20	30	40	50	60	70	80 90	(m^3/kg TS)
Materials									
Human wastes	40.7 *	81.5 *	94.1 **	98.2	98.7	100			0.478
Pig manure	46.0 *	78.1 *	93.9 **	97.5	99.1	100			0.405
Green grass	-	-	-	98.2 **	-	100			0.410
Cattle dung	34.4 *	74.6 *	86.2	92.7 **	97.3	100			0.300
Wheat straw	8.8	30.8	53.7 *	78.3 **	88.7	93.2 **	96.7	98.9 100	0.435

* Biogas production is at the highest speed.

** Amount of Biogas produced to more than 90% of the total yield of a fermentation period.

Experimental conditions: - Fermenting temperature 35^{o}C, the total length of fermentation period being

60 days for the excrement material and 90 days for the stalk type, the materials concentration; total solid content of the fermentative fluid being 6%.

ANNEXURE- VI

TABLE -6. CARBON-NITROGEN RATIOS OF SOME COMMON FERMENTATION MATERIALS (APPROX.)

Material	Carbon content of material (%)	Nitrogen content of materials(%)	Carbon-nitrogen ration (C/N)
Dry wheat straw	46	0.53	87:1
Dry rice straw	42	0.53	67:1
Corn stalks	40	0.75	53:1
Fallen leaves	41	1.00	41:1
Soybean stalks	41	1.30	32:1
Wild grass	14	0.54	27:1
Peanut stems and leaves	11	0.59	19:1
Fresh sheep droppings	16	0.55	29:1
Fresh cattle dung	7.3	0.29	25:1
Fresh horse droppings	10	0.42	24:1
Fresh pig manure	7.8	0.60	13:1
Fresh human wastes	2.5	0.85	29:1

ANNEXURE- VII

TABLE-7 AMOUNT OF HUMAN AND ANIMAL WASTES DISCHARGED PER DAY (APPROX.)

Kinds	Body weight (kg)	Daily amount of excrement (kg)	Daily amount of urine (kg)	Annual amount of excrement discharged (kg)	Annual amount of excrement collection (kg)	Daily yield of biogas per capita (m3)
Pig	50	6	15	2190	1752	0.18 ~ 0.25
Ox	500	34	34	12410	9928	0.36 ~ 0.96
Horse	500	10	15	3650	2920	
Sheep	15	1.5	2	548	438.4	
Chicken	1.5	0.10	0	36.80	29.44	0.0076 ~ 0.0112
Human	50	0.50	1	182.50	146.00	0.028

Note: The annual amount of excrements collected accounts for 80% of that discharge.