Training Material on Biogas Sanitation

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1 INTRODUCTION

1.1 Biogas definition

Biogas originates from bacteria in the process of bio-degradation of organic material under anaerobic (without air) conditions. The natural generation of biogas is an important part of the biogeochemical carbon cycle. Methanogens (methane producing bacteria) are the last link in a chain of microorganisms, which degrade organic material and return the decomposition products to the environment. In this process biogas is generated, a source of renewable energy [1].

1.2 Composition and properties of biogas

Biogas is a mixture of gases that is composed chiefly of:

- **methane** (CH_4): 40 - 70 vol.%
- **carbon dioxide** (CO_2): 30 - 60 vol.%
- **other gases**: 1 - 5 vol.%

including:

- hydrogen (H_2): 0 - 1 vol.%
- hydrogen sulfide (H_2S): 0 - 3 vol.%

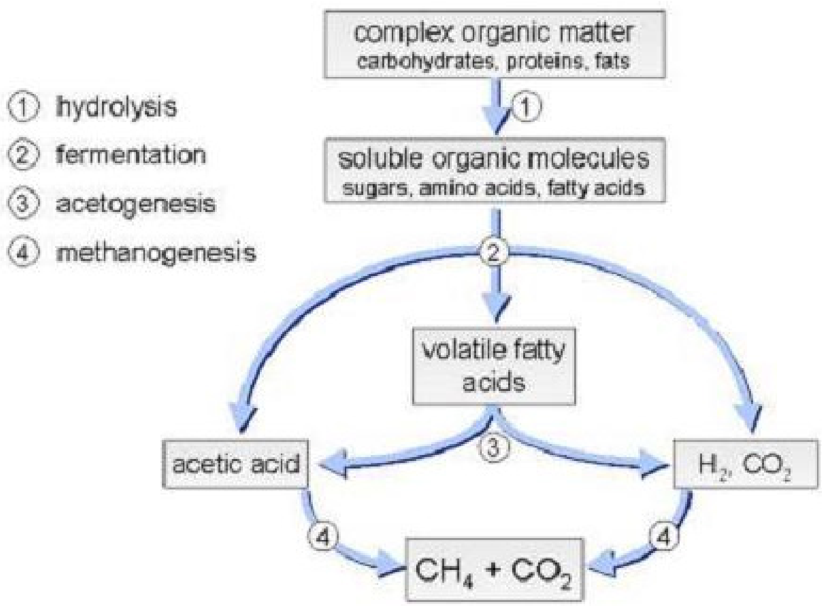
Like those of any pure gas, the characteristic properties of biogas are pressure and temperature-dependent. They are also affected by the moisture content. The factors of main interest are:

- change in volume as a function of temperature and pressure,
- change in calorific value as a function of temperature, pressure and water-vapor content, and
- change in water-vapor content as a function of temperature and pressure.

Biogas is used as an ecologically friendly and future oriented technology in many countries. The calorific value of biogas is about 6 kWh/m^3 - this corresponds to about half a litre of diesel oil. The net calorific value depends on the efficiency of the burners or appliances. Methane is the valuable component under the aspect of using biogas as a fuel [1].

1.3 How is it produced (the three steps of biogas production)

The general model for degradation of organic material under anaerobic conditions operates principally with three main groups of bacteria: fermenting, acetogenic and methanogenic bacteria, which degrade organic mater in four stages viz., hydrolysis, fermentation, acidification and methane formation (see figure 1).



(source: [2])

figure 1: Anaerobic digestion pathway

1.3.1 Hydrolysis and fermentation

In the first step (hydrolisis), the organic matter is enzymolyzed externally by extracellular enzymes (cellulase, amylase, protease and lipase) of microorganisms. Bacteria decompose the long chains of the complex carbohydrates, proteins and lipids into shorter parts. For example, polysaccharides are converted into monosaccharides. Proteins are split into peptides and amino acids [1].

1.3.2 Acidification

Acid-producing bacteria, involved in the second step, convert the intermediates of fermenting bacteria into acetic acid (CH_3COOH), hydrogen (H_2) and carbon dioxide (CO_2).

These bacteria are facultatively anaerobic and can grow under acid conditions. To produce acetic acid, they need oxygen and carbon. For this, they use the oxygen solved in the solution or bound oxygen. Hereby, the acid-producing bacteria create an anaerobic condition, which is essential for the methane-producing microorganisms. Moreover, they reduce the compounds with a low molecular weight into alcohols, organic acids, amino acids, carbon dioxide, hydrogen sulphide and traces of methane. From a chemical standpoint, this process is partially endergonic (i.e. only possible with energy input), since bacteria alone are not capable of sustaining that type of reaction [1].

1.3.3 Methane formation

Methane-producing bacteria, involved in the third step, decompose compounds with a low molecular weight. For example, they utilize hydrogen, carbon dioxide and acetic acid to form methane and carbon dioxide. Under natural conditions, methane producing microorganisms occur to the extent that anaerobic conditions are provided, e.g. under water (for exemple in marine sediments), in ruminant stomaches and in marshes. They are obligatory anaerobic and very sensitive to environmental changes [1].

1.3.4 Symbiosis of bacteria

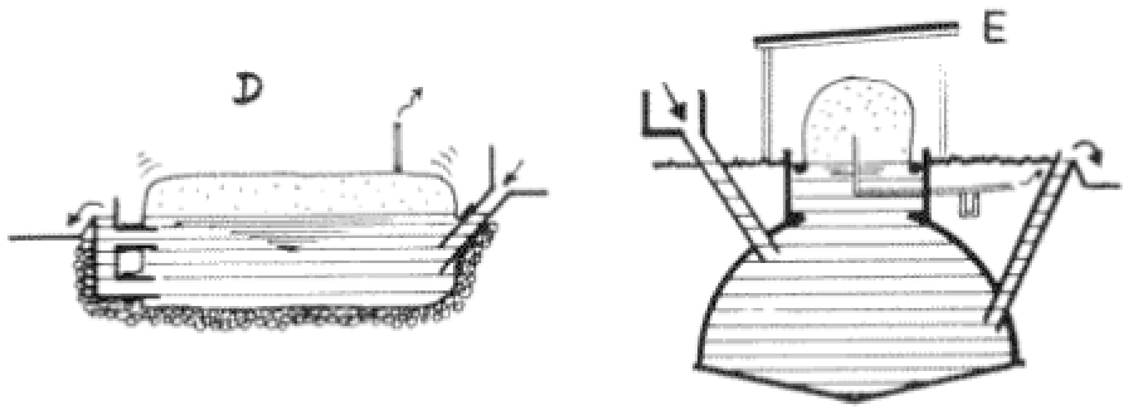
Methane- and acid-producing bacteria act in a symbiotical way. On the one hand, acidproducing bacteria create an atmosphere with ideal parameters for methane-producing bacteria (anaerobic conditions, compounds with a low molecular weight). On the other hand, methane-producing microorganisms use the intermediates of the acid-producing bacteria. Without consuming them, toxic conditions for the acid-producing microorganisms would develop.

In practical fermentation processes the metabolic actions of various bacteria all act in concert. No single bacterium is able to produce fermentation products alone [1].

1.4 Description of smale scale biogas plants

1.4.1 Balloon digester

The balloon plant (figure 2, left hand side) consists of a digester bag (e.g. PVC) in the upper part of which the gas is stored. The inlet and outlet are attached directly to the plastic skin of the balloon. The gas pressure is achieved through the elasticity of the balloon and by added weights placed on the balloon. A variation of the balloon plant is the channel-type digester, which is usually covered with plastic sheeting and a sunshade



(source: [1])

figure 2: Conceptual sketches of balloon-type digesters

(figure 2, right hand side). Balloon plants can be recommended wherever the balloon skin is not likely to be damaged and where the temperature is even and high [1].

Advantages and disadvantages of balloon digesters are summarized in table 1.

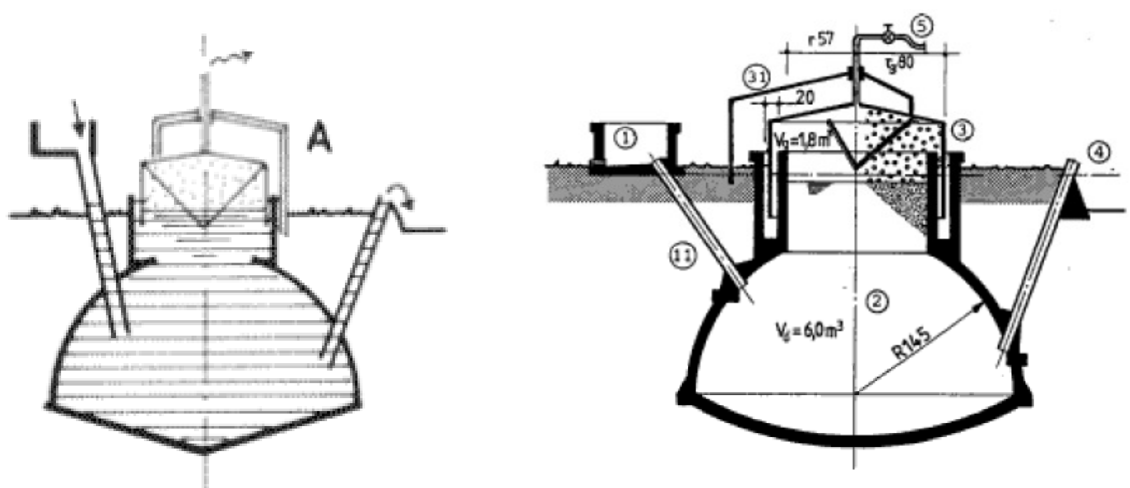
table 1: Advantages and disadvantages of balloon digesters

Advantages:	**Disadvantages:**
• low cost;	• relatively short life (about five years);
• ease of transportation;	• susceptibility to damage;
• low construction sophistication;	• little creation of local employment;
• high digester temperatures;	• limited self-help potential;
• uncomplicated cleaning, emptying and maintenance;	• little knowledge for repairing by local craftsmen [3]

(source: [1])

1.4.2 Floating-drum digester

Floating-drum plants consist of an underground digester and a moving gasholder. The gasholder floats either directly on the fermentation slurry (figure 3, left hand side) or in a water jacket of its own (figure 3, right hand side). The gas is collected in the gas drum, which rises or moves down, according to the amount of gas stored. The gas drum is prevented from tilting by a guiding frame [1]. Water-jacket digesters are universally applicable and especially easy to maintain. The drum won't stick, even if the substrate has a high solids content. Floating-drums made of glass-fibre reinforced plastic and high-density polyethylene have been used successfully, but the construction cost is higher than for its steel counterpart. Floating-drums made of wire-mesh-reinforced concrete are liable to hairline cracking and are intrinsically porous. They require a gastight, elastic internal coating. PVC drums are unsuitable because they are not resistant to UV radiation [3].



(source: [1])

figure 3: Conceptual sketches of floating-drum type digesters

Advantages and disadvantages of floating-drum type digesters are summarized in table 2.

table 2: Advantages and disadvantages of floating-drum type digesters

Advantages:	**Disadvantages:**
• simple, easily understood operation;	• high material costs of the steel drum;
• they volume of stored gas is directly visible;	• susceptibility of steel parts to corrosion (because of this, floating drum plants have a shorter life span than fixed-dome plants);
• the gas pressure is constant (determined by the weight of the gas holder);	• regular maintenance costs for the painting of the drum

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• the gas pressure is constant (determined by the weight of the gas holder);	• regular maintenance costs for the painting of the drum
• construction is relatively easy;	• if fibrous substrates are used, the gasholder shows a tendency to get "stuck" in the resultant floating scum [3];
• construction mistakes do not lead to major problems in operation and gas yield;	

(source: [1])

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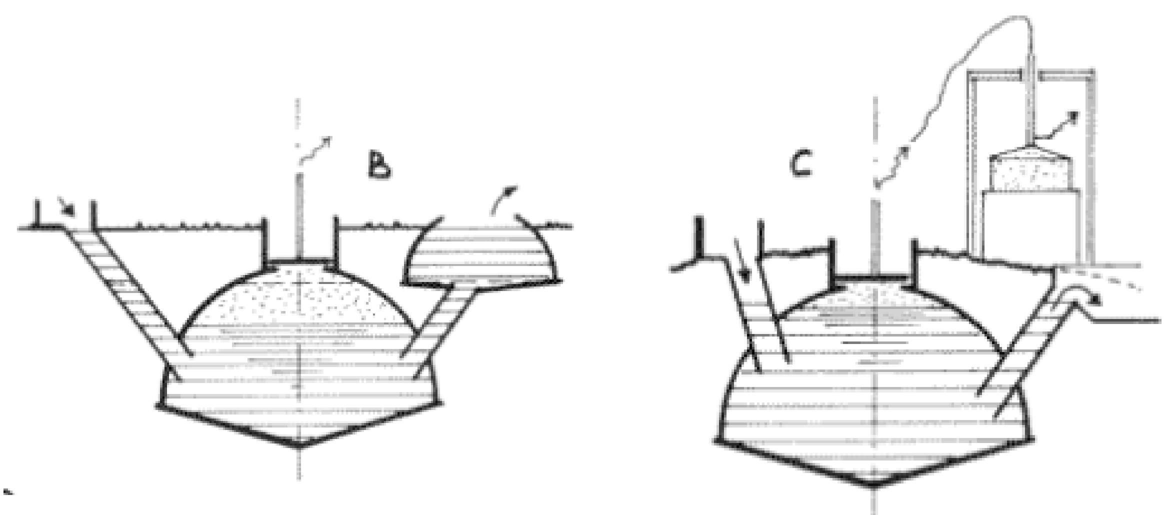
- construction mistakes do not lead to major problems in operation and gas yield;
- if fibrous substrates are used, the gasholder shows a tendency to get "stuck" in the resultant floating scum [3];

(source: [1])

1.4.3 Fixed-dome digester

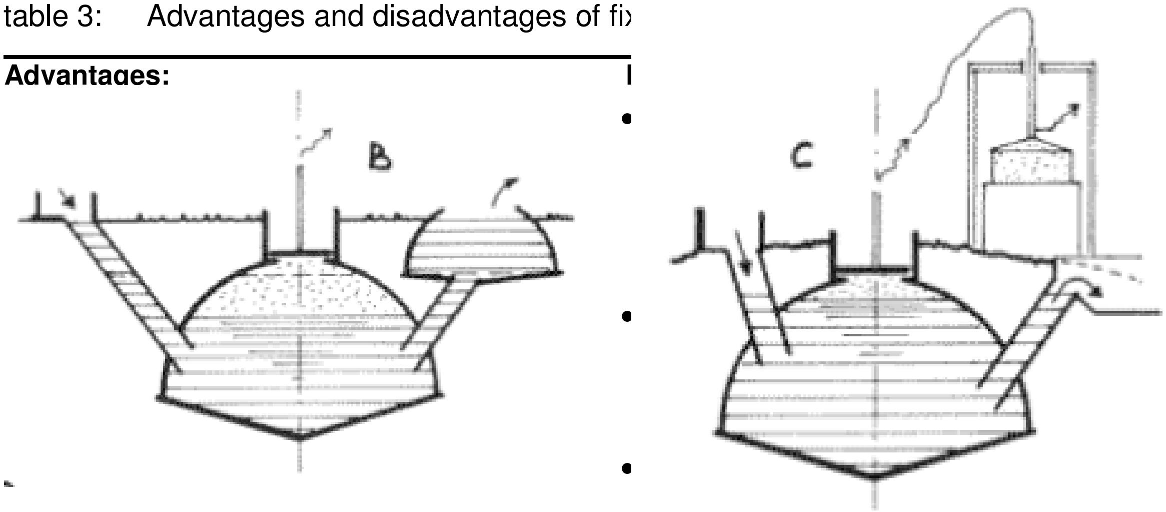
Fixed-dome biogas plants (figure 4) consist of a digester with a fixed, non-movable gas holder, which sits on top of the digester. When gas production starts, the slurry is displaced into the compensation tank. Gas pressure increases with the volume of gas stored and the height difference between the slurry level in the digester and the slurry level in the compensation tank [1].



(source: [1])

figure 4: Conceptual sketches of fixed-dome type digesters

table 3: Advantages and disadvantages of fi



(source: [1])

figure 4: Conceptual sketches of fixed-dome type digesters

Advantages:	I
	extremes, digester temperatures are generally low;
• underground construction saves space and protects the digester from temperature changes;	
• construction provides opportunities for skilled local employment;	

(source: [1])

table 3: Advantages and disadvantages of fixed-dome type digesters

Advantages:	Disadvantages:
• relatively low construction costs;	• frequent problems with the gas-tightness of the brickwork gas holder (a small crack in the upper brickwork can cause heavy losses of biogas);
• absence of moving parts and rusting steel parts;	• gas pressure fluctuates substantially depending on the volume of the stored gas;
• long life span if well constructed;	• even though the underground construction buffers temperature extremes, digester temperatures are generally low;
• underground construction saves space and protects the digester from temperature changes;	
• construction provides opportunities for skilled local employment;	

(source: [1])

Advantages and disadvantages of fixed-dome type digesters are summarized in table 3.

2 BIOGAS SANITATION CONCEPTS

2.1 Properties of different feed materials

Most simple biogas plants are "fueled" with manure (dung and urine), because such substrates usually ferment well and produce good biogas yields [4].

It is difficult to offer approximate excrement-yield values, because they are subject to wide variation. In the case of cattle, for example, the yield can amount to anywhere from 8 to 40 kg per head and day, depending on the strain in question and the housing intensity. Manure yields should therefore be either measured or calculated on a liveweight basis, since there is relatively good correlation between the two methods. The quantities of table 4: Properties of different feed materials

animal species/ feed material	daily manure yield			fresh-manure solids		liveweight	C/N	gas yield	
	manure [kg/d]	[%lw]	urine [%lw]	DM [%]	ODM [%]	[kg]	[-]	range [l/kg ODM]	average [l/kg ODM]
cattle manure	8	5	4 - 5	16	13	135 - 800	10 - 25	150 - 350	250
buffalo manure	12	5	4 - 5	14	12	340 - 420	20		
pig manure	2	2	3	16	12	30 - 75	9 - 13	340 - 550	450
sheep/goat droppings	1	3	1 - 2	30	20	30 - 100	30	100 - 310	200
chicken manure	0.08	4.5	-	25	17	1.5 - 2	5 - 8	310 - 620	460
human excreta	0.5	1	2	20	15	50 - 80	8		
corn straw	-	-	-	80	73	-	30 - 65	350 - 480	410
water hyacinths	-	-	-	7	5	-	20 - 30	300 - 350	325
vegetable residues	-	-	-	12	10	-	35	300 - 400	350
fresh grass	-	-	-	24	21	-	12	280 - 550	410

(source: ÖKOTOP in [4], [5])

manure listed in table 4 are only then fully available, if all of the animals are kept in stables all of the time and if the stables are designed for catching urine as well as dung. Thus, the stated values will be in need of correction in most cases. If cattle are kept in night stables, only about 1/3 to 1/2 as much manure can be collected. For cattle stalls with litter, the total yields will include 2 - 3 kg litter per animal and day [4].

2.2 Objectives of reuse-oriented wastewater management

The very basic objective of wastewater management is to protect public health and the environment in a socio-culturally and economically sustainable manner. Wastewater management systems should also account for the willingness and ability of users to operate their own system (user-friendliness). The basic objectives of a household or community wastewater management system can be summarised as follows (adopted from [6]):

- **Protection of public health:** A wastewater management system should create an effective physical barrier between contaminated blackwater and user, as well as avoid odour emissions and stagnant water leading to breeding sites for mosquitoes.

- **Protection of the environment:** A wastewater management system should prevent eutrophication and pollution of sensitive aquatic systems (surface water, groundwater, drinking water reservoirs) as well as terrestrial systems (irrigated soil).
- **Socio-culturally and economically acceptable:** wastewater management systems have to be adapted to the socio-cultural and economic settings of the household or neighbourhood. If waste reuse is culturally not anchored for example, blackwater management systems aiming at irrigation are likely to fail.
- **Simple and user-friendly:** Household or neighbourhood wastewater management systems should be manageable by the user, technically simple and robust and possibly not rely on external fuel, power supply or chemicals.
- **Compliance with national and international regulations and standards:** Qualitative and quantitative effluent standards have to maintain or even enhance the quality of receiving waters, to ensure soil fertility and protect public health.

2.3 Toilet-linked biogas plants

Night-soil based or toilet-linked biogas plants (figure 11) are widely used in Asia for the co-digestion of human excreta along with animal manure (e.g. cattle or buffalo dung, etc.) or the hygienically safe on-site treatment of toilet water and recovery of valuable energy in the form of biogas to be used as a substitute to LPG (Liquefied Petroleum Gas) in cooking and lighting.

table 5: Advantages and disadvantages of on-site treatment of toilet water in biogas plants

Advantages:	Disadvantages:
• no handling of raw (unprocessed) toilet water; • increased biogas production if additional feed material (e.g. animal manure, etc.) is available for co-digestion; • biogas may be used as a substitute to LPG in cooking • application of digested slurry as soil amendment to agricultural plots possible	• limited biogas production if only toilet water is treated;

The centre part of a sanitary biogas unit is the bio-digester (i.e. either a floating-drum or fixed-dome type biogas plant) that receives the animal manure and/or toilet water from pour-flush toilets and degrades the organics (animal manure, excreta, etc.) anaerobically, thus producing biogas and a slurry that can be utilised as soil amendment after advanced treatment in sludge drying beds. As biogas production from human excreta only is limited (ca. 40 litres per person per day), the main focus is however mostly on sanitary aspects, i.e. clean toilets with low maintenance demand, rather than a high gas productivity.

Advantages and disadvantages of toilet-linked biogas plants are summarized in table 5.

2.4 Key factors for the successful implementation of biogas sanitation concepts

For the successful and sustainable implementation of biogas sanitation schemes it's crucial to:

- create awareness amongst future users (sanitation related problems in general and value of wastewater in particular);
- participatory planning and decision making;
- training of users on how to operate and maintain the wastewater system;

3 SIZING OF TOILET-LINKED BIOGAS PLANTS

3.1 Biogas demand vs. anticipated biogas yield

The biogas demand may be estimated by way of appliance consumption data and assumed periods of use, but this approach can only work to the extent that the appliances to be used are known in advance (e.g. a biogas lamp with a specific gas consumption of 120 liter per hour and a planned operating period of 3 hours per day, resulting in a gas demand of 360 liter per day) [4].

Anticipated biogas production must be greater than the energy (i.e. biogas) demand. In case of a negative balance, the planner must check both sides - production and demand - against the following criteria [4]:

energy demand:

- shorter use of gas-fueled appliances, e.g. burning time of lamps;
- omitting certain appliances, e.g. radiant heater, second lamp;
- reduction to a partial-supply level that would probably make operation of the biogas plant more worthwhile.

The aim of such considerations is to reduce the energy demand, but only to such an extent that it does not diminish the degree of motivation for using biogas technology.

Energy supply - biogas production:

- the extent to which the useful biomass volume can be increased (better collecting methods, use of dung from other livestock inventories, including more agricultural waste, night soil, etc.), though any form of biomass that would unduly increase the necessary labor input should be avoided;
- the extent to which prolonged retention times, i.e. a larger digester volume, would increase the gas yield, e.g. the gas yield from cattle manure can be increased from roughly 200 liter per kilogram organic dry matter (ODM) for an hydraulic retention time (HRT) of 40 days to as much as 320 liter per kilogram ODM for an HRT of 80 to 100 days;
- the extent to which the digesting temperature could be increased by modifying the structure.

The aim of such measures is to determine the maximum biogas-production level that can be achieved for a reasonable amount of work and an acceptable cost of investment.

Example:

Calculate the biogas demand for a rural household with 8 persons and estimate the biogas yield from the anaerobically treatment of buffalo manure and toilet water in a small-scale biogas plant. Using a 2-flame biogas cooker, two hot meals (breakfast and dinner) shall be cooked and tea made (in the afternoon). Operating hours of the biogas cooker will be from 5 a.m. to 7 a.m. and 7 p.m. to 10 p.m. for cooking and from 4 p.m. to 5 p.m. for making tea. Both flames will be used for cooking, while for making tea only one flame is used. Gas consumption of one flame is about 175 litres of biogas per hour. The gas shall also be used for lighting a single biogas lamp. The lamp shall be lit from 5 a.m. to 7 a.m. and from 7 p.m. to 10 p.m. Gas consumption of the biogas lamp is ca. 120 litres per hour. The family owns 9 heads of buffalos, which are kept in overnight stabling. Mean manure and biogas yield per buffalo per day is 9 kg and 270 liters, respectively. Specific toilet water production per person per day is ca. 5 liters; expected biogas production is 40 liters per person per day.

The biogas cooker will be used for ca. 5 hours per day (from 5 a.m. to 7 a.m. and 7 p.m. to 10 p.m.) using both flames and about 1 hour per day (4 p.m. to 5 p.m.) using only one flame; gas consumption is ca. 175 litres per flame per hour. Hence biogas demand (D_{C+T}) for cooking and making tea is:

$$D_{C+T} = 175 \cdot 2 \cdot (2+3) + 175 \approx 2{,}000 \; l/d$$

A biogas lamp will be lit for 5 hours per day (from 5 a.m. to 7 a.m. and 7 p.m. to 10 p.m.); gas consumption is ca. 120 litres per hour. Biogas demand for lighting (D_L) is therefore:

$$D_L = 120 \cdot 5 = 600 \; l/d$$

Total biogas demand (D_T) for cooker, making tea and lighting is:

$$D_T = 2{,}000 + 600 = 2{,}600 \; l/d$$

Anticipated biogas yield (Y_B) from the digestion of buffalo manure is about 270 liters per head per day (@ ca. 9 kg of dung per head and 60 days HRT). Hence, estimated biogas yield from all 9 buffaloes is:

$$Y_B = 270 \cdot 9 \approx 2,400\ l/d$$

Specific biogas production from the co-digestion of toilet water is about 40 liters per person per day. Estimated biogas yield (Y_S) from all 8 family members is:

$$Y_S = 40 \cdot 8 \approx 300\ l/d$$

Total biogas production (Y_T) from the anaerobic treatment of buffalo manure and toilet water is:

$$Y_T = 2,400 + 300 = 2,700\ l/d$$

Anticipated biogas production (Y_T) matches gas demand (D_T), hence it is not necessary to either decrease energy demand or increase biogas yield.

3.2 Scaling of gasholder

The required gasholder capacity, i.e. the gasholder volume (V_G), is an important planning parameter and depends on the relative rates of biogas generation and gas consumption. If the gasholder capacity is insufficient, part of the gas produced will be lost. The remaining gas will not be sufficient to meet the demand. If the gasholder is made too large, construction costs will be unnecessarily high, but plant operation will be more convenient. The gasholder must therefore be made large enough to [4]:

- cover the peak consumption rate (V_{G1}) and
- hold the gas produced during the longest zero-consumption period (V_{G2}),
- furthermore, the gasholder must be able to compensate for daily fluctuations in gas production. These fluctuations range from 75 % to 125 % of calculated gas production.

Example:

Calculate the required gasholder capacity for a biogas plant to treat manure from 9 buffaloes and toilet water from a household with 8 persons. The produced biogas will be used for cooking meals, making tea and lighting a biogas lamp. Operating hours of the biogas cooker (2-flame cooker) are from 5 a.m. to 7 a.m. and 7 p.m. to 10 p.m. for cooking and from 4 p.m. to 5 p.m. for making tea. For cooking both flames will be used, while for making tea only one flame is used. Gas consumption of one flame is ca. 175 litres per hour. Lighting a single biogas lamp (from 5 a.m. to 7 a.m. and from 7 p.m. to 10 p.m.) consumes ca. 120 litres of biogas per hour. Average biogas yield is about 2,700 liters per day. To simplify calculation uniform gas production and consumption is assumed.

Daily gas yield is ca. 2,700 liter, therefore mean hourly biogas production (Y_M) is:

$$Y_M = \frac{2,700}{24} \approx 110\ l/h$$

Maximum gas consumption happens if the biogas is used for both, cooking (using both flames) and lighting at the same time. Hence maximum hourly biogas consumtion (D_M) is:

$$D_M = 175 \cdot 2 + 120 = 470\ l/h$$

As biogas is also produced during consumption, only the difference between the maximum consumption and average production is relevant to the calculation of the necessary gas storage capacity (V_{G1}):

$$D_M - Y_M = 470 - 110 = 360\ l/h$$

The longest period of maximum biogas consumption is 3 hours (from 7 p.m. to 10 p.m.). Hence the necessary gasholder volume (V_{G1}) during consumption is:

$$V_{G1} = 360 \cdot 3 = 1,080\ l$$

The longest interval between periods of consumption is from 7 a.m. to 4 p.m. (9 hours). The necessary gasholder volume (V_{G2}) is therefore:

$$V_{G2} = 110 \cdot 9 = 990\ l$$

The larger volume (V_{G1} or V_{G2}) determines the size of the gasholder. V_{G1} is the larger volume and must therefore be used as the basis. Allowing for the safety margin of 25%, the gasholder volume (V_G) is thus:

$$V_G = 1,080 \cdot 1.25 = 1,350\ l$$

3.3 Scaling of digester

The size of the digester, i.e. the detention volume (V_D), is determined on the basis of the chosen detention time and the daily substrate input quantity [4]. The detention time (HRT) indicates the period spent by the feed material in the digester and, in turn, is determined by the chosen/given digesting temperature [4] or chosen by economic criteria and is appreciably shorter than the total time required for complete digestion of the feed material [5]. For an unheated biogas plant, the temperature prevailing in the digester can be assumed as 1-2 K (°C) above the soil temperature. Seasonal variation must be given due consideration, however, i.e. the digester must be sized for the least favorable season of the year. For a plant of simple design, the retention time should amount to at least 40 days. Practical experience shows that retention times of 60-80 days, or even 100 days or more, are no rarity when there is a shortage of substrate. On the other hand, extra-long retention times can increase the gas yield by as much as 40% [4].

3.3.1 Estimation of feed material production and calculation of digester volume

Adding water or urine gives the substrate fluid properties. This is important for the operation of a biogas plant; it is easier for the methane bacteria to come into contact with feed material, thus accelerating the digestion process [5]. Slurry with a solids content (DM) of about 4 – 10% ([4], [5]) is particularly well suited to the operation of continuous biogas plants.

Common substrate mixing ratios to obtain well-suited slurry are given in table 6:

table 6: Common substrate mixing ratios

type of substrate	substrate/water
fresh cattle manure	1/0.5 – 1/1
semi-dry cattle manure	1/1 – 1/2
pig dung	1/1 – 1/2
cattle and pig dung fro, a floating removal device	1/0
chicken manure	1/4 – 1/6
stable manure	1/2 – 1/4

(source: ÖKOTOP in [4])

Example:

Estimate the daily amount of feed material for a biogas plant to anaerobically treat manure of 9 heads of buffalo and toilet wasterwater produced by a household of 8 persons. Assume mean dung yield per buffalo to be ca. 9 kilogram per day (@ 300 – 450 kg live weight per buffalo and overnight stabling). The buffalo manure is mixed with water in the proportions of 1:1 to prepare the fermentation slurry having a solids content of 7% and a water content of 93%. Specific toilet wastewater production is ca. 5 liter per person per day. Hence calculate the required dedention volume (V_D) to provide for a HRT of 60 days.

The amount of fermentation slurry (Q_B) prepared from 9 heads of buffaloes (@ a specific manure yield of 9 kg per buffalo per day and a substrate mixing ratio of 1:1) is:

$$Q_B = 9 \cdot 9 \cdot 2 \approx 160\ l/d$$

Daily amount of toilet water (Q_S) produced by 8 persons (@ a specific toiletwater production of 5 liters per person per day) is:

$$Q_S = 8 \cdot 5 = 40\ l/d$$

Total volume of feed material (Q_T) is thus:

$$Q_T = 160 + 40 = 200\ l/d$$

Based upon a substrate input of ca. 200 liter per day and a chosen HRT of 60 days, the detention volume (V_D) is:

$$V_D = 200 \cdot 60 = 12{,}000\ l$$

3.3.2 Scaling of floating-drum type biogas plant

For a given volume (V_D), the dimensionsion of a floating-drum type biogas plant (KVIC biogas plant) can be taken from standard designs (see table 7).

Example:

Chose appropriate dimensions of a floating-drum type biogas plant for given volume (V_D = ca. 12,000 liter) and gas storage volume (V_G = ca. 1,350 liter).

From table 7 two designs are possible: (i) a biogas plant having an inner diameter and height of 2.20 meter and 3.07 meter, respectively (please note that the approximate net volume of the digester is a bit on the smaller side) and (ii) a digester having an inner diameter and height of 2.75 meter and 2.42 meter, respectively.

table 7: Common dimensions of floating-drum type biogas plants

aprox. volume [m³]	digester inner dia. [m]	digester outer dia. [m]	digester height [m]	floating drum volume [m³]	floating drum dia. [m]	floating drum height [m]
1.8 / 2.2 / 2.5	1.20	1.66	1.64 / 1.95 / 2.27	0.5	1.05	0.60
2.6 / 3.6 / 4.6	1.35	1.81	1.87 / 2.57 / 3.27	1.2	1.25	1.00
4.0 / 5.5 / 7.5	1.60	2.06	2.02 / 2.77 / 3.77	1.7	1.50	1.00
5.7 / 7.8 / 10.8	1.80	2.26	2.27 / 3.07 / 4.27	2.1	1.65	1.00
8.6 / 11.6 / 16.2	2.20	2.66	2.27 / 3.07 / 4.27	3.1	2.00	1.00
10.9 / 15.6 / 21.5	2.40	2.86	2.42 / 3.47 / 4.77	4.9	2.25	1.25
14.3 / 20.6 / 28.3	2.75	3.21	2.42 / 3.47 / 4.77	6.6	2.60	1.25
29.4 / 38.3	3.20	3.90	3.66 / 4.77	8.8	3.00	1.25
37.2 / 53.6	3.60	4.40	3.66 / 5.27	11.3	3.40	1.25
41.5 / 65.4	3.80	4.60	3.66 / 5.77	12.7	3.60	1.25
59.5 / 93.8	4.55	5.45	3.66 / 5.77	19.0	4.40	1.25
76.2 / 120.1	5.15	6.05	3.66 / 5.77	23.0	4.85	1.25
101.7 / 160.4	5.95	6.85	3.66 / 5.77	32.4	5.75	1.25
140.8 / 222.0	7.00	7.90	3.66 / 5.77	45.3	6.80	1.25

3.3.3 Scaling of fixed-dome type biogas plant

While calculating the net volume (V_{BP}) of fixed-dome biogas plant, two distinct volumes viz., the volume for recommended hydraulic detention time (V_D) and the volume for gas storage (V_G), have to be considered (see figure 5).

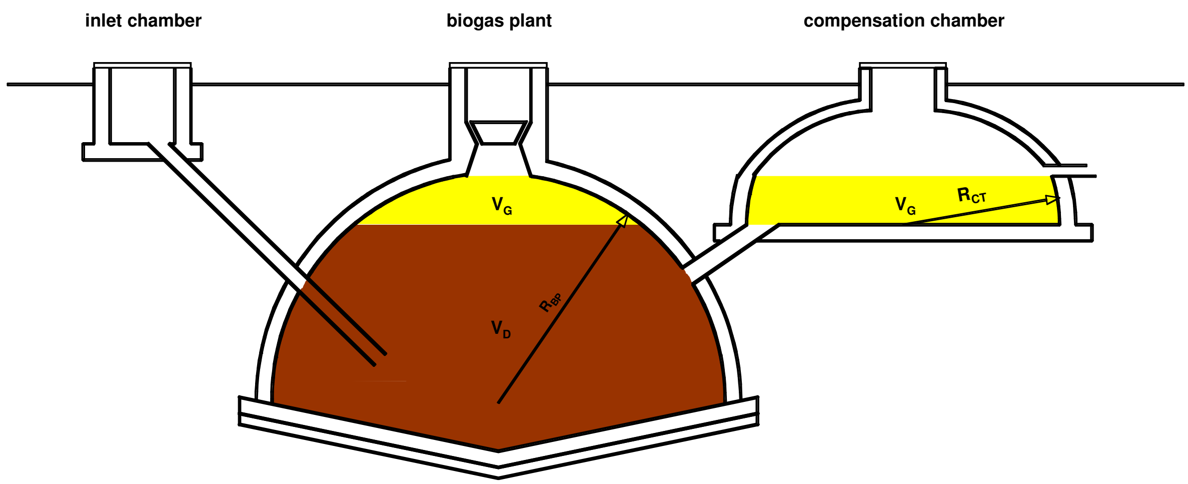


figure 5: Distinct volumes to be considered while calculating net volume of biogas plant

Example:

Calculate the dimensions of a fixed-dome type biogas plant for given digester volume (V_D = ca. 12,000 liter) and gas storage volume (V_G = ca. 1,350 liter).

The required net volume (V_{BP}) of a fixed-dome biogas plant provides for detention volume (ca. 12,000 liter) and gas storage volume (ca. 1,350 liter):

$$V_{BP} = 12,000 + 1,3500 \approx 13,500\ l$$

The volume of a half round biogas plant is determined by the equation for calculation of the volume of a hemisphere (V_{HSP}):

$$V_{HSP} = \frac{2 \cdot R^3 \cdot \pi}{3}$$

The equation of the volume of a hemisphere can be rearranged to calculate the halfmeter/radius (R_{BP}) of the biogas plant. Assume the net volume of the biogas plant (V_{BP}) is 13.5 m^3 (13,500 liter). Hence halfmeter R_{BP} is:

$$R_{BP} = \sqrt[3]{\frac{3 \cdot 13.5}{2 \cdot \pi}} \approx 1.86\ m$$

For construction of the dome, the radius R_{BP} has to be increased by the thickness of the plaster (e.g. 0.02 meter). Hence, the actual readius of the brick dome is ca. 1.88 meter.

A common design for the compensation tank is to provide a hemisphere with the overflow at height H above the base (or “zero line”). Usually the radius R_{CT} of the compensation tank is reduced by 1.5 cm per course of bricks above the overflow level (see figure 6).

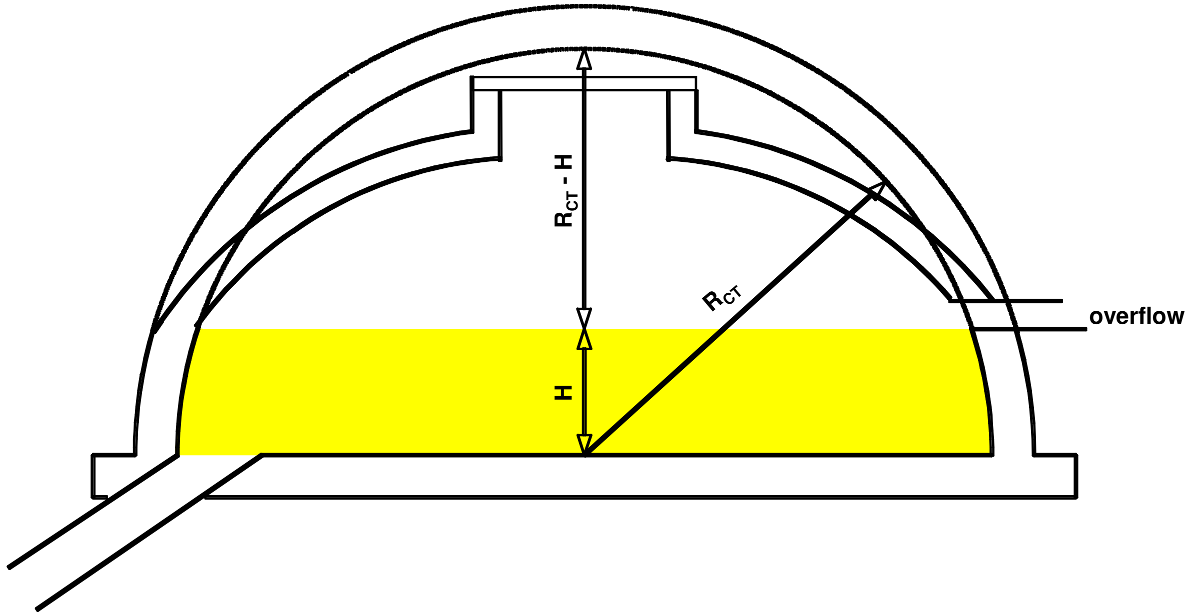
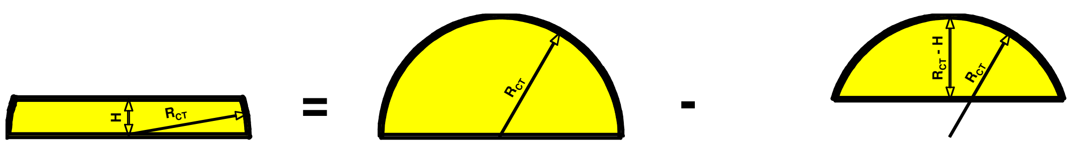


figure 6: Conceptual sketch of compensation tank (above the overflow level radius R_{CT} is reduced by 1.5 cm per course of bricks)

The net volume of the compensation tank (V_{CT}) is calculated by subtracting the volume of the free space above the overflow (R_{CT} – H) from the volume of the hemisphere (see figure 7):



$$V_{CT} = \frac{2}{3} \cdot R_{CT}^3 \cdot \pi - (R_{CT} - H)^2 \cdot \pi \cdot \left(R_{CT} - \frac{R_{CT} - H}{3} \right)$$

figure 7: Calculation of net volume of compensation tank

For calculation of radius R_{CT}, the thickness of the plaster is set with 0.02 meter.

$$V_{CT} = V_G = \frac{2 \cdot (R_{CT} - 0.02)^3 \cdot \pi}{3} - \left[(R_{CT} - H)^2 \cdot \pi \cdot \left(R_{CT} - \frac{R_{CT} - H}{3} \right) \right]$$

The net volume of the compensation tank (V_{CT}) equals the gas storage capacity (V_G). By trial and error (for H = 0.45 m and V_G = 1.35 m^3), R_{CT} lies between 1.0 and 1.1 meter, adopt 1.1 meter for a volume of ca. 1.5 m^3.

$$1.5 = \frac{2 \cdot (1.10 - 0.02)^3 \cdot \pi}{3} - \left[(1.10 - 0.45)^2 \cdot \pi \cdot \left(1.10 - \frac{1.10 - 0.45}{3} \right) \right]$$

Maximum gas pressure occurs at a level P below the overflow level of the compensation tank, which is also the lowest slurry level (figure 8).

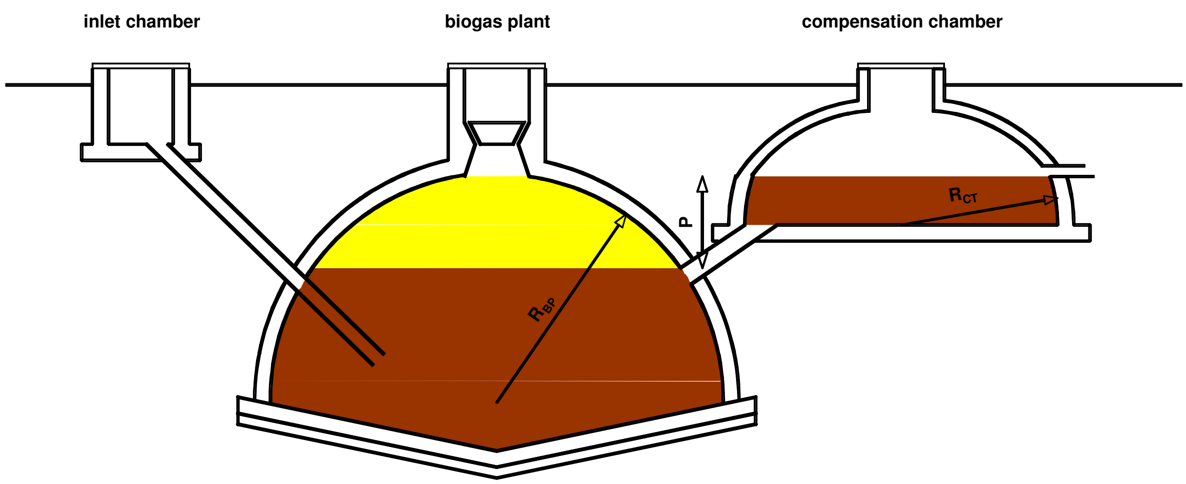
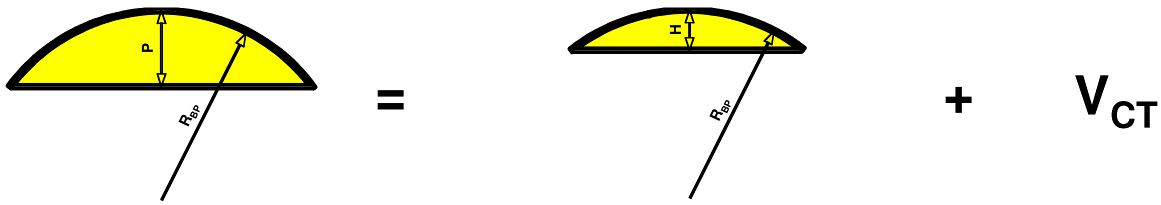


figure 8: Fixing lowest slurry level („P-line“)

For calculation of level P the equation of the spherical calotte volume is applied to the total volume of the free space (R_{BP} - H) above maximum slurry level and the net volume of the compensation tank (V_{CT}) (see figure 9).



$$P^2 \cdot \pi \cdot \left(R_{BP} - \frac{R_{BP} - P}{3} \right) = H^2 \cdot \pi \cdot \left(R_{BP} - \frac{R_{BP} - H}{3} \right) + V_{CT}$$

figure 9: Calculation of “P-line”

By trial and error (for R_{BP} = 1.86 m; H = 0.45 m and V_{CT} = 1.5 m^3), P is 0.71 meter

$$0.71^2 \cdot \pi \cdot \left(1.86 - \frac{0,71}{3} \right) = 0.45^2 \cdot \pi \cdot \left(1.86 - \frac{0.45}{3} \right) + 1.5$$

Construction details and other important information

- An experienced company/organisation must do detailed project planning and construction of the biogas plant.

3.4 Slurry collection, treatment and application

The slurry, i.e. the fermented sludge, may be directly applied as liquid soil amendment to agricultural land or collected and further processed in socalled sludge drying beds for dewatering.

3.4.1 Direct application of the slurry

The slurry is directly applied to agricultrural plots using a trench or pipe system for distribution.

3.4.2 Advanced treatment of slurry in sludge drying beds

If the slurry is not used directly used, it may be collected and treated in sludge drying beds. The simplest way of providing for sludge drying beds is to partially dig up the ground and pile up the excavated soil to earthen bunds (figure 10). These perimeter bunds will also help in keeping surface run-off water from entering the sludge drying beds.

figure 10: View of simple sludge drying beds

It is recommended to provide for at least 2 beds, which are used alternately. One bed receives slurry on a daily basis while the other lays idle or provides for additional resting period. The volume of each drying bed should allow for collection of slurry producted within a period of one month. Thus taking care on reduced infiltration and evaporation rates during rainy season.

Construction details and other important information

- The location of the sludge drying beds should be safe from flooding.
- If available, natural slope avoids the need for pumps.

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5 SKETCHES, TECHNICAL DRAWINGS

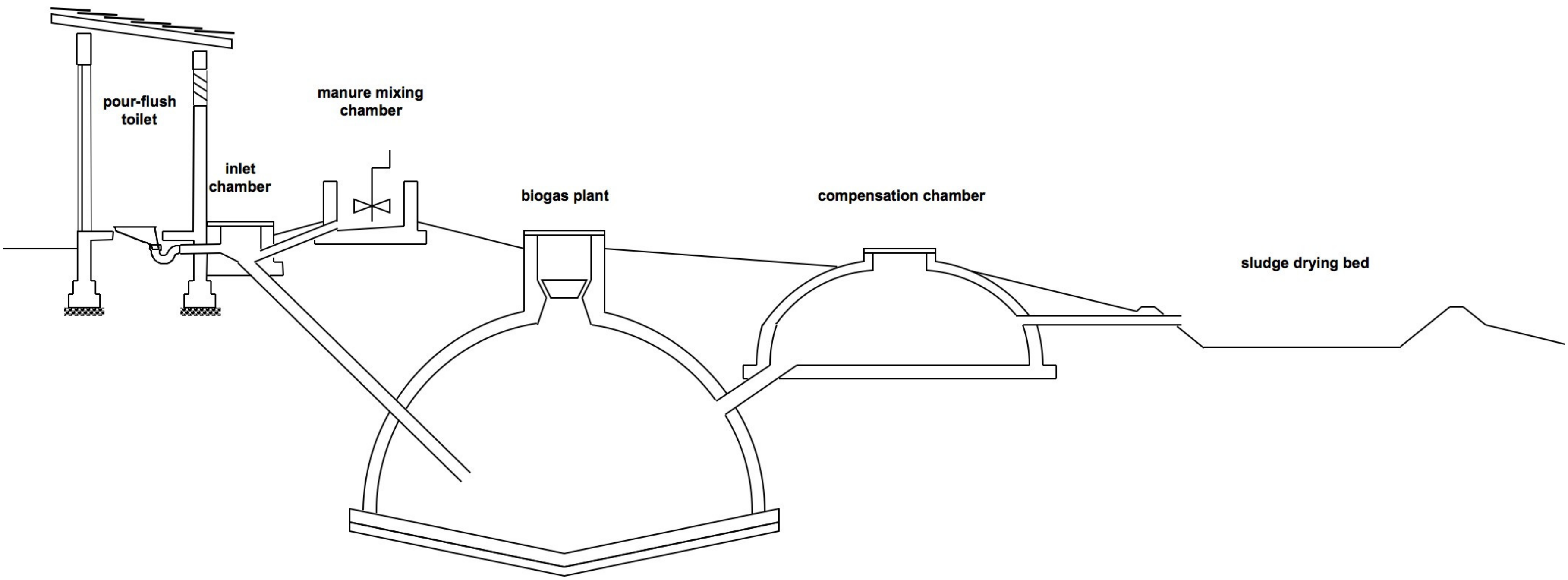

figure 11: Conceptual sketch of toilet-linked biogas unit

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