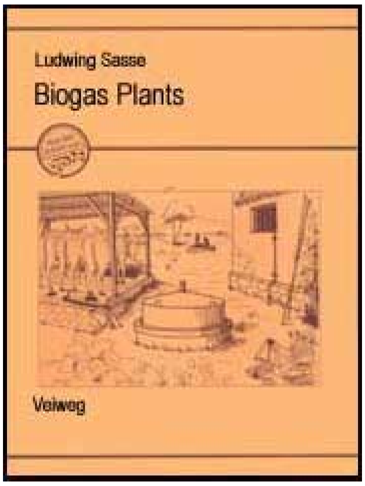

Biogas Plants

by Ludwig Sasse

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Content

Preface

Everyone is talking about biogas - politicians and ecologists, technicians and economists, laymen and experts. Biogas has become fashionable.

The energy crisis of the next few years is the shortage of fuel for the daily needs of millions of people. Simple biogas plants are intended to help solve this problem. It is time to set about this task in a "professional" manner in the best sense of this word.

Simple biogas plants are complicated enough to require total involvement with their specific technology. After all, a biogas plant can only help to solve the problems of the future if it works! But many plants work badly. They are operated wrongly, are deficient in detail and are often incorrectly scaled.

Simple biogas plants have been constructed in Third World countries for about thirty years. We have been able to learn from the biogas pioneers for thirty years. But good and bad solutions are featured side by side without comment in articles and books. The same mistakes are repeated over and over again. This need not be the case. The designer of a biogas plant must be able to distinguish between valid and invalid solutions. This little book is intended to help him in this respect.

The figures and tables reproduced here constitute practical guides. They have been assembled from external and internal sources and simplified or modified in accordance with the author's own experience. They should not be confused with laboratory values.

All power to the elbow of the practical worker, whom I wish every success. I am always grateful for suggestions and criticism.

In addition to some minor changes, this second, revised edition contains three important supplementary observations:

- The biogas system must include a tie-in to the animal shelter,
- As a rule, floating-drum plants should be of the water jacket type,
- The covers of fixed-dome plants must have a conical fit.

I would like to express my appreciation to all those who have provided impulses and constructive criticism, in particular the members of the GATE Biogas Extension Program, whose ideas concerning "user-friendly" biogas plants have yielded valuable impetus.

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0. Biogas as appropriate technology

A technology is appropriate if it gains acceptance. Biogas plants have hitherto gained little acceptance. Simple biogas plants have up to now presumably been inappropriate. Bicycles are appropriate: if a person buys a bicycle, he is proud. It is a sign of his advance, his personal progress. The bicycle is appropriate to the need for social recognition. If the person mounts the bicycle and falls off because he does not know how to ride it, it is not appropriate to the abilities of its owner. The person learns to ride and thus adapts himself to his cherished bicycle. The person goes to work on his bicycle. It is appropriate to his need for convenience and low-cost transport. The bicycle breaks down. The person has no money to spare to have it mended. He saves on other expenditure, because the bicycle is important for his pride and his convenience. He walks long distances to the repairer. He adapts to the needs of the bicycle.

The person can afford this expenditure without getting into economic difficulties. The bicycle is appropriate to his economic capacity.

A biogas plant is correctly operated and maintained if it satisfies the user's need for recognition and convenience. He for his part is then prepared to adapt to the needs of the biogas plant.

Biogas plants are appropriate to the technical abilities and economic capacity of Third World farmers. Biogas technology is extremely appropriate to the ecological and economic demands of the future. Biogas technology is progressive.

However, a biogas plant seldom meets the owner's need for status and recognition. Biogas technology has a poor image ("Biogas plants are built by dreamers for poor people". If you do not want to seem one of the poor, you do not buy a biogas plant. The image of the biogas plant must be improved.

The designer makes his contribution by supplying a good design. A "professional design" that works. One that is built in conformity with contemporary requirements and models. The biogas plant must be a symbol of social advancement. The biogas plant must be technically progressive.

A biogas plant as an investment is in competition with a bicycle or moped, a radio set or diesel pump, a buffalo or an extension to the farmhouse.

The economic benefit of a biogas plant is greater than that of most competing investments. However, the plant must also be worthwhile as a topic for the "chat in the market place".

So the design must not be primitive. So it must be well made.
So the gas bell must be attractively painted. So the gas pipe must be laid tidily.
So the fermentation slurry tank must be decently designed and constructed.
So giant pumpkins and flowers must grow around the plant.

A good biogas plant is appropriate. Appropriate to the needs of its owner and his abilities and capacity. It is appropriate to the necessities of the future.

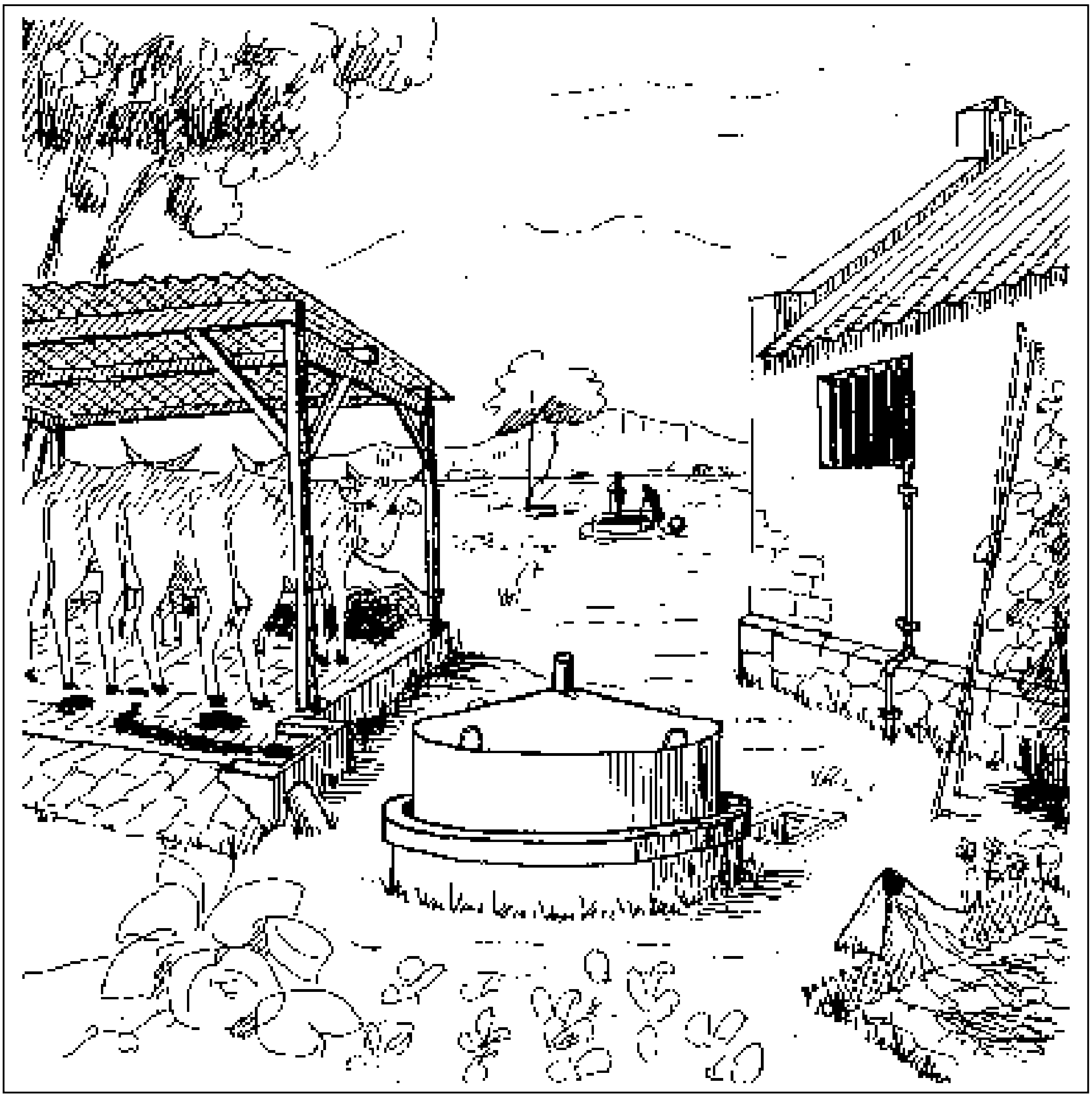


Fig. 1: A farmyard biogas plant

This is a floating-drum plant with internal gas outlet. The gas pipe is securely mounted on the wall and leads directly to the kitchen. Ideally, as in this example, the digester should be located directly beside the animal shelter, which should have a paved floor. Urine and dung can be swept into the inlet pipe with little effort. The plant has a sunny location, and the vegetable garden is situated directly adjacent to the digested slurry store. The well is an adequate distance away from the biogas plant.

1. Benefits and costs of a biogas plant

A biogas plant supplies energy and fertilizer. It improves hygiene and protects the environment. A biogas plant lightens the burden on the State budget and improves working conditions for the housewife. A biogas plant is a modern energy source. A biogas plant improves life in the country.

A biogas plant can satisfy these high expectations only if it is well designed.

A biogas plant supplies energy. However, a biogas plant also consumes energy. Energy is already consumed in the production of the construction material:

- for 1 m^3 of masonry, about 1000 kWh or 180 m^3 of biogas,
- for 100 kg of steel, about 800 kWh or 150 m^3 of biogas,
- for 1 kg of oil paint, about 170 kWh or 28 m^3 of biogas.

Energy is consumed in transporting the materials of a biogas plant. Construction and maintenance also consume energy:

- for 1 km of transport by lorry, about 1.5 kWh or 1.05 m^3 of biogas
- for 1 km of transport by car, about 0.5 kWh or 0.35 m^3 of biogas.

A biogas plant must operate for one or two years before the energy put into it is recovered.

The degree of digestion increases with the retention time. Long retention times save energy. The net energy gain is smaller with short retention times: if the retention time for 50 kg of cattle dung is reduced from 90 to 45 days, some 790 kWh or 240 m^3 of biogas per year is lost.

A biogas plant eases the work of the housewife. However, a biogas plant also creates additional work for the housewife: dung and mixing water have to be supplied to it. The fermentation slurry has to be mixed. Long retention times help the housewife. Biogas plants with short retention times need more labour: To replace 20 kg of firewood by biogas, a housewife must supply 121 kg of dung and 121 litres of water if the retention period is 45 days. For a 90-day retention period, only 84 litres of dung and of water are required. This represents a difference of nearly 9 kg of dung and nearly 9 litres of water per m^3 of gas per day.

If the plant is filled only every other day, working time is saved - because of the saving of preparation time.

If the biogas plant is too far from the source of water or from the animal housing, the housewife must perform additional work: the housewife's workload is lightened by a biogas plant only if the distance to the water source and that to the byre together are less than a quarter of the distance to the wood collection point.

The least amount of work results from locating the biogas plant directly beside the animal shelter (byre), which should have a paved floor. This makes it easy to sweep urine and dung into the plant's inlet pipe. Often enough, no extra mixing water is needed' and the gas yield is considerably higher.

The designer decides in whose interests the biogas plant is economic: a biogas plant for short retention times is economic for a farmer with many animals and cheap labour.

A plant with long retention times is beneficial to:

- a farmer with few animals,
- the housewife,
- the national economy.

The personal benefit of a biogas plant to the owner depends on how he previously met his energy and fertilizer requirements: the benefit is greater the more energy had to be bought in (diesel oil, coal, wood) and the higher the cost of that energy. However, there is always a close relationship between energy costs and those of construction.

Energy costs are set out in the tables in Fig. 38 (page 44).

Example:
Previous wood consumption say 200 kg/ month,
Biogas equivalent (Fig. 38): 0.18 m^3/kg, Comparable biogas volume: 0.18 x 200= 36 m^3,
Required daily biogas volume: 36/30= 1.20 m^3.

If daily gas production is at least 1.20 m^3, all fuel costs are saved. The excess is available free of charge; The excess can be counted on the credit side only if practical use is made of it.

The benefit of the fertilizer depends primarily on how well the farmer knows how to use it. Assuming that the digested slurry is immediately utilized - and properly applied - as fertilizer, each daily kg can be expected to yield roughly 0.5 kg extra nitrogen, as compared with fresh manure. If the slurry is first left to dry and/or improperly applied, the nitrogen yield will be considerably lower.

If parasitic diseases had previously been common, the improvement in hygiene also has economic benefits (reduced working time). The more fully the sludge is digested, the more pathogens are killed. High temperatures and long retention times are more hygienic.

The following are the principal organisms killed in biogas plants: Typhoid, paratyphoid, cholera and dysentery bacteria (in one or two weeks), hookworm and bilharzia (in three weeks).

Tapeworm and roundworm die completely only when the fermented slurry is dried in the sun.

2. The digestion process

Biogas is produced by putrefactive bacteria, which break down organic material under airless conditions. This process is called "anaerobic digestion".

The digestion process consists of two main phases:

- acid formation,
- methane formation.

In the first phase, protein, carbohydrate and fat give rise to fatty acids, amino acids and alcohols. Methane, carbon dioxide and ammonia form in the second phase. The slurry becomes somewhat thinner during the process of digestion.

The better the two phases merge into each other, the shorter the digestion process. The conditions for this are particularly favourable in the "fermentation channel" arrangement (Fig. 27,b).

The following types of digestion are distinguished according to the temperature in the digester:

- psychrophilic digestion (10-20 °C, retention time over 100 days),
- mesophilic digestion (20-35 °C, retention time over 20 days),
- thermophilic digestion (50-60 °C, retention time over 8 days).

Thermophilic digestion is not an option for simple plants.

The pH of the fermentation slurry indicates whether the digestion process is proceeding without disturbance. The pH should be about 7. This means that the slurry should be neither alkaline nor acid.

Biogas can in principle be obtained from any organic material. Cattle manure can be used as a "starter". Feed material containing lingnin, such as straw, should be precomposted and preferably chopped before digestion. More than ten days' preliminary rotting is best for water hyacinths. Gas production is substantially improved if the preliminary rotting time is twenty days.

2.1 The fermentation slurry

All feed materials consist of

- organic solids,
- inorganic solids,
- water.

The biogas is formed by digestion of the organic substances. The inorganic materials (minerals and metals) are unused ballast, which is unaffected by the digestion process.

Adding water or urine gives the substrate fluid properties. This is important for the operation of a biogas plant. It is easier for the methane bacteria to come into contact with feed material which is still fresh when the slurry is liquid. This accelerates the digestion process. Regular stirring thus speeds up the gas production.

Slurry with a solids content of 5-10% is particularly well suited to the operation of continuous biogas plants.

Example:

Fresh cattle manure is made up of 16 % solids and 84% water. The cattle dung is mixed with water in the proportions of 1:1. The prepared fermentation slurry then has a solids content of 8% and a water content of 92%.

All feed materials consist to a great extent of carbon (C) and also contain nitrogen (N). The C/N ratio affects gas production. C/N ratios of 20:1 to 30:1 are particularly favourable. Mixtures of nitrogen-rich feed material (e.g., poultry manure) and carbon-rich feed material (e.g., rice husks) give high gas production.

If there is any suspicion that the digestion process is impaired by pollutants (Fig. 2), water or "clean" feed material must be mixed in. This reduces the concentration of toxic substances.

Properties of feed materials

Animal species/ feed material	Daily arisings Dung		Urine	Proportions in fresh feed material		C/N
	approx. kg	% live wt.	% live wt.	% DM	% ODM	
Cattle dung	8	5	4	16	13	25
Buffalo dung	12	5	4	14	12	20
Pig manure	2	2.5	3	17	14	13
Sheep droppings	1			30	20	30
Horse manure	10			25	15	25
Poultry manure	0.08			25	16	5
Human excrement	0.5			20	15	8
Straw/husks						70
Leaves/grass				approx. 80		35
Water hyacinths	25 kg/m³			7	5	25

Gas production of different feed materials relative to cattle dung

Feed material	% of cattle dung
Cattle dung	100 %
90 % cattle 10 % pig	125 %
80 % cattle 20 % rice husks	120 %*
Pig manure	200 %
Horse manure	150 %
Goat droppings	70 %
Poultry manure	60 %

Harmful concentrations of toxic substances in feed material

Toxic substance		mg/l
Cu	Copper	100
Cr	Chromium	200
Ni	Nickel	200
CN^-	Cyanide compounds	25
NH_3	Ammonia	1500
Na	Sodium	3500
K	Potassium	2500
Ca	Calcium	2500
Mg	Magnesium	1000

Fig. 2: Feed material tables

Straw, leaves and, in particular, water hyacinths can be digested only in certain types of plants or using special conditioning techniques. For this reason, reliable information of general validity concerning gas production cannot be given. *Intense surface scum formation

2.2 Fermentation slurry as fertilizer

During the digestion process, gaseous nitrogen (N) is converted to ammonia (NH3). In this water-soluble form the nitrogen is available to the plants as a nutrient. A particularly nutrient-rich fertilizer is obtained if not only dung but also urine is digested.

Compared with solid sludge from fermented straw and grass, the liquid slurry is rich in nitrogen and potassium. The solid fermentation sludge, on the other hand, is relatively richer in phosphorus. A mixture of solid and liquid fermented material gives the best yields. The nutrient ratio is then approximately $N:P_2O_5:K_2O$= 1:0.5:1. A fermented slurry with a lower C/N ratio has better fertilizing characteristics. Compared with fresh manure, increases in yield of 5 - 15 % are possible. Particularly good harvests are obtained from the combined use of compost and fermentation slurry.

The fertilization effect depends on the type of crop and on the soil. Information given in specialized literature is seldom applicable directly. Tests of one's own are always better. Reliable information is possible only after three to five years.

When fermentation slurry is used as fertilizer for years, the soil structure is improved. The proportion of organic materials in the soil is increased, enabling the soil to store more water.

If fermentation slurry is to be stored before spreading on the field, it should be covered with earth in layers. This reduces evaporative nitrogen losses even further.

2.3 Biogas

Biogas is somewhat lighter than air and has an ignition temperature of approximately 700 °C (diesel oil 350 °C; petrol and propane about 500 °C). The temperature of the flame is 870 °C.

Biogas consists of about 60 % methane (CH_4) and 40 % carbon dioxide (CO_2). It also contains small proportions of other substances, including up to 1% hydrogen sulphide (H_2S). See also the table in Fig. 38 on page 44.

The methane content and hence the calorific value is higher the longer the digestion process. The methane content falls to as little as 50% if retention time is short. If the methane content is considerably below 50 %, biogas is no longer combustile. The first gas from a newly filled biogas plant contains too little methane. The gas formed in the first three to five days must therefore be discharged unused.

The methane content depends on the digestion temperature. Low digestion temperatures give high methane content, but less gas is then produced.

The methane content depends on the feed material. Some typical values are as follows:

Cattle manure	65%
Poultry manure	60%
Pig manure	67%
Farmyard manure	55%
Straw	59%
Grass	70%
Leaves	58%
Kitchen waste	50%
Algae	63%
Water hyacinths	52%

3. Biogas plants

3.1 Feed methods

A distinction is made between batch and continuous plants.

Batch plants are filled completely and then emptied completely after a fixed retention time. Each design and each fermentation material is suitable for batch filling.

Large gasholders or a number of digesters are required for uniform gas supply from batch plants.

Continuous plants are filled and emptied regularly -normally daily. Each design is suitable for continuous operation, but the feed material must be flowable and uniform.

Continuous plants empty automatically through the overflow.

Continuous plants are more suitable for rural households. The necessary work fits better. into the daily round. Gas production is constant, and somewhat higher than in batch plants.

If straw and dung are to be digested together, a biogas plant can be operated on a semibatch basis. The slowly digested straw-type material is fed in about twice a year as a batch load. The dung is added and removed regularly.

3.2 Plant types

Three main types of simple biogas plants can be distinguished (see Figure 3):

- balloon plants,
- fixed-dome plants,
- floating-drum plants.

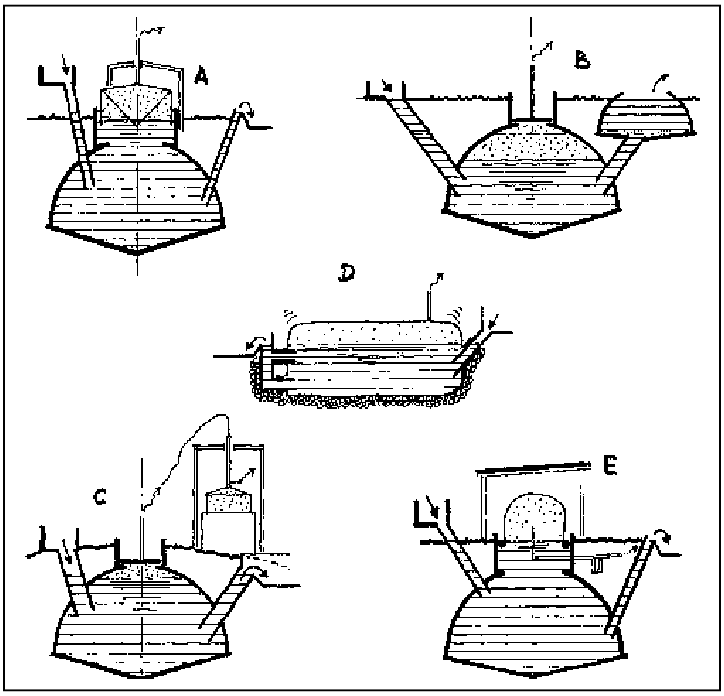


Fig. 3:
Simple biogas plants A Floating-drum plant B Fixed-dome plant C Fixed-dome plant with separate gasholder. The gas pressure is kept constant by the floating gasholder. The unit can be operated as a continuous overflow-type plant with no compensating tank. The use of an agitator is recommended. D Balloon plant E Channel-type digester with folia and sunshade

3.2.1. Balloon Plants

A balloon plant consists of a plastic or rubber digester bag, in the upper part of which the gas is stored. The inlet and outlet are attached direct to the skin of the balloon. When the gas space is full, the plant works like a fixed-dome plant - i.e., the balloon is not inflated; it is not very elastic.

The fermentation slurry is agitated slightly by the movement of the balloon skin. This is favourable to the digestion process. Even difficult feed materials, such as water hyacinths, can be used in a balloon plant. The balloon material must be UV-resistant. Materials which have been used successfully include RMP (red mud plastic), Trevira and butyl.

Advantages:
Low cost, ease of transportation, low construction (important if the water table is high), high digester temperatures, uncomplicated cleaning, emptying and maintenance.

Disadvantages:
Short life (about five years), easily damaged, does not create employment locally, little scope for self-help.

Balloon plants can be recommended wherever the balloon skin is not likely to be damaged and where the temperature is even and high. One variant of the balloon plant is the channel-type digester with folia and sunshade.

3.2.2. Fixed-Dome Plants

A fixed-dome plant (Figure 4) consists of an enclosed digester with a fixed, non-movable gas space. The gas is stored in the upper part of the digester. When gas production commences, the slurry is displaced into the compensating tank. Gas pressure increases with the volume of gas stored, therefore the volume of the digester should not exceed 20 m³. If there is little gas in the holder, the gas pressure is low.

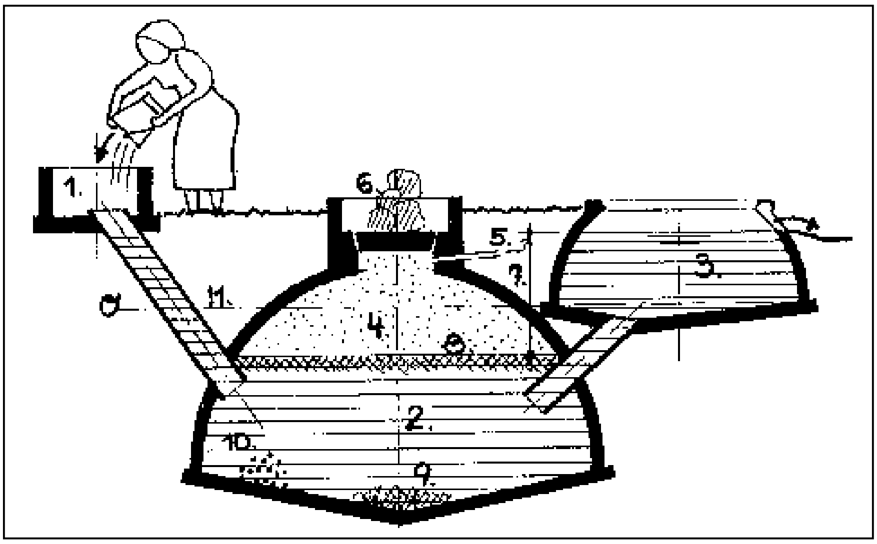


Fig. 4: Fixed-dome plant 1. Mixing tank with inlet pipe. 2. Digester. 3. Compensating and removal tank. 4. Gasholder. 5. Gaspipe. 6. Entry hatch, with gaslight seal and weighted. 7. Difference in level = gas pressure in cm WC. 8. Supernatant scum; broken up by varying level. 9. Accumulation of thick sludge. 10. Accumulation of grit and stones. 11. Zero line: filling height without gas pressure.

If the gas is required at constant pressure (e.g., for engines), a gas pressure regulator or a floating gasholder is required. Engines require a great deal of gas, and hence large gasholders. The gas pressure then becomes too high if there is no floating gasholder.

Advantages:
Low construction cost, no moving parts, no rusting steel parts, hence long life (20 years or more), underground construction, affording protection from winter cold and saving space, creates employment locally.

Disadvantages:
Plants often not gaslight (porosity and cracks), gas pressure fluctuates substantially and is often very high, low digester temperatures.

Fixed-dome plants can be recommended only where construction can be supervised by experienced biogas technicians.

3.2.3. Floating-Drum Plants

Floating-drum plants (Figure 5) consist of a digester and a moving gasholder. The gasholder floats either direct on the fermentation slurry or in a water jacket of its own. The gas collects in the gas drum, which thereby rises. If gas is drawn off, it falls again. The gas drum is prevented from tilting by a guide frame.

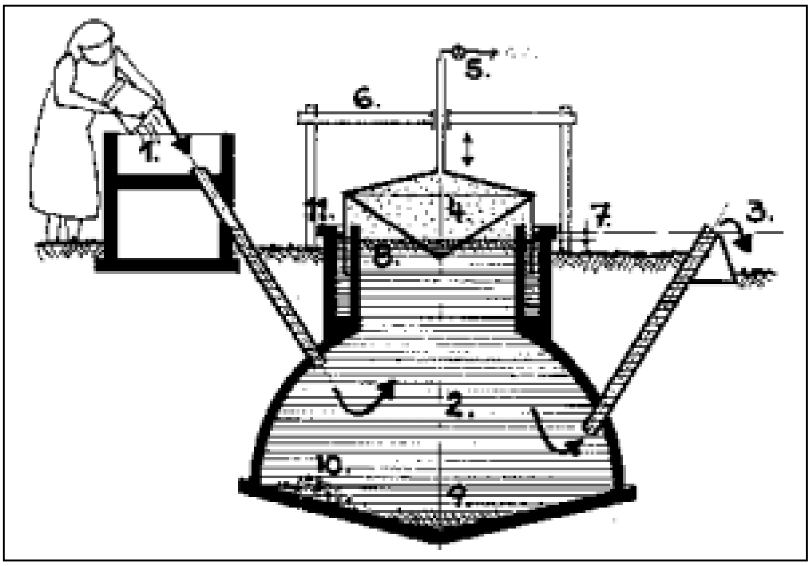


Fig. 5: Floating-drum plant 1. Mixing tank with inlet pipe. 2. Digester. 3. Overflow on outlet pipe. 4. Gasholder with braces for breaking up surface scum. 5. Gas outlet with main cock. 6. Gas drum guide structure. 7. Difference in level = gas pressure in cm WC. 8. Floating scum in the case of fibrous feed material. 9. Accumulation of thick sludge. 10. Accumulation of grit and stones. 11. Water jacket with oil film.

Advantages:
Simple, easily understood operation, constant gas pressure, volume of stored gas visible directly, few mistakes in construction.

Disadvantages:
High construction cost of floating-drum, many steel parts liable to corrosion, resulting in short life (up to 15 years; in tropical coastal regions about five years for the drum), regular maintenance costs

due to painting.

In spite of these disadvantages, floating-drum plants are always to be recommended in cases of doubt. Water-jacket plants are universally applicable and especially easy to maintain. The drum won't stick, even if the substrate has a high solids content.

Floating-drums made of glass-fibre reinforced plastic and highdensity polyethylene have been used successfully, but the construction cost is higher than with steel. Floating-drums made of wire-mesh-reinforced concrete are liable to hairline cracking and are intrinsically porous. They require a gaslight, elastic internal coating. PVC drums are unsuitable because not resistant to UV.

The floating gas drum can be replaced by a balloon above the digester. This reduces construction costs (channel type digester with folia), but in practice problems always arise with the attachment of the balloon at the edge. Such plants are still being tested under practical conditions.

4. Scaling of biogas plants

4.1 Definitions

To calculate the scale of a biogas plant, certain characteristic parameters are used. These are as follows for simple biogas plants:

- Daily fermentation slurry arisings (Sd),
- Retention time (RT),
- Specific gas production per day (Gd), which depends on the retention time and the feed material.

The following additional concepts and parameters are also used in the theoretical literature:

- Dry matter (DM). The water content of natural feed materials varies. For this reason the solids or dry matter content of the feed material is used for exact scientific work (see table in Fig. 2).

- Organic dry matter (ODM or VS). Only the organic or volatile constituents of the feed material are important for the digestion process. For this reason, only the organic part of the dry matter content is considered.

- Digester loading (R). The digester loading indicates how much organic material per day has to be supplied to the digester or has to be digested. The digester loading is calculated in kilograms of organic dry matter per cubic metre of digester volume per day (kg ODM/m³/day). Long retention times result in low digester loadings. In a simple biogas plant, 1.5 kg/m3/day is already quite a high loading. Temperature-controlled and mechanically stirred large-scale plants can be loaded at about 5 kg/m3/day. If the digester loading is too high, the pH falls. The plant then remains in the acid phase because there is more feed material than methane bacteria.

Example:

Calculation of digester loading
Digester volume (VD): 48001 (4.8 m³) Retention time (RT): 80 days
Daily amount of fermentation slurry (Sd): 60 kg
Proportion of organic matter: 5 %

R = 5x60/100 x 4.8 = 0.625 kg/m3/day

Retention time (RT or t) indicates the period spent by the feed material in the digester. It is chosen by economic criteria. The retention time is appreciably shorter than the total time required for complete digestion of the feed material.

Specific gas production may be quoted for the amount of fermentation slurry, the dry matter, content or only the organic dry matter. In practice, it represents the gas production of a specific feed material in a specific retention time at specific digester temperatures.

Degree of digestion is measured as a percentage. It indicates the amount of gas obtained as a proportion of total specific gas production. The difference from 100% indicates the proportion of feed material which is not yet fully digested. In simple biogas plants, the degree of digestion is about 50 %. This means that half the feed material is not used.

Biochemical oxygen demand (BOD) is an important parameter in effluent treatment. It indicates the degree of pollution of effluents or sewage. The BOD is a measure of the amount of oxygen consumed by bacteria in biological purification.

4.2 Scaling of the digester

The size of the digester - the digester volume (VD) - is determined by the length of the retention time (RT) and by the amount of fermentation slurry supplied daily (Sd). The amount of fermentation slurry consists of the feed material (e.g., cattle dung) and the mixing water.

Example:

30 l dung + 30 l water = 60 l fermentation slurry

The digester volume is calculated by the formula

$VD(l) = S_d(l/day) \times RT\ (days)$

Example:

Daily supply (S_d): 60 l
Retention time (RT): 80 days
Digester volume (VD):
60 l/day x 80 days = 4800 1 (4.8 m^3)

For a specific digester volume and a known amount of fermentation slurry, the actual retention time is given by the formula

$RT(days) = V_D\ (l)$ -:-S_d (l/day)

Example:

Digester volume (VD): 4800 l
Daily supply (Sd): 60 l/day
Retention time (RT):
4800 l -:- 60 l/day = 80 days

If the digester size is given and a specific retention time is required, the daily amount of feed is calculated by the formula

Sd (l/day) = VD (l) . RT(days)

Example:

Digester volume (VD): 4800 l
Retention time (RT): 80 days
Daily fermentation slurry requirement (Sd):
4800 l -:- 80 days = 60 l/day

If a biogas plant is loaded not daily but at relatively long intervals, the daily supply (Sd) decreases although the fermentation slurry proportion (S) remains the same. The retention time is correspondingly prolonged.

Example:

Digester volume (VD): 4800 l
Fermentation slurry proportion (S): 60 l

1. Daily loading, i.e. S_d = S = 60 l/day:
Retention time (RT):
4800l -:- 60 l/day = 80 days
2. Loading every other day, i.e.
S_d=S 2=30Q/day:
Retention time (RT):
4800 l -:- 30 £/day = 160 days
3. Loading twice a week, i.e.
S_d = S x 2/7 = 17.2 l/day:
Retention time (RT):
4800 l -:- 17.2 l/day = 279 days

4.3 Scaling of gasholder

The size of the gasholder - the gasholder volume (VG, see Figure 6)—depends on gas production and the volume of gas drawn off.

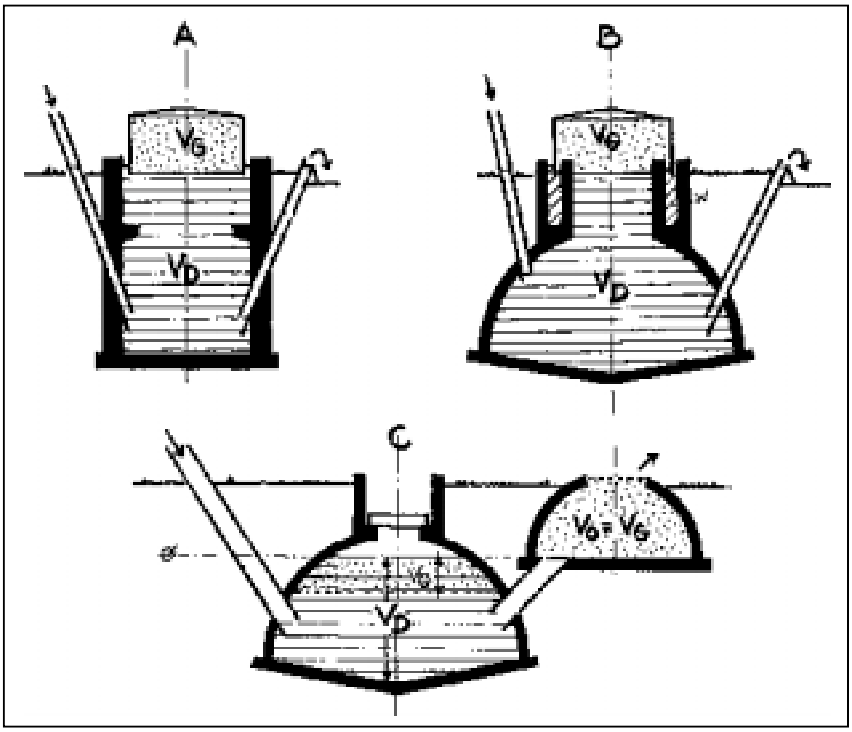


Fig. 6:
Digester and gasholder Each biogas plant consists of a digester (VD) and a gasholder (VG). For calculation purposes, only the net digester volume or gas space is relevant. In the fixed-dome plant (C), the net gas space corresponds to the size of the compensating tank (Vo) above the zero line. The zero line is the filling limit.

Gas production depends on the amount and nature of the fermentation slurry, digester, temperature and retention time (Figures 7,8).

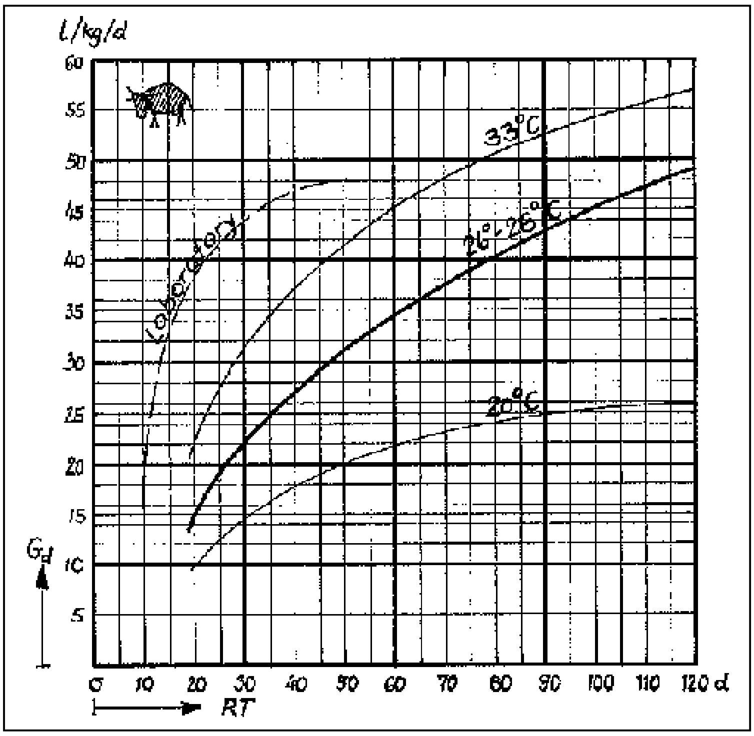


Fig. 7:
Gas production from fresh cattle manure depending on retention time and digester temperature

The curves represent averages of laboratory and empirical values. The values vary a wide range owing to differences in the solids content of the dung, animal feeds and types of biogas plant. Regular stirring increases gas production. The 26-28 °C line is a secure basis for scaling in the majority of cases.

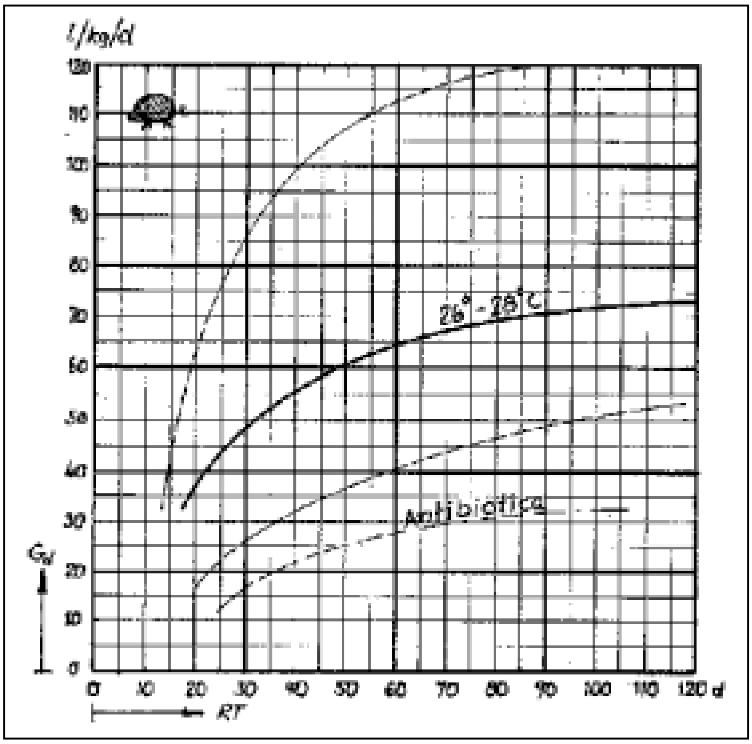


Fig. 8:
Gas production from fresh pig manure depending on retention time and digester temperature

The curves represent averages of laboratory and empirical values. The measured values show an even wider range of variation than in the case of cattle dung. Particularly large variations occur if antibiotics are added to the feed. The 26-28 °C curve is a realistic guide for the planning of a plant.

Gas production is encouraged by high, uniform temperatures (e.g., 33°C), long retention times (e.g., 100 days) and thorough mixing of the slurry.

Gas production is adversely affected by low and fluctuating temperatures (15-25 °C), short retention times (e.g., 30 days) and poor mixing.

Example:

1 kg of cattle dung yields only 15 lof biogas in a retention time of 30 days at a digester temperature of 20 °C. If the retention time is increased to 100 days and the digester temperature to 33 °C, 1 kg of cattle dung gives 54 lof biogas (Figure 7). The size of the gasholder is determined, primarily by the amount of gas drawn off and when it is drawn.

Examples:

A refrigerator operating round the clock consumes all the gas produced on a given day. The gasholder merely has to compensate for fluctuations in the,daily volume of gas produced.
A water pump consumes the entire daily gas production in a few hours. The gasholder must every day collect the entire daytime and night-time production and compensate for daily production fluctuations.

The ratio of gasholder volume (VG) to daily gas production (G) is called the gasholder capacity (C).

Example:

Gasholder volume (VG): 1.5m³ (1500l)
Daily gas production (G): 2.4 m³
Gasholder capacity (C):
1.5 m³ 2.4 m³ = 0.625 = 62.5 %.

The required gasholder capacity and hence the required gasholder size is an important planning parameter. If the gasholder capacity is insufficient' part of the gas produced will be lost. The remaining volume of gas will not be enough. If the gasholder is made too large, construction costs will be unnecessarily high, but plant operation will be more convenient. The gasholder must therefore be made large enough to be able to accept the entire volume of gas consumed at a time. It must also be able to accept all the gas produced between consumption times. Furthermore, the gasholder must be able to compensate for daily fluctuations in gas production. These fluctuations range from 75 % to 125 % of calculated gas production.

Calculation examples for gasholder size:

Daily gas production: 2400 l
Hourly gas production: 2400 -:- 24 = 100 l/h
Gas consumption

from 0600 to 0800 hrs	=2h
from 1200 to 1400 hrs	=2h
from 1900 to 2100 hrs	=2h
Duration of gas consumption:	6 h

To simplify the calculation, uniform gas consumption is assumed. Hourly gas consumption:
2400 l -:- 6 h = 400 l/h

Gas is also produced during consumption. For this reason, only the difference between consumption and production is relevant to the calculation.

D_G = 400 l/h - 100 l/h = 300 l/h

The necessary gasholder size during consumption is therefore:

V_G(1)=300l/h x 2h=600l.

The longest interval between periods of consumption is from 2100 to 0600 hrs (9 hours). The necessary gasholder size is therefore:

V_G(2) = 100 l/h x 9 h = 900 Q.

V_G(2) is the maximum relevant gasholder size. With the safety margin of 25%, this gives a gasholder size of

V_G = 900 l x 1.25 = 1125 £.

The required gasholder capacity is thus:

C = 1 125 l -:- 2400 l= 0.47 = 47 %

Daily gas production: 2400 l
Hourly gas production: 100 l/h
Gas consumption
from 0530 to 0830 hrs =3h
from 1830 to 2000 hrs =1.5h
Duration of gas consumption: 4.5 h

Gas consumption per hour:

2400 l -:- 4.5 h = 533 l/h.

Difference between gas production and consumption:

D_G = 533 l/h -100 l/h = 433 l/h.

Hence the necessary gasholder size during consumption is:

V_G(1)= 433 l/h x 3 h = 1299 l.

The necessary gasholder size in the intervals between consumption results from the period from 0830 to 1830 hrs (10 h). The necessary gasholder size is therefore:

V_G(2) = 100 l/h x 10 h = 1000 Q.

V_G(1) is the larger volume and must therefore be used as the basis. Allowing for the safety margin of 25 %, the gasholder size is thus

V_G = 1299 l X 1.25 = 1624 Q.

The required gasholder capacity thus works out as
C = 1624 l -:- 2400 l= 0.68 = 68 %.

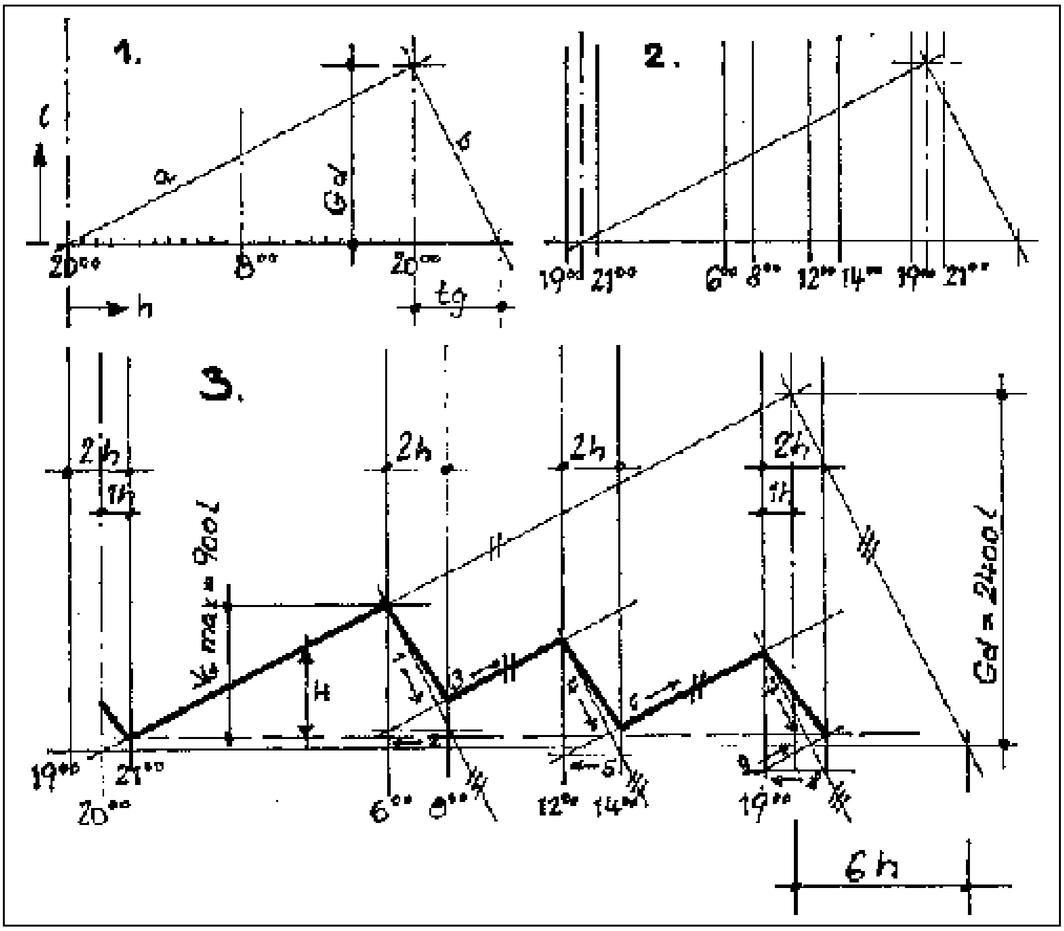


Fig 9: Graphic determination of required gasholder volume in accordance with the first example, page 21/22. Working steps: 1. Plotting of gas production curve (a) and gas consumption curve (b). 2. Plotting of gas consumption times. 3. The gasholder curve (thick line) is determined by parallel shifting in accordance with the numbered arrows (1-9). The value VG does not yet include the safety margin of 25 %

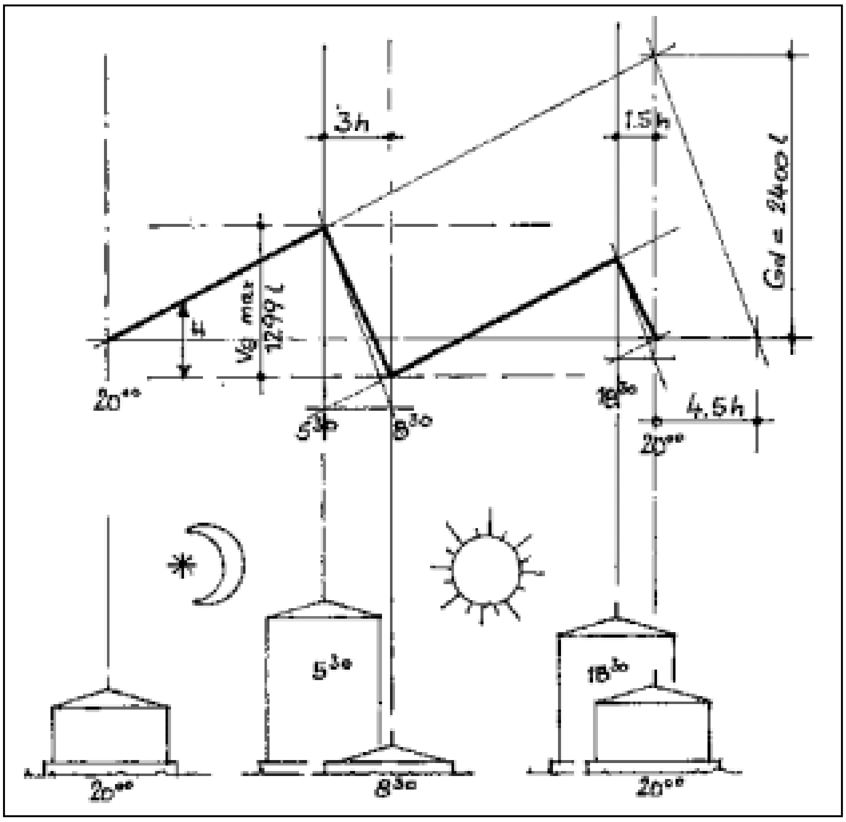


Fig. 10:
Graphic determi-nation of the required gasholder volume in accordance with the second example on page 23/24. The safety margin of 25 % for fluctuating gas production must be added to the value VG. The distance H can also be regarded as the height of the floating gas drum. Experience shows that about the same volume of gas per hour is produced day and night.

A gasholder capacity of 50-60% is normally correct for peasant households in Third World countries. A capacity of 70 % or even more must be allowed only where not more than one meal a day is cooked regularly or where eating habits are highly irregular.

4.4 Digester/gasholder ratio

The form of a biogas plant is determined by the size ratio between the digester and the gasholder (see Figures 11 - 13).

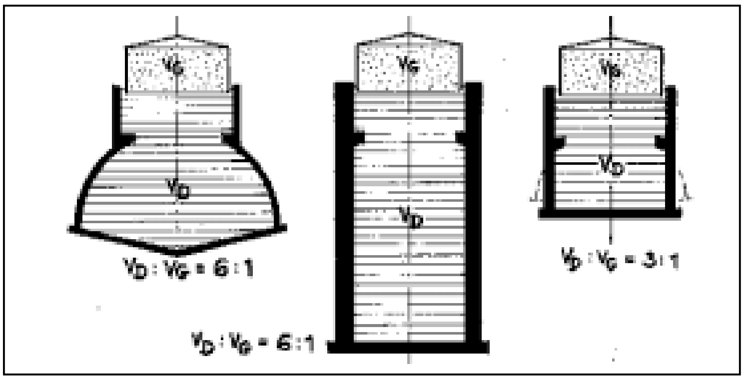


Fig. 11:
Digester/gasholder ratio The ratio of the digester volume (VD) and gasholder volume (VG) substantially determines the shape and design of a biogas plant. These two parameters must be calculated before any project is planned. For a digester/gasholder volume ratio of VD:VG = 6:1, a spherical shell is far more economical than a cylinder even in floating-drum plants.

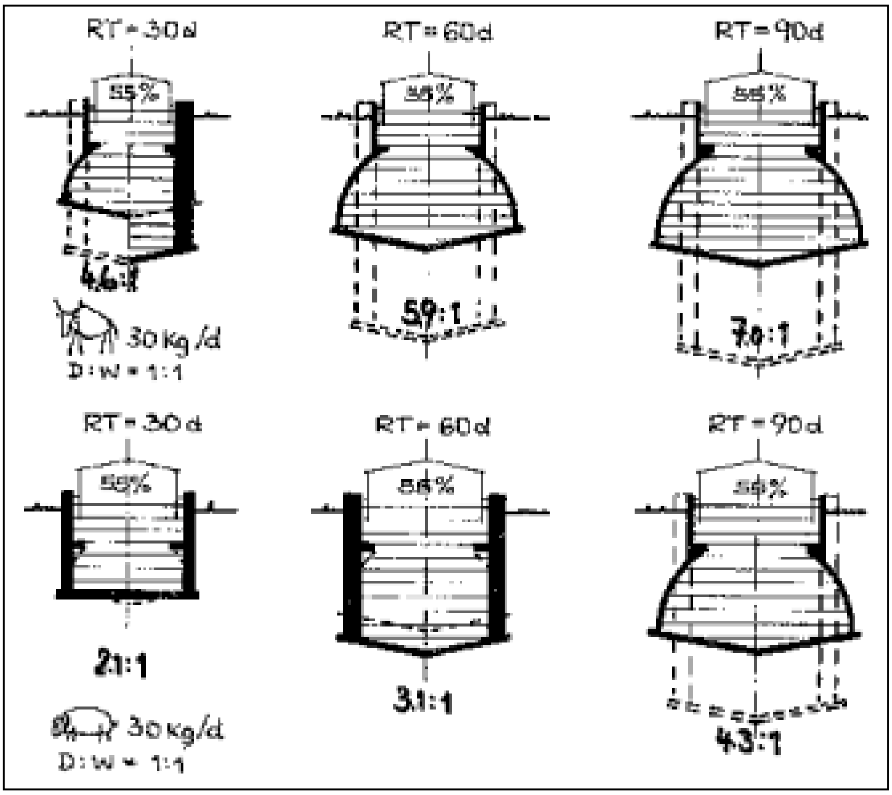


Fig. 12: Dependence of shape on retention time on a floating-drum plant (cattle dung above; pig manure below) Filling volume and gasholder capacity (C = 55 %) are the same in each case. The differences in digester/ gasholder ratios result solely from the differing retention times (RT).

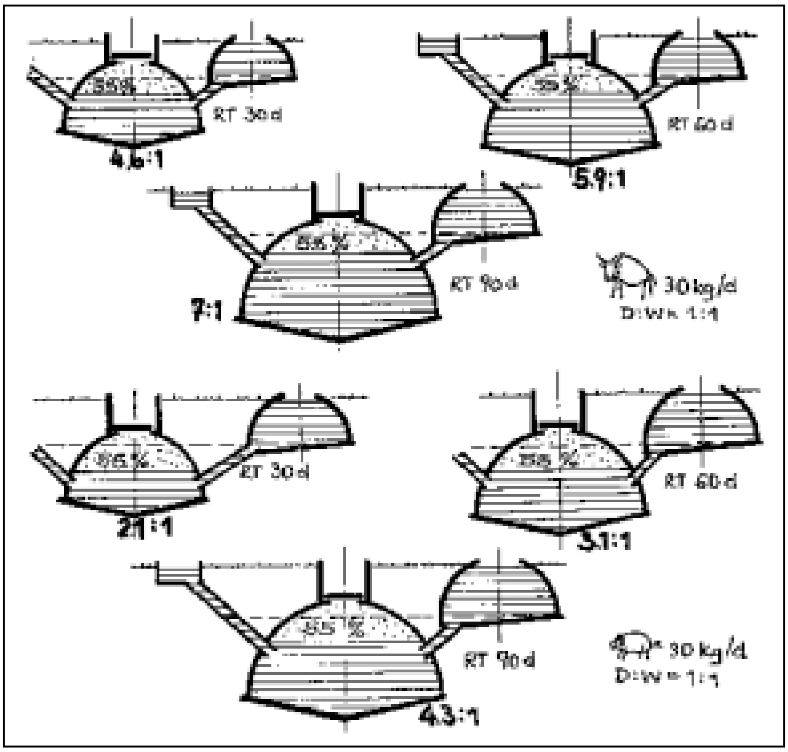


Fig. 13:
Dependence of shape on retention time on a fixed-dome plant (cattle dung above; pig manure below) The filling volume and gasholder capacity (C = 55 %) are the same in each case. The differences in digester/ compensating tank ratios result solely from the different retention time (Gd as a result of RT, Figures 7 and 8).

For floating-drum plants with a low digester/ gasholder ratio (1:1 to 3:1), the best shape for the digester is a cylinder. If the ratio is larger, shell and vault structures are worthwhile.

The digester/gasholder ratio depends primarily on:

- retention time (RT),
- specific gas production (Gd),
- gasholder capacity (C).

The digester/gasholder ratio chosen must be correct regardless of the type of plant, otherwise the biogas plant will not serve its purpose.

In a fixed-dome plant, the digester/gasholder ratio corresponds to the size ratio between the net digestion space and the compensating tank above the zero line (see Figure 6): VD: VG corresponds to VD: VO

The examples given below show the importance of the specific gas production for the scaling of the plant and for the digester/ gasholder ratio.

For extensive biogas plant construction programmes, a knowledge of the specific gas production and the necessary gasholder capacity is particularly important. It is then a good plan to carry out measurements and tests of one's own (see Section 4.5).

Examples for the Calculation:

Feed material: cattle dung, amount (D_d):
30 kg/day
Mixing ratio: dung: water = 1:1
Fermentation slurry amount (S_d):
30 kg/day x 2 = 60 l/day
Retention time (RT): 80 days
Digester volume (V_D):
60 l/day x 80 days = 4800 l
Digester temperature (t): 26 - 28 °C
Specific -gas production (G_d) from Fig. 7:
40 l/kg
Daily gas production (G):
40 l/kg x 30 kg/day = 1200 l/day
Gasholder capacity (C): 60 %
Gasholder volume (V_G):
1200 l x 0.60= 720 l

Digester/gasholder ratio:

V_D:V_G= 4800l: 720 l =6.67: 1
Feed material: pig manure, amount (D_d):
20 kg/day
Mixing ratio: manure: water = 1: 2
Fermentation slurry amount (S_d):
20 kg/day x 3 = 60 l/day
Retention time (RT): 80 days
Digester volume (V_D):
60 l/day x 80 days = 4800 l
Digester temperature (t): 26-28 °C

Specific gas production (G_d) from figure 8:
112 l/day
Daily gas production (G):
122 l/kg x 20 kg/day = 2240 l/day
Gasholder capacity (C): 60
Gasholder volume (V_G):
2240 lx 0.60 = 1344 l
Digester/gasholder ratio:
V_D: V_G = 4800 l 1344 l= 3.6: 1

4.5 Measuring and test programmes

The aim of a measuring and test programme is to determine the specific gas production obtained at specific retention times.

Since digester temperature affects gas production, the latter should be measured at both the coldest and hottest time of the year.

The programme consists of a set of at least four biogas plants of different sizes. A given filling volume results in different retention times, in turn yielding different amounts of gas production for one and the same filling volume.

Example (Figure 14):

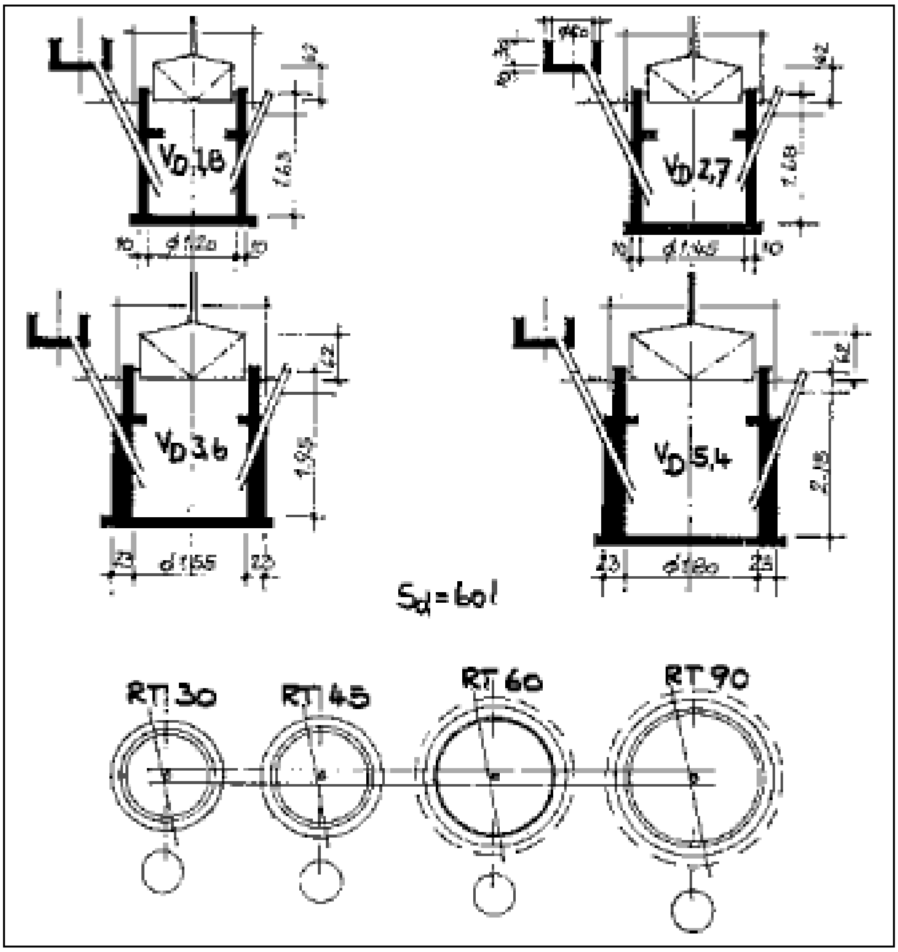


Fig. 14:
Biogas plants for a test programme for determination of gas production The length of the retention time (RT) has the greatest effect on digester size (VD). Test plants may have any shape. However' they should all be identical and should preferably conform to the type to be used later in a biogas programme. The test plants must be filled regularly for at least three months before gas production is measured. The gasholders must be all the larger, the longer the time between tests. Safe spanning of the after-dark hours must be ensured.

Filling volume: 30 kg manure and 30 l water; 60 l/day
Retention times (RT) chosen: 30, 45, 60 and 90 days

Required digester volume:

RT(30): VD = 30 x 60 = 1800 l (1.8 m³)
RT(45): VD = 45 x 60 = 2700 l (2.7 m³)
RT(60): VD = 60 x 60 = 3600 l (3.6 m³)
RT(90): VD = 90 X 60 = 5400 l (5.4 m³)

Specific gas production is determined by dividing the daily volume of gas measured by the amount of slurry loaded into the plant (30 kg).

The results are plotted in a curve(like Figure 7 and 8) and are used for the scaling and calculation of the digester and gasholder volumes.

If a test programme is too expensive or complicated, the actual gas production values can also be derived from the results of measurement of a number of existing plants. For this purpose, the volume of gas stored must be measured before and after each consumption (Figure 15). Measurements must be effected for at least three consecutive days and nights.

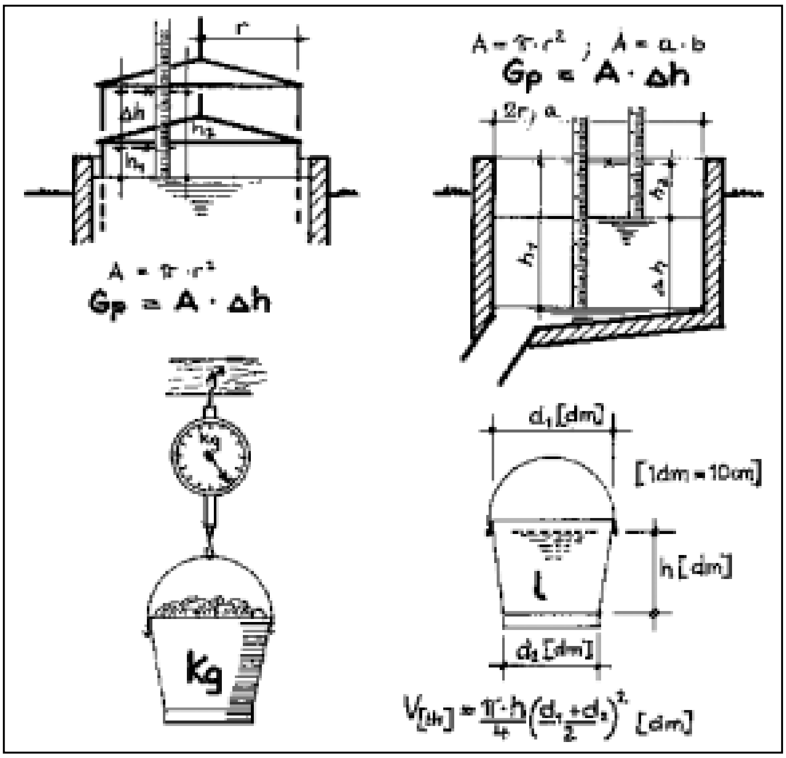


Fig. 15:
Measuring gas production on the plant In a floating-drum plant, the height of the gasholder is measured (top left), In a fixed-dome plant, the height of the slurry level is measured (top right). The manure is either weighed or measured in litres before introduction to the plant. Containers whose shape is easy to calculate are more accurate. If the lengths are measured in dm (1 dm = 10 cm), the volume in litres is obtained directly.

5. Design of biogas plants

5.1 Shape and static loading

A biogas plant should be watertight. The gasholder must be gaslight. For this reason a biogas plant must have no cracks. But structures of masonry or concrete always crack. One can try to keep the cracks small. And one can determine the position where the cracks are to arise.

Cracks always arise where the tensile stresses are highest. Tensile stresses arise from tensile forces, flexure, displacements, settling and temperature fluctuations. When mortar or concrete sets, shrinkage cracks also form.

Stresses are high where the "external" forces are high. "External" forces are earth pressure, dead weight and applied load. Stresses are highest where the "internal" forces are highest. "Internal" forces are flexural, normal, gravitational and torsional forces.

The "external" forces can be reduced by favourable shaping of the structure. The liquid pressure and earth pressure are less in a low biogas plant. This is because both depend directly on the height (see Figure 57).

The "internal" forces can also be reduced by favourable shaping of the structure. If the "external" forces can act in one direction only, high "internal" forces arise. If, however, the "external" forces can be distributed in a number of directions, small "internal" forces arise. This is the case with all curved surfaces or "shells" (see Figure 16).

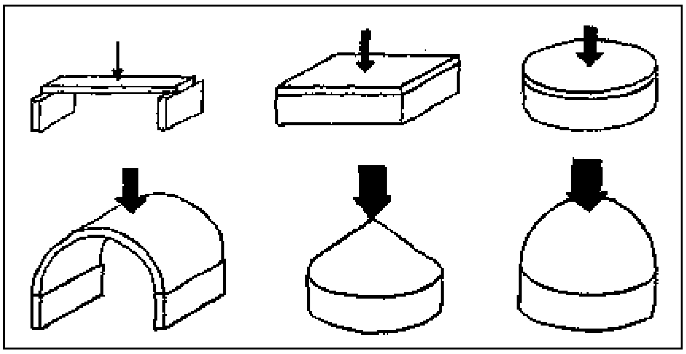


Fig. 16: Shape and load-bearing capacity.

Slabs will support a heavier load than beams for a given thickness of material. A curved shell supports more than a flat slab. A shell cuned in more than one dimension supports more than a shell of simple curvature. Curved structural components are more rigid; the stresses are smaller in them. Just imagine how thick the shell of a hen's egg would have to be if it were shaped like a cube!

Cracks arise where stresses are high. Particularly high stresses - "peak stresses" - arise at points where the stress pattern is disturbed.

Such disturbances occur at edges, angles, corners and under concentrated, applied or other loads. Disturbances arise along the line of intersection of surfaces. Cracks form at these points due to peak stresses.

Peak stresses always arise at the edges of angular structures. For this reason the gas space of a fixed-dome plant must never be angular.

Cracks arise owing to tensile stresses. If a component is under compression, it is free from cracks. The gas space of a fixed-dome plant should therefore always be under pressure at every point.

The liquid pressure of the fermentation slurry is directed outwards. The earth pressure is directed inwards. If the two forces balance reliably, the load on the structure is relieved. In a vaulted shape' the external loading is obtained even if the earth is stiff and cracked owing to drought (Figure 17-19).

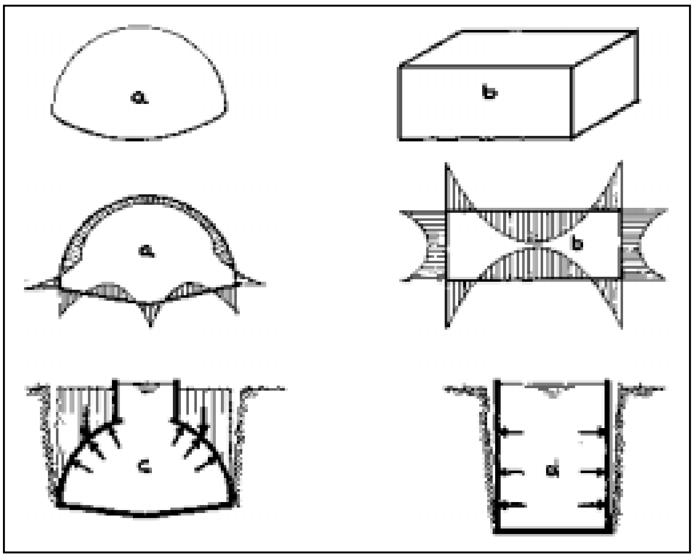


Fig. 17:
Same volume - different shape Different shapes have different stress patterns under the same load (a and b). The round shape has lower stresses. The angular shape has high stresses and many stress peaks. Different shapes are often loaded differently. In a vaulted shape, the loads acting in different directions are more reliably balanced than with a vertical wall (c and d).

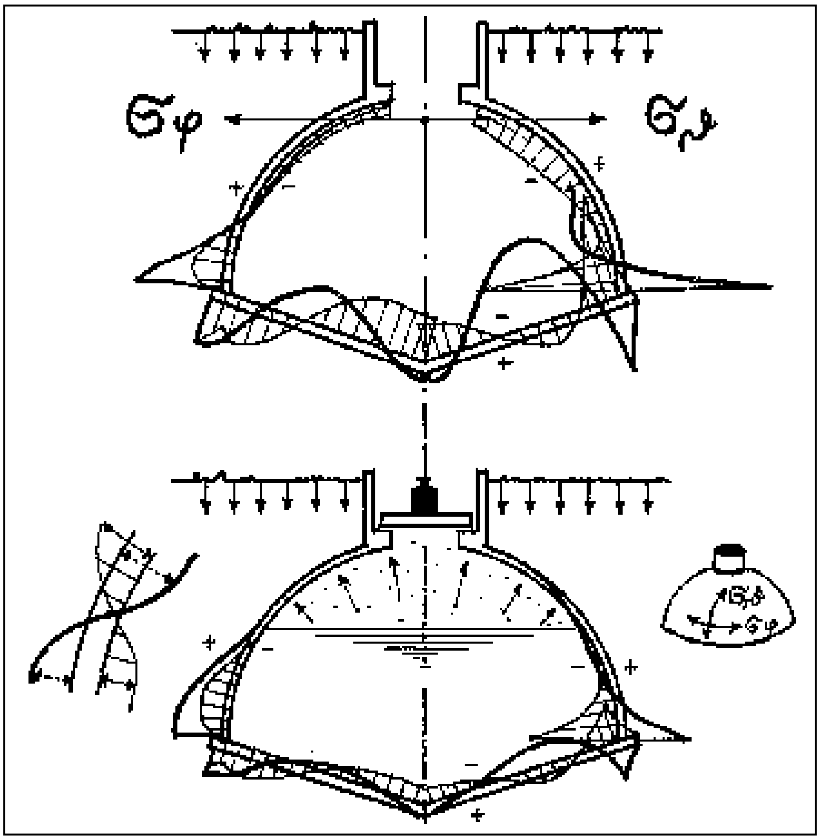


Fig. 18:
Pattern of stresses in a fixed-dome plant of masonry construction Top: empty; bottom: filled and with maximum gas pressure. The peak stresses shown are those resulting from the first approximation calculation. In practice they are reduced by deformation (with or without cracking). Positive (+) tensile stresses do not occur in the gas space.

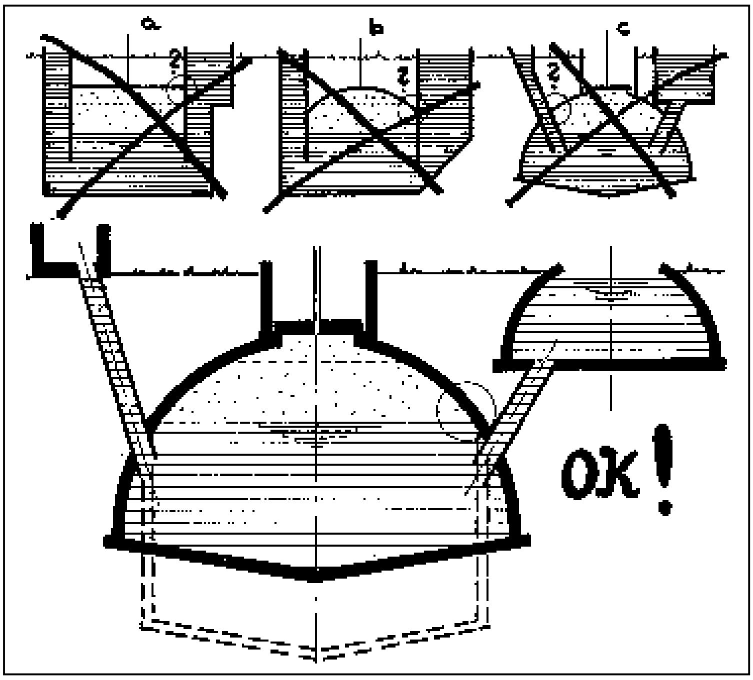


Fig. 19:
Cracks in the gas space of a fixed-dome plant Angular gas spaces must on no account be used (a)! The transition from the roof arch to the wall must never be at a higher level than the lowest slurry line (b). Inlet and outlet penetrations must never be situated in the gas space (c). The gas space must remain undisturbed. Only the entry hatch at the top is allowed, because it can easily be checked.

A round shape is always a good shape, Because a round shape has no corners. Because its load pattern is more favourable. And because it uses less material. A round shape is often easier to build than an angular one (see Section 5.3). The rounder the better!

5.2 Bottom slab

The bottom slab is loaded at its edge by the weight of the digester wall. In the case of a spherical shell, the weight of the earth load also acts on it. The bottom slab distributes the weight over the ground of the site. The larger the foundation area, the less settlement will be experienced. The more even the loads, the more even the settlement. The more even the settlement, the less the risk of cracking.

A "rigid" shell distributes the weight better than a "soft" slab.

The weight of the fermentation slurry presses uniformly on the ground. Where the ground is of unequal consistency (e.g., boulders in loamy soil), loads must be distributed within the bottom slab. If the slab is too weak, it will break and cease to be watertight.

A "rigid" shell distributes the loads better than a "soft slab".

A vaulted shell is the best foundation shape. But a concial shell is easier to excavate. The only implement required is a straight piece of wood.

Building material available locally is used for the bottom slab. One of the following will be chosen on grounds of economy:

- quarrystone with a cement mortar filling and a cement floor,
- brick masonry with a cement floor,
- concrete.

Steel ring reinforcement at the outer edge increases the loadbearing capacity of the bottom.

However, such reinforcement is not usually necessary. It is more important for the ground to be firm and clean. If the soil consists of muddy loam, it must first be covered with a thin layer of sand.

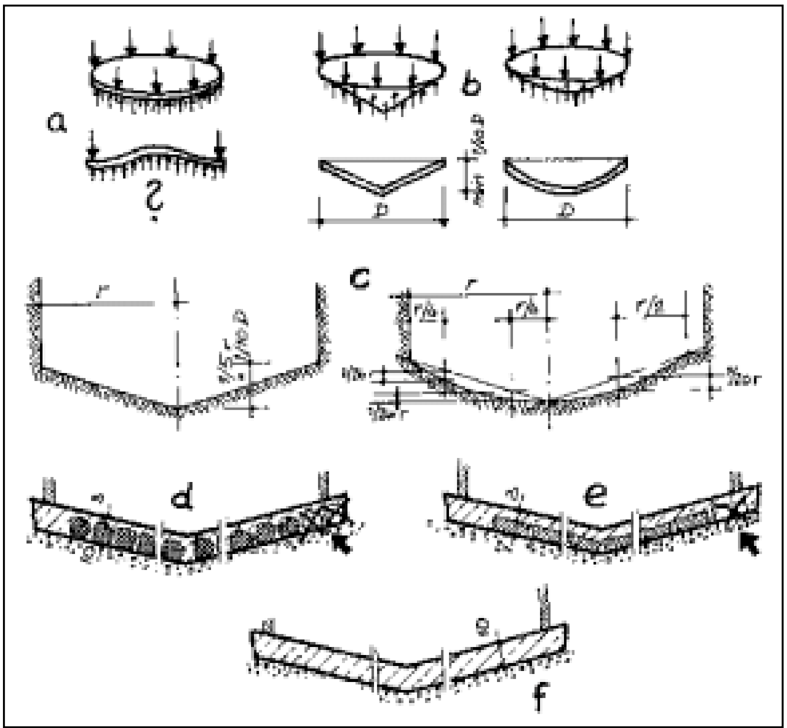


Fig. 20:
The bottom slab A flat slab must be flexurally rigid if it is to distribute the edge loads over the entire surface (a). Shells ate flexurally rigid (b). Proceeding from a conical shell to a spherical shell (c). Possible forms of construction: Quarrystone with cement mortar (d). Masonry with cement floor (e) and concrete (f). Underneath the wall the bottom slab should be made out of massive concrete.

5.3 Spherical shell of masonry construction

The construction of a spherical shell from masonry (Figure 21) is completely problem-free. Every bricklayer can master this technique after once being shown how to do it. Concreting a vault, on the other hand, calls for much more skill and craftsmanship owing to the complicated formwork - the one exception being when the masoned shell is intended to serve as permanent formwork. A spherical shell of masonry is simple to construct because the radius always extends from the same centre. A trammel (A) is the only aid required. Bricks are stacked to get the right height for the centre. Lean mortar is used for the stack, which is subsequently demolished (M). No centring is necessary for laying the bricks.

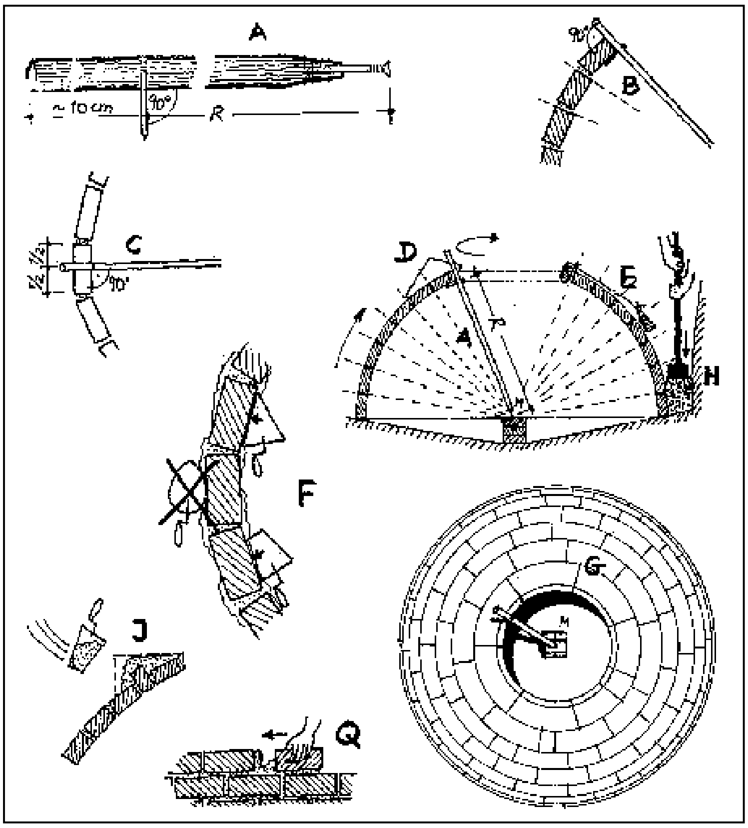


Fig. 21:
Construction of a spherical shell from masonry
When the bricks are laid, it is important for their tops to be parallel with the bottom edge of the trammel (B), from the very first course. The bricks are laid perpendicularly and centrally to the trammel (C). In the upper part - when the trammel is standing at a steeper angle than 45° - the first brick in each course must be held until the circle is complete. Each brick inbetween must be held only until the next brick is set. For this purpose, clamps (D) or counterweights of stones tied together (E) are used. The bricks can also be supported with sticks.

The mortar must be mixed from finely sieved sand (maximum particle size 3 mm). If the sand is too coarse, the mortar will be difficult to work. It has to "stick" to the sloping, narrow surface of the brick. Compo (cement/ lime) mortar is "stickier" than pure cement mortar. "Squeezed joints" (Q) should be used. The trowel should have straight sides, so that the squeezed-out mortar can be scraped off and reused (F). As in any masonry construction, the joints must be offset (G). The terminal ring is rendered. The last but one course of bricks is laid on end (J).

When backfilling, the footing point must be tamped particularly well: one man filling and two men tamping (H).

5.4 Masonry and mortar

The mortar and bricks should have about the same strenght. If the bricks are soft, the mortar must also not be too hard. If a good brick is thrown on to the ground three metres away, it must not break. If the bricks are of poor quality, the walls must be thicker. Mortar consists of sand, water and the binders. Cement gives a solid, watertight mortar. Cement mortar is brittle in masonry construction. Lime gives a soft, sticky mortar.

For masonry construction, cement mortar should always include a certain amount of lime. This makes it more workable, and the masonry becomes more watertight.

Mixing ratio:

Masonry mortar	2 (cement)	: 1 (lime)
		: 10(sand)
or	1 (cement)	: 6 (sand)
Rendering mortar	1 (cement)	: 4 (sand)
better	1 (cement)	: 3 (sand)

The most important part of the mortar is the sand. It must be clean. It should not contain any loam, dust or organic matter. Mortar sand with a high proportion of dust or loam "eats up" much more cement than clean sand.

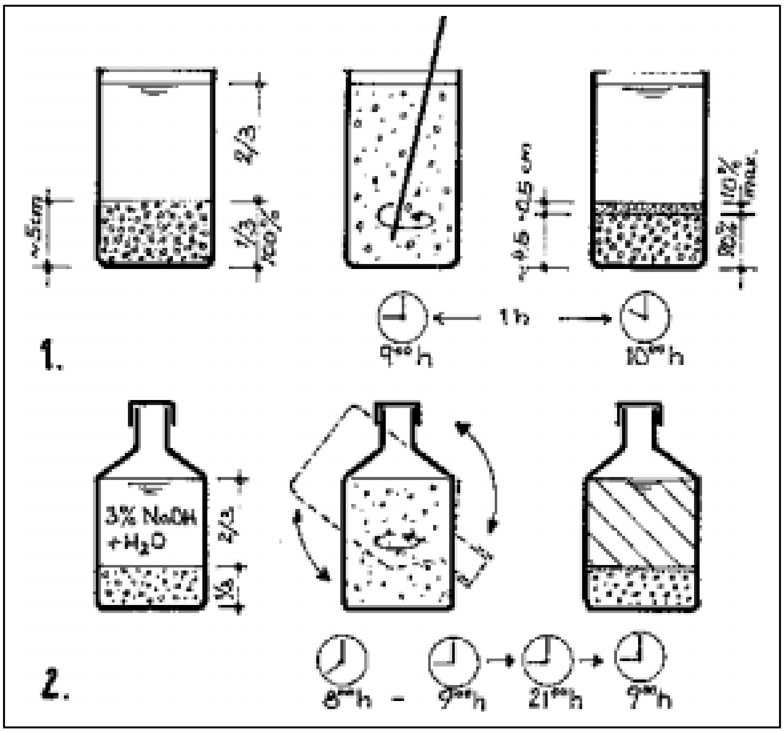


Fig. 22: T
esting of mortar sand 1. Fines (loam, dust): Water glass 1/3 sand, 2/3 water. stir vigorously. Leave to stand for one hour. Measure fines. A maximum of 10 % of the amount of sand is permissible. 2. Organic matter: Bottle with stopper (not cork) to be filled with 1/3 sand and 2/3 soda lye (3 %). Shake repeatedly within an hour. Leave to stand for 24 hours. Water colour clear or light yellow: good; red or brown: bad.

The bricklayer or works foreman must check the sand before use (Figure 22). Sand may contain not more than 10% dust or loam, otherwise it must be washed. Soda Iye can be used to test whether the sand contains excessive organic matter. The following points are important when rendering:

- The rendering mortar must be compressed by vigorous, circular rubbing.
- All edges must be rounded.
- All internal angles must be rounded with a glass bottle.

5.5 The parts of a biogas plant and their functions

The feed material is mixed with water in the mixing tank (Figure 23). Impurities liable to clog the plant are removed here. The fermentation slurry flows through the inlet (Figure 24) into the digester. A stick is inserted through the inlet pipe' to poke and agitate the slurry. The bacteria from the fermentation slurry are intended to produce biogas in the digester (Figure 25). For this purpose they need time. Time to multiply and to spread through- ' out the slurry. The digester must be designed so that only fully digested slurry can leave it. Partitions (Figure 26) ensure that the slurry in the digester has long flow paths. The bacteria are distributed in the slurry by stirring (with a stick or stirring facilities, see Figure 27). If stirring is excessive, the bacteria have no time "to eat". The ideal is gentle but intensive stirring about every four hours. Optimum stirring substantially reduces the retention time.

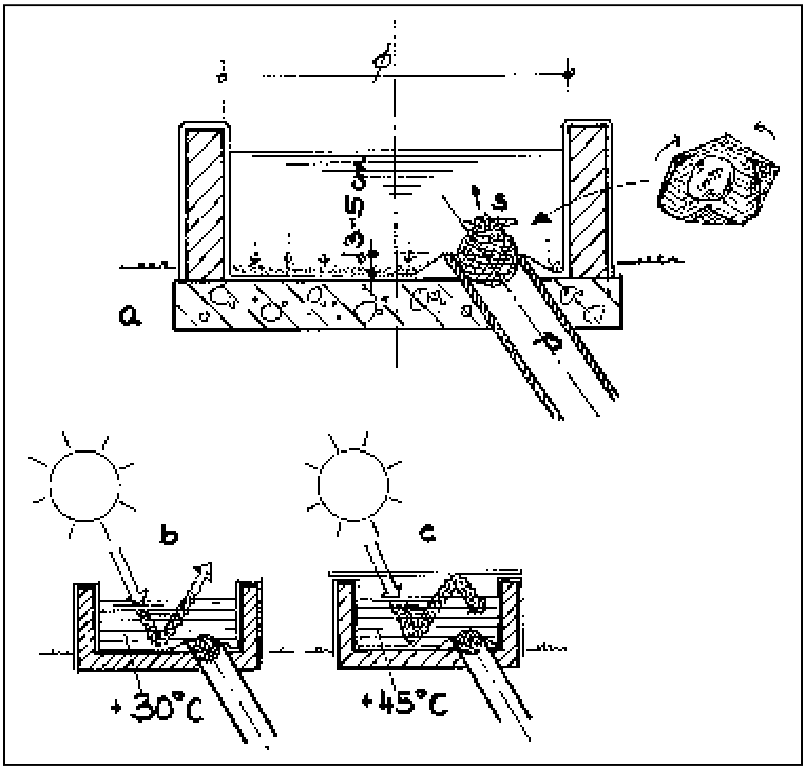


Fig. 23:
Mixing tank at inlet Grit and stones settle at the bottom of the mixing tank. For this reason the inlet pipe (p) should be 3-5 cm higher than the tank bottom. A round, cylindrical shape is cheapest and best for the mixing tank. If the tank is filled in the morning and then covered, the slurry heats up in the sun until the evening (c). Only then is the plug removed (s).

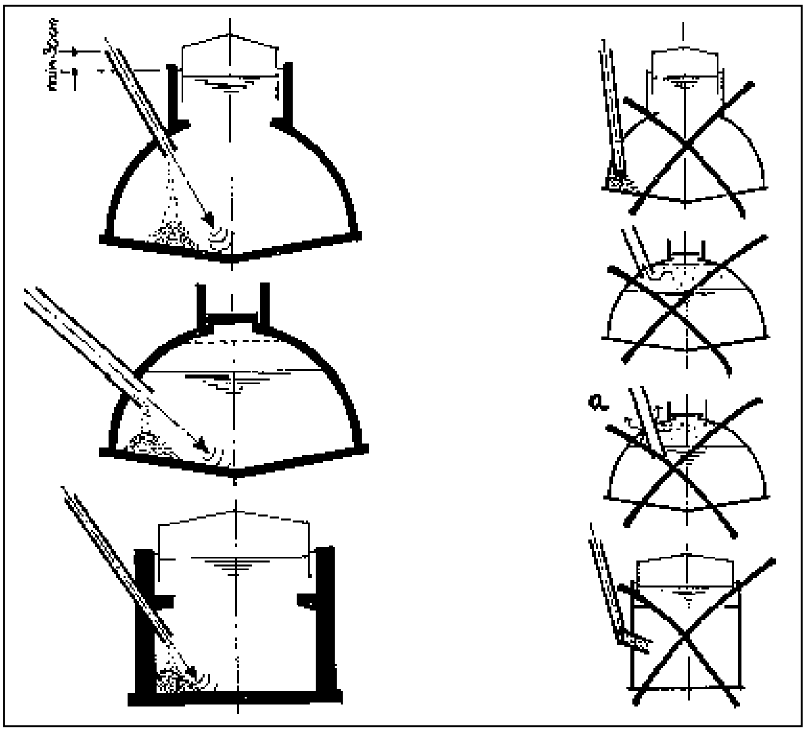


Fig. 24:
The inlet The inlet must be straight. The axis of the inlet pipe should, as far as possible, be directed into the centre of the digester. This facilitates stirring and poking. The inlet should be as high as possible, so that gritty deposits do not block the inlet pipe. In fixed-dome plants, the inlet pipe must not pass through the gas space (a). For fibrous feed material, the diameter should be 200-400 mm.

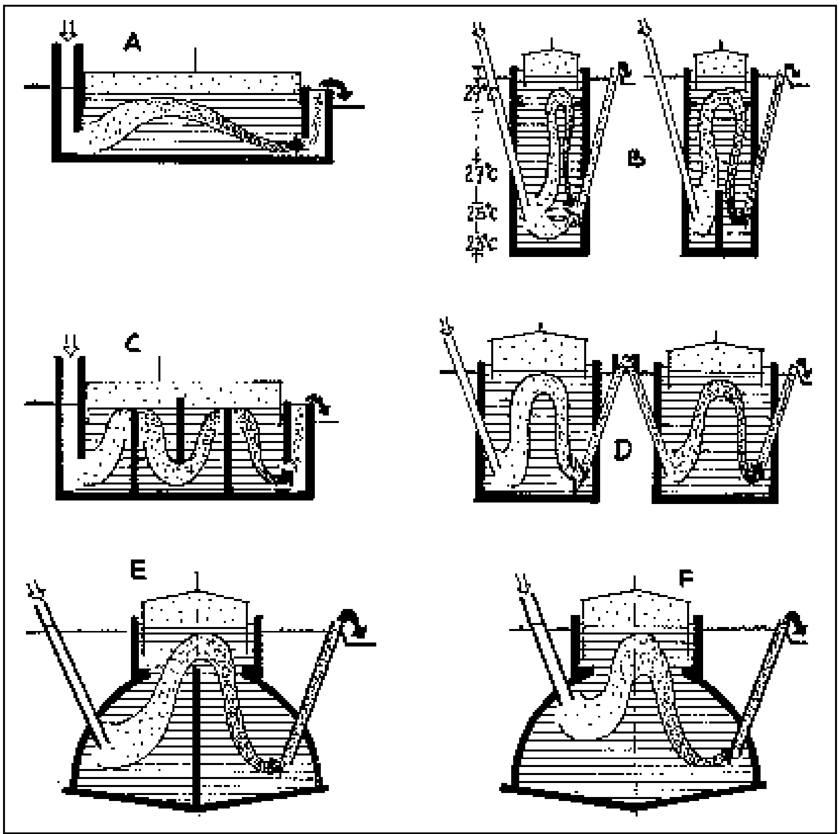


Fig. 25:
Path of the fermentation slurry in the digester Fresh fermentation material is lighter than fully digested sludge. For this reason the former quickly rises to the surface and then sinks only gradually. The digestion process has two phases. The better these phases are separated, the more intensive the gas production. The fermentation channel (A) satisfies these conditions best. Tandem plants are expensive and complicated (D). The deeper the digester, the lower and less uniform its temperature.

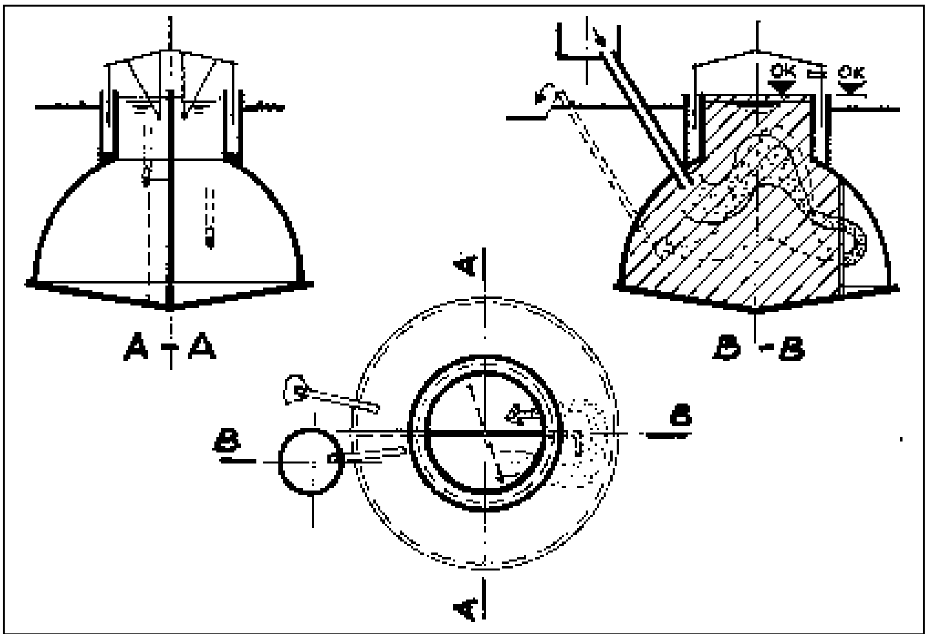


Fig. 26: Hemispherical plant with partition wall The principle of the fermentation channel is obtained by the fact that the inlet and outlet pipes are close together. The partition wall extends up above the surface level of the fermentation slurry. The gasholder must therefore float in a water jacket. The "horizontal KVIC gobar gas plant", which is similar in design, works perfectly with high gas production.

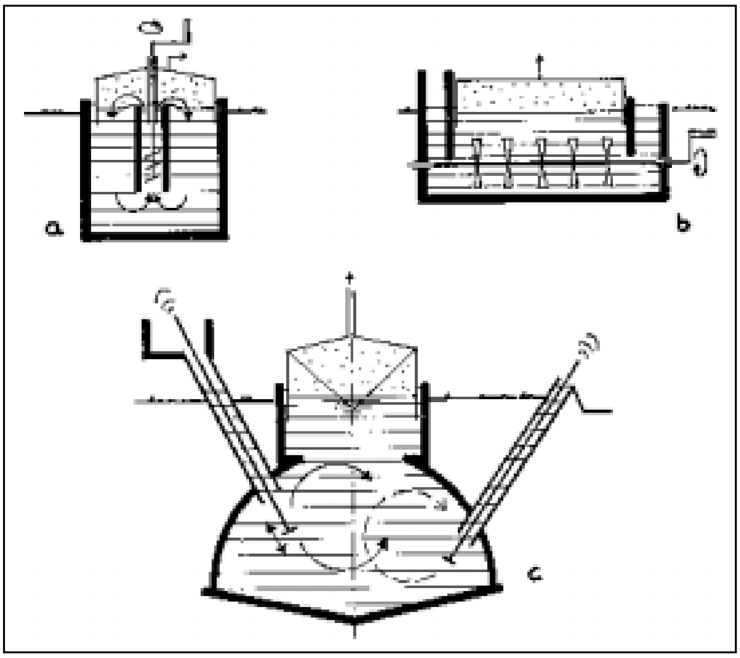


Fig. 27:
Stirring facilities in the digester The impeller stirrer (a) has given good results especially in sewage treatment plants. The horizontal shaft (b) stirs the fermentation channel without mixing up the phases. Both schemes originate from large-scale plant practice. For simple household plants, poking with a stick is the simplest and safest stirring method (c). What matters is not how good the stirring arrangements are but how well the stirring is performed.

The fully digested slurry leaves the digester through the outlet (Figure 28).

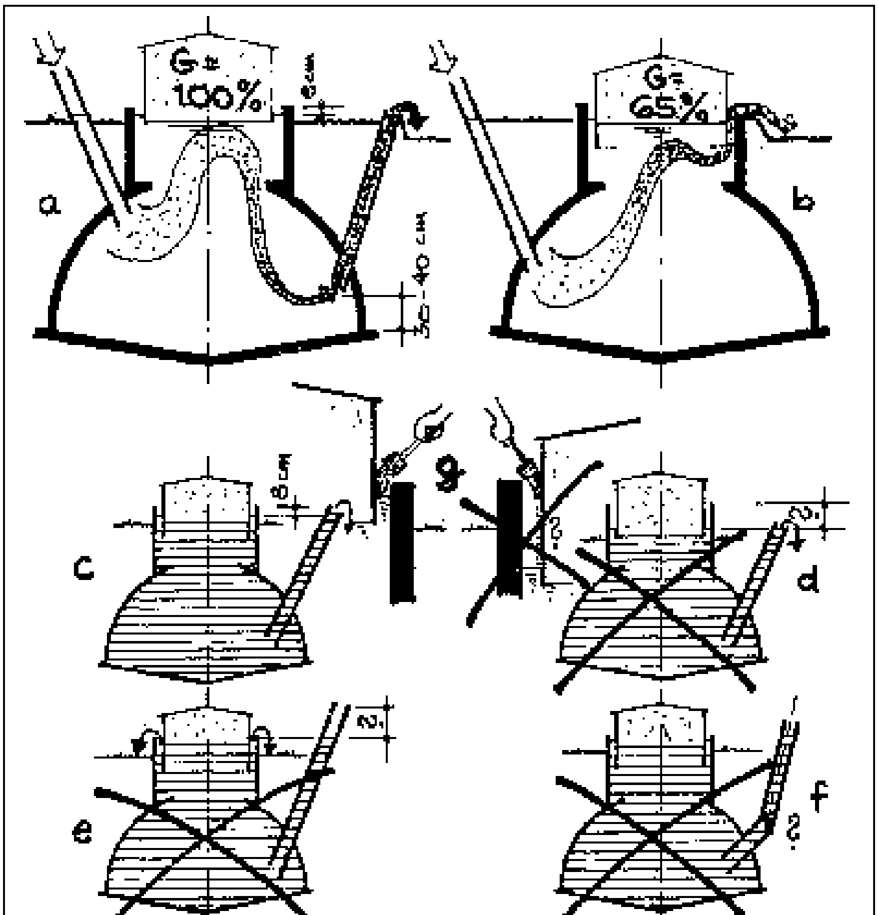


Fig 28:
Outlet (overflow) of a floating-drum plant The outlet should be placed below the middle of the digester, otherwise too much fresh feed material will flow out of the plant too soon, thus reducing gas production by as much as 35 % (b). The height of the outlet determines the level of the surface of the fermentation slurry (c-f). This should be 8cm below the top edge of the wall. If this is not the case, difficulty will be experienced in painting. If the outlet is too low, digester volume is lost (d). If it is too high, the slurry will overflow the edge of the wall (e).

The biogas is collected and stored until the time of consumption in the gasholder. The prime requirement for the gasholder is that it must be gaslight. Floating gasholders are held by a guide.

In fixed-dome plants, the compensating tank acts as a storage facility for the slurry displaced by the biogas. In this case the gas is collected and stored in the upper part of the digester.

The gas pipe carries the biogas to the place where it is consumed. Condensation collecting in the gas pipe is removed by a tap or water trap. Flexible gas pipes laid in the open must be UV-resistant.

5.6 Floating gas drum

The gas drum normally consists of 2.5 mm steel sheet for the sides and 2 mm sheet for the cover. It has welded-in braces. These break up surface scum when the drum rotates.

The drum must be protected against corrosion. Suitable coating products are oil paints, synthetic paints and bitumen paints. Correct priming is important.

One coat is as good as no coat. Two coats are not enough. There must be at least two preliminary coats and one topcoat.

Coatings of used oil are cheap. They must be renewed monthly. Plastic sheeting stuck to bitumen sealant has not given good results. In coastal regions, repainting is necessary at least once a year, and in dry uplands at least every other year. Gas production will be higher if the drum is painted black or red than with blue or white, because the digester temperature is increased by solar radiation. Gas drums made of 2 cm wire-mesh-reinforced concrete or fibrocement must receive a gaslight internal coating.

The gas drum should have a slightly sloping roof (Figure 29), otherwise rainwater will be trapped on it, leading to rust damage. An excessively steep-pitched roof is unnecessarily expensive. The gas in the tip cannot be used because the drum is already resting on the bottom and the gas is no longer under pressure.

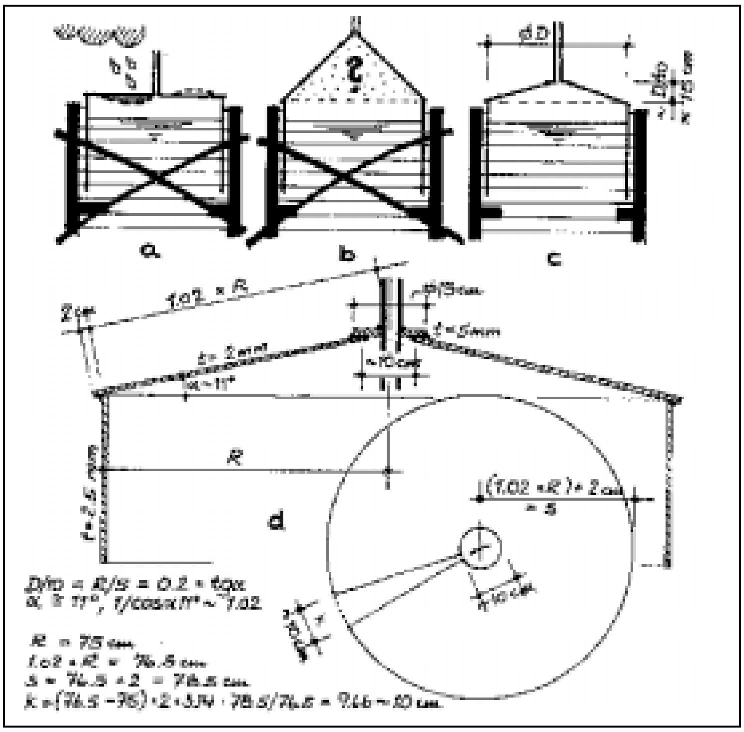


Fig. 29:
The gas drum The gas drum should have a slightly sloping roof. When the cover plate is cut, a wedge (k) should be cut out. The cover plate must be rather larger than the diameter of the drum (see calculation at bottom left). Inaccuracies can more easily be corrected if a lateral overhang of 2 cm is allowed.

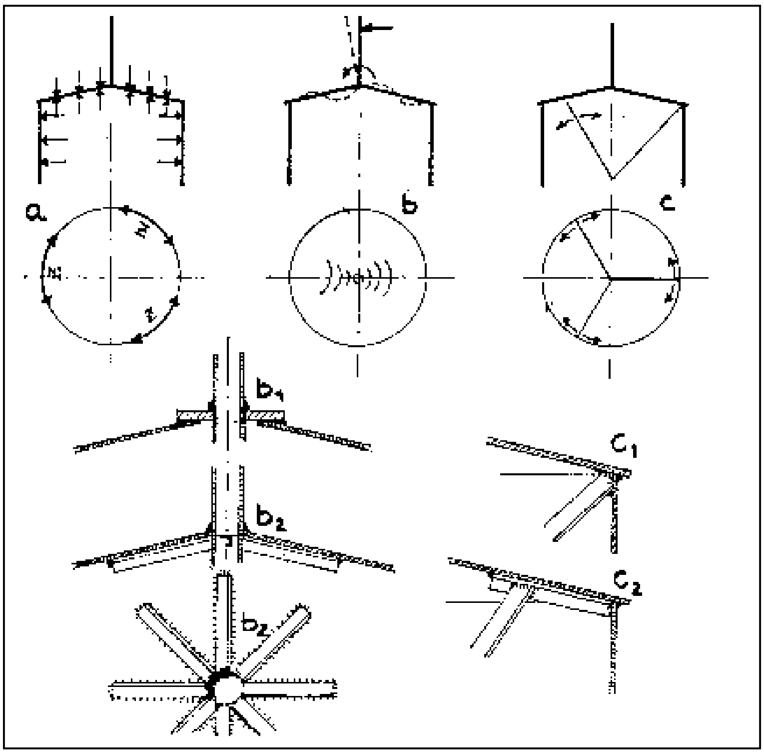


Fig. 30:
Forces on the gas drum The gas pressure and the weight of the metal itself give rise only to tensile forces in the jacket sheet. No reinforcements are necessary for these to be withstood (a). The loads from the guide tube must be reliably transmitted to the cover plate (b). A flange plate (b1) or angle iron (b2) is required for this purpose. The braces are stressed when the drum i,s rotated (c). They should not simply butt on to the metal but end in a corner (c,) or at an angle (c2).

The side wall of the gas drum should be just as high as the wall above the support ledge. The floating-drum must not scrape on the outer walls. It must not tilt, otherwise the paintwork will be damaged or it will jam. For this reason a floating-drum always requires a guide (see Figures 31 and 32). The guide frame must be designed so that the gas drum can be removed for repair. The drum can only be removed if air can flow into it, either the gas pipe should be uncoupled and the valve opened, or the water jacket emptied.

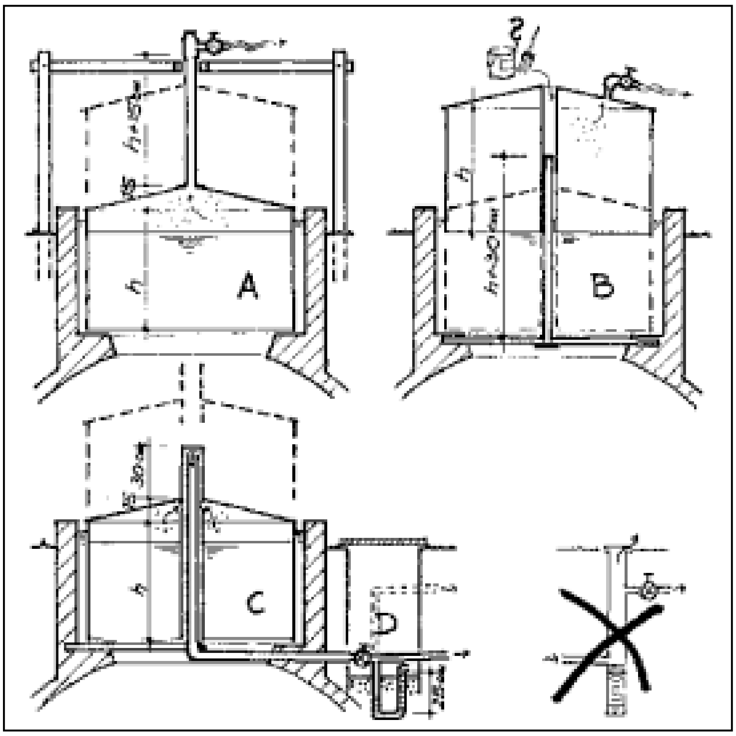


Fig. 31:
Floating drum guide frame An external guide frame (A) is cheapest. It is made of tubular steel, sectional steel or wood. The guide tube also acts as the gas outlet. With scheme (B), the open pipe is problematic. It cannot be reliably painted. The tidiest, but also the most expensive, solution is a guide with internal gas outlet (C). For the water trap (D) see also Figure 40. Guide frames for heavy gas drums must withstand large forces. All joints and anchor points must be just as strong as the pipes themselves.

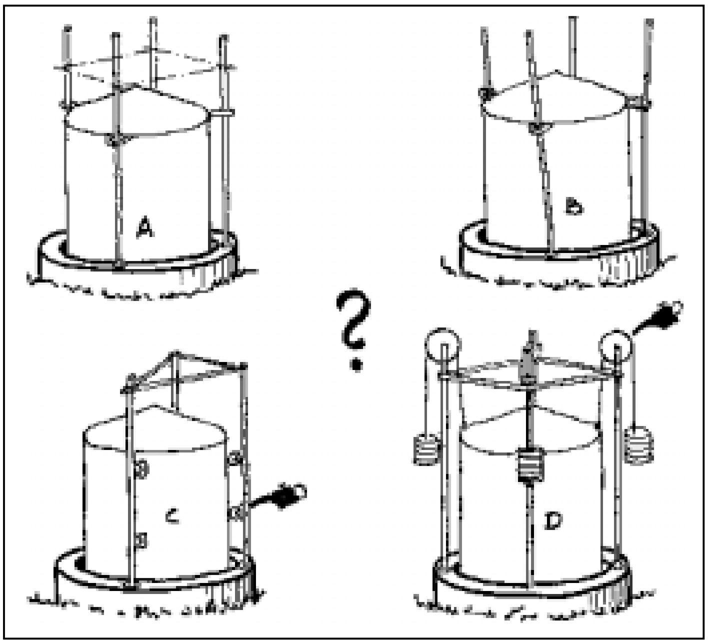


Fig. 32:
Unsuitable guidance systems for floating drums With these guides, the gas drum cannot be rotated. This means that floating scum cannot be broken up. The rollers and bearings must be lubricated. In arrangement (C), the paintwork of the drum is damaged. Plant (B) is jammed if only one of the guide rods is not vertical. A central guide tube is always better!

5.7 Water-lacket plant

The water-jacket plant (Figure 33) is a special case of the floating-drum plant. The drum floats in a water bath and not direct in the slurry. Water-jacket plants can handle substrates with a high solids content without danger of drum blockage due to crust formation.

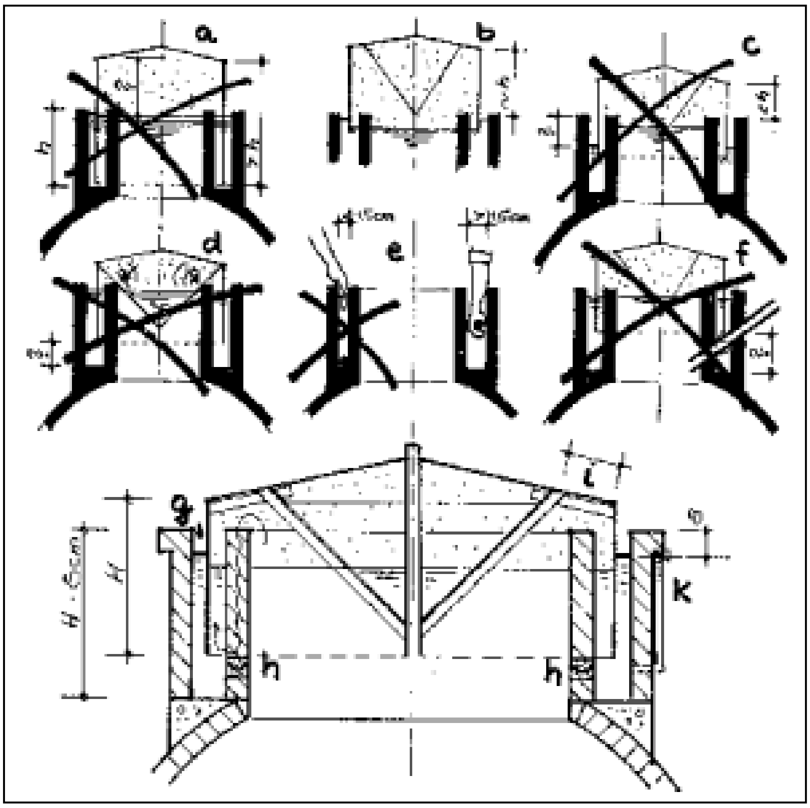


Fig. 33:
The water jacket.
The floating-drum must be able to move freely up and down in the water jacket. It must be free to rotate. The inner braces must not rest on the inner edge of the wall (d). They must therefore begin offset at least 20 cm inwards (i). The water jacket must always be filled to the top, as the gas space will otherwise be reduced (c). A few drops of oil slow down the evaporation of water (g). The inner wall must either be gaslight at the base or rest on a ring of "gaslight" mortar (h). An overflow pipe can be installed to keep excessive rainwater from carrying off the oil film during the rainy season (k). The overflow pipe must not protrude into the water jacket.

The water-jacket is particularly suitable where human excrement is to be digested. Of all simple systems, the water-jacket plant is the cleanest. The gas drum rusts less in the water jacket than if it were floating directly in the slurry.

The water in the jacket evaporates quickly. For this reason the water level must be checked regularly. A few drops of used oil on the water surface prevent rapid evaporation and protect against corrosion (Figure 33,g). A rainwater overflow pipe can be quite helpful.

The inner wall of the water jacket is inside the gas space. Its upper part must receive a gaslight coating or rest on a gaslight ring, otherwise the gas will escape through the porous wall (Figure 33,h).

The water jacket must be kept absolutely free. If it is not, the floating drum cannot move up and down without impediment. The inlet or gas pipes must of course not be fed through the water jacket (Figure 33, f). The water jacket must be wide enough to allow objects inadvertently dropped into it to be retrieved (Figure 33, e).

The walls of the water jacket are as high as those of the gas drum.

If the drum is too high, the last gas cannot be used. The weight of the gas drum cannot then exert any more pressure on the gas (Figure 33, a).

If the walls of the ring are too high, unnecessary construction costs arise.

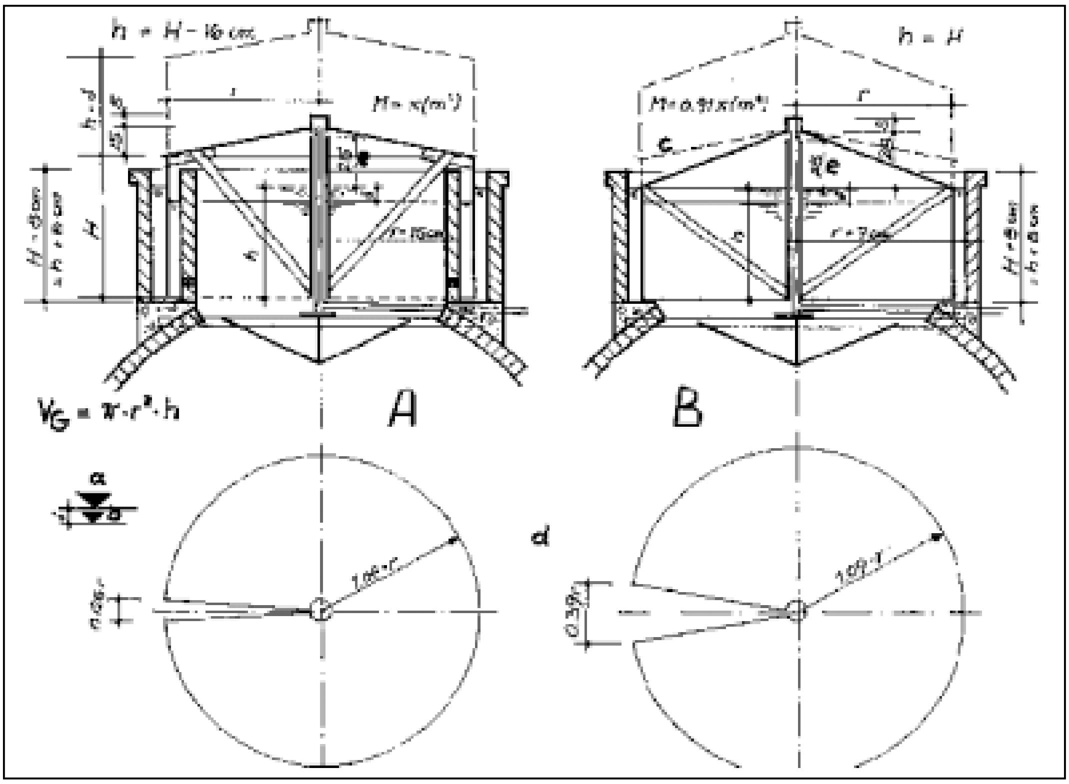


Fig. 34: Comparison of floating drums for water-jacket plants (A) and for plants with internal gas outlet (B): Bot types of plant are assumed to have the same gas-holding capacity. The distance between the top rim of the gas outlet pipe and the slurry level (A) depends on the shape of the drum. a: Overflow level or unpressurized slurry level; b: Pressurized slurry level; c: gasholder configuration as in A; d: Comparison of sheet metal cutouts for drum lids.

5.8 Fixed-dome plants

The top part of a fixed-dome plant (the gas space) must be gaslight. Concrete, masonry and cement rendering are not gaslight. The gas space must therefore be painted with a gaslight product.

Gastight paints must be elastic, This is the only way to bridge cracks in the structure.

Latex or synthetic paints (PVC or polyester) are suitable. Epoxy resin paints are particularly good. Polyethylene is not very gaslight. Hot paraffin coatings also serve well. The walls are first heated with a torch. Then hot paraffin (as hot as possible) is applied. Since the paraffin will only adhere to thoroughly dry masonry, it may have to be dried out first with the aid of a charcoal fire.

Fixed-dome plants produce just as much gas as floating-drum plants - but only if they are gaslight. However, utilization of the gas is less effective as the gas pressure fluctuates substantially. Burners cannot be set optimally.

Figures 35 and 36 show mayor details of the compensating tank.

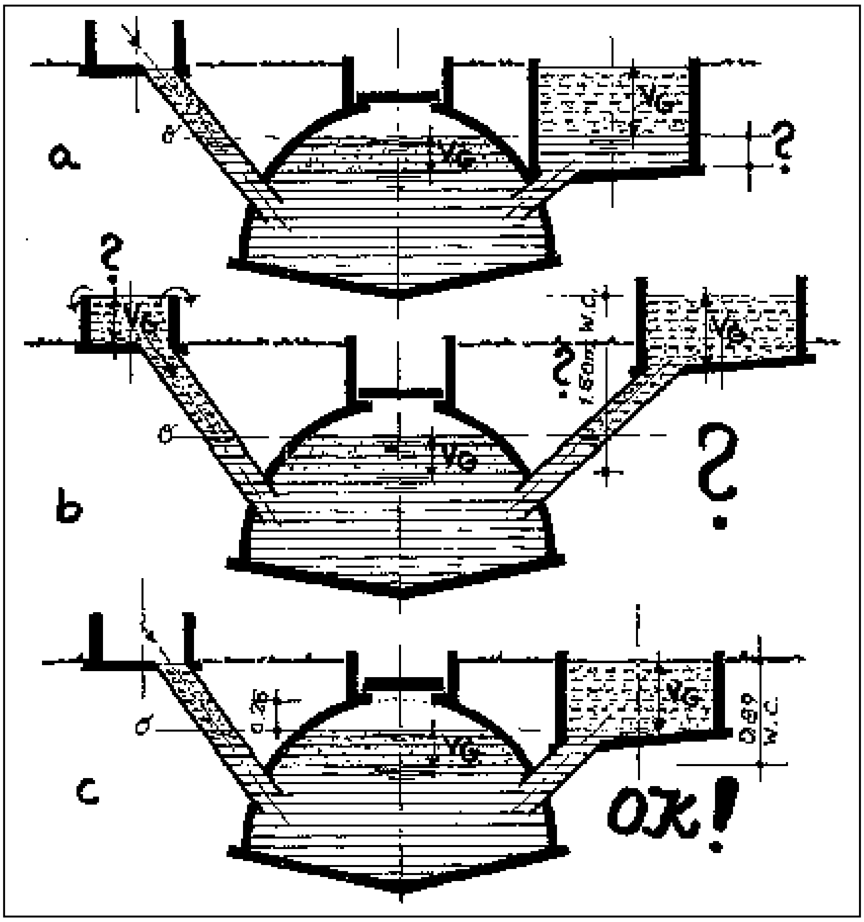


Fig. 35: Correct height of compensating tank The bottom of the compensating tank is at the level of the zero line (filling line). The zero line is 25 cm below the head of the digester dome (c). Wrong: (a) the bottom of the compensating tank is too low. Part of the slurry is always in contact with air. Gas is lost. Unnecessary cost. (b) The bottom of the compensating tank is too high. The gas pressure rises very fast and to a very high level.

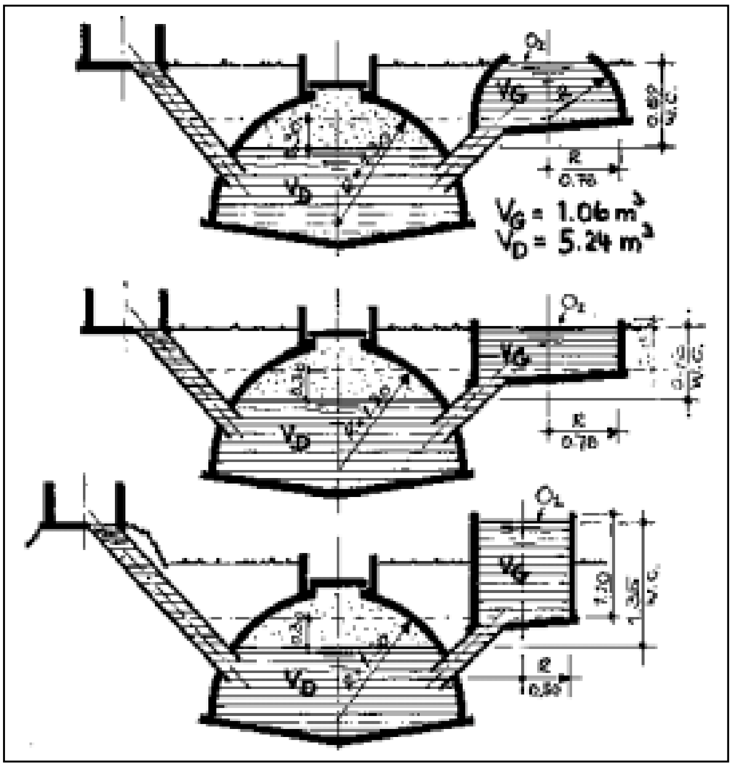


Fig. 36:
Shape of compensating tank The shape of the compensating tank determines the height of the slurry surface and hence the gas pressure (cm WC). The lower the compensating tank, the lower and more even the gas pressure. However, the lower the tank, the larger the area exposed to atmospheric oxygen. Differences in building costs due to shape are slight.

Figure 37 shows details of the entry hatch.

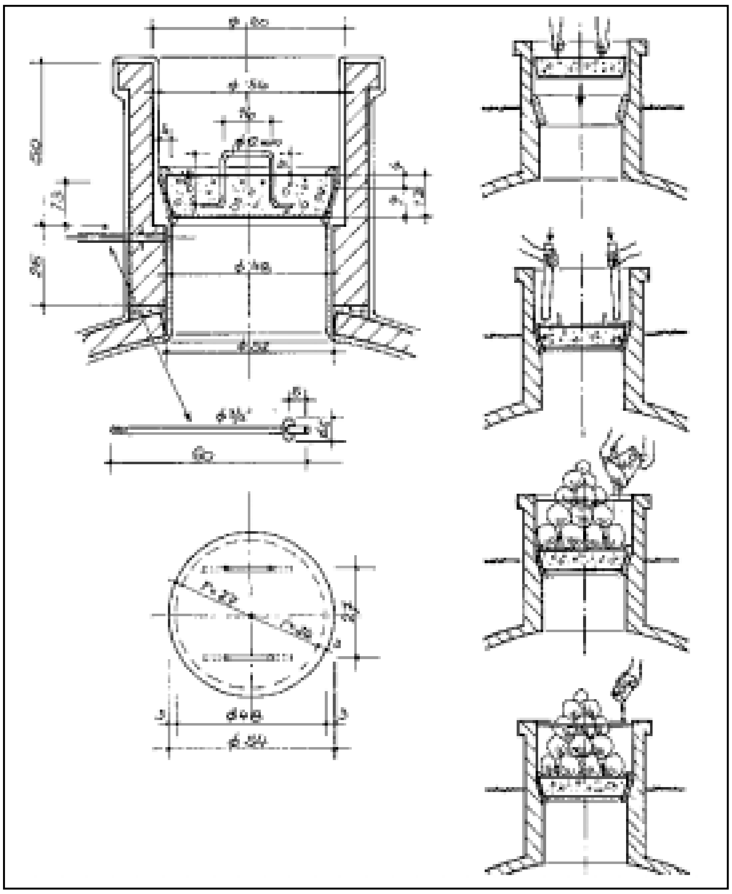


Fig. 37:
Detail of a fixed-dome entry hatch The gas pipe penetrates the shaft a few centimeters below the cover. The cover is sealed with screened and well-worked clay. The bottom of the cover is sealed with paraffin. Rocks are placed on the lid to weigh it down, and the shaft is filled with water to keep the clay gaslight. A few drops of oil keep the water from evaporating.

5.9 Large-scale plants

Large plants do not come under the heading of "simple" plants. For this reason they are not described in detail here. However, the designer must know that he cannot "simply" enlarge the plans for a "simple" plant to any degree.

The digester can be enlarged without major changes in the design. However, large floating drums quickly become awkward and heavy: to manufacture, to transport, to maintain.

A floating drum 5 m in diameter cannot be turned by one person. The surface scum in the plant is not broken. It will become more and more solid. Gas production will fall. In plants with digester volumes exceeding 50 m³, poking no longer provides sufficient agitation. Stirring or agitation facilities are required.

A floating drum with a diameter exceeding 5 m requires a more precise guide frame, otherwise the drum will tilt so badly that it jams. Water-jacket plants are particularly at risk in this respect.

In fixed-dome plants, the gas pressure also varies directly with size. If the shape of the structure is unaltered but the size is doubled, the gas pressure doubles. For this reason, large fixed-dome plants always require a separate gasholder and an agitator.

In large plants, large quantities of feed material and water must be obtained and mixed. Mechanical mixers become necessary. Large volumes of fermentation slurry require a larger drying area, as the thickness of the slurry layer cannot be increased indefinitely. Feed material or fermentation slurry often has to be stored for several weeks. This calls for large and expensive containers.

5.10 Biogas plants in cold regions

Simple biogas plants are usable only conditionally in tropical uplands or in temperate climatic zones. At latitudes as high as only 25 - 30°, gas production in winter generally falls to about half the summer level.

Whether it is worthwhile to heat a plant must be decided on an individual-case basis. In Europe, large-scale plants use up 20-30 % of their gas production for heating. Practicable heating systems for simple plants have not yet been developed.

Utilization of solar energy in the mixing tank (Figure 23) and insulation by covering with straw are insufficient where frost occurs. Floating drums have the highest heat losses. Underground fixed-dome plants maintain more even but generally lower temperatures. Fixed-dome plants with floating gasholders (Figures 3 and 52) may be a valid solution for cold regions although more expensive. Good results are obtained with roofed-over biogas plants. However, the cost of a "greenhouse" superstructure is relatively high. It is worthwhile only where low temperatures are combined with high insolation. Good results have been obtained by placing the plant under a compost heap. If the digester is surrounded externally by soft insulation, the wall cannot be "relieved of its load" by the earth pressure (see Figure 17).

Again, insulation must always remain dry. The only exception is special insulation with closed pores. Biogas plants are completely shut down in winter in the north of China; they are used for only six to eight months per year.

Where frost occurs, mixing and filling tanks must be roofed over. Transport of feed material is difficult in snow. It is essential to consider in detail how the plant is to be operated before commencing construction. Energy is particularly expensive in cold regions. This is why biogas plants have to be used in these regions. Unfortunately, appropriate types of simple plants have not yet been developed.

6. Biogas utilization

Biogas can be used in the same way as any other combustible gas. When biogas is mixed with air in the proportions of 1:20, highly explosive detonating gas forms. Leaky gas pipes in enclosed spaces constitute a hazard! However, there have been no reports of dangerous explosions caused by biogas. The calorific value of biogas is about 6 kWh/m³ - this corresponds to about half a litre of diesel oil. The net calorific value depends on the efficiency of the burners or appliances (see Table, Figure 38).

Properties of combustible gases

Gas	Composition Constituents	Composition %	Calorific value kWh/m³	Density (air = 1) (ρ = 1.2 kg/m³)	Combustion speed cm/s	Air requirement m³/m³
Methane	CH_4	100	9.94	0.554	43	9.5
Propane	C_3H_8	100	25.96	1.560	57	23.8
Butane	C_4H_{10}	100	34.02	2.077	45	30.9
Natural gas	CH_4; H_2	65; 35	7.52	0.384	60	7.0
Town gas	H_2; CH_4; N_2	50; 26; 24	4.07	0.411	82	3.7
Biogas	CH_4; CO_2	60; 40	5.96	0.940	40	5.7

Biogas compared with other fuels

Fuel	Unit u	Calorific value kWh/u	Application	Efficiency η	Net calorific value kWh/u	Biogas equiv. m³/u	1 m³ biogas = u/m³
Cow dung	kg	2.5	Cooking	12 %	0.30	0.09	11.11
Wood	kg	5.0	Cooking	12 %	0.60	0.18	5.56
Charcoal	kg	8.0	Cooking	25 %	2.00	0.61	1.64
Hard coal	kg	9.0	Cooking	25 %	2.25	0.69	1.45
Butane	kg	13.6	Cooking	60 %	8.16	2.49	0.40
Propane	kg	13.9	Cooking	60 %	8.34	2.54	0.39
Diesel oil	kg (ℓ)	12.0	Cooking	50 %	6.0	1.83	0.55
			Engine	30 %	4.0	2.80	0.36
Electricity	kWh	1	Cooking	67 %	0.67	0.20	5.00
			Light	9 %	0.09	0.50	2.00
			Motor	80 %	0.80	0.56	1.79
Biogas	m³	5.96	Cooking	55 %	3.28	1	1
			Light	3 %	0.18	1	1
			Engine	24 %	1.43	1	1

Utilization and consumption of biogas

Household burners	200–450 ℓ/h	Biogas/diesel engine per bhp	420 ℓ/h
Industrial burners	1000–3000 ℓ/h		
Refrigerator 100 ℓ depending on outside temperature	30–75 ℓ/h; 720–1800 ℓ/day	Generation of 1 kWh of electricity with biogas/diesel mixture	700 ℓ/h
Gas lamp, equiv. to 60 W bulb	120–150 ℓ/h	Plastics moulding press (15 g, 100 units) with biogas/diesel mixture	140 ℓ/h

Biogas for cooking (practical values from India)

Amount cooked	Time (min)	Gas (ℓ)	Amount cooked	Time (min)	Gas (ℓ)
1 ℓ water	10	40	1000 g rice	37	175
5 ℓ water	35	165	350 g pulses	60	270
500 g rice	30	140	700 g pulses	70	315

A family of five consumes 850–2500 ℓ of gas per day depending on eating and other habits (e.g., bath-water?). A family of ten consumes 15–30 % more.

Fig. 38: Biogas: properties and utilization

Efficiency is high if, for example, a litre of water boils quickly. This takes longer if the burner is wrongly set. Efficiency is then poor. The air supply substantially determines the efficiency.

A gas pressure of 5-20 cm WG is best for cooking. Lamps require a pressure of about 10 cm WG.

The hydrogen sulphide in the biogas combines with condensate to form corrosive acids. Water-heating appliances and utensils and refrigerators are particularly at risk. The combustion chambers and burners should be made of cast steel, high-grade steel or enamel.

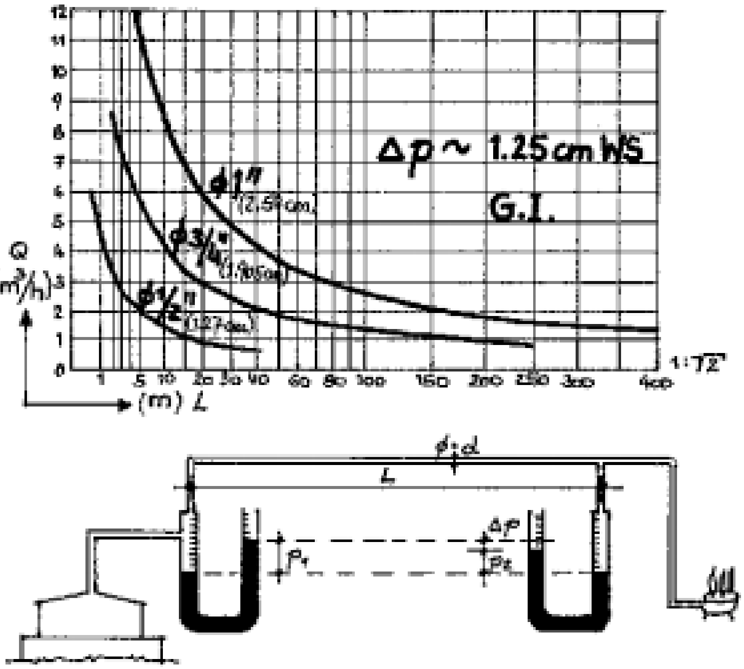
Biogas can be rid of sulphur by iron oxide filters

($FeO + H_2S \rightarrow FeS + H_2O$; $2FeS + O_2 \rightarrow 2FeO + 2S$).

With large volumes of gas, the filter material has to be replaced frequently and this becomes a laborious task. In this case filtration should be omitted and high-grade steel utensils should be used despite the higher cost. The gas does not have to be filtered for use in engines. The gas pressure may be low because the engine aspirates the gas. It is seldom worthwhile using the gas from simple plants to run engines.

Biogas cannot be economically liquefied. Gas pipes may be made of steel, copper, ruber or plastic. Rubber hoses and rigid PVC pipes quickly become porous and leaky when exposed to the sun and should therefore either be shaded or wrapped in some sort of protective material.

The longer the gas pipes are the greater is the decrease of pressure (Figure 39). The gas pipe must have an outlet for perspiration water (Figure 40).



$$Q_{[m^3/h]} = c \cdot \sqrt{\frac{\Delta p_{[cm]} \cdot d^5_{[cm]}}{s \cdot L_{[m]}}}$$

Fig. 39:
Pressure drop in gas pipes The gas pressure (p) falls with pipe length (L). The density relative to air is indicated by "s". The pressure drop depends on the pipe friction (c) and especially on the diameter of pipe (c = 2.24 in galvanized steel pipes (G.I.); c = 2.80 in smooth plastic pipes). The curve shows the gas flow (Q) in a galvanized steel pipe allowing for a pressure drop of p = 1.25 cm WC. Bends increase the pressure drop.

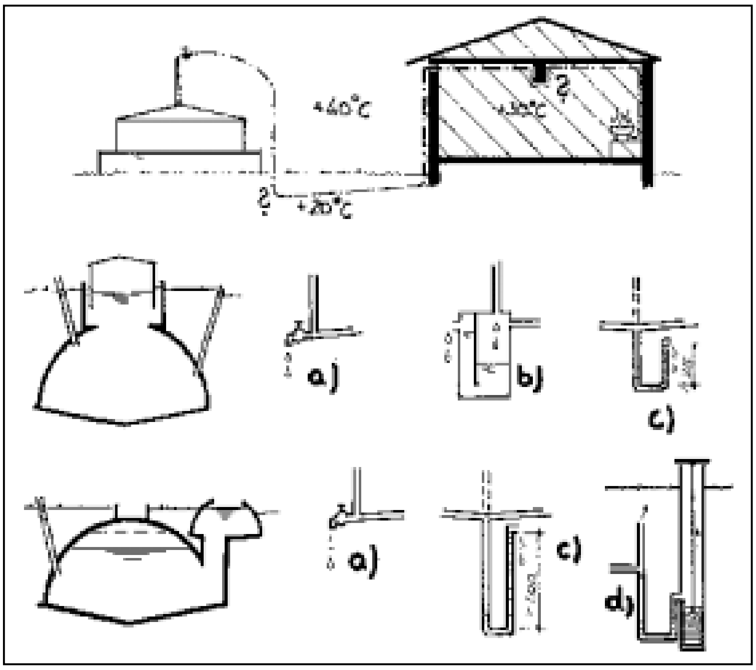


Fig. 40:
Condensate trap Biogas contains water vapour. If the gas is cooled, condensate forms. It always collects at the lowest point in the pipe. It must be possible to drain condensate from this point, otherwise the pipe will be blocked. Water pockets must be avoided. Condensate may be drained by: (a) a gaslight water tap (ball valve), (b) a Patel type overflow water trap, or (c) a simple U-shaped trap (see also Figure 31). Approach (d) is recommended for cases involving a high groundwater level.

6.1 Biogas appliances

Biogas appliances are domestic appliances. They serve a practical purpose. However, they are also relevant to the self-image of the housewife or master of the house. The biogas plant will be looked after better the higher the prestige value of the gas appliances. For this reason even simple, inexpensive gas appliances made in the village should be of appealing design. They must be not only cheap but also, and in particular, "modern".

Most households cook on two flames. Two-flame burners are preferred. The burners (Figure 41) should be set initially and then fixed. Efficiency will then remain at a high practical level.

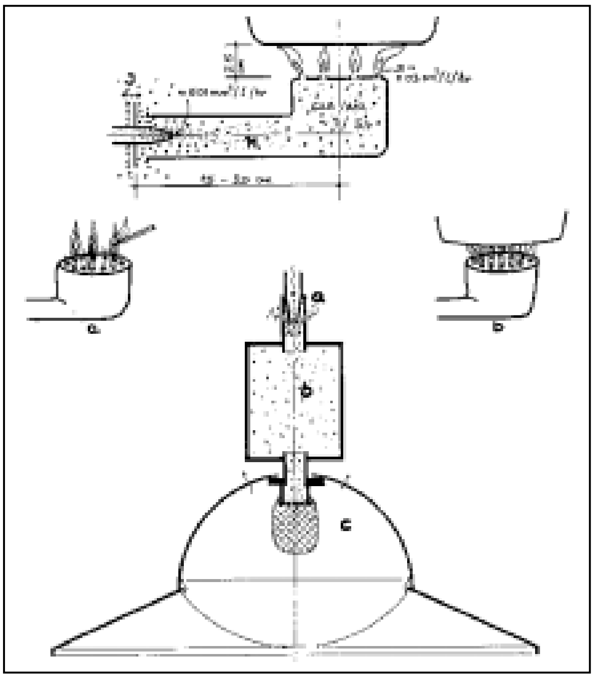


Fig. 41:
Diagram of a gas burner and a lamp
Burner: The values given are rules of thumb for a gas pressure of 5-10 cm WG. If the pressure is higher, the mixing chamber (M) must be enlarged so that the gas particles can mix adequately with oxygen. The gas/air mixture is regulated by means of the adjusting screw (J). A burner is correctly adjusted if only half of all the flames are burning before the pan is placed in position.
Lamp: Things to watch for include the right area ratio between the air hole and the gas nozzle (a), adequately sized gas/air mixing chamber (b) and an air trap (c) that ensures a sufficiently high temperature around the gas mantle without causing a shortage of oxygen for combustion.

In villages without electricity, lighting is a basic peed and a status symbol. However, biogas lamps have low efficiency. This means that they also get very trot.' If they hang directly below the roof, there is a fire risk. The mantles do not last long. It is important that the gas and air in a biogas lamp be thoroughly blended before the mixture reaches the gas mantle, and that the air space around the mantle be adequately warm.

Particular problems also arise with biogas-operated refrigerators. The composition of biogas varies substantially from day to day. The gas pressure fluctuates excessively with the amount of gas stored even in a floating-drum plant. Special' stable-burning jets are therefore needed - especially if the refrigerator is thermostatically controlled and the flame burns only when required. On every ignition there is a risk of the flame going out. Gas will then discharge without burning. The gas supply must therefore automatically be cut off if the flame goes out.

A gas appliance specialist must always be called in where biogas is to be used in refrigerators!

For use of biogas in engines see Figure 42.

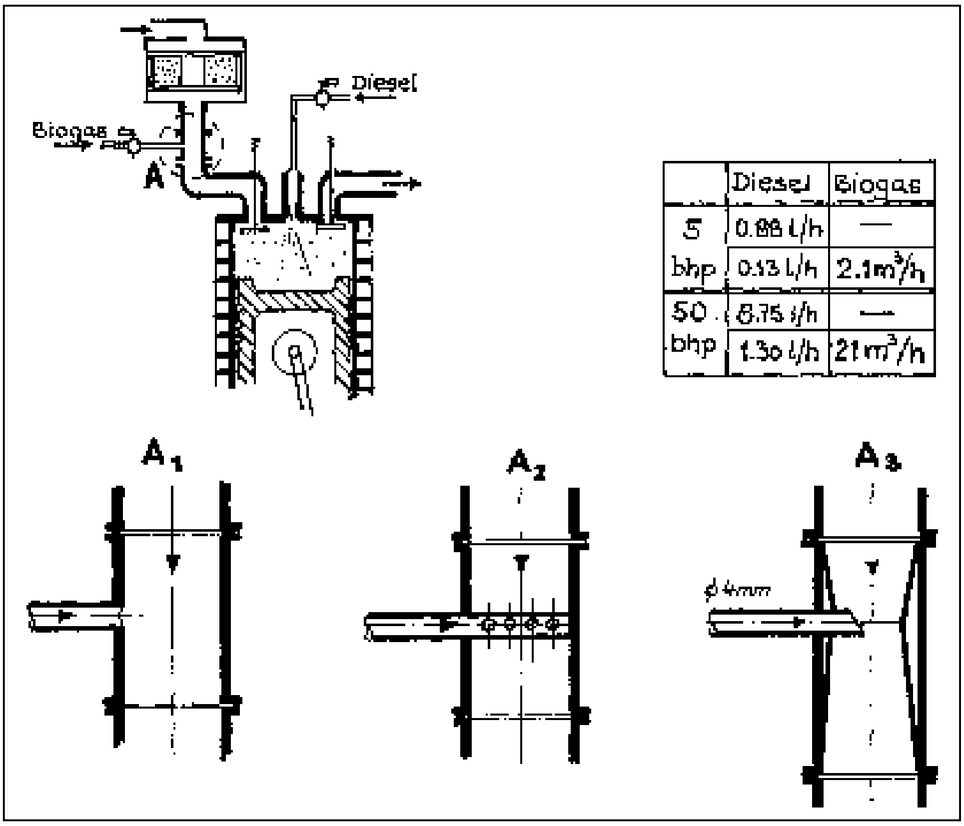


Fig. 42: Gas connection to diesel engine.
The gas is drawn into the cylinders together with the combustion air. The connection to the intake manifold may take different forms. Detail A2 gave the best results in Chinese tests. Owing to the high ignition temperature of biogas, a diesel engine must always be operated with a mixture of biogas and diesel oil. A spark-ignition engine will also operate on 100% biogas. Biogas burns less rapidly than diesel fuel. Consequently, engines designed for less than 2000 rpm are the better choice. Spark-ignition engines run about twice as fast as diesel engines, thus leading to lower efficiency when operating on biogas.

7. Planning, design and construction

Floating-drum plant with filler funnel
Floating-drum
Floating-drum plant without water jacket
Floating-drum plant with water jacket
Fixed-dome plant without upper opening
Fixed-dome plant with upper opening
Floating-drum plant (quarrystone masonry)
Floating-drum plant with extremely low VD/VG ratio
Channel-type digester with folia

The following pages contain constructional drawings for different types of biogas plants.

The form of the plant is determined when the size of the digester and that of the gasholder are known.

The nature of the feed material is another important fundamental planning parameter. The plant shown in Figure 43 is intended particularly for long-fibre feed material. It has a larger outlet diameter to cope with this. The light but hard fibrous constituents accumulate on the surface and form a floating scum. This has to be broken up and if necessary removed. Gas is lost through the inlet funnel. But the floating scum can be raked off without removing the gas bell. Inlet and outlet pipes with a diameter of 100 mm are sufficient for pure manure without litter or for toilet contents. Supernatant scum formation is virtually no problem here.

The plant shown in Figure 51 has an extremely low digester/gasholder volume ratio. The plant is of low construction. The distance from the inlet pipe to the outlet is short. A partition will prevent fresh feed material from discharging again immediately.

In the case of shell structures, the construction dimensions are somewhat difficult to calculate. Consequently, the results of calculation have been simplified, i.e. rendered in tabular form.

The vertical, cylindrical plant (Figure 50) is not optimal, because the digester temperature is lower at the bottom and the water pressure increases with depth. However, this plant may be economic if quarrystone masonry is used instead of brickwork and a shell structure is too complicated.

The cover plate of a floating drum is always thinner than the metal of the side walls, because the covers rust less than the sides. For the guide frame, the cheapest solution is the best.

Floating-drum plant with filler funnel

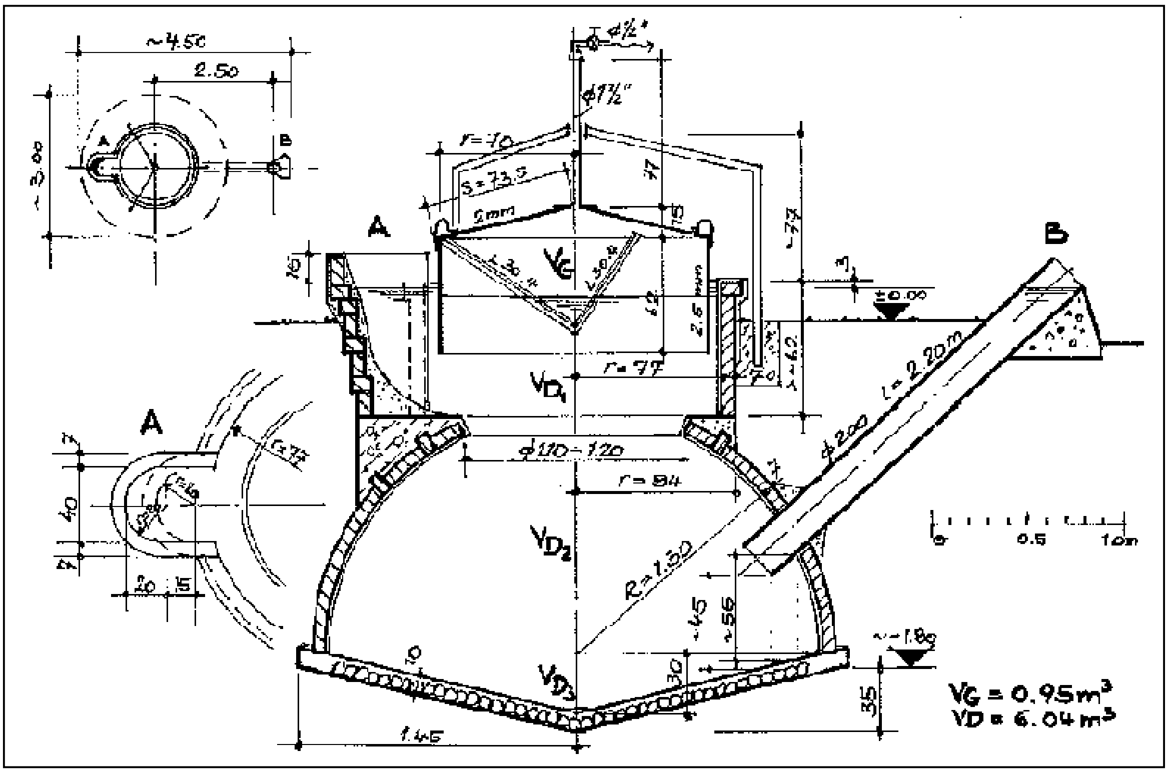


Fig. 43: Constructional drawing of a floating-drum plant with filler funnel for long-fibre feed material; external guide, external gas outlet.

Floating-drum

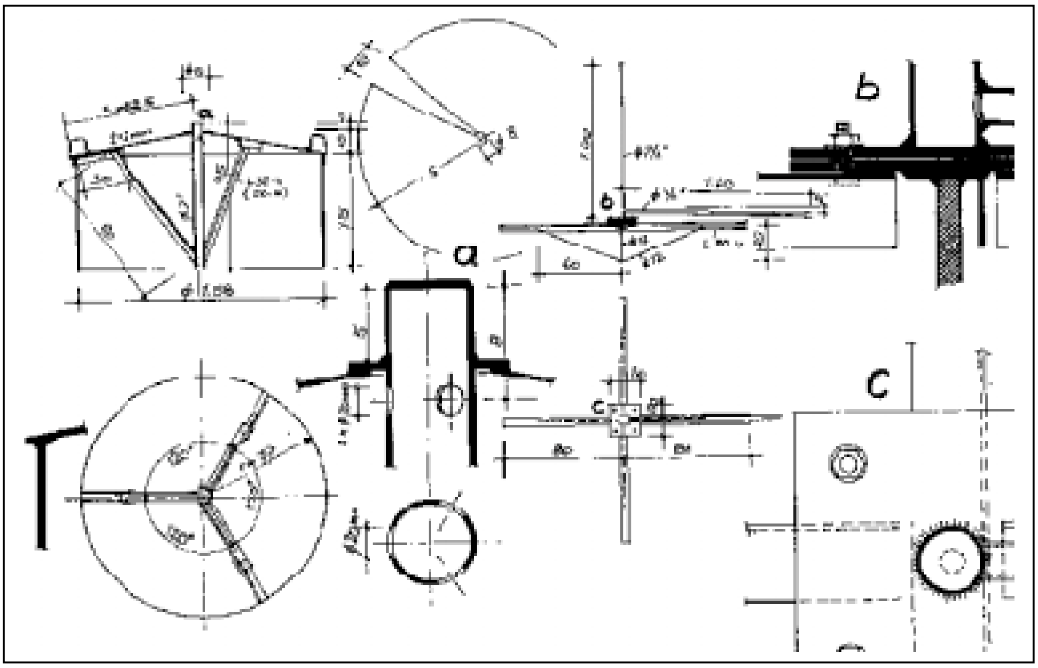


Fig. 44: Constructional drawing of a floating-drum plant

Floating-drum plant without water jacket

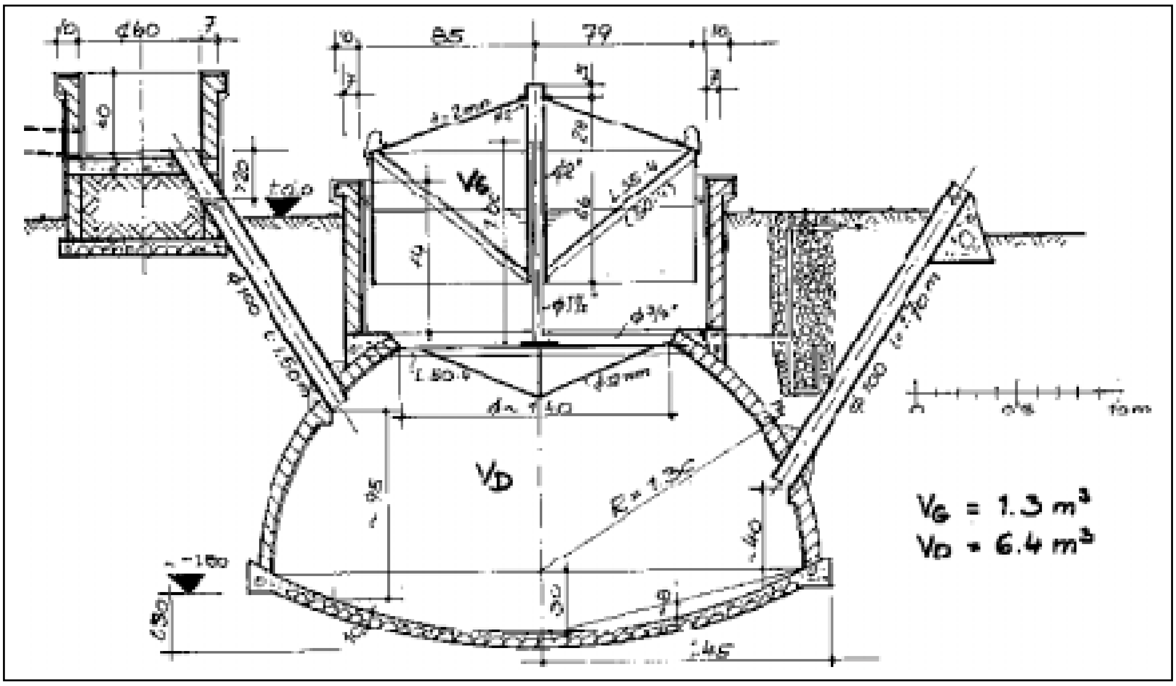
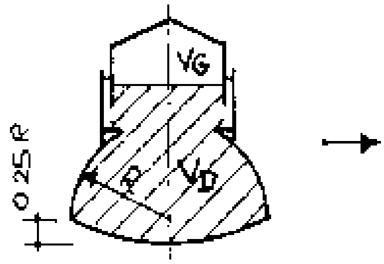
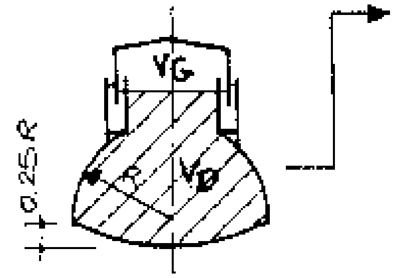


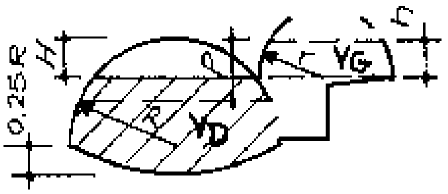
Fig. 45: Constructional drawing of a floating-drum plant with an internal gas outlet and no water jacket



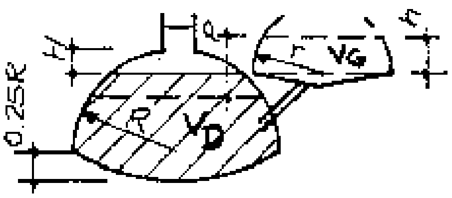
VG:VD	1:4	1:5	1:6
R	$\sqrt[3]{0.32 V_D}$	$\sqrt[3]{0.34 V_D}$	$\sqrt[3]{0.35 V_D}$



VG:VD	1:4	1:5	1:6
R	$\sqrt[3]{0.38 V_D}$	$\sqrt[3]{0.39 V_D}$	$\sqrt[3]{0.40 V_D}$



VG:VD	1:5	1:6	1:8
R	$\sqrt[3]{0.48 V_D}$	$\sqrt[3]{0.48 V_D}$	$\sqrt[3]{0.46 V_D}$
r	0.6[illegible]R	0.6[illegible]R	0.[illegible]R
H	0.37 R	0.35R	0.32 R
h	0.32 R	0.30R	0.28R
p	0.51R	0.47R	0.41R



VG:VD	1:5	1:6	1:8
R	$\sqrt[3]{0.42 V_D}$	$\sqrt[3]{0.42 V_D}$	$\sqrt[3]{0.42 V_D}$
r	0.70R	0.66R	0.60R
H	0.16 R	0.15 R	0.14 R
h	0.33R	0.31R	0.28R
p	0.64R	0.60R	0.53R

n	$\sqrt[3]{n}$	n	$\sqrt[3]{n}$	n	$\sqrt[3]{n}$	n	$\sqrt[3]{n}$	n	$\sqrt[3]{n}$	n	$\sqrt[3]{n}$
0.001	0.10	0.22	0.60	1.33	1.10	4.10	1.60	9.26	2.10	17.58	2.60
0.003	0.15	0.27	0.65	1.53	1.15	4.49	1.65	9.94	2.15	18.61	2.65
0.008	0.20	0.34	0.70	1.73	1.20	4.91	1.70	10.65	2.20	19.68	2.70
0.016	0.25	0.42	0.75	1.95	1.25	5.36	1.75	11.39	2.25	20.80	2.75
0.027	0.30	0.51	0.80	2.20	1.30	5.83	1.80	12.17	2.30	21.95	2.80
0.043	0.35	0.61	0.85	2.46	1.35	6.33	1.85	12.98	2.35	23.15	2.85
0.064	0.40	0.73	0.90	2.74	1.40	6.86	1.90	13.82	2.40	24.39	2.90
0.091	0.45	0.86	0.95	3.05	1.45	7.41	1.95	14.71	2.45	25.67	2.95
0.125	0.50	1.00	1.00	3.38	1.50	8.00	2.00	15.63	2.50	27.0	3.00
0.166	0.55	1.16	1.05	3.72	1.55	8.62	2.05	16.58	2.55	28.37	3.05

Fig. 46: Calculation of dimensions

Floating-drum plant with water jacket

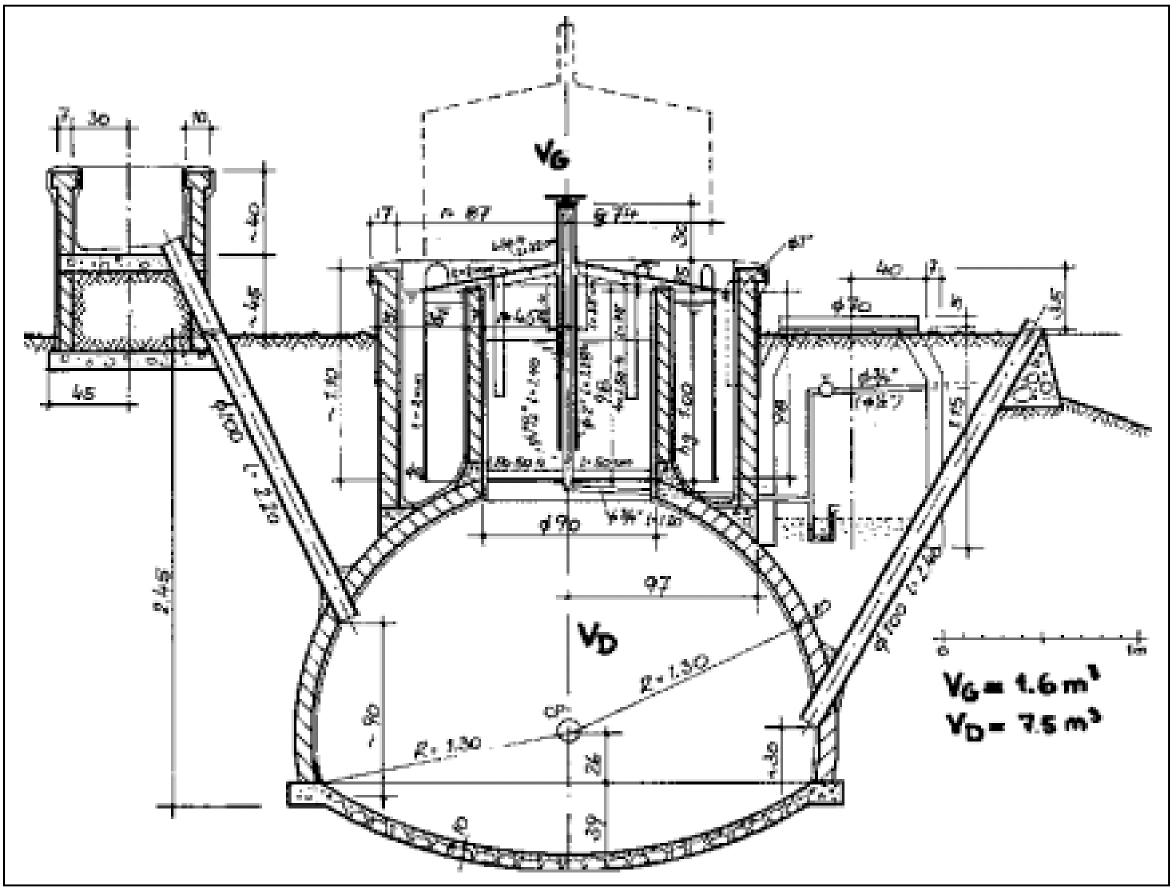


Fig. 47: Constructional drawing of a floating-drum plant with water jacket. Compared to the one is shown in figure 45, this plant is about 40% more expensive but can be expected to last twice as long and will handle substrate that tends to form substantial amounts of scum. Detailed building instructions for a system of this kind are available in several different languages.

Fixed-dome plant without upper opening

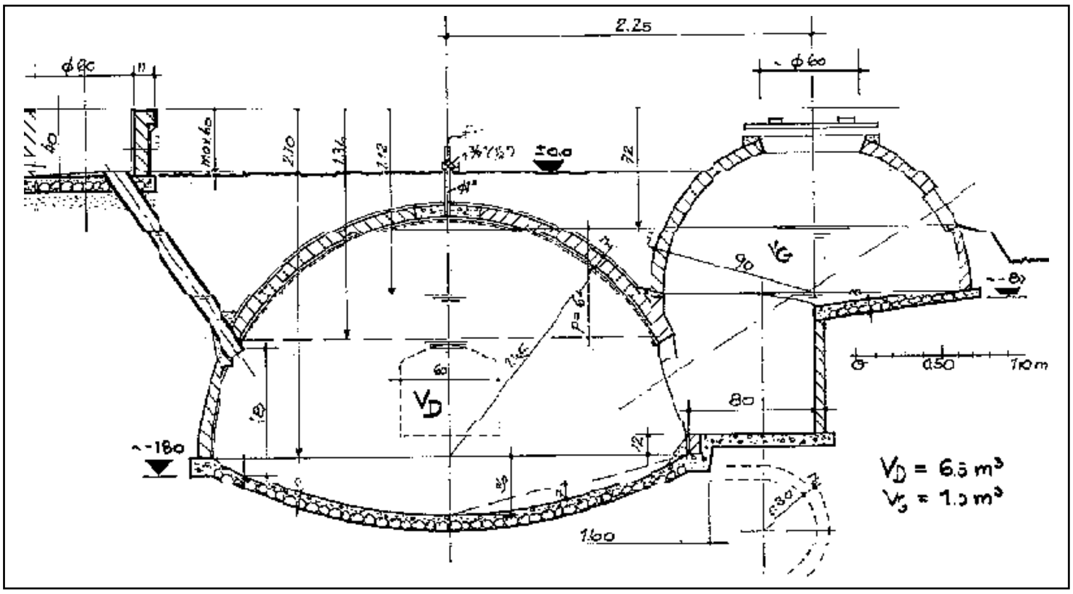


Fig. 48: Constructional drawing of a fixed-dome plant without upper opening

Fixed-dome plant with upper opening

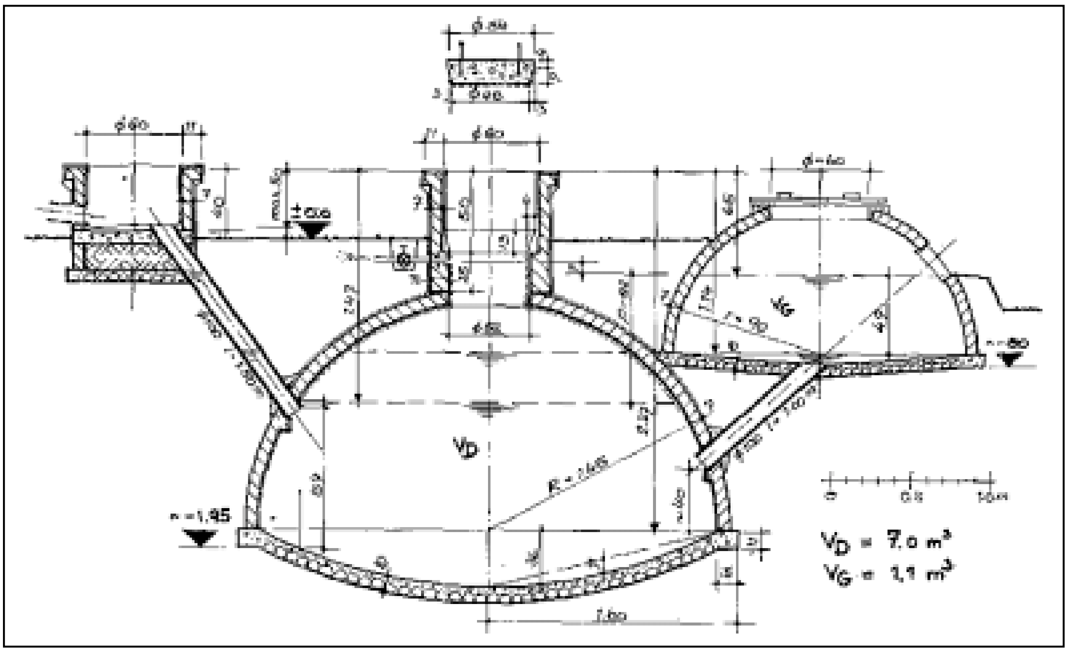


Fig. 49: Constructional drawing of a fixed-dome plant with upper opening

Floating-drum plant (quarrystone masonry)

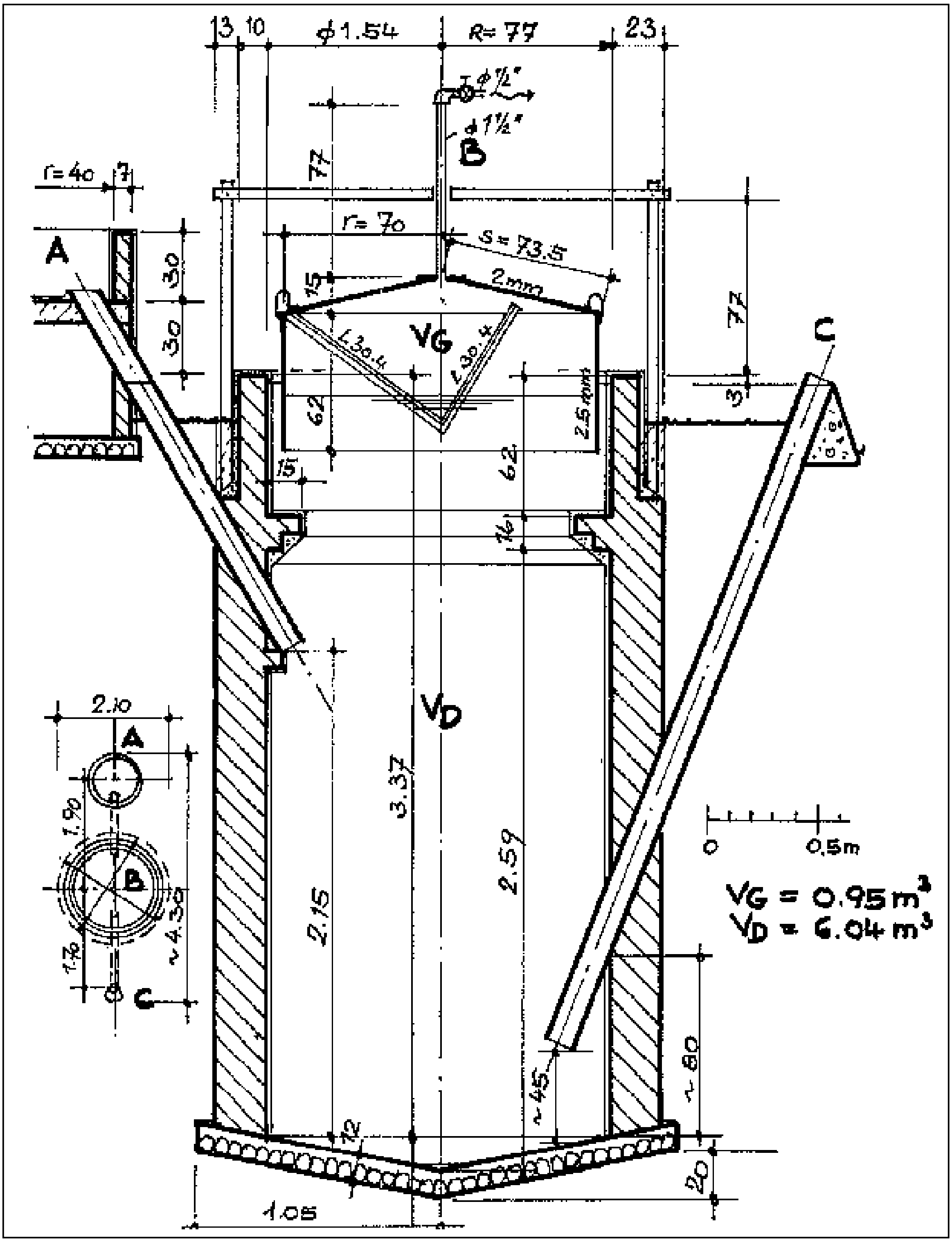


Fig 50: Constructional drawing of a floating-drum plant for quarrystone masonry (vertical plant)

Floating-drum plant with extremely low VD/VG ratio

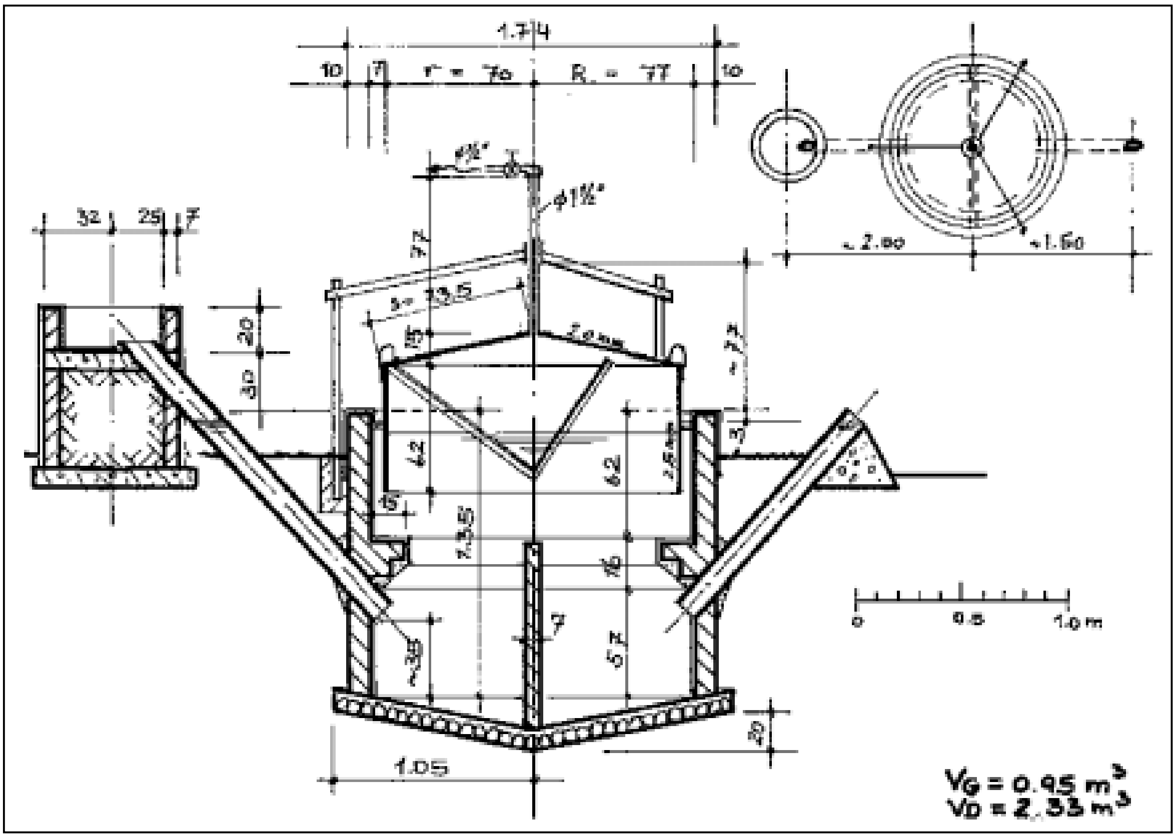


Fig. 51: Constructional drawing of a plant with an extremely low digester/gasholder volume ratio

Channel-type digester with folia

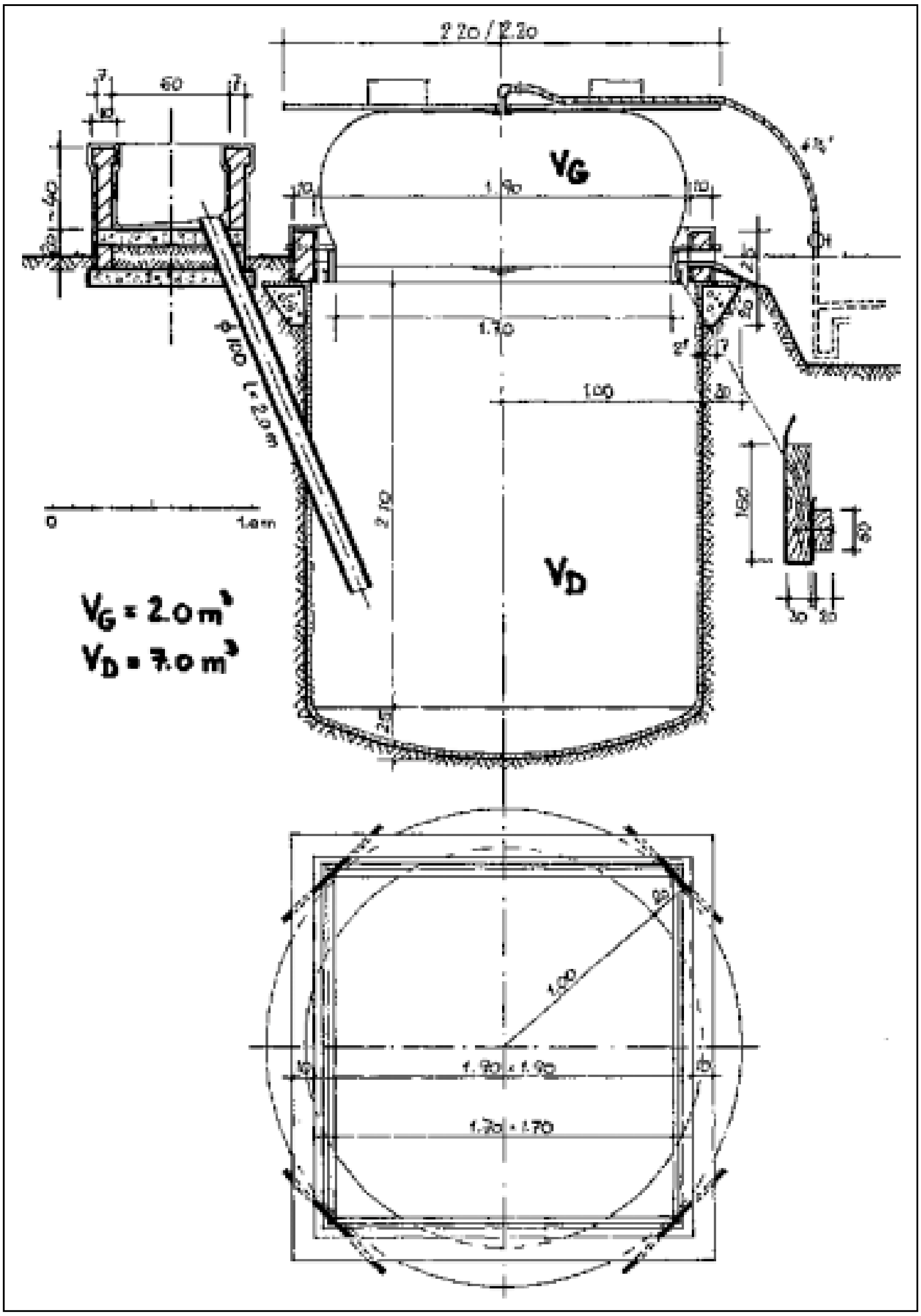


Fig. 52: Constructional drawing of a channel-type digester with folia (Henning system) The digester walls consists of netting-wire-reinforced rendering on the surrounding ground. The balloon serving as gasholder is mounted on a wooden frame. A plywood panel or straw mat on lathing serves as a sunshade. Weights placed on top make the gas pressure higher.

8. Appendix

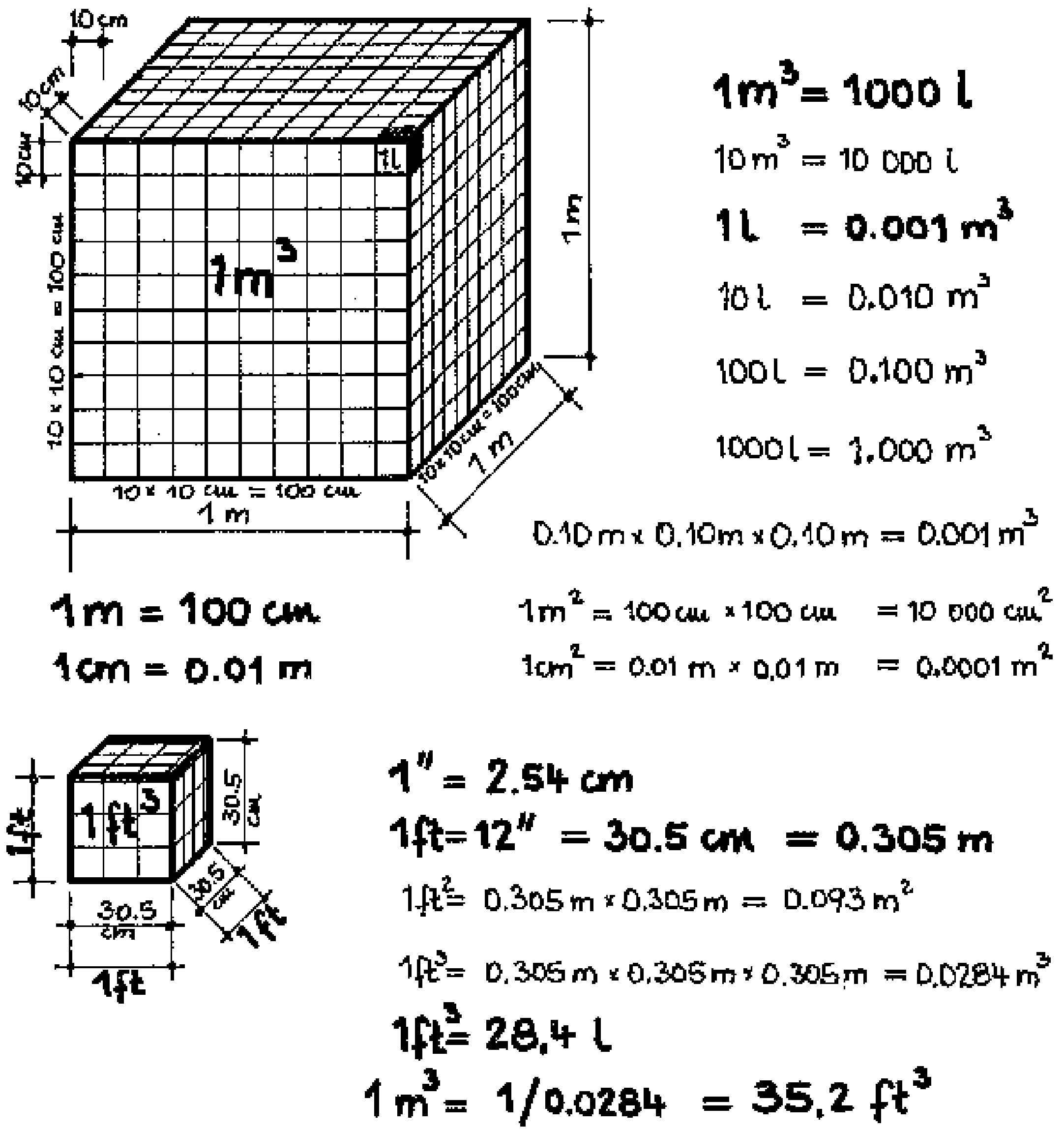
SI units of calculation. Conversion of imperial measures
Cubic metres and cubic feet; powers of ten
Fundamental geometric formulae
Fundamental static formulae
Water pressure and earth pressure
Change in volume of ideal gases under pressure and temperature
Cross sections of common steels and pipes

SI units of calculation. Conversion of imperial measures

SI units of calculation (selection)			
Magnitude	Symbol	Unit	Conversion
Length	ℓ	m	1 m = 10 dm = 100 cm = 1000 mm
Area	A	m^2	1 m^2 = 100 dm^2 = 10000 cm^2
Volume	V	m^3	1 m^3 = 1000 dm^3 = 1 million cm^3
Mass	m	t; kg	1 t = 1000 kg;
Density	ρ_0	t/m^3	1 t/m^3 = 1 kg/dm^3
Force, load	F	kN	1 kN = 100 kgf
Line load	g, p	kN/m	1 kN/m = 100 kgf/m
Stress	σ, τ	MN/m^2	1 MN/m^2 = 1 N/mm^2 = 10 kgf/cm^2
Pressure	p	MN/m^2	1 MN/m^2 = 10 kgf/cm^2 = 1 MPa
Elongation	e	m/m	
Energy	W	kWh	1 kWh = $3.6 \cdot 10^6$ Ws = $3.6 \cdot 10^5$ kgfm
Work	W	kNm	1 J = 1 Ws = 1 Nm; 1 kNm = 100 kgfm
Quantitiy of heat	Q	kWh	1 kWh = $3.6 \cdot 10^6$ Ws; 1 kcal = 4187 Ws
Power	P	kW	1 kW = 100 kgfm/s = 1.36 bhp (DIN)
Temperature	t, T	°C, K	0K = −273 °C; 0 °C = 273 K

Conversion of imperial measures		
Length	1 m = 1.094 yd	1 yd = 0.914 m
	1 cm = 0.0328 ft	1 ft = 30.5 cm
	1 cm = 0.394 inch	1 inch = 2.54 cm
Area	1 m^2 = 10.76 sq.ft	1 sq.ft = 0.093 m^2
	1 cm^2 = 0.155 sq.in	1 sq.in = 6.45 cm^2
	1 ha = 2.47 acre	1 acre = 0.405 ha
Volume	1 ℓ = 0.220 gall.	1 gall. = 4.55 ℓ
	1 m^3 = 35.32 cbft	1 cbft = 28.3 ℓ
Mass	1 kg = 2.205 lbs	1 lb = 0.454 kg
Pressure	1 MN/m^2 = 2.05 lb/sq.ft	1 lb/sq.ft = 0.488 MN/m^2
	1 cmWG = 205 lb/sq.ft	1 lb/sq.in = 70.3 cmWG
Quantitiy of heat	1 kcal = 3.969 BTU	1 BTU = 0.252 kcal
	1 kWh = 3413.3 BTU	1000 BTU = 0.293 kWh
	1 kcal/kg = 1799 BTU/lb	1 BTU/lb = 0.556 kcal/kg
Power	1 bhp (DIN = 0.986 HP	1 HP = 1.014 bhp (DIN)
	1 kgfm/s = 7.246 ftlb/s	1 ftlb/s = 0.138 kgfm/s

Fig. 53: Units of measurement



$10^1 = 10$	da	(deca)
$10^2 = 100$	h	(hecto)
$10^3 = 1000$	k	(kilo)
$10^4 = 10\,000$	–	
$10^5 = 100\,000$	–	
$10^6 = 1\,000\,000$	M	(mega)
$10^{-1} = 0.1 = 1/10$	d	(deci)
$10^{-2} = 0.01 = 1/100$	c	(centi)
$10^{-3} = 0.001 = 1/1000$	m	(milli)
$10^{-4} = 0{,}000\,1 = 1/10\,000$	–	
$10^{-5} = 0.000\,01 = 1/100\,000$	–	
$10^{-6} = 0.000\,001 = 1/1$ Mill.	µ	(micro)

	kp/m^3	N/m^2	Pa	cm WG	mbar	at
kp/m	1	10	10	0.1	0.1	0.0001
N/m^2	0.1	1	1	0.01	0.01	10^{-5}
Pa	0.1	1	1	0.01	0.01	10^{-5}
cm WG	10	100	100	1	1	0.001
mbar	10	100	100	1	1	0.001
at	10 000	10^5	10^5	1000	1000	1

Fig. 54: Cubic metres and cubic feet; powers of ten

Fundamental geometric formulae

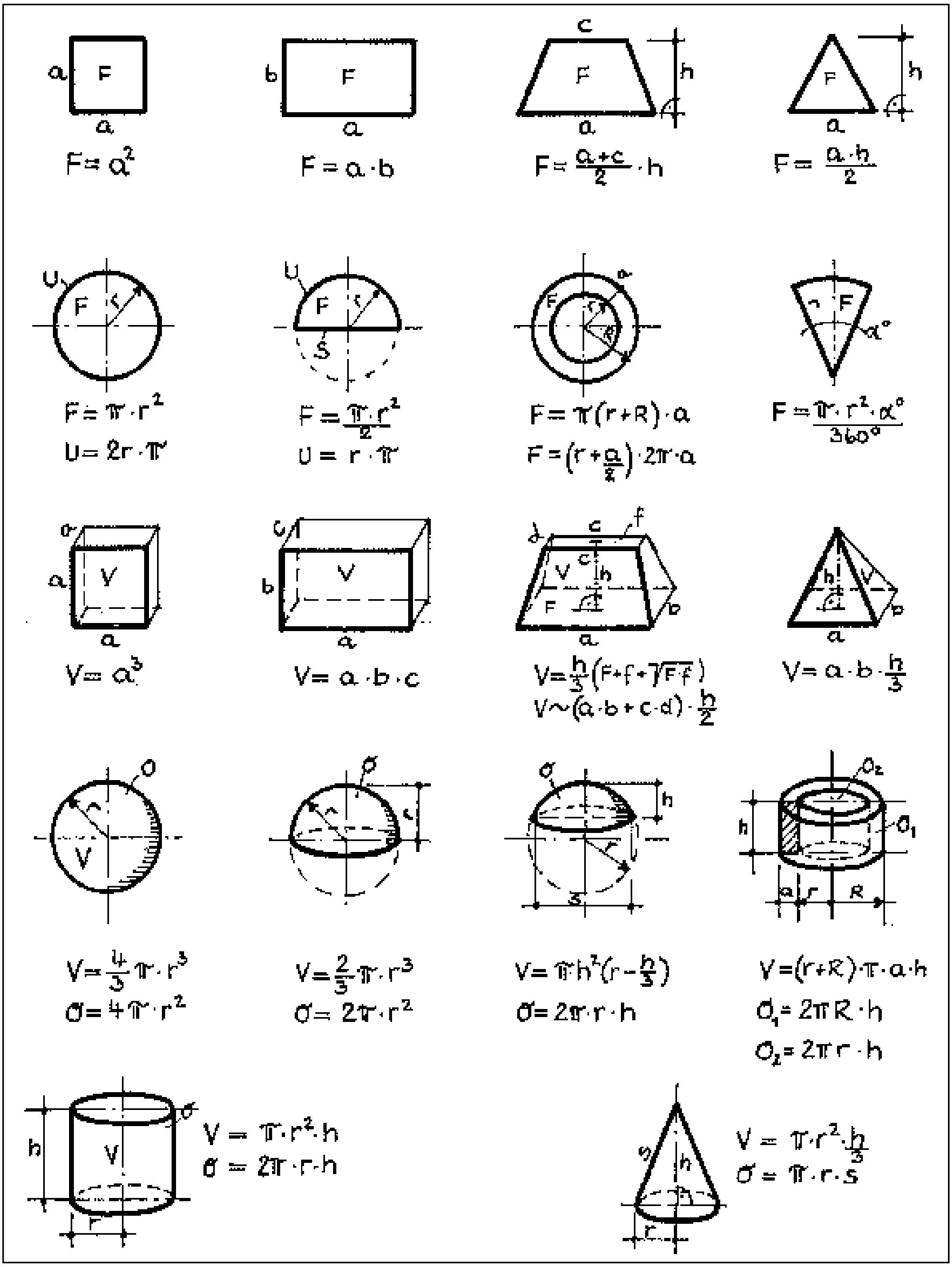


Fig. 55: Fundamental geometric formulae

Fundamental static formulae

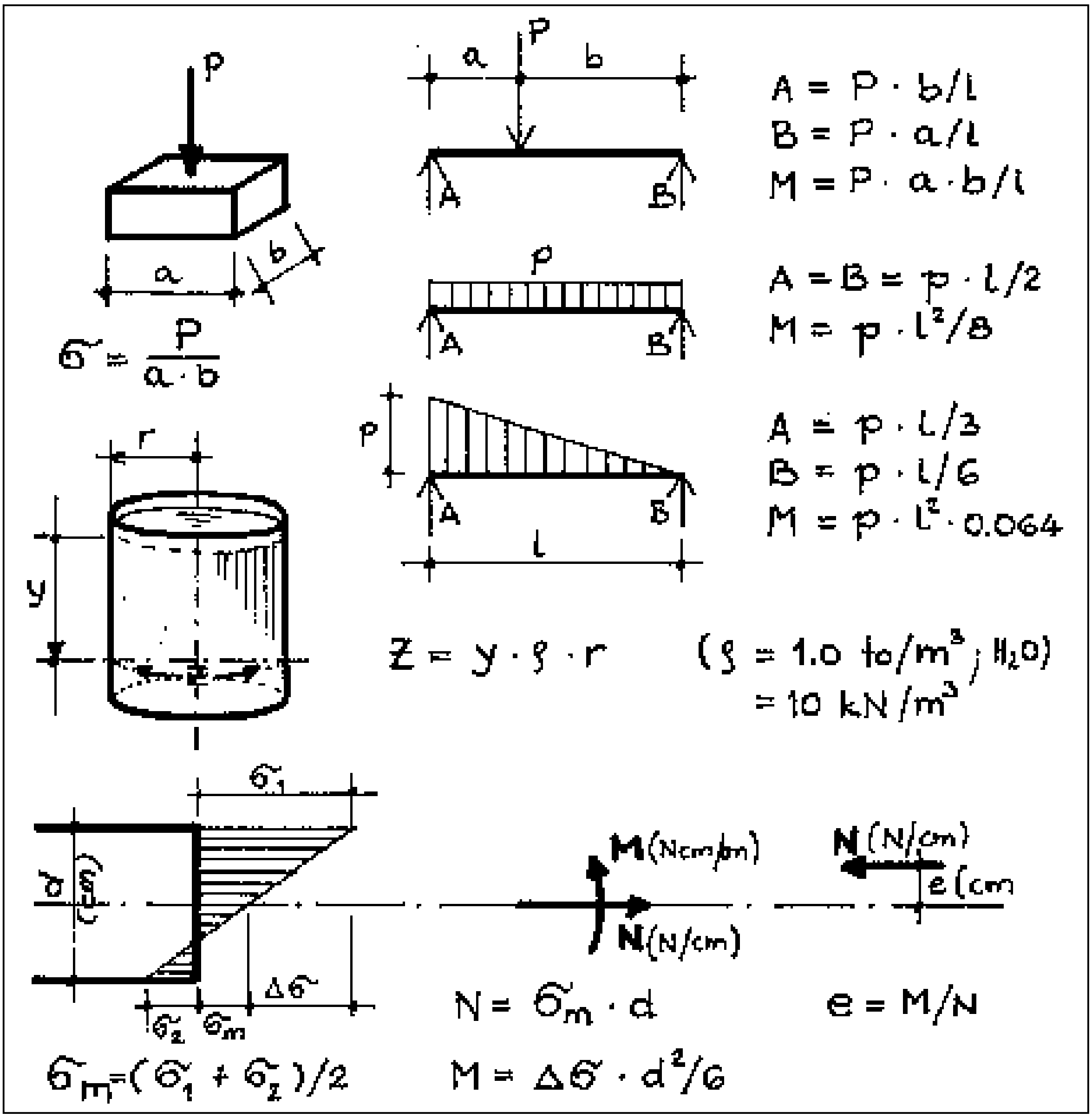


Fig. 56: Fundamental static formulae Static calculations are not usually necessary for small, simple biogas plants. For larger plants, a rough calculation should be carried out to determine whether the loads and stresses are likely to be high enough for an exact calculation to be necessary. Spherical and conical shells are complicated forms. They are very difficult to estimate by rough calculation. As a rule, only the edges are loaded to the permissible limit.

Water pressure and earth pressure

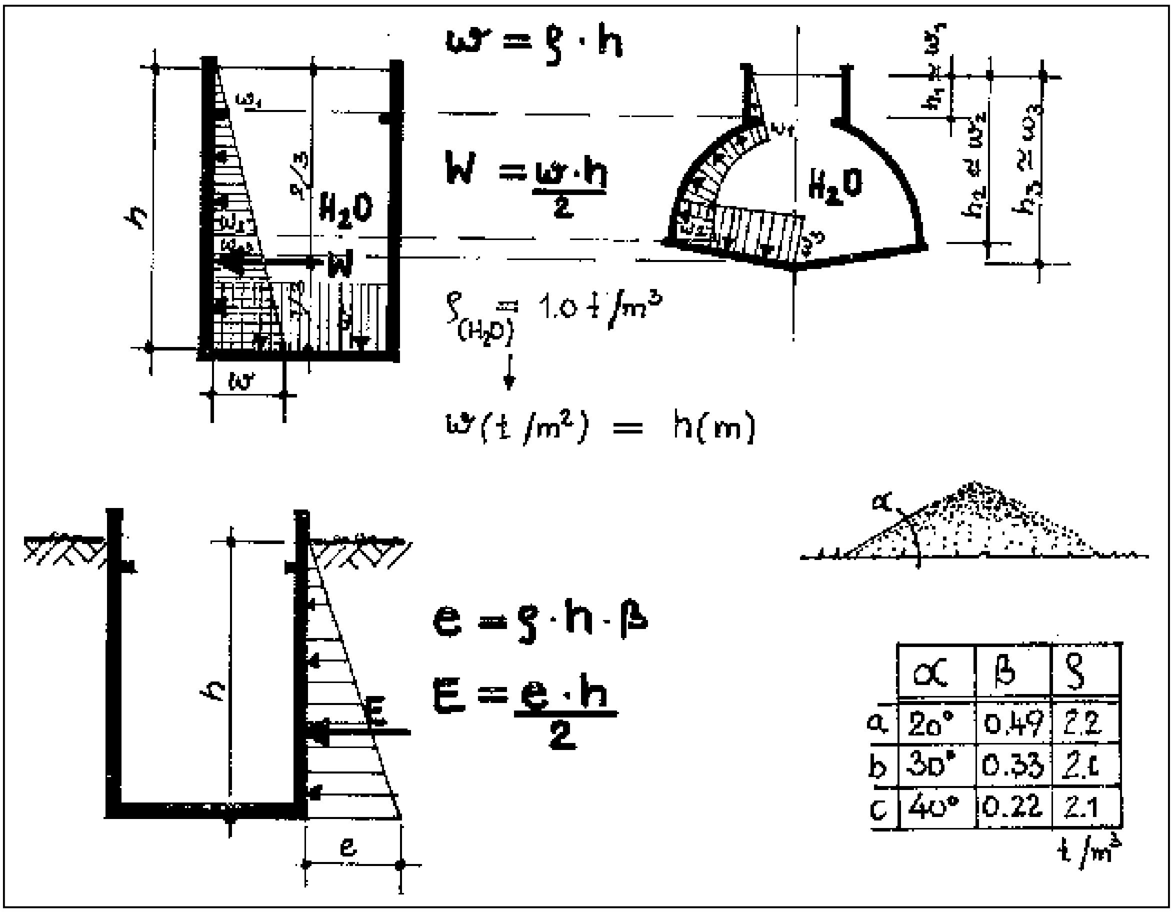


Fig. 57: Water pressure and earth pressure Water pressure depends directly on height. The amount of water has no effect on the pressure. The earth pressure depends on height, the angle of repose (alfa) and density (ro) of the earth. In the table, (a) is soft loam or clayey sand, (b) is pure sand and (c) is marl or murrum.

Change in volume of ideal gases under pressure and temperature

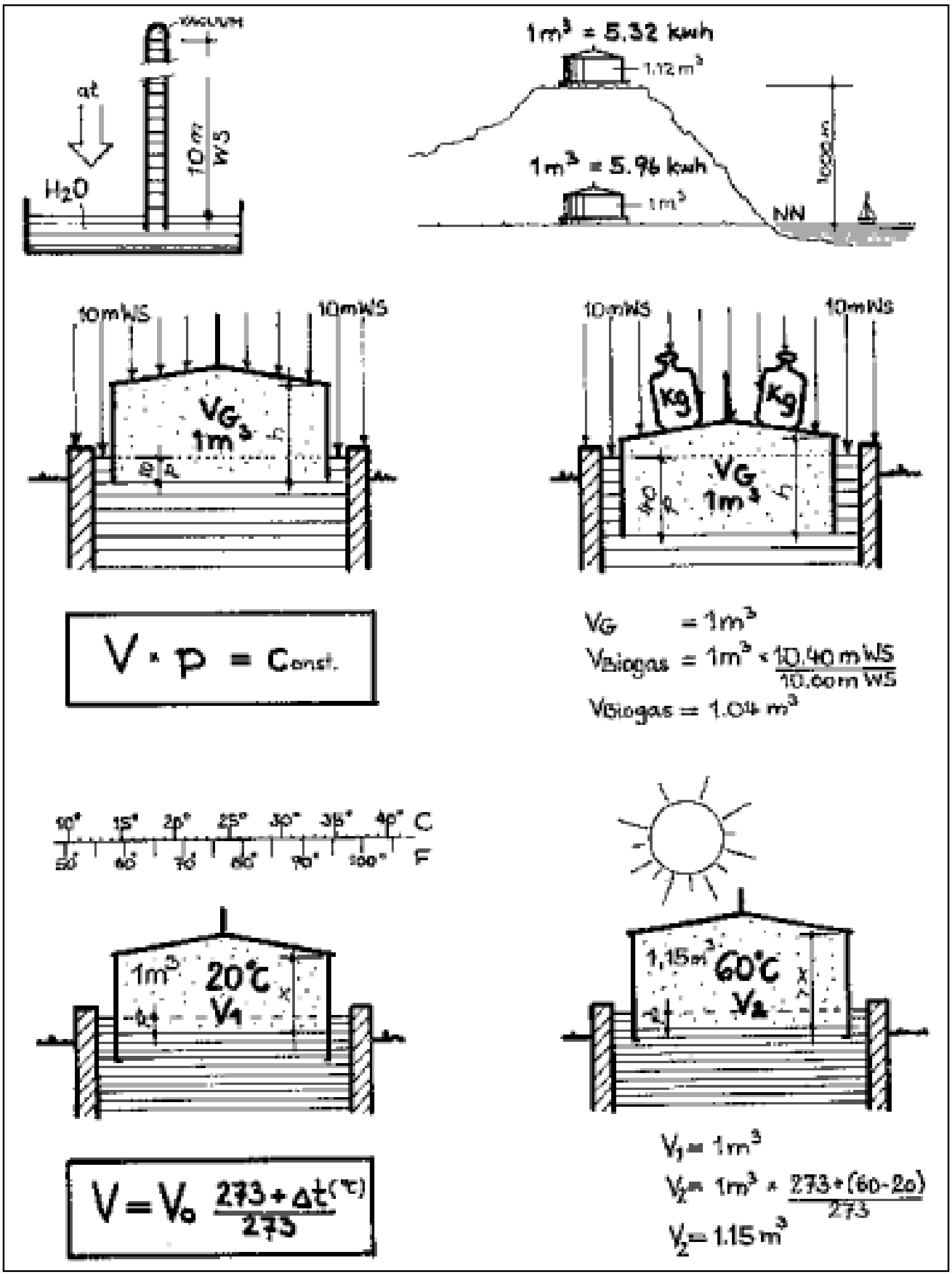
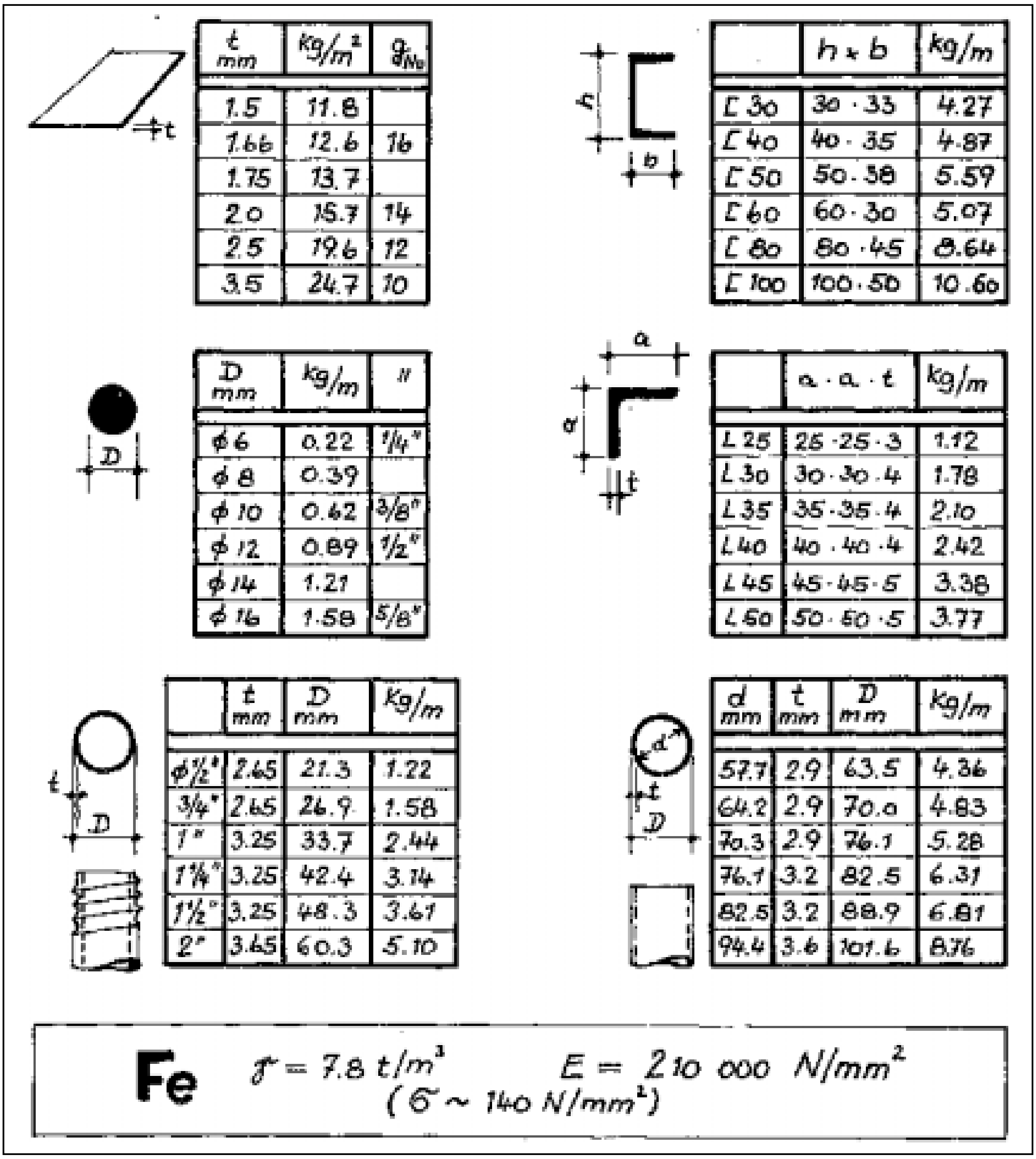


Fig. 58: Change in volume of ideal gases under pressure and temperature

Cross sections of common steels and pipes



t mm	kg/m²	g_{No}
1.5	11.8	
1.66	12.6	16
1.75	13.7	
2.0	15.7	14
2.5	19.6	12
3.5	24.7	10

	h × b	kg/m
C 30	30 · 33	4.27
C 40	40 · 35	4.87
C 50	50 · 38	5.59
C 60	60 · 30	5.07
C 80	80 · 45	8.64
C 100	100 · 50	10.60

D mm	kg/m	"
ϕ 6	0.22	1/4"
ϕ 8	0.39	
ϕ 10	0.62	3/8"
ϕ 12	0.89	1/2"
ϕ 14	1.21	
ϕ 16	1.58	5/8"

	a · a · t	kg/m
L 25	25 · 25 · 3	1.12
L 30	30 · 30 · 4	1.78
L 35	35 · 35 · 4	2.10
L 40	40 · 40 · 4	2.42
L 45	45 · 45 · 5	3.38
L 50	50 · 50 · 5	3.77

	t mm	D mm	kg/m
ϕ 1/2"	2.65	21.3	1.22
3/4"	2.65	26.9	1.58
1"	3.25	33.7	2.44
1 1/4"	3.25	42.4	3.14
1 1/2"	3.25	48.3	3.61
2"	3.65	60.3	5.10

d mm	t mm	D mm	kg/m
57.7	2.9	63.5	4.36
64.2	2.9	70.0	4.83
70.3	2.9	76.1	5.28
76.1	3.2	82.5	6.31
82.5	3.2	88.9	6.81
94.4	3.6	101.6	8.76

Fe $\gamma = 7.8\ t/m^3$ $E = 210\,000\ N/mm^2$ $(\sigma \sim 140\ N/mm^2)$

Fig. 59: Cross sections of common steels and pipes

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Individual articles and index of persons:

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List of figures