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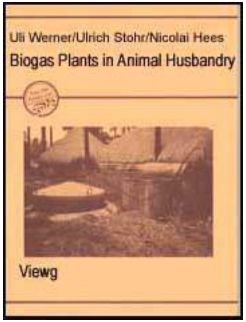

Biogas plants in Animal Husbandry (GTZ, 1989, 153 p.)

4. Balancing the energy demand with the biogas production

Biogas plants in Animal Husbandry (GTZ, 1989, 153 p.)

4. Balancing the energy demand with the biogas production

All extension-service advice concerning agricultural biogas plants must begin with an estimation of the quantitative and qualitative energy requirements of the interested party. Then, the biogas-generating potential must be calculated on the basis of the given biomass incidence and compared to the energy demand. Both the energy demand and the gas-generating potential, however, are variables that cannot be very accurately determined in the planning phase.

In the case of a family-size biogas plant intended primarily as a source of energy, implementation should only be recommended, if the plant can be expected to cover the calculated energy demand.

Since determination of the biogas production volume depends in part on the size of' the biogas plant, that aspect is included in this chapter.

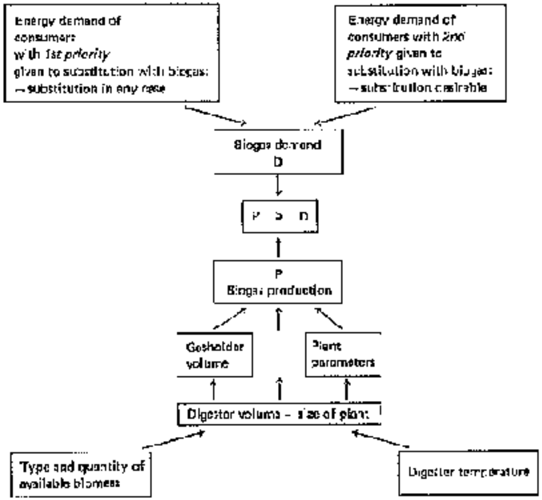

Fig. 4.1: Balancing the energy demand with the biogas production (Source: OEKOTOP)

4.1 Determining the Energy Demand

The energy demand of any given farm is equal to the sum of all present and future consumption situations, i.e. cooking, lighting, cooling, power generation, etc. With deference to the general orientation of this manual, emphasis is placed on determining the energy demand of a typical family farm.

Experience shows that parallel calculations according to different methods can be useful in avoiding errors in calculating the gas/ energy demand.

Table 4.1: Outline for determining biogas demand (Source: OEKOTOP)

Energy consumers	**data**	**Biogas demand**
		(l/d)
1. Gas for cooking (Chapter 5.5.3)		
Number of persons	....	
Number of meals	....	
Present energy consumption	....	
Present source of energy	....	
Gas demand per person and meal (Table 5.17)	....	
Gas demand per meal	....	
Anticipated gas demand		....
Specific consumption rate of burner	....	
Number of burners -	....	
Duration of burner operation	....	
Anticipated gas demand		....
Total anticipated cooking-gas demand		....
2. Lighting (Chapter 5.5.3)		
Specific gas consumption per lamp (Table 5.20)	....	
Number of lamps	....	
Duration of lamp operation	....	
Gas demand		....
3. Cooling (Chapter 5.5.3)		
Specific gas consumption X 24 h (Table 5.22)	....	....
4. Engines (Chapter 5.5.4)		

Specific gas consumption per kWh	....	
Engine output	....	
Operating time	....	
Gas demand		....
5. Miscellaneous consumers		
Gas demand	....	....
Anticipated increase in consumption (%)		....
Total biogas demand		....
1st-priority consumers		....
2nd-priority consumers		....
3rd-priority consumers		....

The following alternative modes of calculation are useful:

Determining biogas demand on the basis of present consumption

. . ., e.g. for ascertaining the cooking-energy demand. This involves either measuring or inquiring as to the present rate of energy consumption in the form of wood/charcoal, kerosene and/or bottled gas.

Calculating biogas demand via comparable-use data

Such data may consist of:

- empirical values from neighboring systems, e.g. biogas consumption per person and meal,

- reference data taken from pertinent literature (cf. chapter 5.5), although this approach involves considerable uncertainty, since cooking-energy consumption depends on local culture-dependent cooking and eating habits and can therefore differ substantially from case to case.

Estimating biogas demand by way of appliance consumption data and assumed periods of use
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 1201/h and a planned operating period of 3 in/d, resulting in a gas demand of 360 l/d.

Then, the interested party's energy demand should be tabulated in the form of a requirements list (cf. table 4.1). In that connection, it is very important to attach relative priority values to the various consumers, e.g.:

1st priority: applies only when the biogas plant will cover the demand.
2nd priority: coverage is desirable, since it would promote plant usage.
3rd priority: excess biogas can be put to these uses.

4.2 Determining the biogas production

The quantity, quality and type of biomass available for use in the biogas plant constitutes the basic factor of biogas generation. The biogas incidence can and should also be calculated according to different methods applied in parallel.

Measuring the biomass incidence (quantities of excrement and green substrate)

This is a time-consuming, somewhat tedious approach, but it is also a necessary means of adapting values from pertinent literature to unknown regions. The method is rather inaccurate if no total-solids measuring is included. Direct measurement can, however,

provide indication of seasonal or fodder-related variance if sufficiently long series of measurements are conducted.

Determining the biomass supply via pertinent-literature data
(cf. tables 3.2/3.3)

According to this method, the biomass incidence can be determined at once on the basis of the livestock inventory. Data concerning how much manure is produced by different species and per liveweight of the livestock unit are considered preferable.

Dung yield = liveweight (kg) x no. of animals x specific quantity of excrements (in % of liveweight per day, in the form of moist mass, TS or VS).

Determining the biomass incidence via regional reference data

This approach leads to relatively accurate information, as long as other biogas plants are already in operation within the area in question.

Determining biomass incidence via user survey

This approach is necessary if green matter is to be included as substrate.
It should be kept in mind that the various methods of calculation can yield quite disparate results that not only require averaging by the planner, but which are also subject to seasonal variation.

The biomass supply should be divided into two categories:

Category 1: quick and easy to procure,
Category 2: procurement difficult, involving a substantial amount of extra work.

Table 4.2: Outline for determining biomass incidence (Source: OEKOTOP)

Source of biomass	**Moist weight**	**TS/VS weight**
	(kg/d)	**(kg/d)**
Animal dung		
Number of cattle:		
Dung yield per head	....	....
Amount collected		
Dung yield from cattle	....	....
Number of pigs:		
Dung yield per pig	....	....
Amount collected:		
Dung yield from pigs	....	....
Sheep, camels, horses etc................	....	....
Green matter		
1. grass, etc.	....	....
2..................................	....	....
Night soil		
Number of persons:		
Dung yield from night soil	....	....
Total biomass incidence	....	....
Category 1	....	....
Category 2	....	....

4.3 Sizing the plant

The size of the biogas plant depends on the quantity; quality and kind of available biomass and on the digesting temperature.

Sizing the digester

The size of the digester, i.e. the digester volume (Vd), is determined on the basis of the chosen retention time (RT) and the daily substrate input quantity (Sd).

Vd = Sd x RT ($m^3 = m^3$/day x number of days)

The retention time, in turn, is determined by the chosen/given digesting temperature (cf. fig 5.2).

For an unheated biogas plant, the temperature prevailing in the digester can be assumed as 1-2 K 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%.

The substrate input depends on how much water has to be added to the substrate in order to arrive at a solids content of 4-8%.

Substrate input (Sd) = biomass (B) + water (W) (m^3/d)

In most agricultural biogas plants, the mixing ratio for dung (cattle and/or pigs) and water (B: W) amounts to between 1: 3 and 2: 1 (cf. table 5.7).

Calculating the daily gas production (G)

The amount of biogas generated each day (G, m^3 gas/d), is calculated on the basis of the specific gas yield (Gy) of the substrate and the daily substrate input (Sd).

The calculation can be based on:

a) The volatile-solids content

G = kg VS-input x spec. Gy (solids)

b) the weight of the moist mass

G = kg biomass x spec. Gy (moist mass)

c) standard gas-yield values per livestock unit (LSU)

G = no. of LSU x spec. Gy (species)

Table 4.3 lists simplified gas-yield values for cattle and pigs. A more accurate estimate can be arrived at by combining the gas-yield values from, say, table 3.5 with the correction factors for digester temperature and retention time shown in figure 5.2.

$GY_{T,RT} = mGy \times f_{T,RT}$

$GY_{T,RT}$ **= gas yield as a function of digester temperature and retention time**
mGy = average specific gas yield, e.g. 1/kg VS (table 3.5)
$f_{T,RT}$ **= multiplier for the gas yield as a function of digester temperature and retention time (cf. fig. 5.2)**

As a rule, it is advisable to calculate according to several different methods, since the available basic data are usually very imprecise, so that a higher degree of sizing certainty can be achieved by comparing and averaging the results.

Establishing the plant parameters

The degree of safe-sizing certainty can be increased by defining a number of plant parameters:

Specific gas production (Gp)
i.e. the daily gas-generation rate per m^3 digester volume (Vd), is calculated according to the following equation:

$Gp = G: Vd$ (m^3 gas/m^3 Vd x d)

Digester loading (Ld)

Ld - TS (VS) input/m^3 digester volume (kg TS (VS)/m^3 Vd x d)

Then, a calculated parameter should be checked against data from comparable plants in the region or from pertinent literature.

Table 4.3: Simplified gas-yield values for substrate from cattle and pigs (digesting temperature: 22-27 °C) (Source: OEKOTOP)

Type of housing/ manure	Cattle, live wt. 200 - 300 kg		Buffalo, live wt. 300 - 450 kg		Pigs, live wt 50 - 60 kg	
	manure yield	Gas yield (I/d)	manure yield	Gas yield (I/d)	manure yield	Gas yield (l/d)

	(kg/d)	RT=60	RT=80	(kg/d)	RT=60	RRT=80	(kg/d)	RT=40	RT=60
24-h stabling									
- dung only (moist),unpaved floor (10% losses)	9-13	300-450	350-500	14-18	450-540	300-620	-	-	-
- dung and urine,concrete floor	20-30	350-510	450-610	30-40	450-600	5440-710	2.5-3.0	120-140	150-180
- stable manure (dung + 2 kg litter), concrete floor	22-32	450-630	530-730	32-42	550-740	630-890	-	-	-
Overnight stabling									
- dung only (10% losses)	5-8	180-270	220-310	8-10	240-300	2290-360	-	-	-
- dung and urine,concrete floor	11-16	220-320	260-380	16-20	260-330	330-410	-	-	-
1 kg/d moist dung		~35	~40		~34	~40		-	-
1 l/d manure		~20	~25		~20	~24		~50	~60
1 kg/d manure		~22	~27		~22	~26		-	-
1 kg TS/d	~200	~240		~200	~240		~2270	~340	
1 kg VS/d	~250	~300		~250	~300		~3350	~430	

Sizing the gasholder

The size of the gasholder, i.e. the gasholder volume (Vg), depends on the relative rates of gas generation and gas consumption. The gasholder must be designed to:

- cover the peak consumption rate (Vg 1) and
- hold the gas produced during the longest zero-consumption period (Vg 2).

Vg1 = gc, max x tc, max = vc, max
Vg2 = G x tz, max

gc, max = maximum hourly gas consumption (m^3/h)
tc, max = time of maximum consumption (h)
vc, max = maximum gas consumption (m^3)
G = gas production (m^3/h)
tz, max = maximum zero-consumption time (h)

The larger Vg-value (Vgl or Vg2) determines the size of the gasholder. A safety margin of 10-20% should be added. Practical experience shows that 40-60% of the daily gas production normally has to be stored. Digester volume vs. gasholder volume. (Vd: Vg) The ratio

Vd : Vg

is a major factor with regard to the basic design of the biogas plant. For a typical agricultural biogas plant, the Vd/Vg-ratio amounts to somewhere between 3: 1 and 10: 1, with 5: 1 - 6: 1 occurring most frequently.

4.4 Balancing the gas production and gas demand by iteration

As described in subsection 4.1, the biogas/ energy production (P) must be greater than the energy demand (D).

P>D

This central requirement of biogas utilization frequently leads to problems, because small farms with only a few head of livestock usually suffer from a shortage of biomass. In case of a negative balance, the planner must check both sides - production and demand - against the following criteria:

Energy demand (D)

Investigate the following possibilities:
- **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 (P)

Examine/calculate the following options/ factors:

- **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 1/kg VS for an RT of 40 days to as much as 320 1/kg VS for an RT of 80-100 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.

If the gas production is still smaller than the gas demand ($P < D$), no biogas plant should be installed.

If, however, the above measures succeed in fairly well matching up the production to the demand, the plant must be resized according to subsection 4.3.

4.5 Sample calculations

Energy demand (D)

Basic data
8-person family, 2 meals per day. Present rate of energy consumption: 1.8 1 kerosene per day for cooking and fueling 1 lamp (0.6 1 kerosene = 1 m^3 biogas).

Desired degree of coverage with biogas
Cooking: all
Lighting: 2 lamps, 3 hours each
Cooling: 60 I refrigerator

Daily gas demand (D)
Cooking
1. Present fuel demand for cooking:
1.21 kerosene = 2 m^3 gas
2. Gas demand per person and meal:
0.15 m^3 biogas

Gas demand per meal: 1.2 m^3 biogas
Cooking-energy demand: 2.4 m^3 biogas
3. Consumption rate of gas burner:
175 l/h per flame (2-flame cooker)
Operating time: 2 x 3 h + 1 h for tea
Biogas demand: 7 h x 3501 = 2.5 m^3

Defined cooking-energy demand:
2.5 m^3 biogas/d

Lighting
Gas consumption of lamp: 120 1/h
Operating time: 2 x 3 h = 6 h
Biogas demand: 0.7 m^3/day

Cooling (60 l refrigerator)
Specific gas demand: 30 1/h
Biogas demand: 0.7 m^3/day
Total biogas demand: 3.9 m^3/d

1st priority: cooking	2.5 m^3
2nd priority: 1 lamp	0.35 m^3
3rd priority: 1 lamp/refigerator	1.05 m^3

Biomass supply/Biogas production (P)

Basic data
9 head of cattle, 230 kg each, 24-h stabling,

green matter from garden as supplement.

Daily biomass incidence
Animal dung, calculated as % liveweight (as per 1.) or as daily yield per head (as per 2.) as listed in pertinent literature..

1. Dung as % liveweight
Daily yield per head of cattle: 10% of
230 kg = 23 kg/d
Volatile solids/d: 1.8 kg VS per day and animal
Total yield: 207 kg/d (16 kg VS/d)

2. Manure yield on per-head basis
Dung yield per head of cattle: 15 kg/d
Urine: 9 1/d
Volatile solids: 9% = 2.1 kg VS/d
Total yield: 216 kg/d (19 kg VS/d)

Useful percentage: 75%
The lowest values are used as the basis of calculation.

Green matter: 20 kg agricultural waste with 30% VS.

Total biomass incidence 170 kg/d (18 kg VS/d)

Category 1: cattle 150 kg (12 kg)
Category 2: green matter 20 kg (6 kg)

Sizing the plant

Basic data (calculation for category 1)
Daily biomass: 150 kg/d
VS: 12kg/d
TS-content: 12%
Soil temperature: max 31 °C, min. 22 °C, average 25 °C

Digester volume (Vd)
Retention time (chosen): RT = 60 d (at 25 °C, i.e. f = 1.0)
Substrate input: Sd = biomass + water
Digester TS-content: = 7% (chosen)
Daily water input: Wd = 100 kg
Sd= 100+ 150=250 l
Digester volume: Vd = 250 1 x 60 d = 15 000 = 15 m^3

Daily biogas yield
G = kg/d VS x Gy,vs .
= 12 kg/d x 0.25 = 3.0 m^3/d
G = kgid biomass x Gy (moist)
= 150 x 0.02 = 3.0 m^3/d
G = number of animals x Gy per animal x d
= 9 x 0.35 = 3.2 m^3/d

Anticipated daily biogas yield = 3.0 m^3/d
Balancing the biogas production and demand
Demand: 3.9 m^3/d
Production: 3.0 m^3/d

Changes/accommodations

On the demand side: 1 less lamp, reducing the demand to 3.55 m^3
Production side: increasing the digester volume to 18 m^3, resulting in a retention time of 75 days (f = 1.2) and a daily gas yield of 3.6 m^3

Plant parameters

Digester volume: Vd = 18m^3
Daily gas production: G = 3.6 m^3
Daily substrate input: Sd = 2501
Specific gas production:
Gp = G : Vd
Gp = 3.6 (m^3/d): 18 m^3 = 0.2 m^3/m^3 Vd x d
Digester loading:
Ld = TS/VS-input: Vd
Ld = 18: 18 = 1.0 kgTS/m^3 Vd
Ld = 12: 18 = 0.7 kg VS/m^3 Vd
Gasholder volume:
Vg = 1.6 m^3, as calculated on the basis of:
consumption volume:
Vg1 = 0.175 m^3/h x 2 flames x 3 h = 1.05 m3
Storage volume:
Vg2 = 10 h x 0.15 m^3 gas/h = 1.5 m^3
Vd:Vg=18: 1.6=11 :1

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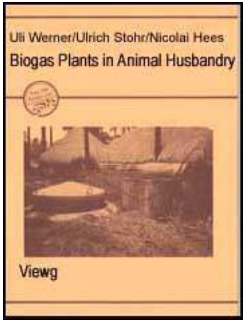


Biogas plants in Animal Husbandry (GTZ, 1989, 153 p.)

5. Biogas technique

The design aspects dealt with below concentrate solely on the principles of construction and examples of simple biogas plants, i.e. plants:

- **for small family farms requiring digester volumes of between 5 m^3 and 30 m^3,**
- **with no heating or temperature control,**
- **with no motor-driven agitators or slurry handling equipment,**
- **with simple process control,**
- **built with (at least mostly) local materials,**
- **built by local craftsmen.**

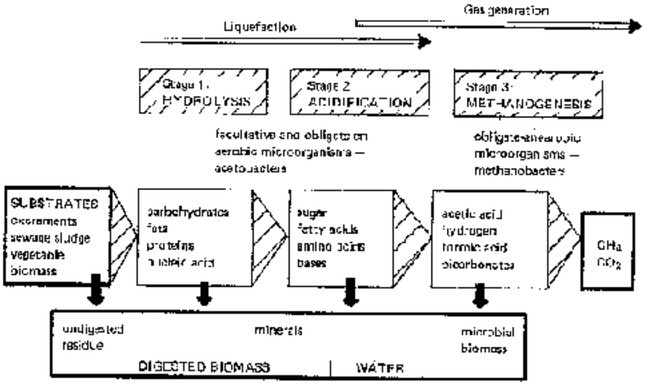


Fig. 5.1: Three-stage anaerobic fermentation (Source: Baader et. al 1978)

5.1 Fundamental principles, parameters, terms

Biochemical principles

The generation of biogas by organic conversion (anaerobic fermentation) is a natural biological process that occurs in swamps, in fermenting biomass and in intestinal tracts, particularly those of ruminants.

The symbiotic relationships existing between a wide variety of microorganisms leads, under air exclusion, to the degradation and mineralization of complex biomass in a sequence of intermeshing stages. The resultant biogas, consisting primarily of methane (CH_4) and carbon dioxide (CO_2) and the mineralized slurry constitute the ultimate catabolites of the participating bacteria and residual substances.

The process of anaerobic fermentation can be illustrated in the form of a three-stage model, as shown in figure 5.1.

Table 5.1: Basic criteria for acetobaeters (acid-forming bacteria) and methanobacters (methane-forming bacteria) (Source: OEKOTOP, compiled from various sources)

Criterion	**Acetobacter**	**Methanobacter**
Dominant microorganisms	facultative anaerobes	obligate anaerobes
Temperature range	3 °C - 70 °C	3 °C - 80 °C
Optimum temperature	approx. 30 °C	approx. 35 °C (sensitive to temperature fluctuations of 2-3 °C or more)
pH range	acidic (3.0) 5.0-6.5 relatively short duplication period, usually less than 24 hours	alkaline, 6.5-7.6 relatively long duplication period (20 - 10 days)
End metabolites	org. acids, H_2, CO_2	CO_2, CH_4
Mass transfer by . . .	intensive mixing	gentle circulation
Medium	aqueous (water content > 60%)	
Sensitivity to cytotoxins	low	substantial
Requirements regarding nutrient composition	well-balanced supply of nutrients	
Special features	viable with or without free oxygen	viable only in darkness and in absence of free oxygen

Table 5.2: Energy potential of organic compounds (Source: Kaltwasser 1980)

Material	**biogas (I/kg)**	**CH_4**	**CO_2**	**Energy content**
		vol. fraction %		**(Wh/g)**
Carbohydrates	790	50	50	3.78
Organic fats	1270	68	32	8.58
Protein	704	71	29	4.96

Anaerobic fermentation converts the "volatile solids" (proteins, carbohydrates, fats). The "nonvolatile solids" are essential to the bacteria as "roughage" and minerals. Water serves simultaneously as the vital medium, solvent and transport vehicle.

Theoretical/laboratory data on maximum gas yields from various organic materials show that anaerobic fermentation is just as capable of achieving complete mineralization as is the process of aerobic fermentation. Note: The theoretical maximum biogas yield can be ascertained by way of the basic composition of the biomass.

Table 5.3: Energetical comparison of aerobic and anaerobic fermentation (Source: Inden 1978)

Metabolite	**aerobic**	**anaerobic**
	energy fraction (%)	
Cytogenesis	60%	10%
Heat	40%	-
Methane	-	90%

Characteristics that set anaerobic fermentation apart from aerobic fermentation (e.g. composting) include:

- **fixation of biochemical energy in biogas**
- **little formation of new biomass**
- **low heat development**
- **fixation of minerals in the digested slurry.**

It is important to know that anaerobic fermentation involves a steady-state flux of acetobacters and methanobacters, with the methanobacters, being more specialized and, hence, more sensitive, constituting the defining element. Any biogas plant can develop problems during the starting phase and in the case of overloading or uneven loading of the digester, and as a result of poisoning. This underlines the importance of cattle dung, which is rich in methanobacters and therefore serves as a good "starter" and "therapeutic instrument" in case of a disturbance.

With regard to technical exploitation, anaerobic fermentation must be regarded from a holistic point of view, since the "organism" is only capable of operating at optimum efficiency under a certain set of conditions. The process of anaerobic fermentation is quite variable and capable of stabilizing itself as long as a few basic parameters are adhered to.

Parameters and terminology of biomethanation

Feedstock/substrate:
As a rule, all watery types of biomass such as animal and human excrements, plants and organic wastewater are suitable for use in generating biogas. Wood and woody substances are generally unsuitable.

The two most important defining quantities of the biomethanation process are the substrate's solids content, i.e. total solids (TS, measured in kg TS/m³) and its total

organic solids content, i.e. volatile solids (VS, measured in kg VS/m³). Both quantities are frequently stated as weight percentages.

The total-solids and water contents vary widely from substrate to substrate (cf. table 3.2 for empirical values). The most advantageous TS for the digester of a continuoustype biogas plant is 5-10%, compared to as much as 25% for a batch-operated plant. A TS of 15% or more tends to inhibit metabolism. Consequently, most substrates are diluted with water before being fed into the digester.

Substrate composition
All natural substrates may be assumed to have a nutritive composition that is adequately conducive to fermentation. Fresh green plants and agroindustrial wastewater, however, sometimes display a nutritive imbalance.

An important operating parameter is the ratio between carbon content (C) and nitrogen content (N), i.e. the C/N-ratio, which is considered favorable within the range 30 :1 to 10: 1. A C/N-ratio of less than 8: 1 inhibits bacterial activity due to an excessive ammonia content.

Fermentation/digester temperature
As in all other microbial processes, the rate of metabolism increases along with the temperature. The fermentation/digester temperature is of interest primarily in connection with the time required for complete fermentation, i.e. the retention time: the higher the temperature, the shorter the retention time. It has no effect on the absolute biogas yield, which is a constant that depends only on the type of biomass in the digester.

For reasons of operating economy, a somewhat shorter period of fermentation, the technical retention time (RT, t, measured in days) is selected such as to achieve an advantageous, temperature-dependent relative digestion rate (Dr, measured in Yo), also referred to as the yield ratio, since it defines the ratio between the actual biogas yield and

the theoretical maximum. The average agricultural biogas system reaches a Dr-value of 30-60%..

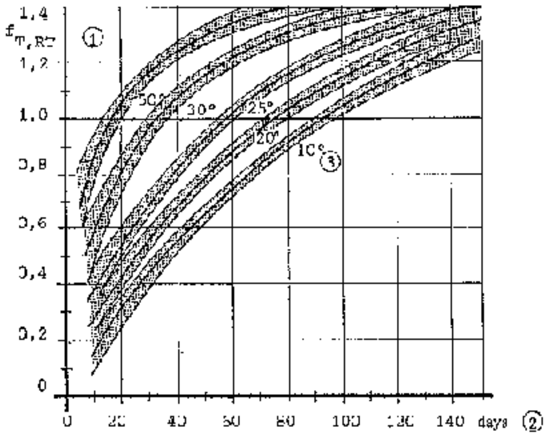


Fig. 5.2: Gas yield as a function of temperature and retention time ($f_{T,RT}$-curves). 1 $f_{T,RT}$: relative gas yield, serving as a multiplier for the average gas yields, e.g. those listed in table 3.5, 2 retention time (RT), 3 digester temperature (T), measured in °C (Source: OEKOTOP)

Table 5.4: Temperature ranges for anaerobic fermentation (Source: OEKOTOP, compiled from various sources)

Fermentation	**Minimum**	**Optimum**	**Maximum**	**Retention time**
Psycrophilic	4-10 °C	15-18 °C	25-30 °c	over 100 days
Mesophilic	15 - 20 °C	28-33 °C	35-45 °C	30-60 days
Thermophilic	25-45 °C	50-60 °C	75-80 °C	10-16 days

Volumetric digester charge/digester load

The volumetric charge, i.e. how much substrate is added per unit of digester volume each day (Vc, measured in m³/m³ Vd x d), is given by the chosen (technical) retention time (RT).

The digester load (Ld, measured in kg digested TS (VS)/m³ Vd x day) serves as a measure of digester efficiency. The digester load is primarily dependent on four factors: substrate, temperature, volumetric burden and type of plant. For a typical agricultural biogas plant of simple design, the upper limit for Ld is situated at roughly 1.5 kg VS/m³ x day. Excessive digester loading can lead to plant disturbances, e.g. a lower pH. In practice, the amount of TS/VS being added is frequently equated to the digester load.

Specific biogas yields / specific biogas production

The specific gas yield (Gy, measured in m³ gas/kg TS (VS)) tells how much biogas can be drawn from a certain amount of biomass (cf. table 3.5 for empirical values). The rate of gas generation is naturally dependent on the digester temperature and retention time (cf. fig. 5.2).

The term specific gas production (Gp, measured in m³ gas/m³ Vd x day) supplements the above expression by defining the digester's biogas output.

pH/volatile acids

The pH is the central parameter of the biochemical bacterial environment.

As soon as the pH departs from the optimum range, bacterial activity is seriously impaired, resulting in lower gas yields, inferior gas composition (excessive CO_2 content)

and obnoxious odor (H_2S - like rotten eggs).

Table 5.5: pH ranges for biomethanation (Source: OEKOTOP, compiled from various sources)

pH	7-7.2	optimum
pH	< 6.2	acid inhibition
pH	> 7.6	ammonia inhibition

Table 5.6: Substances with an inhibiting effect on biomethanation (Source: OEKOTOP, compiled from various sources)

Substance	Disruptive effects beginning (mg/l)
Copper	10-250
Calcium	8000
Magnesium	3000
Zinc	200-1000
Nickel	350-1000
Chromium	200-2000
Cyanocompounds	25
Chlorinated hydrocarbons	traces
Herbicides	traces
Insecticides	traces

Toxins

Even a slight concentration of cytotoxins suffices to disrupt bacterial activity, with a resultant shift in pH, lower gas yield, higher CO_2 content and pronounced odor nuisance.

5.2 Design principles of simple biogas plants

The technical conception of biogas plants is determined by the aim of achieving optimal parameters for the biological process (cf. chapter 5.1).

That being so, the following operating requirements/limitations must be given due consideration:

- type and composition of organic material, which determines the choice of process

- given demand for biogas and fertilizer, in addition to the available substrate quantities, which determines the size of the biogas plant

- economy of labor input for building and operating the plants, including consideration of the necessary mechanical equipment.

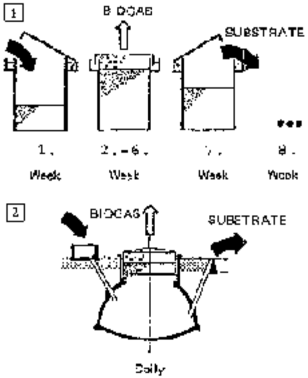


Fig. 5.3: The batch-feed principle (1) vs the continuous feed principle (2) (Source: OEKOTOP)

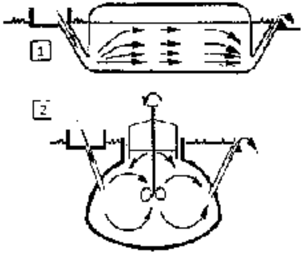


Fig. 5.4: The fermentation channel (1) vs the complete-mixed digester (2) (Source: OEKOTOP)

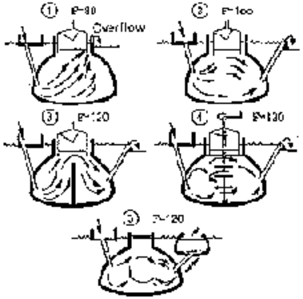


Fig. 5.5: Slurry flow for various configuration of feed, discharge and stirring. 1 Low inlet, outlet at top (beside the gasholder); 2 High inlet, low outlet (normal); 3 Low inlet, low outlet (with partition wall); 4 Vertical agitator; 5 Fixed-dome plant; F: Quality factor for thorough mixing and favorable throughflow conditions, normal situation = 100% (Source: OEKOTOP)

The range of simple biogas plants includes the following basic types:

Batch-type plants are thus referred to because they are charged with successive batches of organic material and a certain amount of seeding slurry to serve as starter. The digestion process is interrupted as soon as the rate of biogas production has slowed down to the point that continued digestion would be uneconomical. Then, the plant is cleaned out and refilled. To achieve a more or less uniform rate of biogas production, several digesters must be operated in parallel, i.e. filled at staggered intervals. Differentiation is made between semi-dry plants (operating on a total-solids content of more than 15%) and liquid plants.

Batch plants are suitable for digesting strawy, fibrous material with a high solids content, usually in areas with low annual precipitation, and for use as simple demonstration plants.

Continuous-feed plants are those in which there is a continuous throughflow of biomass, resulting in a near-constant volume of slurry in the digester. In practice, such plants are fed once or twice each day. There are three main sub-versions:
- complete-mixed digesters
- fermentation channels and
- combinations of the two.

The advantage of continuous-feed plants is that the bacteria receive a regular supply of substrate and are therefore able to generate a more constant supply of biogas. The problem is that buoyant constituents tend to form a stiff layer of scum that impedes biogas production and may even plug up the plant. That drawback can be countered by installing suitable agitators and lengthening the retention time.

The digester inlet, outlet and, to the extent applicable, the agitator must be designed to work together in ensuring the proper retention time, i.e. to avoid short-circuit flow, because the gas production rate would otherwise stay well below the optimum level.

Continuous-feed biogas plants are sized on the basis of the desired retention time for the organic material, in combination with the digester load, which in turn is a function of the prevailing temperature and type of substrate (cf. chapter 4.3).

5.3 Biogas plants of simple design

There are two basic types of tested biogas plants that have gained widespread acceptance in agricultural practice:

- floating-drum plants in which the metal gasholder floats on the digester, and
- fixed-dome plants in which gas storage is effected according to the displacement principle.

5.3.1 Floating-drum plants

A floating-drum biogas plant essentially consists of a cylindrical or dome-shaped digester and a movable, floating gasholder, or drum. The drum in which the biogas collects has an internal or external guide frame that provides stability and keeps the drum upright. Braces can be welded into the drum as a means of breaking up the scum layer when the drum is rotated. The digester is usually made of brick, concrete or quarrystone masonry with rendering, while the gasholder is normally made of metal.

Floating-drum plants are used chiefly for digesting animal and human excrements on a continuous-feed mode of operation, i.e. with daily input. They are used most frequently by:

- small-to-midsize family farms (digester size: 5 - 15 m³)
- institutions and large agroindustrial estates (digester size: 20-100 m³).

Advantages: Floating-drum plants are easy to understand and operate. They provide gas at a constant pressure, and the stored volume is immediately recognizable.

Drawbacks: The steel drum is relatively expensive and maintenance-intensive due to the necessity of periodic painting and rust removal. If fibrous substrates are used, the gasholder shows a tendency to get "stuck" in the resultant floating scum.

Floating-drum plants can be recommended as a mature, easy-to-operate, functionally capable means of producing biogas, particularly when reliability is deemed more important than inexpensiveness.

Floating-drum plants with gasholder in the digester (cf. fig. 5.6)

The dome shape is inherently sturdy, compact and material-sparing. The digester is easy

to build, and the techniques can be learned by local craftsmen in a short time (cf. fig. 5.21).

Water-jacket plant (cf. fig. 5.7)

Water-jacket biogas plants are characterized by a long useful life and a more aesthetic appearance (no dirty gasholder). Due to their superior hygiene, they are recommended for use in the fermentation of night soil and for cases involving pronounced scumming, e.g. due to rapid evaporation, since the gasholder cannot get stuck in the scum. The extra cost of the masonry water jacket is relatively modest.

Cylindrical plant for quarrystone masonry and concrete (cf. fig. 5.8)

It is anything but easy to make a dome-shaped digester out of quarrystone masonry; it is much easier to build a concrete cylinder. In such cases, the classical (Indian) version with a cylindrical digester is quite practical Note: Quarrystone masonry consumes a lot of mortar.

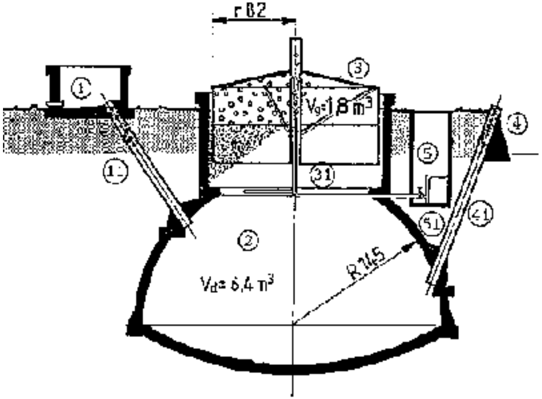


Fig. 5.6: Floating-drum plant with internal guide frame. 1 Mixing pit, 11 Fill pipe, 2 Digester, 3 Gasholder, 31 Guide frame, 4 Slurry store, 41 Discharge pipe, 5 Gas pipe, 51 Water trap (Source: Sasse 1984)

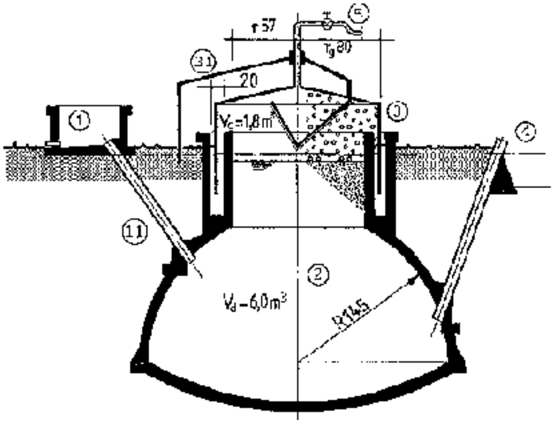


Fig. 5.7: Water-jacket plant with external guide frame. 1 Mixing pit, 11 Fill pipe, 2 Digester, 3 Gasholder, 31 Guide frame, 4 Slurry store, 5 Gas pipe (Source: Sasse 1984)

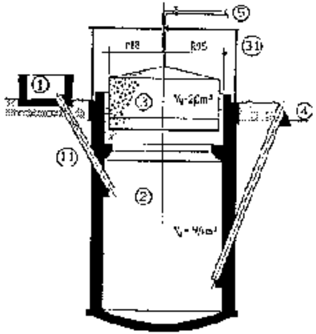


Fig. 5.8: Cylindrical plant design for quarrystone masonry construction. 1 Mixing pit, 11 Fill pipe, 2 Digester, 3 Gasholder, 31 Guide frame, 4 Slurry store, 5 Gas pipe (Source: KVIC)

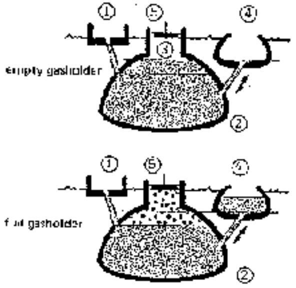


Fig. 5.9: Basic function of a fixed dome biogas plant. 1 Mixing pit, 2 Digester, 3 Gasholder,

4 Displaceinent pit, 5 Gas pipe -(Source: OEKOTOP)

5.3.2 Fixed-dome plants

A fixed-dome plant comprises a closed, dome-shaped digester with an immovable, rigid gasholder and a displacement pit. The gas collects in the upper part of the digester. Gas production increases the pressure in the digester and pushes slurry into the displacement pit. When gas is extracted, a proportional amount of slurry flows back into the digester.

The gas pressure does not remain constant in a fixed-dome plant, but increases with the amount of stored gas. Consequently, a special-purpose pressure controller or a separate floating gasholder is needed to achieve a constant supply pressure. The digesters of such plants are usually made of masonry, with paraffin or bituminous paint applied to the gas-flled area in order to make it gastight.

Fixed-dome plants can handle fibrous substances in combination with animal excrements, since the motion of the substrate breaks up the scum each day. The plant is a continous-feed type, but can accept several days' worth of substrate at a time, if the displacement pit is large enough.

Fixed-dome plants must be covered with earth up to the top of the gas-filled space as a precautionary measure (internal pressure up to 0.1-0.15 bar). As a rule, the size of the digester does not go beyond 20 m³, corresponding to a gasholder volume of 3-4 m³. The earth cover makes them suitable for colder climates, and they can be heated as necessary.

Advantages: Fixed-dome plants are characterized by low initial cost and a long useful life, since no moving or rusting parts are involved. The basic design is compact and well-insulated.

Drawbacks: Masonry is not normally gaslight (porosity and cracks) and therefore requires

the use of special sealants. Cracking often causes irreparable leaks. Fluctuating gas pressure complicates gas utilization, and plant operation is not readily understandable.

Fixed-dome plants are only recommended in cases where experienced biogas technicians are available for building them, and when the user is amply familiar with how the plant operates.

Fixed-dome plant with central entry hatch (cf. fig. 5.10)

The digester has the form of a hemispherical dome which is easy to build. Floating scum can be removed from the full digester through the central entry hatch.

Fixed-dome plant with suspended dome (cf. fig. 5.11)

Providing a separate foundation for the gas dome yields a statically advantageous, material-saving configuration that is very well suited for fixed-dome plants of ample size. The dome's foundation helps prevent cracking due to tensile stress, and the digesting space is made less expensive, since it can be built of thinner masonry, ferrocement rendering or - in the case of impervious soil - even left unlined.

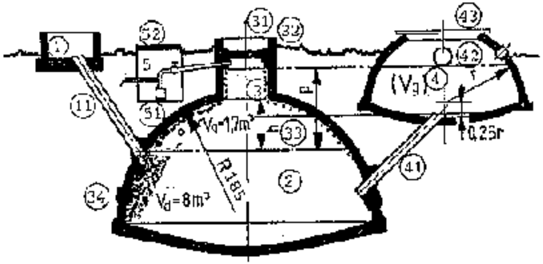


Fig. 5.10: Fixed-dome plant with central entry hatch. 1 Mixing pit, 11 Fill pipe, 2 Digester,

3 Gas holder, 31 Entry hatch, 32 Gas cover, 33 Seal coating, 34 Rated break ring, 4 Displacement pit, 41 Outlet pipe, 42 Overflow, 43 Cover, 5 Gas pipe, 51 Water trap, 52 Cover (Source: Sasse 1984 / BEP Tanzania 1987 / OEKOTOP)

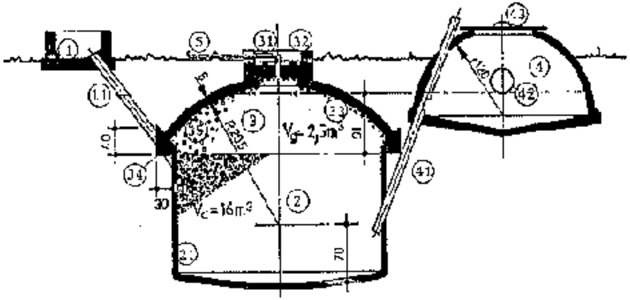


Fig. 5.11: Fixed-dome plant with suspended dome. 1 Mixing pit, 11 Fill pipe, 2 Digester, 21 Digester rendering, 3 Gas holder, 31 Entry hatch, 32 Cas cover, 33 Seal coating, 34 Dome foundation, 35 Dome masonry, 4 Displacement pit, 41 Outlet pipe, 42 Overflow, 43 Cover, 5 Gas pipe (Source: BEP Tanzania 1987/ OEKOTOP)

5.3.3 Other types of construction

In addition to the two most familiar types of biogas plant, as described above, a selection of special-purpose and otherwise promising designs are briefly presented below.

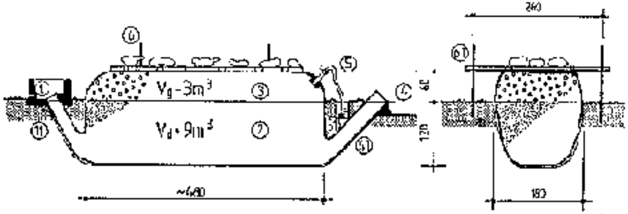


Fig. 5.12: Horizontal balloon-type biogas plant. 1 Mixing pit, 11 Fill pipe, 2 Digester, 3 Gasholder, 4 Slurry store, 41 Outlet pipe, 5 Gas pipe, 51 Water trap, 6 Burden, 61 Guide frame (Source: OEKOTOP)

Inflatable balloon plants (cf. fig. 5.12)

Inflatable biogas plants consist of a heatsealed plastic or rubber bag (balloon), the top and bottom parts of which serve as the gasholder and digester, respectively. The requisite gas pressure is achieved by weighting down the bag. Since the material has to be weather-resistant, specially stabilized, reinforced plastic or synthetic caoutchouc is given preference. The useful life amounts to 2 - 5 years.

Advantages: Standardized prefabrication at low cost; shallow installation suitable for use in areas with a high groundwater table.

Drawbacks: Low gas pressure requires extra weight burden, scum cannot be removed. The plastic balloon has a relatively short useful life, is susceptible to damage by mechanical means, and usually not available locally. In addition, local craftsmen are rarely in a position to repair a damaged balloon.

Inflatable biogas plants are recommended, if local repair is or can be made possible and the cost advantage is substantial.

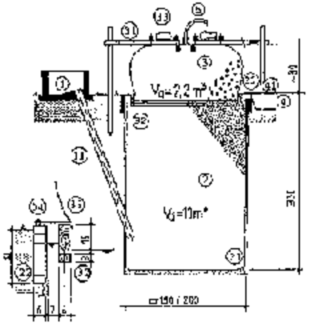


Fig. 5.13: Earth-pit plant with plastic-sheet gasholder. 1 Mixing pit, ll Fill pipe, 2 Digester, 21 Rendering, 22 Peripheral masonry, 3 Plastic-sheet gasholder, 31 Cuide frame, 32 Wooden frame, 33 Weight, 34 Frame anchorage, 35 Plastic sheeting, 4 Slurry store, 41 Overflow, 5 Gas pipe (Source: OEKOTOP)

Earth-pit plants (cf. fig. 5.13)

Masonry digesters are not necessary in stable soil (e.g. laterite). It is sufficient to line the pit with a thin layer of cement (netting wire fixed to the pit wall and rendered) in order to prevent seepage. The edge of the pit is reinforced with a ring of masonry that also serves as anchorage for the gasholder. The gasholder can be made of metal or plastic sheeting. If plastic sheeting is used, it must be attached to a quadratic wooden frame that extends down into the slurry and is anchored in place to counter its buoyancy. The requisite gas pressure is achieved by placing weights on the gasholder. An overflow point in the peripheral wall serves as the slurry outlet.

Advantages: Low cost of installation (as little as 1/5th as much as a floating-drum plant), including high potential for self help.

Drawbacks: Short useful life, serviceable only in suitable, impermeable types of soil.

Earth-pit plants can only be recommended for installation in impermeable soil located above the groundwater table. Their construction is particularly inexpensive in connection with plastic sheet gasholders.

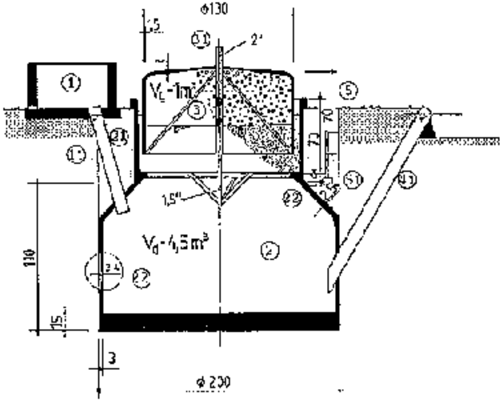


Fig 5.14: Ferrocement biogas plant. 1 Mixing pit, 11 Fill pipe, 2 Digester, 21 Backfill soil, 22 Ferrocement, i.e. rendered lathing on surrounding soil, 3 Ferrocement gasholder, 31 Guide frame, 41 Outlet pipe, 5 Cas pipe, 51 Water trap (Source: OEKOTOP/BEP Caribbean 1986)

Ferrocement plants (cf. fig. 5.14)

The ferrocement type of construction can be executed as either a self-supporting shell or an earth-pit lining. The vessel is usually cylindrical. Very small plants (Vd <6 m³) can be prefabricated. As in the case of a fixed-dome plant, the ferrocement gasholder requires special sealing measures (provenly reliable: cemented-on aluminium foil).

Advantages: Low cost of construction, especially in comparison with potentially high cost of masonry for alternative plants.

Drawbacks: Substantial consumption of necessarily good-quality cement; participating craftsmen must meet high standards; uses substantial amounts of steel; construction technique not yet adequately timetested; special sealing measures for the gasholder.

Ferrocement biogas plants are only recommended in cases where special ferrocement know-how is available.

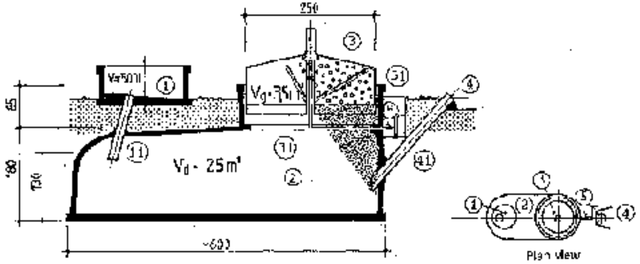


Fig. 5.15: Horizontal biogas plant (KVIC shallow design). 1 Mixing pit, 11 Fill pipe, 2 Digester, 3 Gasholder, 31 Guide frame, 4 Slurry store, 41 Outlet pipe, 5 Gas pipe, 51 Water trap (Source: OEKOTOP / KVIC 1978)

Horizontal plants (cf. fig. 5.15)

Horizontal biogas plants are usually chosen when shallow installation is called for (groundwater, rock). They are made of masonry or concrete.

Advantages: Shallow construction despite large slurry space.

Drawbacks: Problems with gas-space leakage, difficult elimination of scum.

Plants with separate gasholders

Masonry dome plants are sometimes equipped with separate gasholders. That approach always involves substantial extra cost and therefore is rarely recommended. Plants with separate gasholders are justifiable, when the points of gas consumption are a considerable distance away from the digester (at least 1 00 m).

Altematively, a separate gasholder could be useful for restoring the utility value of, say, a fixed-dome plant that has been found to leak at an elevated pressure level.

Table 5.7: Comparison of various plant designs (Source: OEKOTOP)

Design: **Criteria:**	**Floating-drum**	**Water-jacket**	**Fixed dome**
Design principle	continuous-feed, mixed digester	continuous-feed, mixed digester	continuous-feed, mixed digester with slurry store
Main components digester/gasholder	masonry digester, floating metal gasholder	masonry digester, floating metal gasholder in sep. water jacket	masonry with displacement pit
Preferred substrates	animal excrements, with or without vegetable waste	animal excrements with or without vegetable waste	animal excrements plus vegetable waste
Anticipated useful life	8-12 years	10-15 years	12-20 years
Digester volume (Vd)	6-100 m^3	6-100 m^3	6-20 m^3

Suitability:			
- advantages	easy construction and operation, uniform gas pressure, mature technology	very reliable, easy construction and operation, uniform gas pressure, long useful life, mature technology	low cost of construction, long useful life, well-in sulated
- drawbacks	metal gasholder can rust	expensive	sealing of gasholder, fluc tuating gas pressure
- All biogas plants require careful, regular inspection/monitoring of their gas-containing components -			
Operation and maintenance	simple and easy; regular painting of metal gas- holder	simple and easy; regular painting of metal gas- holder	easy after careful familiarization
Daily gas-output	0.3-0.6	0.3-0.6	0.2-0.5
(m³ gas/m³ Vd)			
(depends on substrate composition; here: cattle dung)			
Cost elements	metal gasholder, digester	metal gasholder, digester	combined digester/ gasholder, Excavation
Comparison factor	100	120	60-90
Recommended uses	fully developed, reliable family size system	like floating-drum, plus longer useful life and operational reliability (incl. operation with night soil)	inexpensive equipment, good for agroresidue, extensive building experience required
Suitability for dissemination	+	++	+
	++ highly recommended, + recommended with certain reservations		

	++ highly recommended, + recommended with certain reservations		
balloon-type	Earth pit	Ferrocement	Horizontal (shallow)
continuous-feed, fermentation channel	continuous-feed, mixed digester	continuous-feed, mixed digester	continuous-ffeed, fermentation channel
integrated digester/gas-holder made of plastic sheeting	earth pit as digester, plastic gasholder	ferrocement digester, gasholder made of metal or ferrocement	masonry digester, floating metal gasholder (or separate)
animal excrements only	animal excrements only	animal excrements, with or without vegetable waste	animal excrements, with or without vegetable waste
2-5 years	2-5 years	6-10 years	8-12 years
4-100 m³	4-500 m³	4-20 m³	20-150 m³
prefab. construction, easy operation	extremely inexpensive, easy operation	potentially inexpensive construction, long useful life, easy operation, reliable	shallowness, easy operation
in-site processing and short useful life (2-5 years) of plastic material, low gas pressure	same as with plastic gas holder, plus soil perme- ability	ferrocement construction not yet adequately time	expensive, metal gasholder tested
easy; regular control of gas-pressure weights	easy	simple and easy	simple and easy
0.3-0.8	0.1-0.5	0.3-0.6	0.3-0.7
plastic sheeting	plastic sheeting	concrete (cement), lathing	digester, metal gasholder
20-110	20-40	70-90	90

mostly for large- scale plants and fast solutions	very inexpensive plant	like floating-drum but requires experience in ferrocement construction	medium-size system where shallowness is required
o	o	-	o
o recommended under certain circumstances, - not yet ready for recommendation			

5.4 Design and construction of plant components

Biogas plants of simple design consist of the following main components:
- mixing pit
- inlet/outlet(feed/dischargepipes)
- digester
- gasholder
- slurry store.

Depending on the available building material and type of plant under construction, different variants of the individual components are possible.

Table 5.8: common substrate mixing ratios (Source: OEKOTOP, compiled from various sources)

Type of substrate	Substrate:	water
Fresh cattle manure	1	: 0.5 -1
Semi-dry cattle dung	1	: 1-2
Pig dung	1	: 1-2
Cattle and pig dung from a floating removal system	1	: 0
Chicken manure	1	: 4-6

Stable manure	1	: 2-4

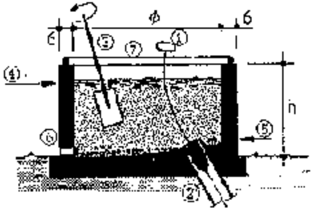


Fig. 5.16: Mixing pit. 1 Plug, 2 Fill pipe, 3 Agitator, 4 Fibrous material, 5 Sand, 6 Drain, 7 Screen cover (Source: OEKOTOP)

5.4.1 Mixing pit

**In the mixing pit, the substrate is diluted with water and agitated to yield a homogeneous slurry.
The fibrous material is raked off the surface, and any stones or sand settling to the bottom are cleaned out after the slurry is admitted to the digester.**

The useful volume of the mixing pit should amount to 1.5-2 times the daily input quantity. A rock or wooden plug can be used to close off the inlet pipe during the mixing process. A sunny location can help warm the contents before they are fed into the digester in order to preclude thermal shock due to the cold mixing water. In the case of a biogas plant that is directly connected to animal housing, it is advisable to install the mixing pit deep enough to allow installation of a floating gutter leading directly into the pit. Care must also be taken to ensure that the low position of the mixing pit does not result in premature digestion and resultant slurry formation. For reasons of hygiene, toilets should have a direct connection to the inlet pipe.

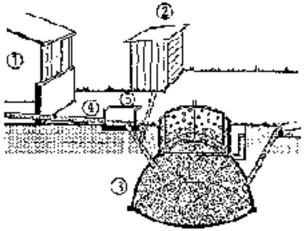


Fig. 5.17: Mixing pit, gutter and toilet drain pipe. 1 Barn, 2 Toilet, 3 Biogas plant, 4 Feed gutter 2% gradient), 5 Mixing pit (Source: OEKOTOP)

5.4.2 Inlet and outlet

The inlet (feed) and outlet (discharge) pipes lead straight into the digester at a steep angle. For liquid substrate, the pipe diameter should be 10-15 cm, while fibrous substrate requires a diameter of 20 - 30 cm. Plastic or concrete pipes are preferred.

Note:

- Both the inlet pipe and the outlet pipe must be freely accessible and straight, so that a rod can be pushed through to eliminate obstructions and agitate the digester contents;

- The pipes should penetrate the digester wall at a point below the slurry level. The points of penetration should be sealed off and reinforced with mortar.

- The inlet pipe ends higher than the outlet pipe in the digester in order to promote more uniform throughflow. In a fixed-dome plant, the inlet pipe defines the bottom limit of the gasholder, thus providing overpressure relief.

- In a floating-drum plant, the end of the outlet pipe determines the digester's slurry level.

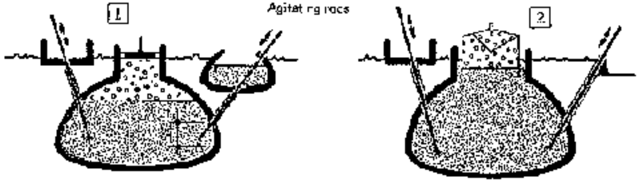


Fig. 5.18: Inlet and outlet for fixed-dome (1) and floating-drum plants (2) (Source: OEKOTOP)

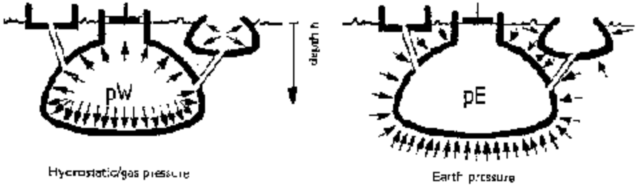


Fig. 5.19: Forces acting on a spherical-dome digester (Source: OEKOTOP)

5.4.3 Digester

Design

The digester of a biogas plant must accommodate the substrate and bacterial activity, as well as fulfill the following structural functions:

- accept the given static forces
- provide impermeability to gas and liquids
- be durable and resistant to corrosion

As a rule, the digesters of simple biogas plants are made of masonry or concrete. Such materials are adequately pressure-resistant, but also susceptible to cracking as a result of

tensile forces.

The following forces act on the digester:

- **external active earth pressures (pE), causing compressive forces within the masonry**
- **internal hydrostatic and gas pressures (pW), causing tensile stress in the masonry.**

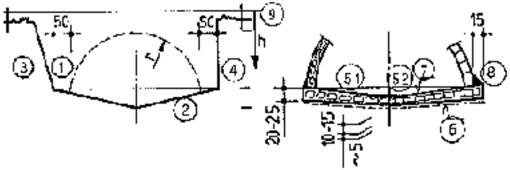


Fig. 5.20: Level line, excavation and foundation. 1 Workspace, 2 Inclination of conical foundation, 3 Sloping excavation, 4 Vertical excavation, 51 Quarrystone foundation, 52 Brick foundation, 6 Packing sand, 7 Mortar screed, 8 Foot reinforcement for fixed-dome plant, 9 Level line (Source: OEKOTOP / Sasse 1984)

Thus, the external pressure applied by the surrounding earth must be greater at all points than the internal forces (pE > pW). For the procedure on how to estimate earth force and hydrostatic forces, please refer to chapter 10.1.4.

Round and spherical shapes are able to accept the highest forces—and do it uniformly. Edges and corners lead to peak stresses and, possibly, to tensile stresses and cracking. Such basic considerations suggest the use of familiar cylindrical and dome designs allowing:

- **inexpensive, material-sparing construction based on modest material thicknesses**
- **a good volume/surface ratio and**
- **better (read: safe) stability despite simple construction.**

The dome foundation has to contend with the highest loads. Cracks occurring around the foundation can spread out over the entire dome, but are only considered dangerous in the case of fixed-dome plants. A rated break ring can be provided to limit cracking.

Groundwork

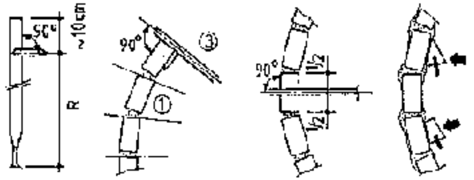
The first step of building the plant consists of defining the plant level line with a taut string. All important heights and depths are referred to that line.

Excavation

The pit for the biogas plant is excavated by hand in the shape of a cylindrical shaft. The shaft diameter should be approx. 2 x 50 cm larger than that of the digester. If the soil is adequately compact and adhesive, the shaft wall can be vertical. Otherwise it will have to be inclined. The overburden, if reusable, is stored at the side and used for backfilling and compacting around the finished plant.

Foundation

The foundation slab must be installed on well-smoothed ground that is stable enough to minimize settling. Any muddy or loose subsoil (fill) must be removed and replaced by sand or stones. The bottom must have the shape of a shallow inverted dome to make it more stable and rigid than a flat slab. Quarrystones, bricks and mortar or concrete can be used as construction materials. Steel reinforcing rods are only necessary for large plants, and then only in the form of peripheral ties below the most heavily burdened part, i.e. the dome foundation.



Trammel

Masonry details

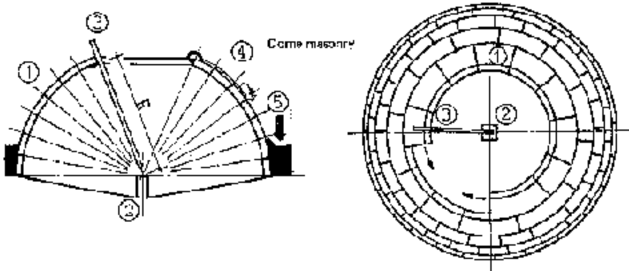


Fig. 5.21: Construction of a spherical dome from masonry. 1 Dome/masonry, 2 Establishing the centerpoint, 3 Trammel, 4 Brick clamp with counterweights, 5 Backfill (Source: Sasse 1984)

Dome

The dome of the biogas plant is hemispherical with a constant radius. Consequently, the masonry work is just as simple as for a cylinder and requires no falsework. The only accessory tool needed is a trammel.

The dome masonry work consists of the following steps:

- finding and fixing the centerpoint of the dome radius in relation to the level line

- layer-by-layer setting of the dome masonry, with the bricks set in mortar, positioned and

aligned with the aid of the trammel and tapped for proper seating

- in the upper part of the dome - when the trammel is standing at a steeper angle than 45°, the bricks must be held in place until each course is complete. Sticks or clamps with counterweights can be used to immobilize them.

Each closed course is inherently stable and therefore need not be held in place any longer. The mortar should be sufficiently adhesive, i.e. it should be made of finely sieved sand mixed with an adequate amount of cement.

Table 5.9: Mortar mixing ratios (Source: Sasse, 1984)

Type of mortar	Cement	Lime	Sand
Masonry mortar	2 :	1 :	10
Masonry mortar	1	:	6
Rendering mortar	1	:	4-8

Table 5.10: Suitability tests for rendering/mortar sands (Source: Sasse, 1984)

Test	Requirement
1. Visual check for coarse particles	Particle size: <7 mm
2. Determining the fines fraction by immersion in a glass of water: 1/21 sand mixed with 1 1 water and left to stand for 1 h, after which the layer of silty mud at the top is measured.	Silt fraction: < 10%
3. Check for organic matter by immersion in an aqueous solution of caustic soda: 1/2 I sand in 1 1 3 % caustic soda with occasional stirring. Notation	Clear-to-light-yellow = low org. content:

of the water's color after 24 h.	suitable for use Reddish brown = high org. content: unsuitable for use

Rendering

Mortar consisting of a mixture of cement, sand and water is needed for joining the bricks and rendering the finished masonry. Biogas plants should be built with cement mortar, because lime mortar is not resistant to water.

The sand for the mortar must be finely sieved and free of dust, loam and organic material. That is, it must be washed clean.

Special attention must be given to the mortar composition and proper application for rendering, since the rendering is of decisive importance with regard to the biogas plant's durability and leaktightness. Ensure that:

- trowelling is done vigorously (to ensure compact rendering)
- all edges and corners are rounded off
- each rendering course measures between 1.0 and 1.5 cm
- the rendering is allowed to set|dry slowly (keep shaded and moist, as necessary)
- the material composition is suitable and mutually compatible
- a rated break ring is provided for a fixed-dome plant

Crack-free rendering requires lots of pertinent experience and compliance with the above points. Neither the rendering nor the masonry is gaslight and therefore has to be provided with a seal coat around the gas space (cf. chapter 5.4.4).

5.4.4 Gasholder

Basically, there are three different designs/ types of construction for gasholders used in simple biogas plants:

- **integrated floating drums**
- **fixed domes with displacement system and**
- **separate gasholders**

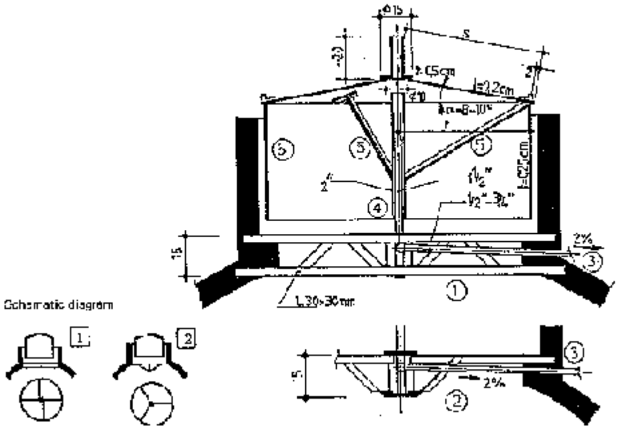


Fig. 5.22: Construction of a metal gasholder with internal guide frame. 1 Lattice beam serving as cross pole, 2 Cross pole with bracing, 3 Gas pipe (2% gradient), 4 Guide frame, 5 Braces for shape retention and breaking up the scum layer, 6 Sheet steel (2-4 mm) serving as the drum shell (Source: OEKOTOP/Sasse, 1984)

Floating-drum gasholders

Most floating-drum gasholders are made of 2 - 4 mm-thick sheet steel, with the sides made somewhat thicker than the top in order to counter the higher degree of corrosive

attack. Structural stability is provided by L-bar bracing that simultaneously serves to break up surface scum when the drum is rotated.

A guide frame stabilizes the gas drum and keeps it from tilting and rubbing on the masonry. The two equally suitable types used must frequently are:

- an internal rod & pipe guide with a fixed (concrete-embedded) cross pole (an advantageous configuration in connection with an internal gas outlet)

- external guide frame supported on three wooden or steel legs (cf. fig. 5.7).

For either design, it is necessary to note that substantial force can be necessary to turn the drum, especially if it is stuck in a heavy layer of floating scum. Any gasholder with a volume exceeding 5 or 6 m³ should be equipped with a double guide (internal and external).

All grades of steel normally used for making gasholders are susceptible to moisture-induced rusting both inside and out. Consequently, a long service life requires proper surface protection consisting of:

- thorough derusting and desoiling.
- primer coat of minium
- 2 or 3 cover coats of plastic/bituminous paint.

The cover coats should be reapplied annually. A well-kept metal gasholder can be expected to last between 3 and 5 years in humid, salty air or 8-12 years in a dry climate.

Materials regarded as suitable alternatives to standard grades of steel are galvanized sheet metal, plastics (glass-reinforced plastic/ GRP, plastic sheeting) and ferrocement with a gaslight lining. The gasholders of waterjacket plants have a longer average service

life, particularly when a film of used oil is poured on the water seal to provide impregnation.

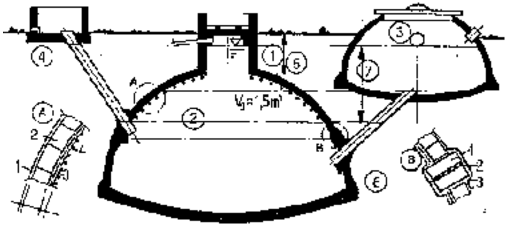


Fig. 5.23: Construction of a fixed-dome gasholder. 1 Slurry level for an empty gasholder (zero line), 2 Slurry level for a full gasholder, 3 Overflow, 4 Inlet = overpressure relief, 5 Earth cover (at least 60 cm), 6 Reinforcing ring at foot of dome, 7 Max. gas pressure. A Detail: wall construction: .1 Outer rendering,.2 Masonry, .3 Twolayer inner rendering, .4 Seal coat. B Detail: rated break point: .1 Masonry bricks (laid at right angles), .2 Joint reinforced with chicken wire, .3 Seal rendering - inside and out (Source: OEKOTOP)

Fixed domes

In a fixed-dome plant the gas collecting in the upper part of the dome displaces a corresponding volume of digested slurry. The following aspects must be considered with regard to design and operation:

- An overflow must be provided to keep the plant from becoming overfilled.

- The gas outlet must be located about 10 cm higher than the overflow in order to keep the pipe from plugging up.

- A gas pressure of 1 mWG or more can develop in the gas space, Consequently, the plant

must be covered with enough earth to provide an adequate counterpressure; special care must be taken to properly secure the entry hatch, which may require weighing it down with 100 kg or more.

The following structural measures are recommended for avoiding or at least limiting the occurrence of cracks in the dome (cf. fig. 5.23):

- For reasons of static stability, the centerpoint of the dome radius should be lowered by 0.25 R (corresponding to bottom center of the foundation). This changes the geometry of the digester, turning it into a spherical segment, i.e. flatter and wider, which can be of advantage for the plant as a whole.

- The foot of the dome should be made more stable and secure by letting the foundation slab project out enough to accept an outer ring of mortar.

- A rated break/pivot ring should be provided at a point located between 1/2 and 2/3 of the minimum slurry level. This in order to limit the occurrence or propagation of cracks in the vicinity of the dome foot and to displace forces through its stiffening/ articulating effect such that tensile forces are reduced around the gas space.

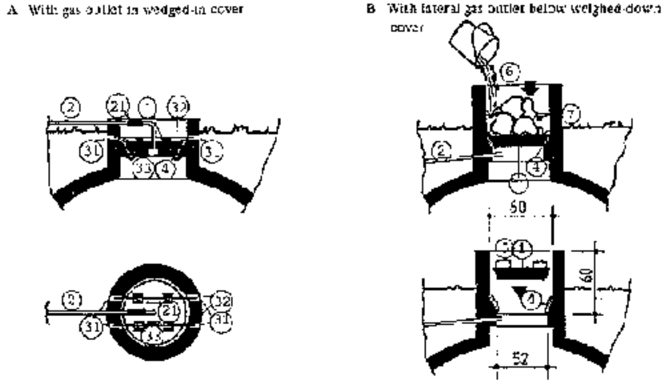


Fig. 5.24: Entry hatch of a fixed-dome biogas plant. 1 Concrete cover, 2 Gas pipe, 21 Flexible connection (hose), 3 Cover wedging, 31 Length of pipe anchored in the masonry, 32 Retaining rod, 33 Wooden/metal wedges, 4 Edge seal made of loam/mastic compound, 5 Handles, 6 Weights, 7 Water (Source: OEKOTOP)

In principle, however, masonry, mortar and concrete are not gaslight, with or without mortar additives. Gastightness can only be achieved through good, careful workmanship and special-purpose coatings. The main precondition is that the masonry and rendering be strong and free of cracks. Cracked and sandy rendering must be removed. In most cases, a plant with cracked masonry must be torn down, because not even the best seal coating can render cracks permanently gaslight.

Some tried and proven seal coats:

- multilayer bitumen, applied cold (hot application poses the-danger of injury by burns and smoke nuisance); solvents cause dangerous/explosive vapors. Two to four thick coats required.

- bitumen with aluminum foil: thin sheets of overlapping aluminum foil applied to the still-sticky bitumen, followed by the next coat of bitumen.

- plastics, as a rule epoxy resin or acrylic paint; very good but expensive.

- paraffin, diluted with 2 - 5% kerosene heated to 100 °C and applied to the preheated masonry. The paraffin penetrates deep into the masonry, thus providing an effective (deep) seal. Use kerosene/gas torch to heat masonry.

In any case, a pressure test must be performed before the plant is put in service (cf. chapter 7.1).

Table 5.11: Quality ratings for various dome-sealing materials (Source: OEKOTOP)

Material	**Processing**	**Seal**	**Durability**	**Costs**
Cold bitumen	++	o	o	++
Bitumen with alu-foil	+	++	+	+
Epoxy resin	++	+	++	-
Paraffin	+	o	o	++
++ very good	+ good	o satisfactory	- problematic	

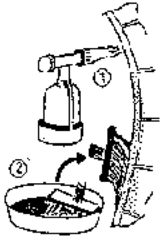


Fig. 5.25: Sealing the masonry with paraffin. 1 Heat wall to 60 - 80 °C with soldering torch, 2 Apply hot (100 °C) paraffin (Source: OEKOTOP/ BEP Tanzania)

Plastic gasholders

Gasholders made of plastic sheeting serve as integrated gasholders (cf. chapter 5.3.3: earth pits), as separate balloon/bag-type gasholders and as integrated gas-transport/ storage elements.

For plastic (sheet) gasholders, the structural details are of less immediate interest than the question of which materials can be used. Table 5.12 (p. 74) surveys the relative suitability of various commercial grades of plastic sheeting.

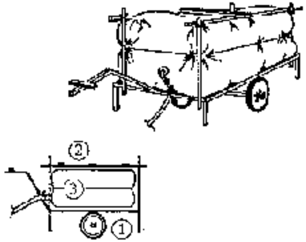


Fig. 5.26: Separate, mobile, plastic-sheet gasholder. 1 Cart for gasholder volumes of 1 m³

and more, 2 Stabilizing weights and frame, 3 Reinforced plastic gasholder (Source: Wesenberg 1985)

Separate gasholders

Differentiation is made between:

- low-pressure, wet and dry gasholders (10 - 50 mbar) Basically, these gasholders are identical to integrated and/or plastic (sheet) gasholders. Separate gasholders cost more and are only worthwhile in case of substantial distances (at least 50-100 m) or to allow repair of a leaky fixed-dome plant.

- medium- or high-pressure gasholders (8 - 10 bar/200 bar)

Neither system can be considered for use in small-scale biogas plants. Even for large-scale plants, they cannot be recommended under the conditions anticipated in most developing countries. High-pressure gas storage in steel cylinders (as fuel for vehicles) is presently under discussion. While that approach is possible in theory, it would be complicated and, except in a few special cases, prohibitively expensive. It would also require the establishment of stringent safety regulations.

Table 5.12: Properties of plastic sheeting - gasholder suitability ratings (Source: UTEC 1985)

Description		Mechanical properties				Stability/resistance values		
	Material	Spec. weight	Permisible Internal Presure	Slit-tear Resistance	Mechanical Properties	Temperature Stability	Weather Resistance	Animal attack, rot/mold
		g/m²	mbar	N	-	°C	-	-

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Solid	PVC	1400	42	50	-	90/65	o	-/o
sheeting								
per 1.0-	PE	950	42	100	-	90/ 70	-/o	o
mm thick-								
ness	IIR	1300	9	32	+	170/110	++	+
	EPDM	1200	4	32	+	170/120	++	+
Laminated	PVC	750/	59-	240-	++	90/65	o	-/o
	synthetic		1400	80	300			
	fabrics	CPE	1100			-	70	+
of various	CSM	1100			++	140/90	++	+
thickness	CR	1100			++	90	++	+

2 PVC (polyvinyl chloride)	7 Short-term/continuous load
PE (polyethylene)	11 Permeability coefficient, P, for new material
CPE (chlorinated polyethylene)	12 HF = high-frequency seam welding
IIR (isobutylene-isoprene rubber)	HW = hot-wedge seam welding
EPDM (ethylene-propylene diene monomer)	HA = hot-air seam welding
4 Inflatable gasholder, approx. 2.5 m³,	C = cementing
3-fold protection against rupture	HV = hot vulcanizing
6/8/9 - poor, o satisfactory,	FF = fusion firing
10/13 + good, ++ very good	HT = heat-solvent tape sealing

5.4.5 Gas pipe, valves and fittings

Gas pipe

The following types of gas pipes are in use:
- PVC pipes with adhesive joints
- steel pipes (water supply pipes) with screw couplings
- plastic hoses.

Galvanized steel water supply pipes are used most frequently, because the entire piping system (gas pipe, valves and fittings) can be made of universally applicable English/U.S. Customary system components, i.e. with all dimensions in inches. Pipes with nominal dimensions of 1/2" or 3/4" are adequate for small-to-midsize plants of simple design and pipe lengths of less than 30 m. For larger plants, longer gas pipes or low system pressure, a detailed pressure-loss (pipe-sizing) calculation must be performed (cf. chapter 10.2).

Table 5.13: Gas-pipe pressure losses (Source: OEKOTOP)

Volum	**Pipe (galv. steel pipe)**					
flow, Q	**1/2“**		**¾”**		**1”**	
(m³ /h	**v[1]**	**dp/l[2]**	**v[1]**	**dp/l[2]**	**v[1]**	**dp/l[2]**
	m/s	**cmWG/10m**	**m/s**	**cmWG/10m**	**m/s**	**cm WG/10 m**
0.1	0.35	0.03	0.16	0.004	0.09	0.001
0.2	0.71	0.12	0.32	0.02	0.18	0.004
0.4	1.4	0.47	0.64	0.06	0.36	0.016
0.6	2.1	1.06	0.94	0.15	0.53	0.034

0.8	2.8	1.9	1.3	0.27	0.72	0.06
1.0	3.5	2.9	1.6	0.41	0.88	0.09
1.5	5.3	6.7	2.3	0.85	1.33	0.2
2.0	7.0	11.8	3.2	1.6	1.8	0.4

[1] **Velocity of flow in the pipe**

[2] **Differential pressure (pipe only) stated in cm WG per 10 m pipe**

When installing a gas pipe, special attention must be paid to:

- gastight, friction-type joints

- line drainage, i.e. with a water trap at the lowest point of the sloping pipe in order to rule out water pockets

- protection against mechanical impact.

Some 60% of all system outages are attributable to defective gas pipes. For the sake of standardization, it is advisable to select a single size for all pipes, valves and fittings.

Valves and fittings

To the extent possible, ball valves or cock valves suitable for gas installations should be used as shutoff and isolating elements. Gate valves of the type normally used for water pipes are conditionally suitable. Any water valves used must first be checked for gastightness.

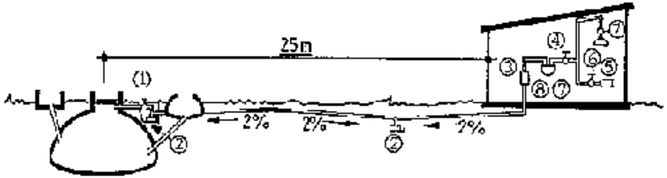


Fig. 5.27: Gas pipe, valves and fittings of a biogas plant. 1 Plant shutoff valve, 2 Water trap, 3 Pressure gauge, 4 House shutoff valve, 5 Cookstove, 6 Lamp, 7 Appliance shutoff valve, 8 Gasmeter (Source: OEKOTOP)

Gas manometer

A U-tube pressure gauge is quick and easy to make and can normally be expected to meet the requirements also of a fixed-dome system.

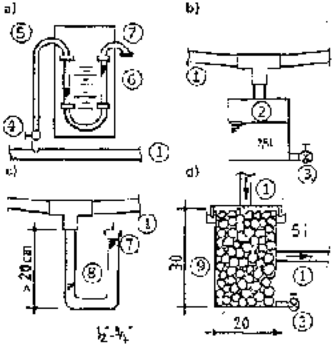


Fig. 5.28: Gas valves and fittings: U-tube pressure gauge (a), water trap with drain valve (b), U-tube water separator (c), "gravel-pot" flashback arrestor (d). 1 Gas pipe, 2 Condensate collector, 3 Shutoff valve, 4 Manometer valve, 5 U-tube pressure gauge made of transparent hose, 6 Wooden balls, 7 Antievaporation cap, 8 U-tube, 9 "Gravel-pot"

flashback arrestor (approx. 51) filled with 20 mm gravel (Source: OEKOTOP)

Pressure relief

The task of running a fixed-dome system can be made easier by installing a spring-loaded pressure reducing valve that guarantees a constant (adjustable) supply pressure.

Water separation

If at all possible, the water trap should operate automatically. However since fixed-dome systems need a high water seal, often amounting to more than 1 m WG, the use of condensate collector with a manually operated drain valve is advisable.

Backflow prevention

As a rule, the water trap also functions as a flashback chamber. If deemed necessary, a gravel trap can be installed for added safety.

5.5 Biogas utilization

5.5.1 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 H_2	0-1 vol. %
- hydrogen sulfide, H_2S	0-3 vol. %

Like those of any gas, the characteristic values of biogas are pressure and temperature-dependent. They are also affected by water vapor. The factors of main interest are:

- volumetric change as a function of temperature and pressure,
- change in value as a function of temperature, pressure and water-vapor con" tent, and
- change in water-vapor content as a function of temperature and pressure.
Chapter 10.2 contains pertinent tables, formulae and nomograms for use in calculating conditions of state.

5.5.2 Conditioning of biogas

While the biogas produced by the plant can normally be used as it is, i.e. without further treatment/conditioning, various conditioning processes are described in this chapter to cover possible eventualities.

Reducing the moisture content of the biogas, which is usually fully saturated with water vapor. This involves cooling the gas, e.g. by routing it through an underground pipe, so that the excess water vapor condenses out at the lower temperature. When the gas warms up again, its relative vapor content decreases (cf. chapter 10.2 for calculations). The "drying" of biogas is especially useful in connection with the use of dry gas meters, which otherwise would eventually fill up with condensed water.

Table 5.14: Composition and properties of biogas, and its constituents under s.t.p. conditions (0 °C, 1013 mbar)
(Source: OEKOTOP, compiled from various sources)

Constituents and properties	CH_4	CO_2	H_2	H_2S	60% CH_4/	65% CH_4/

					40% CO2	**34% C02/ 1% rest**
Volume fraction (%)	55-70	27-44	1	3	100	100
Net calorific value (kWh/m^3)	9.9	-	3.0	6.3	6.0	6.8
Ignition threshold (% in air)	5-1S	-	4-80	4-45	6-12	7.7 - 23
Ignition temperature (°C)	650-750	-	585	-	650-750	650-750
Crit.pressure (bar)	47	75	13	89	75-89	75-89
Crit. temp. (°C)	-82.5	31.0	-240	100.0	-82.5	-82.5
Normal density (g/1)	0.72	1.98	0.09	1.54	1.2	1.15
Gas/air-density ratio	0.55	2.5	0.07	1.2	0.83	0.91
Wobbe index, K (kWh/m^3)	13.4	-	-	-	6.59	7.15
Spec. heat, cp (kI/m^3 °C)	1.6	1.6	1.3	1.4	1.6	1.6
Flame propagation (cm/s)	43	-	47	-	36	38

Reduction of the hydrogen-sulfide content (H_2S) may be necessary if the biogas is found to contain an excessive amount, i.e. more than 2%, and is to be used for fueling an engine. Since, however, most biogas contains less than 1% H_2S, desulfurization is normally unnecessary, especially if it is to be used for operating a stationary engine.

For small-to-midsize systems, desulfurization can be effected by absorption onto ferric hydrate (Fe (OEI)3), also referred to as bog iron, a porous form of limonite. The porous, granular purifying mass can be regenerated by exposure to air.

The absorptive capacity of the purifying mass depends on its iron-hydrate content: bog iron containing 5-10% $Fe(OH)_3$ can absorb about 15 g sulfur per kg without being

regenerated and approximately 150 g/ kg through repetitive regeneration. It is a very noteworthy fact that many types of tropical soil (laterites) are naturally ferriferous and, hence, suitable for use as purifying mass.

Reduction of the carbon-dioxide content (CO_2) is very complicated and expensive. In principle, CO_2 can be removed by absorption onto lime milk, but that practice produces "seas" of lime paste and must therefore be ruled out, particularly in connection with large-scale plants, for which only high-tech processes like microscreening are worthy of consideration. CO_2 "scrubbing" is rarely advisable, except in order to increase the individual bottling capacity for high-pressure storage.

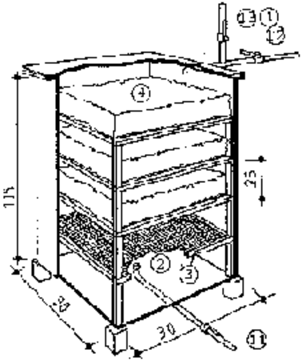


Fig. 5.29: Ferric-hydrate gas purifier. 1 Gas pipe, 11 Raw-gas feed pipe, 12 Clean-gas discharge pipe, 13 Purging line, 2 Metal gas purifier, 3 Shelves for purifying mass, 4 Purifying mass (Source: Muche 1984)

Table 5.15: Pointers on flame adjustment (Source: OEKOTOP)

Problem	Cause - Remedy

elongated, yellow- ish flame	lack of combustion air - open the air supply
flame "lifts off"	excessive exit velocity - use smaller injector, reduce the gas pressure, reduce the air supply
flame "flashes back"	exit velocity too low - use larger injector, increase the gas pressure, open the air supply, reduce the size of the burner jets
flame "too small"; not enough fuel	fuel shortage - use larger injector, increase the gas pressure
flame "too big"; excessive fuel supply/consumption	excessive fuel supply - reduce the gas pressure, use smaller injector

5.5.3 Biogas appliances

Biogas is a lean gas that can, in principle, be used like any other fuel gas for household and industrial purposes, the main prerequisite being the availability of specially designed biogas burners or modified consumer appliances. The relatively large differences in gas quality from different plants, and even from one and the same plant (gas pressure, temperature, calorific value, etc.) must be given due consideration.

The heart of any gas appliance is the burner. In most cases, atmospheric-type burners operating on premixed air/gas fuel are considered preferable.

Due to complex conditions of flow and reaction kinetics, gas burners defy precise calculation, so that the final design and adjustments must be arrived at experimentally.

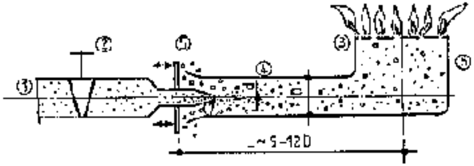


Fig. 5.30: Schematic drawing of a biogas burner and its parts. 1 Gas pipe, 2 Gas-flow shutoff/reducing valve, 3 Jets (f = 1-2 mm), 4 Mixing chamber for gas and combustion air, 5 Combustion air intake control, 6 Burner head, 7 Injector (Source: Sasse 1984)

Accordingly, the modification and adaptation of commercial-type burners is an experimental matter. With regard to butane and propane burners, i.e. the most readily available types, the following pointers are offered:

- Butane/propane gas has up to 3 times the calorific value of biogas and almost twice its flame-propagation rate.

- Conversion to biogas always results in lower performance values.

Practical modification measures include:

- expanding the injector cross section by a factor of 2-4 in order to increase the flow of gas

- modifying the combustion-air supply, particularly if a combustion-air controller is provided - increasing the size of the jet openings (avoid if possible) The aim of all such measures is to obtain a stable, compact, slightly bluish flame.

Table 5.16: Comparison of various internationally marketed biogas burners (Source: OEKOTOP, compiled. from various sources)

Type of burner¹	Number of flames	Gas consumption	Burning properties	Handling
Peking No. 4/PR China (3)	1	200 l/h	+	o
Jackwal/Brazil (1)	2	2 X 1501/h	++	+
Patel GC 32/ludia	2	2 X 2501/h	o	++
Patel GC 8/India	1	2301/h	+	++
KIE burner/Kenya (2)	2	?	+	++

++ very good +good o average

[1] Number of burner shown in figure 5.31

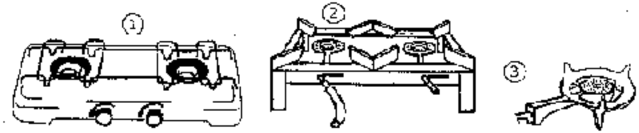


Fig. 5.31: Various types of biogas burners. 1 2-flame lightweight burner (2 X 1501/h), 2 2-flame stable burner (2 X 2501/h), 31-flame burner (200 I/h) (Source: OEKOTOP)

Gas cookers/stoves

Biogas cookers and stoves must meet various basic requirements:
- simple and easy operation
- versatility, e.g. for pots of various size, for cooking and broiling
- easy to clean
- acceptable cost and easy repair
- good burning properties, i.e. stable flame, high efficiency
- attractive appearance

A cooker is more than just a burner. It must satisfy certain aesthetic and utility

requirements, which can vary widely from region to region. Thus, there is no such thing as an all round biogas burner.
Field data shows that 2-flame stable burners are the most popular type (cf. fig. 5.31).

Table 5.17: Biogas consumption for cooking (Source: OEKOTOP, compiled from various sources)

To be cooked:	**Gas consumption**	**Time**
11 water	30-40 l	8-12 min
51 water	110-140 l	30-40 min
31 broth	~60 l/h	
1/2 kg rice	120-140 l	~40 min
1/2 kg legumes	160-190 l	~60 min
1 tortilla(fried)	10-20 l	~3 min
Gas consumption per person and meal	150-300 l/d	
Gas consumption per 5-member family	1500 -2400 l/d	
(2 cooked meals)		

Single-flame burners and lightweight cookstoves tend to be regarded as stop-gap solutions for want of suitable alternatives.

Biogas cookers require purposive installation with adequate protection from the wind.
Before any cooker is used, the burner must be carefully adjusted, i.e.:

- for a compact, bluish flame,
- the pot should be cupped by the outer cone of the flame without being touched by the inner cone,

- the flame should be self-stabilizing, i.e. flameless zones must re-ignite automatically within 2 to 3 seconds.

Test measurements should be performed to optimize the burner setting and minimize consumption. The physical efficiency of a typical gas burner ranges from 0.6 to 0.8.

Table 5.18: Tests for biogas cookers/stoves (Source: OEKOTOP)

1. Measuring the efficiency with water

$$\eta = \frac{QW \cdot (T1 - T2) \cdot cW + EW \cdot L}{n.c.v \cdot Q}$$

η =- burner efficiency (-)
QW = quantity of heated water (kg)
T1,T2 = initial and final temperature (°C)
cW = spec. heat capacity = 4.2 kJ/kg
EW = quantity of evaporated water (kg)
L = evaporation heat loss = 2260 kJ/kg
n.c.v. = net cal. value of biogas (kJ/m3)
Q = quantity of biogas (m3)

2. Gas consumption for holding the temperature at boiling point (simmering temperature - 95 °C), i.e. the amount of gas needed per unit of time to maintain a water temperature of 95 °C

3. Standard cooking test
This test determines how much gas is- needed to cook a standard meal, e.g. 500 g rice and 1000 g water; the standard meal is specified according to the regional staple diet

4. Complete-meal tests

Everything belonging to a complete meal is cooked by a native person.

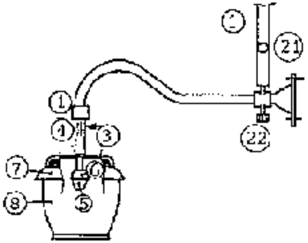


Fig. 5.32: Schematic drawing of a biogas lamp. 1 Gas pipe, 21 Shutoff valve, 22 Adjusting valve, 3 Primary air supply (adjustable), 4 Mixing chamber, 5 Incandescent body - gas mantle, 6 Porcelain head, 7 Disk reflector, 8 Glass (Source: OEKOTOP/ Jackwal)

Biogas lamps

The bright light given off by a biogas lamp is the result of incandescence, i.e. the intense heat-induced luminosity of special metals, so-called "rare earths" like thorium, cerium, lanthanum, etc. at temperature of 1000 - 2000 °C.

At 400-500 lm, the maximum light-flux values that can be achieved with biogas lamps are comparable to those of a normal 25-75 W light bulb. Their luminous efficiency ranges from 1.2 to 2 Im/W. By comparison, the overall efficiency of a light bulb comes to 3-5 Im/W, and that of a fluorescent lamp ranges from 10 to 15 lm/W.

The performance of a biogas lamp is depenent on optimal tuning of the incandescent body (gas mantle) and the shape of the flame at the nozzle, i.e. the incandescent body must be surrounded by the inner (= hottest) core of the flame at the minimum gas consumption rate. If the incandescent body is too large, it wil1 show dark spots; if the flame is too large, gas consumption will be too high for the light-flux yield. The lampshade reflects the

light downward, and the glass prevents the overly rapid loss of heat.

Table 5.19: Standard lighting terms and units of measure (Source: OEKOTOP)

Term/definition	**Unit, formula**
Luminous flux (F)	F, measured in lm (lumen)
The light output defined as the luminous flux of a black body at 2042 °K per cm^2	
Luminous intensity (I)	I, measured in cd (candela)
The solid-angle light power	
I = luminous flux / solid angle (w)	I = F/w (cd = lm/w)
	half-space w = 2 p = 6.28
Illuminance (E)	-E, measured in lux (Ix)
light power per unit area	
E = luminous flux / area (A)	E = F/A (lx = lm/m^2)
Spec. illuminance (Es)	Es = ((E x r^2) / V • n.c.v.)) • (lx • m^2 / kW)
Effective incident illuminance, as measured normal to the light source at a defined distance from the source referred to the input	E = meas. illuminance
	r = distance between the incandescent body and the photoelectric cell
	V = biogas consumption n.c.v. = net calorific value
Luminous efficiency (Re) light power referred to the energy	Re = F/Ei (lm/kW)

Luminous efficiency (Re) light power referred to the energy input (Ei)	Re = F/Ei (lm/kW)
	Sample calculation
Measured values:	Results:
Illuminance	Luminous intensity
E=901x	I = E x r² = 90 cd
meas. distance, r = 1.0 m	luminous flux
gas consumption, V = 110 1/h	F = I x w = 90 x 6.28 = 565 lm
cal. value, n.c.v. = 6 kWh/m³	luminous efficiency
	Re = F:Q = 565:110 = 5.1 lm/lxh
	Re = F/Ei = 565:660 = 0.9 lm/W

Practical experience shows that commercial type biogas lamps are not optimally designed for the specific conditions of biogas combustion (fluctuating or low pressure, varying gas composition). The most frequently observed shortcomings are:

- **excessively large nozzle cross sections**
- **excessively large gas mantles**
- **no possibility of changing the injector**
- **poor or lacking means of combustion-air control.**

Such drawbacks result in unnecessarily high gas consumption and poor lighting. While the expert/extension officer has practically no influence on how a givenlamp is designed, he can at least give due consideration to the aforementioned aspects when it comes to selecting a particular model.

Table 5.20: Comparison of various biogas lamps (Source: Biogas Extension Program)

Type of lamp	**Suitability**[1]	**Gas consumption**
D 80 - 3 Juojiang/PR China	o [2]	?
Avandela - Jackwal/Brazil	+	100 l/h
Patel Outdoor-single/India	++	150 l/h
Camping-Gas	+	?

[1] Quality criteria: gas consumption, brightness, control

[2] Quality ratings: ++ very good, + good, o average

Biogas lamps are controlled by adjusting the supply of gas and primary air. The aim is to make the gas mantle burn with uniform brightness and a steady, sputtering murmer (sound of burning, flowing biogas). To check the criteria, place the glass on the lamp and wait 2 - 5 minutes, until the lamp has reached its normal operating temperature. The lamps compared in table 5.20 operate at a gas pressure of 5 - 15 cmWG. If the pressure is any lower, the mantle will not glow, and if the pressure is too high (fixed-dome systems) the mantle may tear.

Adjusting a biogas lamp requires two consecutive steps:

1. precontrol of the supply of biogas and primary air without the mantle, initially resulting in an elongated flame with a long inner core;

2. fine adjustment with the incandescent body in place, resulting in a brightly glowing incandescent body, coupled with slight further adjustment of the air supply (usually more).

The adjustment is at its best when the dark portions of the incandescent body have just

disappeared. A luxmeter can be used for objective control of the lamp adjustment.

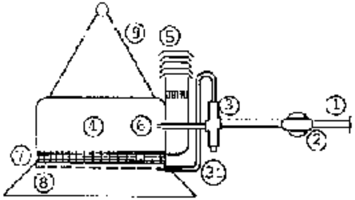


Fig. 5.33: Schematic drawing of a radiant heater. 1 Gas pipe, 2 Shutoff valve, 3 Safety pilot, 31 Heat sensor, 4 Mixing chamber, 5 Air supply, 6 Injector, 7 Ceramic panel with protective screen, 8 Reflector, 9 Hanger (Source: OEKOTOP / SBM)

Radiant heaters

Infrared heaters are used in agriculture for achieving the. temperatures required for raising young stock, e.g. piglets and chicks, in a limited amount of space. The nursery temperature for piglets begins at 30-35 °C for the first week and than gradually drops off to an ambient temperature of 18-23 °C in the 4th/5th week. As a rule, temperature control consists of raising or lowering the heater. Good ventilation is important in the stable/nursery in order to avoid excessive concentrations of CO or CO_2. Consequently, the animals must be kept under regular supervision, and the temperature must be checked at regular intervals.

Radiant heaters develop their infrared thermal radiation via a ceramic body that is heated to 600-800 °C (red-hot) by the biogas flame.

The heating capacity of the radiant heater is defined by multiplying the gas flow by its net calorific value (E = Q x n.v.c.), since 95% of the biogas' energy content is converted to heat. Small-heater outputs range from 1.5 to 10 kW thermal power.

Commercial-type heaters are designed for operating on butane, propane and natural gas at a supply pressure of between 30 and 80 mbar. Since the primary air supply is. factory-set, converting a heater for biogas fueling normally consists of replacing the injector; experience shows that biogas heaters rarely work satisfactorily because the biogas has a low net calorific value and the gas supply pressure is below 20 mbar, in which case the ceramic panel is not adequately heated, i.e. the flame does not reach the entire surface, and the heater is very susceptible to draft.

Biogas-fueled radiant heaters should always be equipped with a safety pilot, and an air filter is required for sustained operation in dusty barns.

Table 5.21: Artificial brooding requirements, exemplified for a chick incubator (Source: Wesenberg 1985)

Incubation heat	37.8 °C at the beginning, declining to 30.0 °C at the end of the incubation period. The temperature should be kept as constant as possible. Any temperature in excess of 39 °c can damage the eggs.
Hatching time:	approximately 21 days
Relative humidity:	60-90 %
Ventilation:	A steady supply of fresh air (but not draft) is required to keep the CO_2 content below 0.8 %.
Turning the eggs:	Incubating eggs must be turned as often as 8 times a day to keep the chicks from sticking to the inside of the shell.
Barren eggs:	Unfertilized eggs and eggs containing dead chicks must be removed (danger of infection). The eggs should be candletested once per week to ensure timely detection.

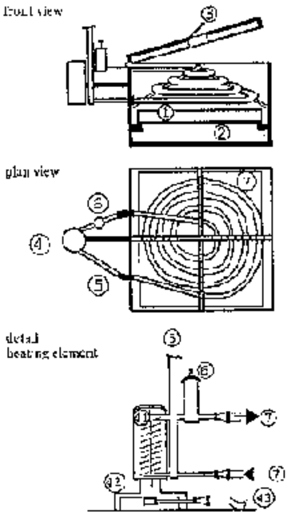


Fig. 5.34: Schematic drawing of an incubator. 1 Incubating chamber, 2 Removable tray, 3 Cover/ venting lid, 4 Heating element, 41 Heating coil, 42 Burner, 43 Gas pipe, 5 Water filler neck and expansion tank, 6 Vent valve, 7 Warming element (plastic hose). Biogas consumption rate: 30-50 1/h (Source: Wesenberg 1985)

Incubators

Incubators are supposed to imitate and maintain optimal conditions for hatching eggs. They are used to increase brooding efficiency. Indirectly warm-water-heated planar-type incubators in which a biogas burner heats water in a heating element for circulation through the incubating chamber are suitable for operating on biogas. The temperature is controlled by ether-cell-regulated vents (cf. fig. 5.34).

Refrigerators

Absorption-type refrigerating machines operating on ammonia and water and equipped for automatic thermosiphon circulation can be fueled with biogas.
Since biogas is only the refrigerator's external source of heat, just the burner itself has to be modified. Whenever a refrigerator is converted for operating on biogas, care must be taken to ensure that all safety features (safety pilot) function properly; remote ignition via a piezoelectric element substantially increases the ease of operation.

Table 5.22: Technical data of absorption refrigerators (Source: OEKOTOP)

Heating medium	gas, kerosene, electricity
Max. ambient temperature	40ºC
Heating temperature	100-150 °C
Cooling temperature	
- refrigerator	5 - 10 °C
- freezer	down to approx. -12 °C
Efficiency	1.5 - 4.0% of the thermal input
Gas consumption	a) calculable via the desired refrigeration capacity
	b) conversion of factory data via power input
Energy-	1-4 W/l useful volume
consumption indices	0.3-0.81 biogas/l useful volume X h

5.5.4 Biogas-fueled engines

Basic considerations

The following types of engines are, in principle, well-suited for operating on biogas:

- Four-stroke diesel engines: A diesel engine draws in air and compresses it at a ratio of 17: 1 under a pressure of approximately 30-40 bar and a temperature of about 700 °C. The injected fuel charge ignites itself. Power output is controlled by varying the injected amount of fuel, i.e. the air intake remains constant (so-called mixture control).

- Four-stroke spark-ignition engines: A spark-ignition engine (gasoline engine) draws in a mixture of fuel (gasoline or gas) and the required amount of combustion air. The charge is ignited by a spark plug at a comparably low compression ratio of between 8: 1 and 12: 1. Power control is effected by varying the mixture intake via a throttle (so-called charge control).

Four-stroke diesel and spark-ignition engines are available in standard versions with power ratings ranging from 1 kW to more than 100 kW. Less suitable for biogas fueling are:

- loop-scavenging 2-stroke engines in which lubrication is achieved by adding oil to the liquid fuel, and

- large, slow-running (less than 1000 r.p.m.) engines that are not built in large series, since they are accordingly expensive and require complicated control equipment.

Biogas engines are generally suitable for powering vehicles like tractors and light-duty trucks (pickups, vans). The fuel is contained in 200-bar steel cylinders (e.g. welding-gas cylinders). The technical, safety, instrumentational and energetic cost of gas compression, storage and filing is substantial enough to hinder large-scale application. Consequently, only stationary engines are discussed below.

Essential terms and definitions

Knowledge of the following terms pertaining to internal combustion engines is requisite to understanding the context:

Piston displacement is the volume (cm^3, l) displaced by a piston in a cylinder in a single stroke, i.e. between the bottom and . top dead-canter positions (BDC and TDC, respectively). The total cylinder capacity (Vtot) comprises the swept volume (Vs) and the compression volume (Vc), i.e. Vtot = Vs+Vc.

The compression ratio (E) is the ratio of the maximum to the minimum volume of the space enclosed by the piston, i.e. prior to compression (Vtot) as compared to the end of the compression stroke (Vc). The compression ratio can be used to calculate the pressure and temperature of the compressed fuel mixture (E = Vtot/Vc).

The efficiency (rl = Pc/Pf) is the ratio between the power applied to the crankshaft (Pc) and the amount of energy introduced with the fuel (Pf = V x n.c.v.).

Ignition and combustion: The firing point (diesel: flash point; spark-ignition engine: ignition point) is timed to ensure that the peak pressure is reached just after the piston passes top dead center (approx. 10° - 15° crankshaft angle). Any deviation from the optimal fiash/ignition point leads to a loss of power and efficiency; in extreme cases, the engine may even suffer damage. The flash/ignition point is chosen on the basis of the time history of combustion, i.e. the rate of combustion, and depends on the compression pressure, type of fuel, combustion-air/ fuel ratio and the engine speed. The ignition timing (combustion) must be such that the air/fuel mixture is fully combusted at the end of the combustion cycle, i.e. when the exhaust valve opens, since part of the fuel's energy content would otherwise be wasted.

Air/Fuel-ratio and control: Proper combustion requires a fuel-dependent stoichiometric air/fuel-ratio (af-ratio). As a rule, the quality of combustion is maximized by increasing the air fraction, as expressed by the air-ratio coefficient (d = actual air

volume/stoichiometric air volume).

For gasoline and gas-fueled engines, the optimal air/fuel ratio is situated somewhere within the range d = 0.8 - 1.3, with maximum power output at 0.9 and maximum efficiency (and clean exhaust) at 1.1. The power output is controlled by varying the mixture intake and, hence, the cylinder's volumetric efficient and final pressure, via the throttle. Diesel engines require an air-ratio of d = 1.3 at full load and 4 - 6 at low load, i.e. fuel intake is reduced, while the air intake remains constant.

Converting diesel engines

Diesel engines are designed for continuous operation (10 000 or more operating hours). Basically, they are well-suited for conversion to biogas according to either of two methods:

The dual-fuel approach

Except for the addition of a gas/air mixing chamber on the intake manifold (if need be, the air filter can be used as a mixing chamber), the diesel engine remains extensively unmodified. The injected diesel fuel still ignites itself, while the amount injected is automatically reduced by the speed governor, depending on how much biogas is introduced into the mixing chamber. The biogas supply is controlled by hand. The maximum biogas intake must be kept below the point at which the engine would begin to stutter. If that happens, the governor is getting too much biogas and has therefore turned down the diesel intake so far that ignition is no longer steady. Normally, 15 - 20% diesel is sufficiency, meaning that as much as 80% of the diesel fuel can be replaced by biogas. Any lower share of biogas can also be used, of course, since the governer automatically compensates with more diesel.

As a rule, dual-fuel diesels perform just as well as a comparable engine operating on pure

diesel.

As in normal diesel operation, the speed is controlled by an accelerator lever, and load control is normally effected by hand, i.e. by adjusting the biogas valve (keeping in mind the maximum acceptable biogas intake level). In case of frequent power changes joined with steady speed, the biogas fraction should be reduced somewhat to let the governer decrease the diesel intake without transgressing the minimum amount. Thus, the speed is kept constant, even in case of power cycling. Important: No diesel engine should be subjected to air-side control.

While special T-pieces or mixing chambers with 0.5 to 1.0 times the engine displacement can serve as the diesel/biogas mixing chamber, at which a true mixing chamber offers the advantage of more thorough mixing.

Conversion according to the dual-fuel method is evaluated as follows

- a quick & easy do-it-yourself technique
- will accommodate an unsteady supply of biogas
- well-suited for steady operation, since a single manual adjustment will suffice
- requires a minimum share of diesel to ensure ignition.

Conversion to spark ignition (Otto cycle)

involves the following permanent alterations to the engine:

- removing the fuel-injection pump and nozzle
- adding an ignition distributor and an ignition coil with power supply (battery or dynamo)
- installing spark plugs in place of the injection nozzles
- adding a gas mixing valve or carburetor
- adding a throttle control device

- reducing the compression ratio to E = 11-12
- observing the fact that, as a rule, engines with a precombustion or swirl chamber are not suitable for such conversion.

Converting a diesel engine to a biogas-fueled spark-ignition engine is very expensive and complicated - so much so, that only preconverted engines of that type should be procured.

Converting spark-ignition engines

Converting a spark-ignition engine for biogas fueling requires replacement of the gasoline carburetor with a mixing valve (pressure-controlled venturi type or with throttle). The spark-ignition principle is retained, but should be advanced as necessary to account for slower combustion (approx. 5°-10° crankshaft angle) and to avoid overheating of the exhaust valve while precluding loss of energy due to still-combustible exhaust gases. The engine speed should be limited to 3000 r.p.m. for the same reason. As in the case of diesel-engine conversion, a simple mixing chamber should normally suffice for continuous operation at a steady speed. In addition, however, the mixing chamber should be equipped with a hand-operated air-side control valve for use in adjusting the air/fuel ratio (opt. d = 1.1).

Table 5.23: Engine-conversion requirements for various duty and control modes (Source: Mitzlaff 1986)

Duty mode	Control mode	Conversion mode
Speed: constant power: constant e.g. for a pump with constant head and constant delivery	Diesel or spark- ignition engine: fixed manual adjustment, no readjustment necessary under normal circumstances	addition of a simple, manually adjusted mixing chamber
Speed: constant power:	Automatic speed control: Spark-	Spark-ignition: carburetor or gas

variable e.g. for a constant-frequency subject to varying power; or for a pump with constant head and varying delivery volume	ignition: electronic governor controls the throttle Diesel: fixed biogas fraction, with speed control via diesel intake governor	mixing valve with throttle; electronic control Diesel: Regulator and hand-adjusted mixing chamber
Speed: variable power: variable e.g. for powering various types of machines	Spark-ignition: by hand (if varying speed is acceptable) or electric with setpoint control Diesel: by hand via accelerator lever	Spark-ignition: electronic with set point control, gas mixing valve or carburetor with throttle, plus regu lator Diesel: simple, hand-adjusted mixing chamber

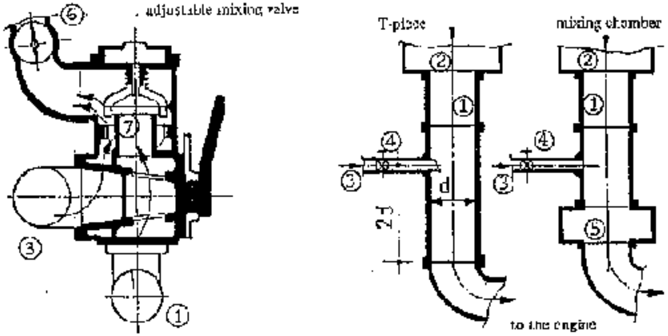


Fig. 5.35: Various gas mixers for spark-ignition and diesel engines. 1 Air intake, 2 Air filter, 3 Biogas supply pipe, 4 Biogas control valve, 5 Mixing chamber (0.5 - 1 X piston displacement) 6 Throttle, 7 Mixing valve (Source: OEKOTOP)

Converting a spark-ignition engine results in a loss of performance amounting to as much as 3070. While partial compensation can be achieved by raising the compression ratio to E

= 11-12, such a measure also in,creases the mechanical and thermal load on the engine.

Spark-ignition engines that are not expressly marketed as suitable for running on gas or unleaded gasoline may suffer added wear & tear due to the absence of lead lubrication.

The speed control of converted spark-ignition engines is effected by way of a hand-operated throttle. Automatic speed control for different load conditions requires the addition of an electronic control device for the throttle.

The conversion of spark-ignition engines is evaluated as follows:

- Gasoline engines are readily available in the form of vehicle motors, but their useful life amounts to a mere 3000 - 4000 operating hours.

- The conversion effort essentially consists of adding a (well-tuned) gas mixer.

- Gasoline engines are not as durable as diesel engines.

Engine selection and operation

Speed

Since biogas burns relatively slowly, biogas-fueled engines should be operated at
- 1300-2000 r.p.m. (diesel)
- 1500-3000 r.p.m. (spark-ignition)

The standard speeds for such engines are 1500 and 3000 r.p.m. (50 Hz) or 1800/3600 r.p.m. (60 Hz) because of connecting a generator. For direct-power applications, i.e. a V-belt drive, the transmission ratio should ensure that the engine operates within its best efficiency range (= lowest fuel consumption) under normal-power conditions.

(f engine-end pulley speed of machine)/(f machine-end pulley)= (speed of machine)/(speed of engine)

Consumption

Depending on the gas composition, barometric pressure and type of engine, the specific consumption will amount to 0.5-0.8 m³/ kWh, i.e. a 10-kW engine will use 5-8 m³ biogas per hour. In a dual-fuel setup, the biogas consumption rate can be reduced by lowering the biogas fraction.

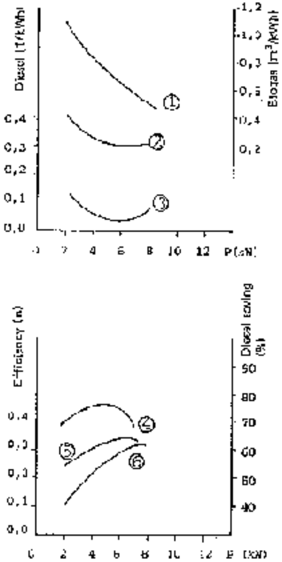


Fig. 5.36: Consumption of diesel and biogas by a 10-kW engine (1 cyl., 1000 ccm), 1300 m above sea level, running at 1500 r.p.m. 1 Biogas consumption in dual-fuel operation, 2

Diesel consumption in pure diesel operation, 3 Diesel consumption in dual-fuel operation, 4 Diesel saving, 5 Efficiency in diesel operation, 6 Efficiency in dual-fuel operation (Source: Mitzlaff 1986)

Maintenance and useful life

In contact with water, the H_2S content of biogas promotes corrosion. Consequently, adherence to the prescribed oil-change intervals is very important (after each 100 operating hours or so for vehicle spark-ignition engines). Dual-fuel engines should be started on pure diesel, with biogas being added gradually after about 2 minutes. For shutdown, the biogas fraction should be gradually reduced prior to stopping the engine. Any engine that has not been in operation for a considerable length of time should first be flushed out with scavenge oil (50% motor oil, 50% diesel oil) and filled with fresh oil. As long as extreme operating conditions are avoided, the engine can expected to achieve its normal useful life.

Exhaust-heat utilization

Internal-combustion engines have efficiency levels of 25 - 30% (gasoline engine) and 33 - 38% (diesel engine). A higher overall efficiency can be achieved by exploiting the heat content of the cooling water and exhaust, e.g. by:

- an exhaust heat exchanger (danger of H_2O-corrosion if the exhaust gas cools down to 150 °C or less)

- coolant heat exchanger (at coolant temperatures of 60 - 70 °C).

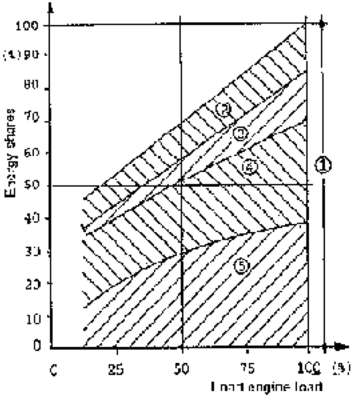


Fig. 5.37: Energy shares of an internal-combustion engine. 1 Energy input, 2 Dissipated energy (radiant heat and exhaust), 3 Useful exhaust energy, 4 Thermal energy in cooling water, 5 Mechanical power applied to crankshaft (Source: Mitzlaff 1986)

The recovered heat can be used for:

- heating utility water
- drying agricultural products
- space heating.

However, the requisite equipment/control effort makes heat recovery uneconomical except for large heavy-duty engines.

Motor-generators

The most frequent use for biogas-fueled engines is the generation of electricity. Suitable components include:

- asynchronous generators for system interconnection, i.e. the generator can only be operated in connection with a central power network. If the network breaks down, the generator cannot stay in operation. System control and network adaptation are relatively uncomplicated.

- asynchronous generators for insular networks, i.e. an electronic control system on the generator stabilizes a constant power network.

Converting one type of generator to the other is very intricate and involves a complicated electronic control arrangement.

In selecting a particular type of motor generator, one must give due consideration to the various operating conditions and network requirements (including the legal aspects of power feed-in).

Checklist for choosing a suitable engine

1. Define the energy requirement and speed of the machine to be powered;

2. Compare the biogas demand with the given storage capacity; if a shortage is possible, opt for the dual-fuel approach;

3. Select an engine with performance characteristics that are sure to provide the required power output in sustained operation in the optimal duty range:

- diesel engines $P_{engine} = P_{machine}/0.8$
- gasoline engines $P_{engine} = P_{machine}/0.G$

This accounts for the fact that the continuous-duty power output is less than the nominal output. On the other hand, choosing an overly powerful engine would make the specific

consumption unnecessarily high. Careful planning is very important in any project involving the use of biogas in engines; experienced technicians are needed to make the engine connections; and access to maintenance and repair services is advisable. Both the biogas plant itself and the engine require protection in the form of a low-pressure cutout that shuts down the latter if the gasholder is empty. Chapter 10.5 lists some recommended types of biogas engines and supplier addresses.

5.6 Measuring methods and devices for biogas plants

The purpose of conducting measurements on a biogas plant is to enable timely detection of developing problems, adjustment to optimum operating conditions, and gathering of practical 'data for comparison with those of other plants. The following variables can be measured quickly and easily:

- **gas production via dry gas meter or by measuring the fill level of the gasholder**
- **weight of inputs via a hand-held spring scale**
- **temperature via an ordinary stem thermometer or electronic temperature sensor**
- **total-solids content by drying a sample at 104 °C and weighing the residue on a precision balance**
- **H_2S content of the gases via a gas test tube**
- **pH via litmus paper.**

The contents of the substrate/slurry can only be determined by a special laboratory.

Various levels of precision are recommended, depending on the set objective and corresponding time, effort and equipment expenditure.

Observation by the user

Procedure

- measuring the gas consumption through daily checking of the calibration marks on the gasholder
- measuring the daily input quantities via defined-volume vessels
- measuring the air/slurry temperature with a thermometer.

Documentation

Daily notation of measured values.

Interpretation/results

Daily gas production as a function of substrate input and temperature.

Field testing by the extension officer

Procedure

- installation and daily reading of a dry gas meter to determine the rate of gas production
- random sampling of the CO_2 and H_2S contents of the biogas
- determination of quantities added by weighing the moist mass and water on a spring scale
- random sampling to determine the total solids content of the substrate
- measuring the digester temperature with the aid of a remote electronic thermometer
- measuring the ambient temperature with a mini-max thermometer
- determining pH levels via litmus paper
- laboratory testing to determine the C/Nratio, volatile solids content and manurial quality of digested slurry.

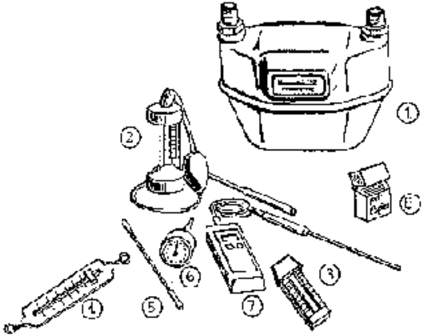


Fig. 5.38: Measuring instruments for biogas field tests. 1 Gas meter, 2 CO2 tester, 3 Mini-max thermometer, 4 Spring scale, 5 Stem thermometer, 6 Insertable thermometer, 7 Electric remote thermometer, 8 Litmus paper (Source: OEKOTOP)

Documentation
Daily entry of measured values in a log book.

Interpretation of results
- time history of daily gas production as a function of temperature and substrate input
- time history of specific gas yield (Gy = m³ gas/kg TS) and of specific gas production (m³ gas/m³ Vd) as a function of temperature
- time history of pH
- time history of maximum and minimum ambient temperatures, i.e. mean monthly and annual temperatures, plus extremes.

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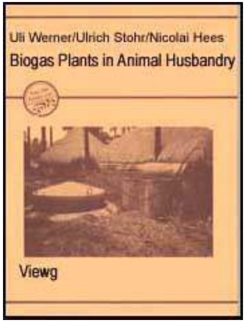

6. Large-scale biogas plants

Biogas technology, or better: anaerobic-process engineering, Is becoming increasingly important as a means of treating and cleaning industrial organic waste materials and highly loaded organic wastewater.

This applies in particular to the following ranges of production:

- large-scale stock farming

- industrial processing of agricultural produce (refining of sugar, production of starch, winning of fibers, processing of coffee, generation of alcohol, slaughterhouses, etc.)

- industrial and urban refuse and sewage (manufacturing of paper, organic household

waste, sewage sludge, biotechnological industries).

Most biogas plants used in those areas are large-scale plant systems with volumes ranging from several hundred to several thousand cubic meters.

Compared to aerobic treatment, anaerobic processes offer comparable performance with regard to purification capacity and conversion rates, but also stand apart from the former in that they:

- require less energy to keep the process going and to generate useful energy in the form of biogas, and

- produce less organic sludge, because the growth rate of anaerobic microorganisms is slower than that of aerobic microorganisms.

Consequently, anaerobic treatment of waste materials and wastewater offer some major advantages for a comparable initial invest" meet. Nonetheless, much of the technology has not yet passed the testing stage.

Due to the size of plant, different objectives and special requirements concerning operation and substrates, the anaerobic treatment of waste materials and wastewater involves a different set of planning mechanisms, plant types and implementational factors. To go into detail on this subject would surpass the intended scope of this manual; besides, extension officers hardly need expect to be confronted with the job of planning such plants. Nevertheless, some basic information is offered here to give the reader a general grasp of what large-scale biogas technology involves.

In discussing the various waste-treatment options, differentiation is made between wastewater (organic - highly loaded) and waste materials/residues (organic solids).

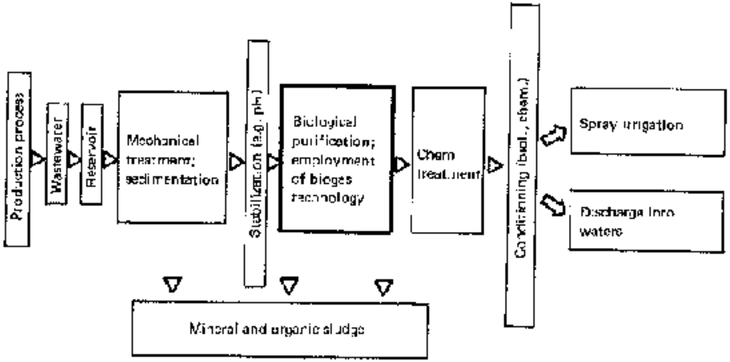

Fig. 6.1: Basic principle of organic wastewater treatment (Source: OEKOTOP)

Table 6.1: Some examples of biogas production from agro-industrial residues and wastewater
(Source: OEKOTOP, compiled from various sources)

Area of production	**Retention time**	**Digester loading**	**Gas production**		**Degradation rate**
	[d]	**[kg/m^3 X d]**	**[m^3/kg]**	**[m^3/m^3 X d]**	**[%]**
Slaughterhouse	0.5- 8.5	1.2-3.5 COD	0.3-0.5 COD	0.1 - 2.4	80 COD
Fruit and vegetables	32.0	0.8-1.6 VS	0.3-0.6 VS	-	-
Olive-oil extraction	20.0-25.0	1.2-1.5 TS	0.7 BOD	-	80-85 BOD
Whey	2.0-5.0	6.4 BOD	0.9 BOD	5.5	92 BOD
Potato starch	-	7.5 COD	0.3-0.4 COD	-	90-95 BOD
Yeast factory	0.5-0.7	1.0-8.0 COD	-	0.5-4	60-70 COD

Sugar mill	0.2-1.0	12.0-16.5 COD	-	-	87-97 COD
Milk processing	3.4-7.4	0.7-2.0 VS	0.1-0.4 VS	-	86-99 BOD
Molasses slop	10.0	3.9 VS	0.9 VS	3.5	97 BOD
Molasses distillery	1.2-3.5	18.3 COD	0.6 COD	6.6	45-65 COD
Brewery	2.3-10.0	1.8-5.5 TS	0.3 - 0.4 TS	-	-
Tannery	0.5	2.7-31.9 COD	-	-	80-91 COD
Pharmaceut.ind.	0.5-2.0	0.2-3.5 COD	0.6 COD	0.1-2.5	94-98 COD
Refuse + sewage sludge	11.0-22.5	1.2-3.1 VS	1.0 VS	-	-
Refuse	25.0-30.0	0.7-3.2 VS	0.1-0.4 VS	-	-
Cattle farming	15.0-35.0	0.5-2.5 VS	0.2-0.4 VS	0.6-1.4	-
Pig farming	10.0-25.0	0.8-4.1 VS	0.1-0.5 VS	0.8-2.1	-
Poultry farming	15.0-35.0	0.6-3.6 VS	0.2-0.5 VS	0.7-1.8	-
Sewage sludge	20.0-30.0	1.2-4.5 VS	0.1-0.6VS	0.8-1.5	-

Wastewater treatment

Organically contaminated wastewater contains mostly dissolved substances that are measured in terms of COD (chemical oxygen demand) and BOD (biochemical oxygen demand, i.e. oxygen required for mineralizing the organic contents).

The main purpose of wastewater treatment is to remove or mineralize the organic substances, i.e. to prepare them for release into a receiving body of water or the agricultural environment.

Anaerobic fermentation serves as the biological purifying process. Purification

performance rates of up to 95% BOD are achievable. The choice of process and the achievable purification performance rates are determined by the type and composition of the substrate/wastewater. In general, dissolved organic substances are readily biodegradable. Retention times ranging from a few hours to a few days are not uncommon. On the other hand, some organic substances are hard to break down (paints, aromates, etc.), while others are toxic and/o,r capable of causing a shortage of nutrients and adverse medium characteristics (e.g. pH-shifts). A number of special-purpose processes have been developed for use in anaerobic wastewater treatment in order to compensate for the high hydraulic loads and lack of bacterial colonization areas:

Contact fermenter

Digested slurry is recycled through a continuously stirred reactor in order to maintain a high level of bacterial concentration and, hence high performance. The contact process is a suitable approach for both mobile substrates and substrates with a high concentration of solids.

Upflow fermenter
An upflow-type fermenter with a special hydraulic configuration serves simultaneously as a suspended-solids filter with a high bacterial density and correspondingly high biodegradation performance.

Fluidized-bed fermenter
A vehicle (balls of plastic or clay) is kept "floating" in the fermenter to serve as a colonizing area for the bacteria.

Fixed-bed fermenter
A vehicle (plastic pellets or lumps of clay, rock or glass) provides a large, stationary colonization area within the fermenter. Fixed-bed fermenters are suitable for wastewater containing only dissolved solids. If the wastewater also contains suspended solids, the

fermenter is liable to plug up.

Two-phase fermentation
The acidic and methanogenic phases of fermentation are conducted separately, each under its own optimum conditions, in order to maximize the fermentation rates and achieve good gas quality.

The treatment of wastewater marked by heavy organic pollution must always be looked upon as an individual problem that may require different processes from one case to the next, even though the initial products are identical. Consequently, trials must always be conducted for the entire chain: production process - purification - wastewater utilization - and energy supply/ use.

Thanks to their uncomplicated, robust equipment, the contact process and fixed-bed fermentation stand the best chance of success in developing countries.

Waste materials/residues
The fact that practically identical production processes often yield residues that hardly resemble one another also applies to industrial waste materials. Here, too, pretrials and individual, problem-specific testing are called for in any case.

The potential range of organic waste materials is practically unlimited. Of particular interest for the purposes of this manual, however, are waste materials from factory farms and slaughterhouses.

Large-scale stock farming
The characteristics of dung from cattle, pigs and chickens were described in chapter 3.2. In factory farming, the dung yield is heavily dependent on the given type of fodder and how the stables are cleaned. Thus, pinpoint inquiries are always necessary.

The large quantities of substrate, often exceeding 50 m³/d, lead to qualitative differences in the planning and implementation of large-scale plants, as opposed to small-scale plants. This has consequences with regard to substrate handling and size of plant:

- Daily substrate-input volumes of more than 1 m³ cannot be managed by hand. Pumps for filing the plant and machines for chopping up the substrate are expensive to buy and run, in addition to being susceptible to wear & tear. In many cases, careful planning can make it possible to use gravity-flow channels for filling the plant.

- Plants of a size exceeding 100 m³ usually cannot be made of masonry, i.e. the types of plant discussed in chapter 5 cannot be used.

The choice of plant is limited to either the mechanized types used in industrial countries or simple, large-scale plants. Experience shows that most simple, large-scale plants are
- of modular design,
- usually equipped with channel digesters,
- and require the use of substrate from which the scum-forming material has been removed in order to get by with either low-power mechanical mixers or none at all.

Since large-scale biogas plants produce accordingly large volumes of biogas, the generation of electricity with the aid of a motor-generator set is of main interest.

The two Ferkessedougou biogas plants situated in the northern part of Cote d' Ivoire stand as examples of a successful large-scale biogas-plant concept based on a simple design. They have been in operation at the local cattle-fattening station and slaughterhouse since 1982 and 1986, respectively, where they serve in the disposal of some of the excrements produced by an average number of 2500 head of cattle. The plant consists of a simple, unlined earth-pit digester with a plastic-sheet cover serving as gasholder. The gas is used for generating electricity, heating water and producing steam.

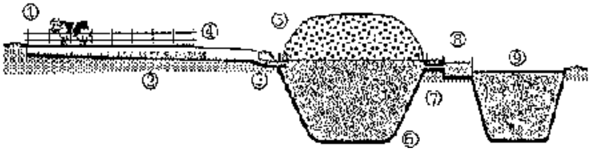

Fig. 6.2: Biogas plant in Ferkessedougou - system OEKOTOP. 1 Cattle feedlot, 2 Manure gutter, 3 Feedpipe, 4 Sluice, 5 Rubber-sheet gasholder, 6 Earth-pit digester, 7 Discharge pipe, 8 Impounding weir, 9 Slurry storage (Source: OEKOTOP)

At present, some 20% of the slaughterhouse's electricity requirement is covered by the biogas plants, and the biogas-driven steam sterilizer saves 50 000 I diesel fuel each year. The total initial investment amounting to 60 million F.CFA yields annual savings of approximately 12 million F.CFA after deduction of the operating costs (1 DM = 150 F.CFA). The Ferkessedougou biogas plants demonstrate how even large-scale installations can keep biogas technology cost-efficient by relying on simple designs, e.g. large digester volume despite low cost of construction.

Table 6.2: Technical data of the Ferkessedougou biogas plant (Source: OEKOTOP)

	Biogas plant I	**Biogas plant II**
No. of animals	700 head of cattle in 12 feedlots	
Digester volume	400 m³	810 m³
Gasholder volume	80 m³	>600 m³
Slurry storage volume	300 m³	3500 m³
Retention time	40-2s days	40 -22 days

Daily substrate input[1]	10-18 m^3/d	20-38 m^3/d
TS-content		4-8%
Daily gas production	250 m^3/d	450 m^3/d
Specific gas production	0.6 m^3/m^3 Vd	0.55 m^3/m^3 Vd
Gas utilization	MWM gas-powered	Deutz gas-powered
	motor-generator set	motor generator set
	15 kWel	32 kWel, with exhaust heat recovery for heating water
Operating time	22 h/d	10 h/d
Power generation	270 kWh/d	245 kWh/d
		Combination gas-oil burner for steam sterilizer, 130-355 kW

[1] **Fluctuation due to seasonal factors (rainy/dry season)**

Slaughterhouses

The proper disposal of paunch and intestinal contents (fecal matter), dung and urine and, in some cases, blood and offal is not always ensured in slaughterhouses. Such residues can be put to good use in a biogas plant, since:

- the energy demand and the substrate incidence are extensively parallel and usually involve short distances for transportation;

- the biogas technique is more cost-efffcient and yields more energy than aerobic processes, so that most slaughterhouses could cover their own energy demand with such a plant.

Slaughterhouses in developing countries span a wide size range. Consequently, various techniques are needed for treating and/or disposing of waste materials and wastewater. While little experience has been gained to date in connection with the disposal of slaughterhouse wastes via biogas technology, the following assessment can nonetheless be arrived at:

- Small, village-scale slaughterhouses

in which 50 - 100 animals are slaughtered each week can make use of simple agricultural biogas plants like those discussed in chapter 5 for disposing of all offal and other residues, and the digested slurry can be used as agricultural fertilizer.

The main problem in such plants is the formation of a thick layer of scum made up of the contents of paunches and fecal matter. For that reason, and in order to achieve good hygiene, retention times of 100 days or more are considered practical.

- Medium-sized slaughterhouses (200-500 slaughterings per week)

Here, too, biogas plants are able to provide complete disposal, although large-scale types like those used in Ferkessedougou are required. Sometimes, it is a good idea to separate the solid wastes from the wastewater and possibly compost the solids.

- Large-scale slaughterhouses

Most such slaughterhouses are quite similar to those found in European cities and are usually located in urban areas. Consequently, proper waste disposal and wastewater

purification call for integrated concepts in line with European standards.

Table 6.3: Slaughterhouse waste quantities (Source: OEKOTOP)

Type of waste	**Cattle**	**Sheep**	**Pigs**
Stomach contents	11.6%[1]	4.3%[1]	2.8%[1]
Intestinal contents	3.3%[1]		
Blood	~14 kg	~2 kg	~4 kg
Offal	2-5 kg	0.5-1 kg	1-1.5 kg
Dung (without fodder)	5 kg	0.8 kg	1.5 kg

[1] Expressed as percentages of live weight

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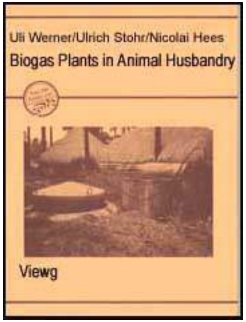

Biogas plants in Animal Husbandry (GTZ, 1989, 153 p.)

7. Plant operation, maintenance and repair

The main objective of any plant owner/user is to have a well-functioning biogas plant that involves a modest amount of work for operating it and requires very little effort and expense for maintenance and repair in the long run. Smooth running of a biogas plant is dependent on good information and careful planning and construction. Operating errors and false expectations are the most frequent causes of plant outage.

7.1 Commissioning of biogas plants

The commissioning procedure for a biogas plant includes:

- **inspection and final acceptance of all components**
- **initial filling**
- **starting the plant**
- **user familiarization**

Inspection and final acceptance

Prior to filing the plant, all components must be carefully inspected for proper function and suitability for acceptance. Of particular importance at the time of final acceptance is seal testing of the digester, gasholder and gas pipes.

It must be kept in mind that the seal tests described below are very laborious without pumps (e.g. hauling of more than 10 m³ water) and may not even be feasible if water is scarce, in which case such testing must be dispensed with. The time and effort involved must be weighed against the risk of having to empty the plant after completely filling it with slurry. In either case, it is very advisable to use a motor pump.

Water-seal testing

Fill the entire digester with water and check the fill level in all components.

Once all components have become saturated with water (after about 1 day), refill to the zero line, wait one day, and then remeasure. If the water loss amounts to less than 2% of the digester volume, the plant may be regarded as leaktight.

Seal testing (water and gas) of a fixed-dome plant

Fixed-dome plants are regarded as leaktight if the water-seal test shows less than 2% water loss, and the gas-seal test shows less than 5% gas loss.

Gas-seal testing of a floating-drum plant

In the case of floating-drum plant, only the metal gasholder must be subjected to gas seal testing; any leaks are detected with the aid of soap water.

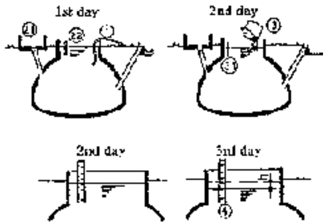

Fig. 7.1: Water-seal testing of a digester. 1 Fill the plant with water, Check the fill levels: 21 Inlet no water in the mixing pit, 22 Digester - at least 10 cm neck height above water level. 3 Refill to compensate for moisture absorbed by the masonry. 31 Mark the water level. 4 Measure the drop in water level as basis for calculating the water loss (W1 = p r² X h). 5 Repeat measurements as necessary. (Source: OEKOTOP)

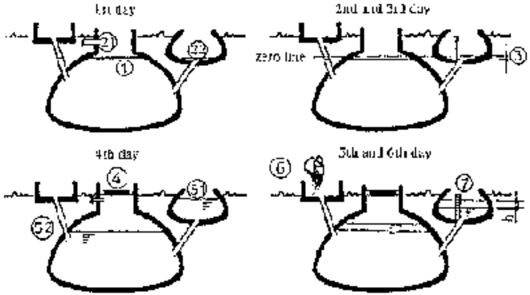

Fig. 7.2: Seal testing (water and gas) of a fixed-dome plant. 1 Fill the plant up to the zero line; Check the fill levels: 21 Gas extraction points at least 10 cm above discharge level, 22 Water level in the displacement pit. 3 Perform water-seal test and level-drop check (cf. fig. 7.1). 4 Close the entry hatch. 5 Fill with gas up to maximum a1lowable plant pressure a) with air (pump), b) with exhaust gas (vehicle exhaust), 51 . . . until the displacement pit overflows, or 52 . . . until gas bubbles out of the inlet pipe. 6 Refill the plant to compensate for saturation losses. 7 Measure the level drop (h) after one day, and calculate the gas losses. (Source: OEKOTOP)

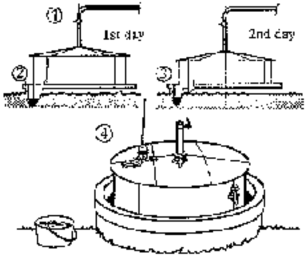

Fig. 7.3: Gas-seal testing of a metal gasholder. 1 Place the gasholder in position with the gas valve closed. 2 Mark the top edge of the digester neck on the gasholder. 3 Check the

location of the mark one day later. 4 If the mark is found to have dropped by 1-3 cm, use soapy water to check for leaks in the gasholder. (Source: OEKOTOP)

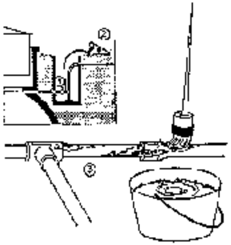

Fig. 7.4: Pressure testing a gas pipe. 1 Close all gas valves and fill the water trap. Find the maximum pipe pressure, i.e. how high the pressure in the pipe can go until the water trap blows off (not more than 50 cmWG). 2 Adjust the test pressure with the aid of a manometer-equipped test pump or the gasholder (10% below max. pressure). Check the pressure loss after one day. 3 Use soapy water to detect leaks. (Source: OEKOTOP)

Pressure testing of the gas pipe

The test must be performed while all gas pipe connections are still accessible. Pressurize the gas pipe with the aid of a test pump or by placing weights on the gasholder. If there is no noticeable loss of gas after one day, the pipe may be regarded as gaslight.

Initial filling of the plant

The initial filling for a new biogas plant should, if possible, consist of either digested slurry from another plant or cattle dung. It is advisable to start collecting cattle dung during the construction phase in order to have enough by the time the plant is finished. When the plant is being filled for the first time, the substrate can be diluted with more water than usual.

Starting the plant

Depending on the type of substrate in use, the plant may need from several days to several weeks to achieve a stable digesting process. Cattle dung can usually be expected to yield good gas production within one or two days. The breaking-in period is characterized by:

- low-quality biogas containing more than 60% CO_2
- very odorous biogas
- sinking pH end
- erratic gas production.

The digesting process will stabilize more quickly if the slurry is agitated frequently and intensively. Only if the process shows extreme resistance to stabilization should lime or more cattle dung be added in order to balance with pH. No additional biomass should be put into the biogas plant during the remainder of the starting phase. Once the process has stabilized, the large volume of unfermented biomass will give rise to a high rate of gas production. Regular loading can commence after gas production has dropped off to the intended level.

As soon as the biogas becomes reliably combustible, it can be used for the intended purposes. Less-than-optimum performance of the appliances due to inferior gas quality should be regarded as acceptable at first. However, the first two gasholder fillings should be vented unused for reasons of safety, since residual oxygen poses an explosion hazard.

User familiarization

The plant owner should be familiarized with the details of plant operation and maintenance at the time of commissioning. It is important that he be not only familiarized with the theory of function but given ample opportunity to practice using all parts of the

plant. The user-familiarization procedure should be built up around an operational/maintenance checklist (cf. table 7.2).

Table 7.1: Checklist for the inspection and acceptance of biogas plants (Source: OEKOTOP)

Check item	**Nonconformance**	**Remedy**	**Remarks**
I Interim inspection prior to backfilling			
Site	• unsuitable	• dismantle/demolish the plant	
Digester masonry	• cracked/broken bricks/ stones	• demolish the masonry	Fixed-dome plants in particular call for high-quality work. Tearing down the plant at this point is often . the least-painful solution
	• seriously false dimensigns		
	• improperly jointed masonry	• fix with mortar, incl. foundation	
inlet/outlet pipes	• false configuration	• demolish	
	• poor backfilling	• refill	
II Final inspection and acceptance			
Rendering in digester/ gasholder	• cracks, sandy rendering, low strength, cavities, poorly worked edges and coving	a) for the gas space of a fixed-dome plant: replace rendering	Ensure high-quality work manship for fixed-dome plants
		b) for the slurry	

		space: repair or add a new layer of rendering (usually sufficient)	
Masonry seal coats	• cracks, flaws, thin spots, voids	• renew the coating	(applies only to fixed-dome plants)
Mixing pit/slurry sotre/displacement pit	• cracks, poor workmanship	• demolish or repair	
Inlet/outlet pipes	• plugged, poorly worked transitions	• remove mortar plug, repair with mortar/ concrete	
Earth fill	• insufficient fill height	• recompact, add	
	• poorly compacted earth		
Water-fill check of all component heights(relative): inlet, outlet, digester, gas- holder cf. chapter 7.1	for floating-drum plants:		
	• water in mixing pit, too low; water spills over the digester, i.e. digester too low; outlet too low for fixed dome plants:	• shorten the outlet	Differentiation must be made between nonconfor mances that impair the plant's function and nonconformances that merely prevent optimal utilization

	• water above gas zero line -	• add wall height to digester	
		• lengthen the outlet	
		• alter the elevation of the	
		a) gas outlet	
		b) displacement pit	
	• water in mixing pit	• alteration too much trouble	
	• water in displacement pit	• alteration too much trouble	
Seal testing (see chapter 7.1 for details)	for floating-drum plants:		
	• water loss < 2%	• acceptable as is	In case of doubt, locate and repair all defects, even if it seems like a lot of trouble at the moment; repairs at a later date would be more troublesome!
	• water loss > 10% for fixed-dome plants:	• repair masonry	
	• water loss < 2%	• acceptable as is	
	(pressureless) > 10%	• repair masonry	
	• water loss < 5 %	• acceptable as is	

	(pressurized) > 10%	• repair masonry	
Gasholder (of floating- drum plants only)	•false dimensions,wrong	• reject gasholder,	
	• grade of steel,	build new one	
	• faulty welds	• repair welds	
	• faulty painting	• repaint	
Gas valves	• stuck valves	• repair or replace	Check carefully; defects most likely in the gas system
	• missing valves		
	• false water trap		
Gas pipe	• false gradient	• re-install	
	• leak found upon pressure testing	• repair leaks	
	• poor workmanship	• re-install	
Gas appliances	• functional defects	• repair or replace	

7.2 Plant operation

The operation of a simple biogas plant is relatively uncomplicated. The user must be given all the information and practical assistance he needs before and during the early phases of plant operation.

Collecting substrate

The collection of substrate is a simple matter when combined with work that has to be

done anyway, e.g. cleaning the stables. It can be made even easier by arranging for the manure to flow directly into the mixing pit. Experience shows that it is not a good idea to gather dung from fields, roads, etc. or to go to the trouble of elaborately chopping up or otherwise preprocessing plant material for use as substrate. The work involved is usually underestimated, while the motivation is overestimated.

Filling the plant

Filling means: mixing the substrate with water, removing bouyant materials, allowing the fill material to warm up, flushing it into the digester, and removing sand and stones. The simple mixing pit shown in figure 5.16 can handle a daily fill quantity of up to 500 1.

Digested-slurry storage/utilization

The further processing of digested slurry is a critical point in that it can be quite toilsome (cf. chapter 3.4).

In designing the plant, care must be taken to ensure that the slurry store will be large enough. Fixed-dome plants in particular should be equipped with an overflow, so that the digested slurry does not have to be hauled away every day.

Table 7.2: Checklist for the daily operation and regular maintenance of biogas plants (Source: OEKOTOP)

Daily activities:
- **fill the plant**
- **clean the mixing pit**
- **agitate the digester contents**
- **check the gas pressure**
- **check the gasholder contents**

- check the appearance and odor of the digested slurry

Weekly/monthly activities:

- remove/use the digested slurry
- clean and inspect the gas appliances
- check the gas valves, fittings and appliances for leaks
- inspect the water trap

Annual activities:

- inspect the digester for scum formation and remove as necessary by opening the plant
- inspect the plant for water tightness and gas tightness
- pressure-test the gas valves, fittings and pipes
- check the gasholder for rust and repaint as necessary

Monitoring the process

If the plant is properly started before being handed over to the user, it may be assumed to be in proper working order. The user will have become familiar with what optimum plant operation involves. This is very important, because from then on he himself will have to watch for any appreciable changes in how the plant functions; the main indication of a beginning malfunction is a change in the daily gas output.

7.3 Plant maintenance

The maintenance scope for a biogas plant includes all work and inspections needed to ensure smooth functioning and long service life. To the extent possible, all maintenance work should be done by the user.

Biogas plants can develop a number of operational malfunctions. The most frequent problem, "insufficient gas production", has various causes. Often enough, it takes the

work of a "detective" to locate and remedy the trouble. It may be necessary to experiment with and monitor the plant for months on end in cooperation with the user.

7.4 Plant repair

Repair measures for biogas plants (cf. table 7.5) are necessary in case of acute malfunctions and as indicated by routine monitoring. Repair measures exceeding simple maintenance work usually require outside assistance, since the user himself may not have the necessary tools or know-how.

It is advisable to have the annual maintenance work mentioned in chapter 7.3 performed by external artisans With prior experience in biogas technology. Such maintenance and repair work should be ordered on a contract basis. Past project experience shows that professional biogas repair and maintenance services can be very important for ensuring long-term plant performance. Such services should include general advice, functional testing, troubleshooting, spare-parts delivery and the performance of repair work.

Table 7.3: Checklist for troubleshooting in case of insufficient gas production (Source: OEKOTOP)

Quantity and quality of substrate
- low/less daily input
- excessive dilution with water

Ascertain by control measurements

Gas system leaks
- gasholder
- gas pipe
- valves and fittings

Ascertain by checking all components and connections for leaks with the aid of soapy

water

Disturbance of the biological process
Indications:
- heavy odor
- change of color of digested material
- drop in pH

Possible remedial measures:
- inspect the quality of the substrate
- stop biomass until the process returns to normal
- stabilize the pH, e.g. with lime
- add cattle dung or healthy slurry
- investigate the user's filling methods to determine if pollutants or noxious substances (detergents, pesticides, etc.) are getting into the plant

Table 7.4: Simple-plant malfunctions and remedial measures (Source: OEKOTOP)

Problem	**Possible cause**	**Countermeasures**
Plugged-up inlet pipe	fibrous substrate	use rod to unplug the pipe
Stuck gasholder	floating scum	1. turn the gasholder
		2. take off the gasholder
		and remove the scum
Tilted gasholder	broken guideframe	repair
Low gas production, poor gas quality	cf. table 7.3	cf. table 7.3
Receding slurry level	leak in plant	repair
Inadequate gas storage in fixed-dome	leak in gasholder	repair

plants		
Stuck gas cocks	corrosion	apply oil, ,operate repeatedly
Leaky gas pipe	corrosion, inferior workman-	repair
	ship	
Sudden loss of gas	- broken gas line	repair
	- blown-off water trap	refill with water
	- open gas cock	close
Pulsating gas pressure	water in the gas pipe	pump out the pipe, relocate that
		section of pipe
	plugged-up gas pipe	push rod through pipe
Malfunctioning gas appliances	cf. chapter 5.5.3	cf. chapter 5.5.3
Structural damage	cf. table 7.1	cf. table 7.1

Table 7.5: Potential repair situations for simple biogas plants (Source: OEKOTOP)

Damage	**Detection**	**Remedial measures**
Damaged masonry and rendering	Inspection of open plant, subsiding slurry level,	Inspect the plant and repair any seal test damage; tear down the plant if large cracks are found
Damaged or broken inlet/outlet pipe	(see above)	Replace pipe, repair connection to masonry
Damaged/leaky fixed-dome plants	Gas seal test, visual inspection of open plant	Repair rendering, renew seal coatings
Damaged/corroded gasholder	High gas losses, seal test	Replace gasholder, renew weldings

Broken guide frame	Tilted/immobile gasholder	Remove gasholder, repair guide frame
Leaky/broken/corroded gas pipe	High gas losses, gas seal test of pipe	Locate damage, repair or replace as necessary
Damaged valves/fittings	Functional inspection	as a rule: replace
Damaged gas appliances	Functional inspection	cf. "Gas appliances"

7.5 Safety measures

Biogas is a combustible, explosive gas. Its safe handling and use can be ensured, or at least promoted, by:

- **educational measures and operating instructions**
- **good, careful planning and execution**
- **timely detection of damage and gas leaks**
- **installation of safety equipment**

Safety aspects of planning and implementation

The following basic rules should be adhered to:

- **plant located outside of buildings used for other purposes, e.g. stablings**
- **underground installation of pipes**
- **no use of hoses**
- **careful installation and regular inspection of gas pipes**
- **regular inspection of gas appliances**
- **good ventilation of rooms containing gas appliances without safety pilots**
- **installation of safety stop valves**
- **one directly on the plant, and another on each appliance.**

Educational measures and operating instructions

The user must be made fully aware of the explosive nature of biogas, possibly by way of demonstration (e.g. by producing a flash flame). He must learn by heart the following basic rules:
- Never leave an open flame unattended!
- Always close the gas and safety valves of each appliance properly and immediately after each use!
- Close the plant's safety valves each night and whenever the plant is left unattended!

Experience shows that leaks and open gas cocks can be detected very quickly, i.e. before an explosive mixture forms, by watching for the conspicuous odor of unburned biogas.

Safety devices
As long as the above safety aspects are adhered to, small biogas plants in rural areas require few or no special safety devices, the one major exception being appliances that operate on their own, i.e. refrigerators, radiant heaters, etc., in which case the use of safety pilots is obligatory.