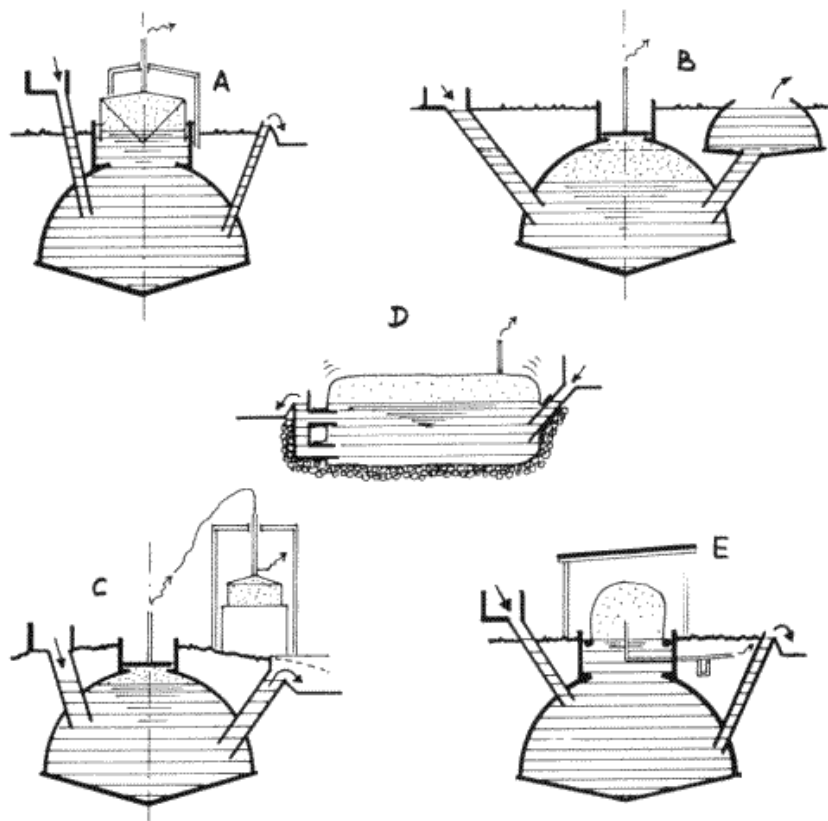




Biogas Digest

Volume II

Biogas - Application and Product Development



**Information and Advisory Service
on Appropriate Technology**



Imprint

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Biogas - Application and Product Development

Planning a biogas plant

Before building a biogas plant, there are different circumstances which should be considered. For instance, the natural and agricultural conditions in the specific countries are as important as the social or the economic aspects. To consider the most important factors, we provide a checklist for the planning procedure, a planning guide and a checklist for construction of a biogas plant.

Failure or unsatisfactory performance of biogas units occur mostly due to planning mistakes. The consequences of such mistakes may be immediately evident or may only become apparent after several years. Thorough and careful planning is, therefore, of utmost importance to eliminate mistakes before they reach irreversible stages.

As a biogas unit is an expensive investment, it should not be erected as a temporary set-up. Therefore, determining siting criteria for the stable and the biogas plant are the important initial steps of planning.

A general problem for the planning engineer is the interference of the customer during planning. As much as the wishes and expectations of customers have to be taken into consideration, the most important task of the planner is to lay the foundation for a well functioning biogas unit. As in most cases the customer has no experience with biogas technology, the planner has to explain all the reasons for each planning step. Planners should have the courage to withdraw from the planning process, if the wishes of the customer will lead to a white elephant on the farm.

Moreover, all extension-service advice concerning agricultural biogas plants must begin with an estimation of the quantitative and qualitative energy requirements of the interested party. Then, the biogas-generating potential must be calculated on the basis of the given biomass production and compared to the energy demand. Both the energy demand and the gas-generating potential, however, are variables that cannot be accurately determined in the planning phase. Sizing the plant (digester, gasholder, etc.) is the next step in the planning process.

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

Information about the economic evaluation of a biogas plant can be found in the section on Costs and Benefits.

Design

Throughout the world, a countless number of designs of biogas plants have been developed under specific climatic and socio-economic conditions. Choosing a design is essentially part of the planning process. It is, however, important to familiarize with basic design considerations before the actual planning process begins. This refers to the planning of a single biogas unit as well as to the planning of biogas-programs with a regional scope.

Physical conditions

The performance of a biogas plant is dependent on the local conditions in terms of climate, soil conditions, the substrate for digestion and building material availability. The design must respond to these conditions. In areas with generally low temperatures, insulation and heating devices may be important. If bedrock occurs frequently, the design must avoid deep excavation work. The amount and type of substrate to be digested have a bearing on size and design of the digester and the inlet and outlet construction. The choice of design will also be based on the building materials which are available reliably and at reasonable cost.

Skills and labor

High sophistication levels of biogas technology require high levels of skills, from the planner as well as from the constructor and user. With a high training input, skill gaps can be bridged,

but the number of skilled technicians will get smaller the more intensive the training has to be. In addition, training costs compete with actual construction costs for scarce (project) resources. Higher technical sophistication also requires more expensive supervision and, possibly, higher maintenance costs. To which extent prefabricated designs are suitable depends largely on the cost of labor and transport.

Standardization

For larger biogas programs, especially when aiming at a self-supporting dissemination process, standards in dimensions, quality and pricing are essential. Standard procedures, standard drawings and forms and standardized contracts between the constructor, the planner, the provider of material and the customer avoid mistakes and misunderstandings and save time. There is, however a trade-off between the benefits of standardization and the necessity of individual, appropriate solutions.

Types of plants

There are various types of plants. Concerning the feed method, three different forms can be distinguished:

- Batch plants
- Continuous plants
- Semi-batch plants

Batch plants are filled and then emptied completely after a fixed retention time. Each design and each fermentation material is suitable for batch filling, but batch plants require high labor input. As a major disadvantage, their gas-output is not steady.

Continuous plants are fed and emptied continuously. They empty automatically through the overflow whenever new material is filled in. Therefore, the substrate must be fluid and homogeneous. Continuous plants are suitable for rural households as the necessary work fits well into the daily routine. Gas production is constant, and higher than in batch plants. Today, nearly all biogas plants are operating on a continuous mode.

If straw and dung are to be digested together, a biogas plant can be operated on a **semi-batch** 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.

Concerning the construction, two main types of simple biogas plants can be distinguished:

- fixed-dome plants
- floating-drum plants

But also other types of plants play a role, especially in past developments. In developing countries, the selection of appropriate design is determined largely by the prevailing design in the region. Typical design criteria are space, existing structures, cost minimization and substrate availability. The designs of biogas plants in industrialized countries reflect a different set of conditions.

Parts of a biogas plant

The feed material is mixed with water in the influent collecting tank. The fermentation slurry flows through the inlet into the digester. The bacteria from the fermentation slurry are intended to produce biogas in the digester. For this purpose, they need time. Time to multiply and to spread throughout the slurry. The digester must be designed in a way that only fully digested slurry can leave it. The bacteria are distributed in the slurry by stirring (with a stick or stirring facilities). The fully digested slurry leaves the digester through the outlet into the slurry storage.

The biogas is collected and stored until the time of consumption in the gasholder. The gas pipe carries the biogas to the place where it is consumed by gas appliances. Condensation collecting in the gas pipe is removed by a water trap.

Depending on the available building material and type of plant under construction, different variants of the individual components are possible. The following (optional) components of a

biogas plant can also play an important role and are described separately: Heating systems, pumps, weak ring.

Construction details

The section on construction of biogas plants provides more information on:

- Agitation
- Heating
- Piping systems
- Plasters and Coats
- Pumps
- Slurry equipment
- Underground water

Starting the plant

Initial filling

The initial filling of a new biogas plant should, if possible, consist of either digested slurry from another plant or cattle dung. The age and quantity of the inoculant (starter sludge) have a decisive effect on the course of fermentation. It is advisable to start collecting cattle dung during the construction phase in order to have enough by the time the plant is finished. When the plant is being filled for the first time, the substrate can be diluted with more water than usual to allow a complete filling of the digester.

Type of substrate

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

- low quality biogas containing more than 60% CO₂
- very odorous biogas
- sinking pH and
- erratic gas production

Stabilization of the process

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

Gas quality

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

Managing input- and output-material

Substrate input

For a simple, small-scale biogas system, only a minimum amount of time and effort must be spent on procuring the feedstock and preparing it for fermentation. The technical equipment is relatively inexpensive. Theoretically any organic material can be digested. Substrate pre-

processing and conveying depends on the type of material to be used. One of the most important problems in substrate management to be considered is the problem of scum.

Effluent sludge

The sludge resulting from the digestion process represents a very valuable material for fertilization. The following aspects of sludge treatment and use are considered here:

- Sludge storage
- Composition of sludge
- Fertilizing effect of effluent sludge
- Sludge application and slurry-use equipment

Biogas - Digester types

In this chapter, the most important types of biogas plants are described:

- Fixed-dome plants
- Floating-drum plants
- Balloon plants
- Horizontal plants
- Earth-pit plants
- Ferrocement plants

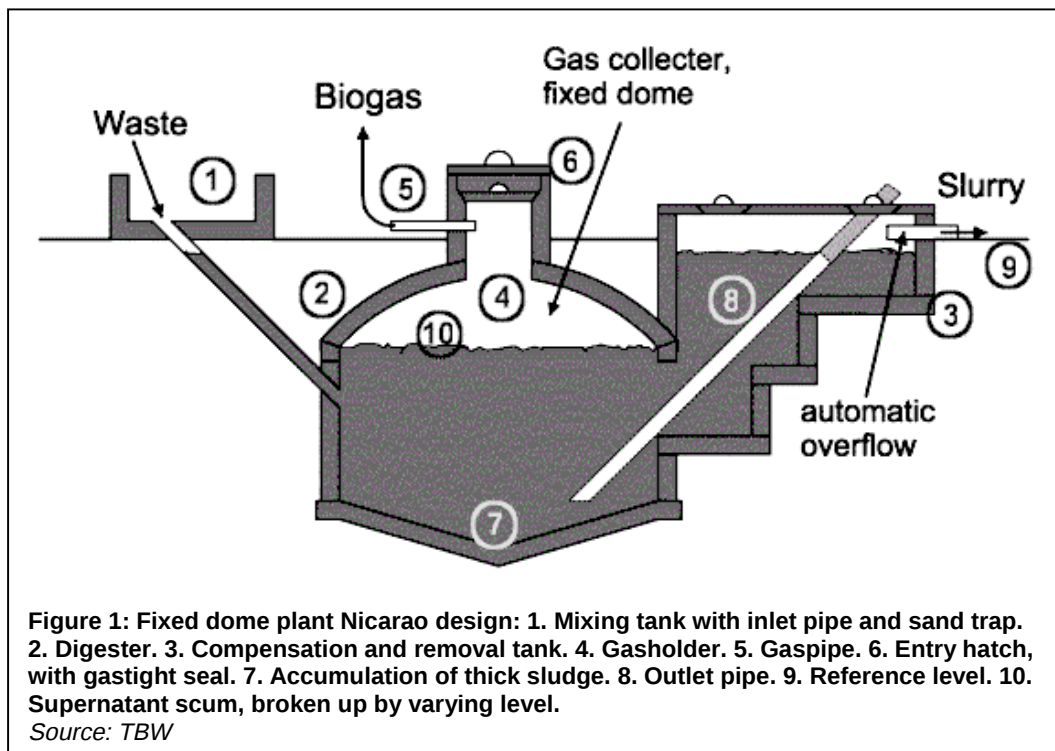
Of these, the two most familiar types in developing countries are the **fixed-dome plants** and the **floating-drum** plants. Typical designs in industrialized countries and appropriate design selection criteria have also been considered.

Fixed-dome plants

The costs of a fixed-dome biogas plant are relatively low. It is simple as no moving parts exist. There are also no rusting steel parts and hence a long life of the plant (20 years or more) can be expected. The plant is constructed underground, protecting it from physical damage and saving space. While the underground digester is protected from low temperatures at night and during cold seasons, sunshine and warm seasons take longer to heat up the digester. No day/night fluctuations of temperature in the digester positively influence the bacteriological processes.

The construction of fixed dome plants is labor-intensive, thus creating local employment. Fixed-dome plants are not easy to build. They should only be built where construction can be supervised by experienced biogas technicians. Otherwise plants may not be gas-tight (porosity and cracks).

The basic elements of a fixed dome plant (here the **Nicarao Design**) are shown in the figure below.



Function

A fixed-dome plant comprises of a closed, dome-shaped digester with an immovable, rigid gas-holder and a displacement pit, also named 'compensation tank'. 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, i.e. with the height difference between the two slurry levels. If there is little gas in the gas-holder, the gas pressure is low.

Digester

The digesters of fixed-dome plants are usually masonry structures, structures of cement and ferro-cement exist. Main parameters for the choice of material are:

- Technical suitability (stability, gas- and liquid tightness);
- cost-effectiveness;
- availability in the region and transport costs;
- availability of local skills for working with the particular building material.

Fixed dome plants produce just as much gas as floating-drum plants, *if they are gas-tight*. However, utilization of the gas is less effective as the gas pressure fluctuates substantially. Burners and other simple appliances cannot be set in an optimal way. If the gas is required at constant pressure (e.g., for engines), a gas pressure regulator or a floating gas-holder is necessary.

Gas-Holder



Figure 3: Fixed-dome plant in Tunisia.
The final layers of the masonry structure are being fixed.

Photo: gtz/GATE

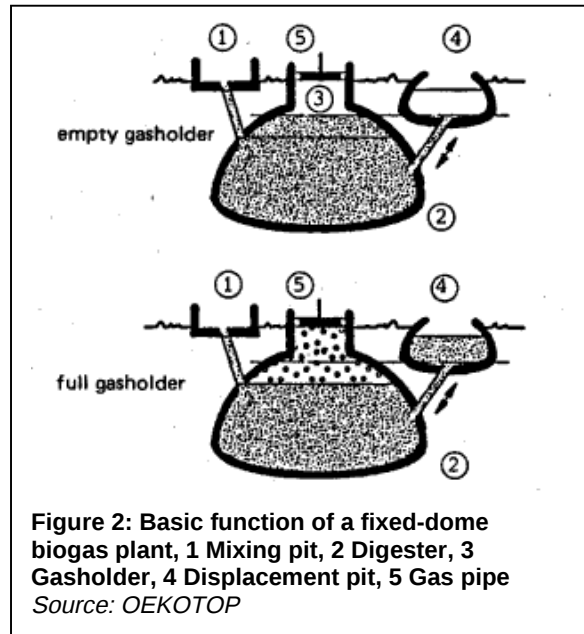


Figure 2: Basic function of a fixed-dome biogas plant, 1 Mixing pit, 2 Digester, 3 Gasholder, 4 Displacement pit, 5 Gas pipe
Source: OEKOTOP

The top part of a fixed-dome plant (the gas space) must be gas-tight. Concrete, masonry and cement rendering are not gas-tight. The gas space must therefore be painted with a gas-tight layer (e.g. 'Water-proofer', Latex or synthetic paints). A possibility to reduce the risk of cracking of the gas-holder consists in the construction of a weak-ring in the masonry of the digester. This "ring" is a flexible joint between the lower (water-proof) and the upper (gas-proof) part of the hemispherical structure. It prevents cracks that develop due to the hydrostatic pressure in the lower parts to move into the upper parts of the gas-holder.

Types of fixed-dome plants

- **Chinese fixed-dome plant** is the archetype of all fixed dome plants. Several million have been constructed in China. The digester consists of a cylinder with round bottom and top.
- **Janata model** was the first fixed-dome design in India, as a response to the Chinese fixed dome plant. It is not constructed anymore. The mode of construction lead to cracks in the gasholder - very few of these plant had been gas-tight.

- **Deenbandhu**, the successor of the Janata plant in India, with improved design, was more crack-proof and consumed less building material than the Janata plant. with a hemisphere digester
- **CAMARTEC model** has a simplified structure of a hemispherical dome shell based on a rigid foundation ring only and a calculated joint of fraction, the so-called weak / strong ring. It was developed in the late 80s in Tanzania.

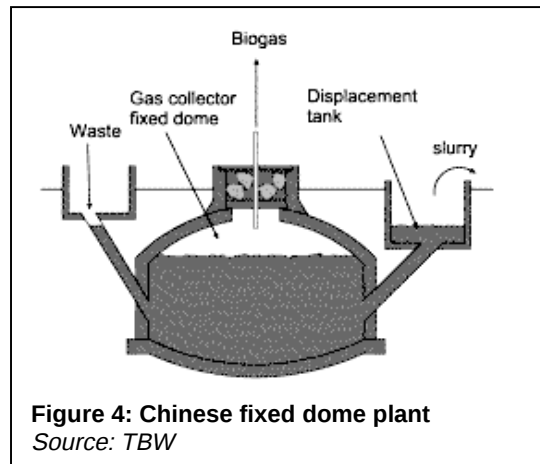


Figure 4: Chinese fixed dome plant
Source: TBW

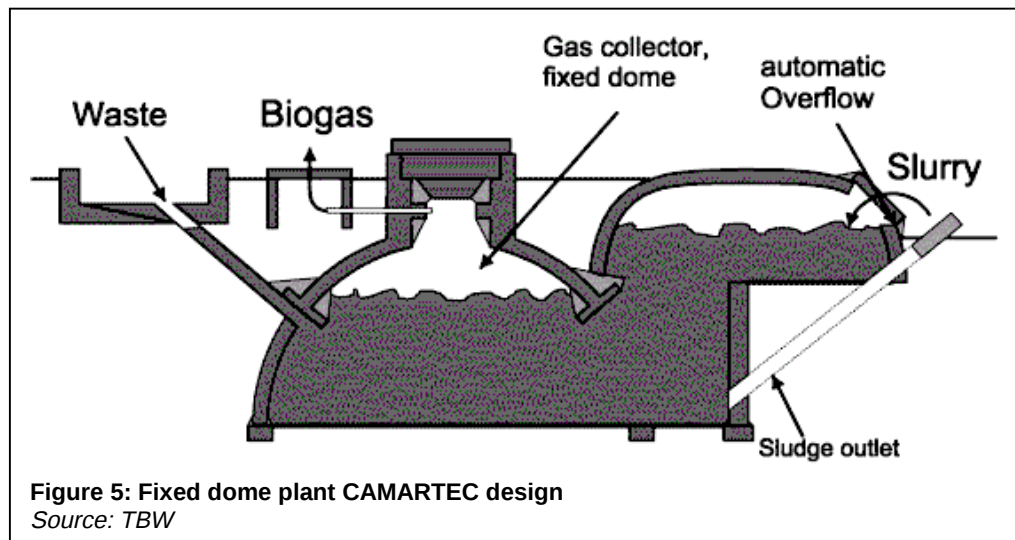


Figure 5: Fixed dome plant CAMARTEC design
Source: TBW

Climate and size

Fixed-dome plants must be covered with earth up to the top of the gas-filled space to counteract the internal pressure (up to 0,15 bar). The earth cover insulation and the option for internal heating makes them suitable for colder climates. Due to economic parameters, the recommended minimum size of a fixed-dome plant is 5 m³. Digester volumes up to 200 m³ are known and possible.

Advantages: Low initial costs and long useful life-span; no moving or rusting parts involved; basic design is compact, saves space and is well insulated; construction creates local employment.

Disadvantages: Masonry gas-holders require special sealants and high technical skills for gas-tight construction; gas leaks occur quite frequently; fluctuating gas pressure complicates gas utilization; amount of gas produced is not immediately visible, plant operation not readily understandable; fixed dome plants need exact planning of levels; excavation can be difficult and expensive in bedrock.

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



Figure 6: Installation of a *Shanghai* fixed-dome system near Shanghai, PR China

Photo: L. Sasse

Floating-drum plants

The drum

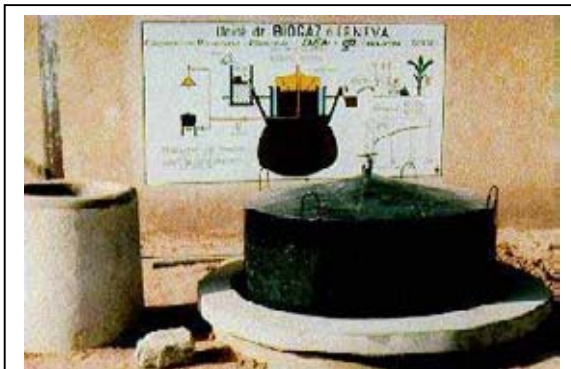


Figure 7: Floating-drum plant in Mauretania

Photo: gtz/GATE

In the past, floating-drum plants were mainly built in India. A floating-drum plant consists of a cylindrical or dome-shaped digester and a moving, floating gas-holder, or drum. The gas-holder floats either directly in the fermenting slurry or in a separate water jacket. The drum in which the biogas collects has an internal and/or external guide frame that provides stability and keeps the drum upright. If biogas is produced, the drum moves up, if gas is consumed, the gas-holder sinks back.

Size

Floating-drum plants are used chiefly for digesting animal and human feces on a continuous-feed mode of operation, i.e. with daily input. They are used most frequently by small- to middle-sized farms (digester size: 5-15m³) or in institutions and larger agro-industrial estates (digester size: 20-100m³).

Advantages: Floating-drum plants are easy to understand and operate. They provide gas at a constant pressure, and the stored gas-volume is immediately recognizable by the position of the drum. Gas-tightness is no problem, provided the gasholder is de-rusted and painted regularly.

Disadvantages: The steel drum is relatively expensive and maintenance-intensive. Removing rust and painting has to be carried out regularly. The life-time of the drum is short (up to 15 years; in tropical coastal regions about five years). If fibrous substrates are used, the gas-holder shows a tendency to get "stuck" in the resultant floating scum.

Water-jacket floating-drum plants

Water-jacket plants are universally applicable and easy to maintain. The drum cannot get stuck in a scum layer, even if the substrate has a high solids content. Water-jacket plants are characterized by a long useful life and a more aesthetic appearance (no dirty gas-holder). Due to their superior sealing of the substrate (hygiene!), they are recommended for use in the fermentation of night soil. The extra cost of the masonry water jacket is relatively modest.

Material of digester and drum

The digester is usually made of brick, concrete or quarry-stone masonry with plaster. The gas drum normally consists of 2.5 mm steel sheets for the sides and 2 mm sheets for the top.

It has welded-in braces which 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. 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 rather than blue or white, because the digester temperature is increased by solar radiation. Gas drums made of 2 cm wire-mesh-reinforced concrete or fiber-cement must receive a gas-tight internal coating. The gas drum should have a slightly sloping roof, otherwise rainwater will be trapped on it, leading to rust damage. An excessively steep-pitched roof is unnecessarily expensive and the gas in the tip cannot be used because when the drum is resting on the bottom, the gas is no longer under pressure.

Floating-drums made of glass-fiber reinforced plastic and high-density polyethylene have been used successfully, but the construction costs are higher compared to using steel. Floating-drums made of wire-mesh-reinforced concrete are liable to hairline cracking and are intrinsically porous. They require a gas-tight, elastic internal coating. PVC drums are unsuitable because they are not resistant to UV.

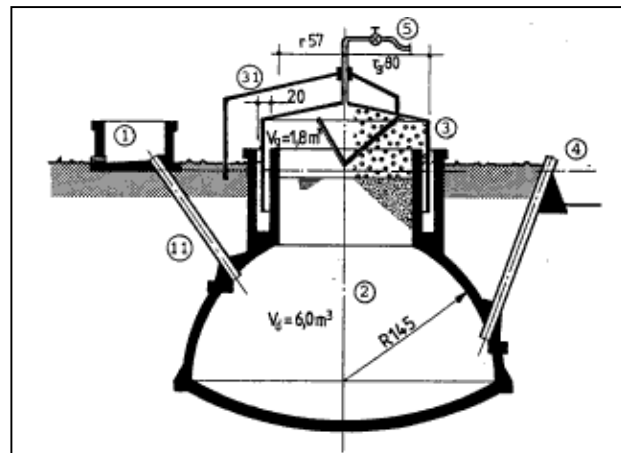


Figure 8: Water-jacket plant with external guide frame. 1 Mixing pit, 11 Fill pipe, 2 Digester, 3 Gasholder, 31 Guide frame, 4 Slurry store, 5 Gas pipe

Source: Sasse, 1984

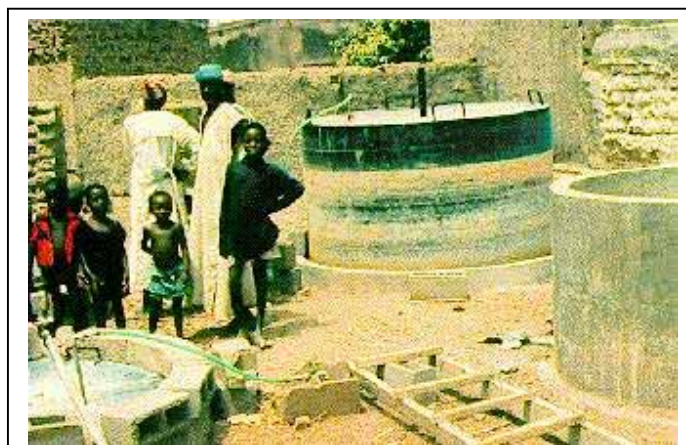


Figure 9: Floating-drum plant in Burkina Faso

Photo: gtz/GATE

Guide frame

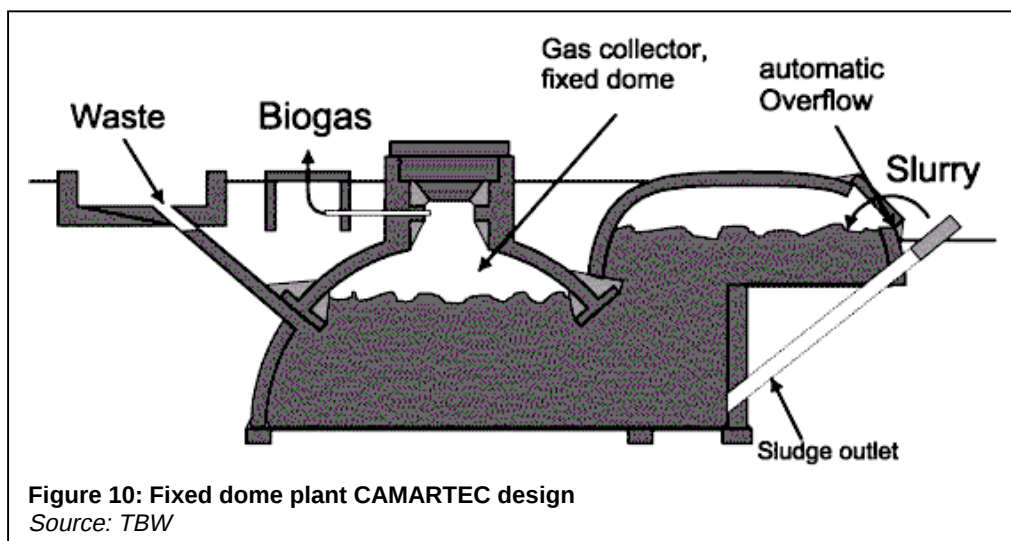
The side wall of the gas drum should be just as high as the wall above the support ledge. The floating-drum must not touch the outer walls. It must not tilt, otherwise the coating will be damaged or it will get stuck. For this reason, a floating-drum always requires a guide. This guide frame must be designed in a way that allows the gas drum to be removed for repair. The drum can only be removed if air can flow into it, either by opening the gas outlet or by emptying the water jacket.

The floating gas drum can be replaced by a balloon above the digester. This reduces construction costs but in practice problems always arise with the attachment of the balloon to the digester and with the high susceptibility to physical damage.

Types of floating-drum plants

There are different types of floating-drum plants (see drawings under Construction):

- **KVIC model** with a cylindrical digester, the oldest and most widespread floating drum biogas plant from India.
- **Pragati model** with a hemisphere digester
- **Ganesh model** made of angular steel and plastic foil
- floating-drum plant made of pre-fabricated reinforced concrete compound units
- floating-drum plant made of fibre-glass reinforced polyester
- **BORDA model:** The BORDA-plant combines the static advantages of hemispherical digester with the process-stability of the floating-drum and the longer life span of a water jacket plant.



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Biogas Plant Types and Design

Digester types in industrialized countries

To give an overview, we have chosen three fictitious designs as they could be found in, for example, Europe. The designs are selected in a way that all the typical elements of modern biogas technology appear at least once. All designs are above-ground, which is common in Europe. Underground structures, however, do exist.

Mixing pit varies in size and shape according to the nature of substrate. It is equipped with propellers for mixing and/or chopping the substrate and often with a pump to transport the substrate into the digester. At times, the substrate is also pre-heated in the mixing pit in order to avoid a temperature shock inside the digester.

Fermenter or digester is insulated and made of concrete or steel. To optimize the flow of substrate, large digesters have a longish channel form. Large digesters are almost always agitated by slow rotating paddles or rotors or by injected biogas. Co-fermenters have two or more separated fermenters. The gas can be collected inside the digester, then usually with a flexible cover. The digester can also be filled completely and the gas stored in a separate gas-holder.

Gas-holder is usually of flexible material, therefore to be protected against weather. It can be placed either directly above the substrate, then it acts like a balloon plant, or in a separate 'gas-bag'.

slurry store for storage of slurry during winter. The store can be open (like conventional open liquid manure storage) or closed and connected to the gas-holder to capture remaining gas production. Normally, the store is not heated and only agitated before the slurry is spread on the field.

Gas use element is in Europe in 95% of the cases a thermo-power unit which produces electricity for the farm, the grid and heat for the house, greenhouses and other uses. The thermo-power unit has the advantage, that the required energy can be produced in any mixture of gas and fossil energy. It can, therefore, react to periods of low gas production and high energy requirements or vice versa.



Figure 11: Control glasses for an industrial digester for solid organic waste, TBW, Germany

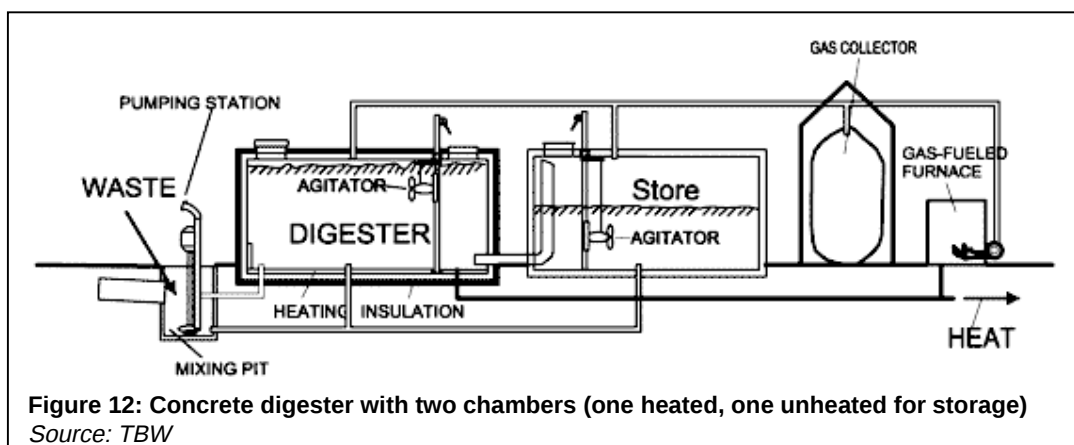
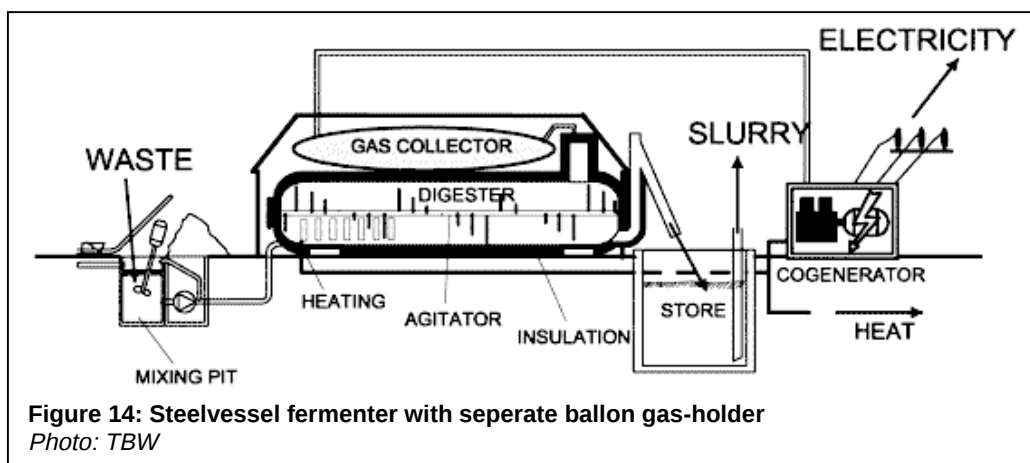
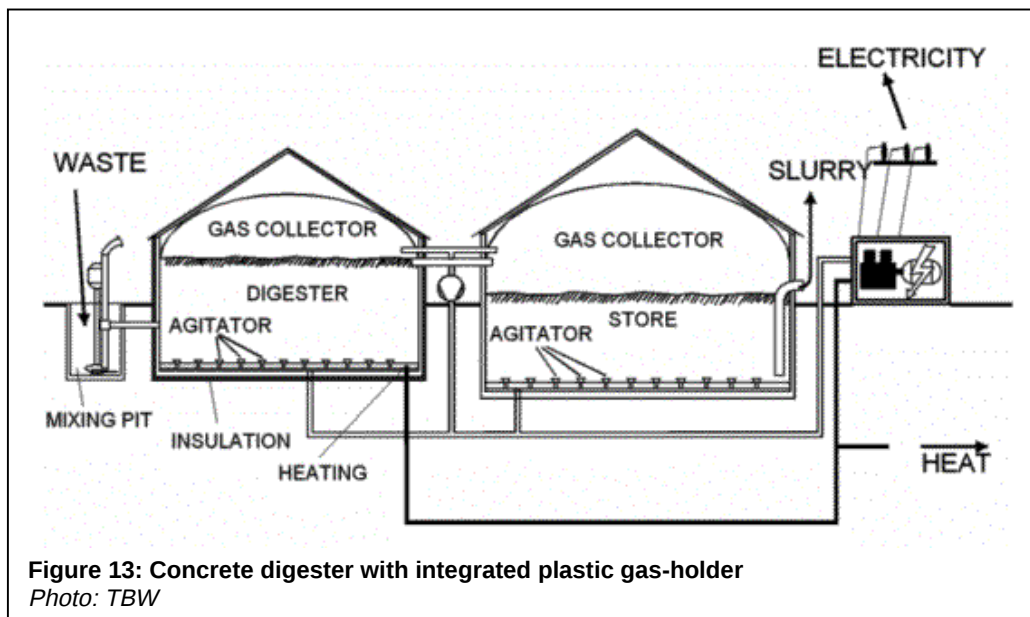


Figure 12: Concrete digester with two chambers (one heated, one unheated for storage)
Source: TBW



Selection of appropriate design

In developing countries, the design selection is determined largely by the prevailing design in the region, which, in turn takes the climatic, economic and substrate specific conditions into consideration. Large plants are designed on a case-to-case basis.

Typical design criteria are:

Space: determines mainly the decision if the fermenter is above-ground or underground, if it is to be constructed as an upright cylinder or as a horizontal plant.

Existing structures may be used like a liquid manure tank, an empty hall or a steel container. To reduce costs, the planner may need to adjust the design to these existing structures.

Minimizing costs can be an important design parameter, especially when the monetary benefits are expected to be low. In this case a flexible cover of the digester is usually the cheapest solution. Minimizing costs is often opposed to maximizing gas yield.

Available substrate determines not only the size and shape of mixing pit but the digester volume (retention time!), the heating and agitation devices. Agitation through gas injection is

only feasible with homogenous substrate and a dry matter content below 5%. Mechanical agitation becomes problematic above 10% dry matter.

Ballon plants

A balloon plant consists of a heat-sealed plastic or rubber bag (balloon), combining digester and gas-holder. The gas is stored in the upper part of the balloon. The inlet and outlet are attached directly to the skin of the balloon. Gas pressure can be increased by placing weights on the balloon. If the gas pressure exceeds a limit that the balloon can withstand, it may damage the skin. Therefore, safety valves are required. If higher gas pressures are needed, a gas pump is required. Since the material has to be weather- and UV resistant, specially stabilized, reinforced plastic or synthetic caoutchouc is given preference. Other materials which have been used successfully include RMP (red mud plastic), Trevira and butyl. The useful life-span does usually not exceed 2-5 years.

Advantages: Standardized prefabrication at low cost; shallow installation suitable for use in areas with a high groundwater table; high digester temperatures in warm climates; uncomplicated cleaning, emptying and maintenance; difficult substrates like water hyacinths can be used.

Disadvantages: Low gas pressure may require gas pumps; scum cannot be removed during operation; the plastic balloon has a relatively short useful life-span and is susceptible to mechanical damage and usually not available locally. In addition, local craftsmen are rarely in a position to repair a damaged balloon.

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

Horizontal plants

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

Advantages: Shallow construction despite large slurry space.

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

Earth-pit plants

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

Advantages: Low cost of installation (as little as 20% of a floating-drum plant); high potential for self help approaches.

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

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

Ferrocement plants

The ferro-cement type of construction can be applied either as a self-supporting shell or an earth-pit lining. The vessel is usually cylindrical. Very small plants (Volume under 6 m³) can be prefabricated. As in the case of a fixed-dome plant, the ferrocement gasholder requires special sealing measures (proven reliability with cemented-on aluminium foil).

Advantages: Low cost of construction, especially in comparison with potentially high cost of masonry for alternative plants; mass production possible; low material input.

Disadvantages: Substantial consumption of essentially good-quality cement; workmanship must meet high quality standards; uses substantial amounts of expensive wire mesh; construction technique not yet adequately time-tested; special sealing measures for the gas-holder are necessary.

Ferro-cement biogas plants are only recommended in cases where special ferro-cement know-how is available.

Parts of Biogas Plants

- Influent collecting tank
- Inlet and outlet
- Digester
- Gasholders
- Gas pipe, valves and accessories
- Stirring facilities
- Heating systems
- Pumps
- Weak Ring

Influent collecting tank

Size and homogenization

Fresh substrate is usually gathered in an influent collecting tank prior to being fed into the digester. Depending on the type of system, the tank should hold one to two days' substrate. An influent collecting tank can also be used to homogenize the various substrates and to set up the required consistency, e.g. by adding water to dilute the mixture of vegetable solids (straw, grass, etc.), or by adding more solids in order to increase the biomass. The fibrous material is raked off the surface, if necessary, and any stones or sand settling at the bottom are cleaned out after the slurry is admitted to the digester. The desired degree of homogenization and solids content can be achieved with the aid of an agitator, pump or chopper. A rock or wooden plug can be used to close off the inlet pipe during the mixing process.

Location

A sunny location can help to warm the contents before they are fed into the digester in order to avoid thermal shock due to the cold mixing water. In the case of a biogas plant that is directly connected to the stable, it is advisable to install the mixing pit deep enough to allow installation of a floating gutter leading directly into the pit. Care must also be taken to ensure that the low position of the mixing pit does not result in premature digestion. For reasons of hygiene, toilets should have a direct connection to the inlet pipe.

Inlet and outlet

Size and material

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

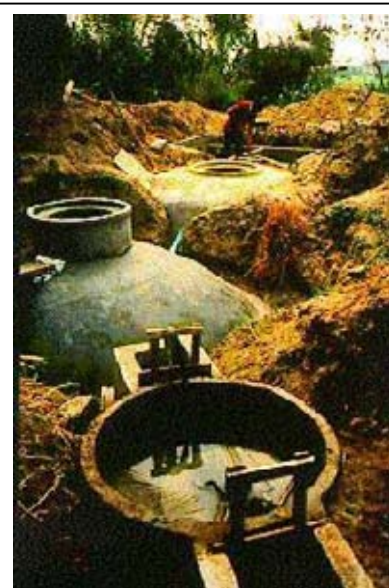


Figure 15: Installation of a fixed-dome plant in Thailand: The influent collecting tank is in front of the photo, the digester and the outlet are located behind it.

Photo: Kossmann (gtz/GATE)

Position of inlet and outlet

Both the inlet and the outlet pipe must be freely accessible and straight, so that a rod can be pushed through to eliminate obstructions and agitate the digester contents. The pipes should penetrate the digester wall at a point below the lowest slurry level (i.e. not through the gas storage). The points of penetration should be sealed and reinforced with mortar.

The inlet pipe ends higher in the digester than the outlet pipe in order to promote more uniform flow of the substrate. In a fixed-dome plant, the inlet pipe defines the bottom line of the gas-holder, acting like a security valve to release over-pressure. In a floating-drum plant, the end of the outlet pipe determines the digester's (constant) slurry level.

Inlet and outlet pipe must be placed in connection with brick-laying. It is not advisable to break holes into the spherical shell afterwards, this would weaken the masonry structure.

Digester

Requirements

No matter which design is chosen, the digester (fermentation tank) must meet the following requirements:

- **Water/gastightness** - watertightness in order to prevent seepage and the resultant threat to soil and groundwater quality; gastightness in order to ensure proper containment of the entire biogas yield and to prevent air entering into the digester (which could result in the formation of an explosive mixture).
- **Insulation** - if and to which extent depends on the required process temperature, the local climate and the financial means; heat loss should be minimized if outside temperatures are low, warming up of the digester should be facilitated when outside temperatures are high.
- **Minimum surface area** - keeps cost of construction to a minimum and reduces heat losses through the vessel walls. A spherical structure has the best ratio of volume and surface area. For practical construction, a hemispherical construction with a conical floor is close to the optimum.
- **Structural stability** - sufficient to withstand all static and dynamic loads, durable and resistant to corrosion.

Internal and external forces

Two relevant forces act on the digester. The external active earth pressure causes compressive forces within the masonry. The internal hydrostatic and gas pressures causes tensile stress in the masonry. Thus, the external pressure applied by the surrounding earth must be greater at all points than the internal forces. Round and spherical shapes are able to accept the highest forces and distribute them uniformly. Edges and corners lead to peak tensile stresses which can result in cracking.

Shapes of digesters

From the standpoint of fluid dynamics and structural strength, an egg-shaped vessel is about the best possible solution. This type of construction, however, is comparatively expensive, so that its use is usually restricted to large-scale sewage treatment plants. The Chinese fixed-dome designs are of similar shape, but less expensive. The hemispherical CAMARTEC design is optimized in structural strength, but does not make optimal use of the excavation required.

Simplified versions of such digester designs include cylinders with conical covers and bottoms. They are much easier to build and are sometimes available on the market as prefabricated units. Their disadvantage lies in their less favorable surface-volume ratio. The cylinder should have a height equal to its diameter. *Prone cylinders* have become quite popular on farms, since they are frequently the more favorable solution for small-scale bio-methanation. *Cuboid digesters* are often employed in batch-fed systems used primarily for fermenting solid material, so that fluid dynamics are of little interest.

Building material of digester

Digesters can be made from any of the following materials:

Steel vessels

Steel vessels are inherently gas-tight, have good tensile strength, and are relatively easy to construct (by welding). In many cases, a discarded steel vessel of appropriate shape and size can be salvaged for use as a biogas digester. Susceptibility to corrosion both outside (atmospheric humidity) and inside (aggressive media) can be a severe problem. As a rule, some type of anticorrosive coating must be applied and checked at regular intervals. Steel vessels are only cost-effective, if second-hand vessels (e.g. train or truck tankers) can be used.



Figure 16: Construction of the digester neck with steel reinforcement
Photo: Krämer (TBW)

Concrete vessels

Concrete vessels have gained widespread acceptance in recent years. The requisite gas-tightness necessitates careful construction and the use of gas-tight coatings, linings and/or seal strips in order to prevent gas leakage. Most common are stress cracks at the joints of the top and the sides. The prime advantage of concrete vessels are their practically unlimited useful life and their relatively inexpensive construction. This is especially true for large digesters in industrialized countries.

Masonry

Masonry is the most frequent construction method for small scale digesters. Only well-burnt clay bricks, high quality, pre-cast concrete blocks or stone blocks should be used in the construction of digesters. Cement-plastered/rendered masonry is a suitable - and inexpensive - approach for building an underground biogas digester, whereby a dome-like shape is recommended. For domes larger than 20 m³ digester volume, steel reinforcement is advisable. Masons who are to build masonry digesters have to undergo specific training and, initially, require close supervision.



Figure 17: Construction of the dome for a 30 m³ digester in Cuba
Photo: Krämer (TBW)

Plastics

Plastics have been in widespread use in the field of biogas engineering for a long time. Basic differentiation is made between flexible materials (sheeting) and rigid materials (PE, GRP, etc.). Diverse types of plastic sheeting can be used for constructing the entire digesting chamber (balloon gas holders) or as a vessel cover in the form of a gas-tight "bonnet".

Sheeting made of caoutchouc (india rubber), PVC, and PE of various thickness and description have been tried out in numerous systems. The durability of plastic materials exposed to aggressive slurry, mechanical stress and UV radiation, as well as their gas permeability, vary from material to material and on the production processes employed in their manufacture. Glass-fibre reinforced plastic (GRP) digesters have proven quite suitable, as long as the in-service static stresses are accounted for in the manufacturing process. GRP vessels display good gas-tightness and corrosion resistance. They are easy to repair and have a long useful life span. The use of sandwich material (GRP - foam insulation - GRP) minimizes the on-site insulating work and reduces the cost of transportation and erection.

Wood

A further suitable material for use in the construction of biogas systems is wood. It is often used for building liquid-manure hoppers and spreaders. Wooden digesters require a vapor-proof membrane to protect the insulation. Closed vessels of any appreciable size are very hard to render gas-tight without the aid of plastic sheeting. Consequently, such digesters are very rare.

Gasholders

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

- floating-drum gasholders
- fixe-domes gasholders
- plastic gasholders
- separate gasholders

Floating-drum gasholders

Most floating-drum gas-holders are made of 2-4 mm thick sheet steel, with the sides made of thicker material than the top in order to compensate for the higher degree of corrosive attack. Structural stability is provided by L-bar bracing that also serves to break up surface scum when the drum is rotated. A guide frame stabilizes the gas drum and prevents it from tilting and rubbing against the masonry. The two equally suitable and most frequently used types are:

- an internal rod & pipe guide with a fixed (concrete-embedded) cross pole (an advantageous configuration in connection with an internal gas outlet);
- external guide frame supported on three wooden or steel legs.

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

All grades of steel normally used for gas-holders are susceptible to moisture-induced rusting both in- and outside. Consequently, a long service life requires proper surface protection, including:

- thorough de-rusting and de-soiling
- primer coat of minimum 2 layers
- 2 or 3 cover coats of plastic or bituminous paint.

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

Materials regarded as suitable alternatives to standard grades of steel are galvanized sheet metal, plastics (glass-fiber reinforced plastic (GRP), plastic sheeting) and ferro-cement with a gas-tight lining. The gas-holders of water-jacket plants have a longer average service life, particularly when a film of used oil is poured on the water seal to provide impregnation.

Fixed-dome gasholders

A fixed-dome gas-holder can be either the upper part of a hemispherical digester (CAMARTEC design) or a conical top of a cylindrical digester (e.g. Chinese fixed-dome plant). In a fixed-dome plant the gas collecting in the upper part of the dome displaces a corresponding volume of digested slurry. The following aspects must be considered with regard to design and operation:

- An overflow into and out of the compensation tank must be provided to avoid over-filling of the plant.
- The gas outlet must be located about 10 cm higher than the overflow level to avoid plugging up of the gas pipe.
- A gas pressure of 1 m WC or more can develop inside the gas space. Consequently, the plant must be covered sufficiently with soil to provide an adequate counter-pressure.
- Special care must be taken to properly close the man hole, which may require to weigh down the lid with 100 kg or more. The safest method is to secure the lid with clamps.

The following structural measures are recommended to avoid cracks in the gas-holder:

- The foot of the dome (gas-holder) should be stabilized by letting the foundation slab project out enough to allow for an outer ring of mortar.
- A rated break/pivot ring should be provided at a point located between 1/2 and 2/3 of the minimum slurry level. This in order to limit the occurrence or propagation of cracks in the vicinity of the dome foot and to displace forces through its stiffening/articulating effect such that tensile forces are reduced around the gas space. Alternatively, the lowest point of the gas-holder should be reinforced by a steel ring or the whole gas-holder be reinforced with chicken mesh wire.

Normally, masonry, *mortar and concrete are not gas-tight*, with or without mortar additives. Gas-tightness can only be achieved through good, careful workmanship and special coatings. The main precondition is that masonry and plaster are strong and free of cracks. Cracked and sandy rendering must be removed. In most cases, a plant with cracked masonry must be dismantled, because not even the best seal coating can render cracks permanently gas-tight.

Some tried and proven seal coats and plasters:

- **multi-layer bitumen**, applied cold (hot application poses the danger of injury by burns and smoke-poisoning; solvents cause dangerous/explosive vapors). Two to four thick coats required;
- **bitumen with aluminum foil**, thin sheets of overlapping aluminum foil applied to the still-sticky bitumen, followed by the next coat of bitumen;
- **plastics**, e.g. epoxy resin or acrylic paint; very good but expensive;
- **paraffin**, diluted with 2-5% kerosene, heated up to 100°C and applied to the preheated masonry, thus providing an effective (deep) seal. Use kerosene/gas torch to heat masonry.
- multi-layer **cement plaster** with water-proof elements

In any case, a pressure test must be carried out before the plant is put in service.

Plastic gas-holders

Gas-holders made of plastic sheeting serve as integrated gas-holders, as separate balloon/bag-type gas-holders and as integrated gas-transport/storage elements. For plastic

(sheet) gas-holders, the structural details are of less immediate interest than the question of which materials can be used.

Separate gas-holders

Differentiation is made between:

- low-pressure, wet and dry gas-holders (10-50 mbar). Basically, these gas-holders are identical to integrated and/or plastic (sheet) gas-holders. Separate gas-holders cost more and are only worthwhile in case of substantial distances (at least 50-100 m) or to allow repair of a leaky fixed-dome plant. This type of separate gas-holder is also used to buffer extreme differences between gas-production and gas-use patterns.
- medium- or high-pressure gas-holders (8-10 bar / 200 bar)



Figure 18: Biogas plant with separate gasholder in Nicaragua

Photo: gtz/GATE

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

Gas pipe, valves and accessories

Biogas piping

At least 60% of all non-functional biogas units are attributable to defect gas piping. Utmost care has to be taken, therefore, for proper installation. For the sake of standardization, it is advisable to select a single size for all pipes, valves and accessories.

The requirements for biogas piping, valves and accessories are essentially the same as for other gas installations. However, biogas is 100% saturated with water vapor and contains hydrogen-sulfide. Consequently, no piping, valves or accessories that contain any amounts of ferrous metals may be used for biogas piping, because they would be destroyed by corrosion within a short time. The gas lines may consist of standard galvanized steel pipes. Also suitable (and inexpensive) is plastic tubing made of rigid PVC or rigid PE. Flexible gas pipes laid in the open must be UV-resistant.

Steel pipes

Galvanized steel water supply pipes are used most frequently, because the entire piping system (gas pipe, valves and accessories) can be made of universally applicable English/U.S. Customary system components, i.e. with all dimensions in inches. Pipes with

nominal dimensions of 1/2" or 3/4" are adequate for small-to-midsize plants of simple design and pipe lengths of less than 30 m. For larger plants, longer gas pipes or low system pressure, a detailed pressure-loss (pipe-sizing) calculation must be performed.

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

- **gas-tight, friction-type joints**
- **line drainage, i.e. with a water trap at the lowest point of the sloping pipe in order to empty water accumulation**
- **protection against mechanical impact**

Stirring facilities

Optimum stirring substantially reduces the retention time. If agitation is excessive, the bacteria have "no time to eat". The ideal is gentle but intensive stirring about every four hours. Of similar importance is the breaking up of a scum layer which has lost contact with the main volume of substrate and is, therefore, not further digested. This top layer can form an impermeable barrier for biogas to move up from the digester to the gas holder.

As a rule of thumb it can be stated that stirring facilities are more important in larger plants than in small scale farm plants.



Figure 19: Stirring device for a european biodigester

Photo: Krieg

Types of stirring facilities

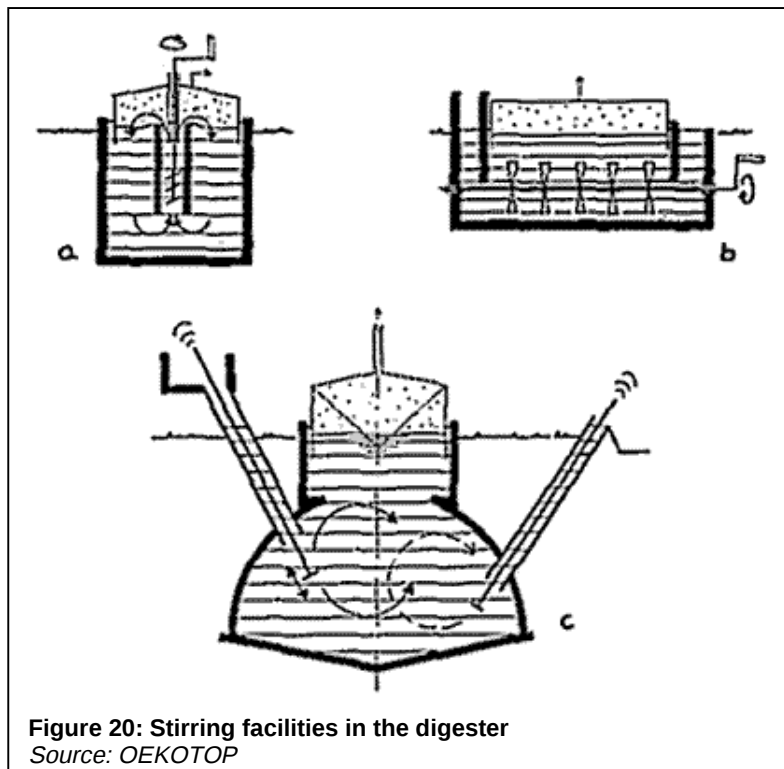


Figure 20: Stirring facilities in the digester

Source: OEKOTOP

- The **impeller stirrer** has given good results especially in sewage treatment plants.
- The **horizontal shaft** 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.

Optional Parts of Biogas Plants

Heating systems

Normally, because of the rather high involved costs, small-scale biogas plants are built without heating systems. But even for small scale plants, it is of advantage for the bio-methanation process to warm up the influent substrate to its proper process temperature before it is fed into the digester. If possible, cold zones in the digester should be avoided. In the following, a number of different ways to get the required amount of thermal energy into the substrate are described. In principle, one can differentiate between:

- **direct heating** in the form of steam or hot water, and
- **indirect heating** via heat exchanger, whereby the heating medium, usually hot water, imparts heat while not mixing with the substrate.

Direct heating

Direct heating with steam has the serious disadvantage of requiring an elaborate steam-generating system (including desalination and ion exchange as water pretreatment) and can also cause local overheating. The high cost is only justifiable for large-scale sewage treatment facilities.

The injection of hot water raises the water content of the slurry and should only be practiced if such dilution is necessary.

Indirect heating

Indirect heating is accomplished with heat exchangers located either inside or outside of the digester, depending on the shape of the vessel, the type of substrate used, and the nature of the operating mode.

4. **Floor heating** systems have not served well in the past, because the accumulation of sediment gradually hampers the transfer of heat.
5. **In-vessel** heat exchangers are a good solution from the standpoint of heat transfer as long as they are able to withstand the mechanical stress caused by the mixer, circulating pump, etc. The larger the heat-exchange surface, the more uniformly heat distribution can be effected which is better for the biological process.
6. **On-vessel** heat exchangers with the heat conductors located in or on the vessel walls are inferior to in-vessel-exchangers as far as heat-transfer efficiency is concerned, since too much heat is lost to the surroundings. On the other hand, practically the entire wall area of the vessel can be used as a heat-transfer surface, and there are no obstructions in the vessel to impede the flow of slurry.
7. **Ex-vessel** heat exchangers offer the advantage of easy access for cleaning and maintenance.

While in Northern countries, often a substantial amount of the produced biogas is consumed to provide process energy, in countries with higher temperatures and longer sunshine hours, solar-heated water can be a cost-effective solution for heating. Exposing the site of the biogas plant to sunshine, e.g. by avoiding tree shade, is the simplest method of heating.

Pumps

Pumps become necessary parts of a biogas unit, when the amounts of substrate require fast movement and when gravity cannot be used for reasons of topography or substrate characteristics. Pumps transport the substrate from the point of delivery through all the stages of fermentation. Therefore, several pumps and types of pumps may be needed. Pumps are usually found in large scale biogas units.

Types of pump

There are two predominant types of pump for fresh substrate: **centrifugal pumps** and **positive-displacement pumps** (reciprocating pumps). Centrifugal pumps operate on the

principle of a rapidly rotating impeller located in the liquid flow. They provide high delivery rates and are very robust, i.e. the internals are exposed to little mechanical stress. They do, however, require a free-flowing intake arrangement, because they are not self-priming (regenerative).

Data of pumps

Practically all centrifugal pump characteristics are geared to water. They show the delivery rates for various heads, the achievable efficiency levels, and the power requirement for the pump motor. Consequently, such data cannot be directly applied to biogas systems, since the overall performance and efficiency level of a pump for re-circulating slurry may suffer a serious drop-off as compared to its standard "water" rating (roughly 5-10%).

Substrate

Sometimes, namely when the substrate is excessively viscous, a centrifugal pump will no longer do the job, because the condition of the substrate surpasses the pump's physical delivery capacity. In such cases, one must turn to a so-called positive-displacement or reciprocating type of pump in the form of a piston pump, gear pump or eccentric spiral pump, all of which operate on the principle of displacing action to provide positive delivery via one or more enclosed chambers.

Positive displacement pumps

Positive displacement pumps offer multiple advantages. Even for highly viscous substrate, they provide high delivery and high efficiency at a relatively low rate of power consumption. Their characteristics - once again for water - demonstrate how little the delivery rate depends on the delivery head. Consequently, most of the characteristics show the delivery rate as a function of pump speed.

The main disadvantage as compared to a centrifugal pump is the greater amount of wear and tear on the internal occasioned by the necessity of providing an effective seal between each two adjacent chambers.

Pump delivery lines

Pump delivery lines can be made of steel, PVC (rigid) or PE (rigid or flexible), as well as appropriate flexible pressure tubing made of reinforced plastic or rubber. Solid substrate, e.g. dung, can also be handled via conveyor belt, worm conveyor or sliding-bar system, though none of these could be used for liquid manure. When liquid manure is conducted through an open gutter, small weirs or barrages should be installed at intervals of 20-30 m as a means of breaking up the scum layer.

Each such barrier should cause the scum to fall at least 20-30 cm on the downstream side. All changes of direction should be executed at right angles (90°). Depending on the overall length, the cross gutter should be laid some 30-50 cm deeper than the main gutter. Transitions between a rectangular channel and a round pipe must be gradual. An inclination of about 14% yields optimum flow conditions. The channel bottom must be laid level, since any slope in the direction of flow would only cause the liquid manure to run off prematurely. All wall surfaces should be as smooth as possible.

Weak ring

Position of the weak ring

The weak/strong ring improves the gas-tightness of fixed-dome plants. It was first introduced in Tanzania and showed promising results. The weak ring separates the lower part of the hemispherical digester, (filled with digesting substrate), from the upper part (where the gas is stored). Vertical cracks, moving upwards from the bottom of the digester, are diverted in this ring of lean mortar into horizontal cracks. These cracks remain in the slurry area where they are of no harm to the gas-tightness. The strong ring is a reinforcement of the bottom of the gas-holder, it could also be seen as a foundation of the gas-holder. It is an additional device

to prevent cracks from entering the gas-holder. Weak and strong ring have been successfully combined in the CAMARTEC design.



Figure 21: Construction of the weak/strong ring of a 16 m³, Tanzania
Photo: Kellner (TBW)

Materials and construction

The weak ring consists of mortar of a mixture of sand, lime and cement (15:3:1). The top of the weak ring restores the horizontal level. It is interrupted only by the inlet pipe passing through. The strong ring rests on the weak ring and is the first layer of the upper part of the hemispherical shell. It consists of a row of header bricks with a concrete package at the outside. In case of soft or uncertain ground soil one may place a ring reinforcement bar in the concrete of the strong ring. The brick of the strong ring should be about three times wider than the brickwork of the upper wall. A detailed description of the weak/strong ring construction can be found in Sasse, Kellner, Kimaro.

Further reading:

- **Ringkamp, M.; Tentscher, W.; Schiller, H.:** Preliminary results on: statical optimization of family-sized fixed-dome digesters. Tilche, A.; Rozzi, A. (ed.): Poster Papers. Fifth International Symposium on Anaerobic Digestion, Bologna 1988, pp. 321-324
- **Sasse, L.; Kellner, Ch.; Kimaro, A.:** Improved Biogas Unit for Developing Countries. Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH, Vieweg & Sohn Verlagsgesellschaft Braunschweig, 1991

Balancing Biogas Production and Energy Demand

Determining the biogas production

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

- Measuring the biomass availability
- Determining the biomass supply via pertinent-literature data
- Determining the biomass supply via regional reference data
- Determining biomass supply via user survey

It should be kept in mind that the various methods of calculation can yield quite disparate results that not only require averaging by the planner, but which are also subject to seasonal variation.

The biomass supply should be divided into two categories:

8. quick and easy to procure
9. procurement difficult, involving a substantial amount of extra work

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

This is a time-consuming, cumbersome approach, but it is also a necessary means of adapting values from pertinent literature to unknown regions. The method is rather inaccurate if no total-solids measuring is included. Direct measurement can only provide indication of seasonal or fodder-related variance if sufficiently long series of measurements are conducted.

Determining the biomass supply via literature data

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

$$\text{Dung yield} = \text{liveweight} \times \text{number of animals} \times \text{specific quantity of excrements [kg/d]}$$

Often, specific quantities of excrement are given in % of liveweight per day, in the form of moist mass, total solids content or volatile solids content

Determining the biomass supply via regional reference data

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

Determining biomass availability via user survey

This approach is necessary if green matter is to be included as substrate.

Determining the energy demand

The energy demand of any given farm is equal to the sum of all present and future consumption situations, i.e. cooking, lighting, cooling, power generation etc. The following table helps to collect all data concerning the energy demand.

Table 1: Outline for determining biogas demand		
Energy consumers	Data	Biogas demand [l/d]
1. Gas for cooking Number of persons Number of meals Present energy consumption Present source of energy Gas demand per person and meal Gas demand per meal Anticipated gas demand Specific consumption rate of burner Number of burners Duration of burner operation Anticipated gas demand Total anticipated cooking-gas demand		
2. Lighting Specific gas consumption per lamp Number of lamps Duration of lamp operation Gas demand		
3. Cooling Specific gas consumption * 24 hours		
4. Engines Specific gas consumption per kWh Engine output Operating time Gas demand		
5. Miscellaneous consumers Gas demand		
Anticipated increase in consumption (%)		
Total biogas demand 1st-priority consumers 2nd-priority consumers 3rd-priority consumers		

The following alternative modes of calculation are useful:

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

Calculating biogas demand via comparable-use data: Such data may consist of

- empirical values from neighboring systems, e.g. biogas consumption per person and day,
- reference data taken from literature, although this approach involves considerable uncertainty, since cooking-energy consumption depends on local cooking and eating habits and can therefore differ substantially from case to case.

Estimating biogas demand by way of appliance consumption data and assumed periods of use: This approach can only work to the extent that the appliances to be used are known in advance, e.g. a biogas lamp with a specific gas consumption of 120 l/h and a planned operating period of 3 h/d, resulting in a gas demand of 360 l/d.

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

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

Biogas Planning Guide

This guide to planning is intended to serve agricultural extension officers as a comprehensive tool for arriving at decisions concerning the suitability of locations for family-sized biogas plants. The detailed planning outline has a **data** column for entering the gathered information and a **rating** column for noting the results of evaluation.

Evaluation criteria are:

- + Siting condition are favorable
- o Siting condition are unfavorable, but
 - a) compensable by project activities
 - b) not serious enough to cause ultimate failure
- Siting condition are not satisfactory

Despite its detailed nature, this planning guide is only a framework within which the extension officer should proceed to conduct a careful investigation and give due consideration, however subjectively, to the individual conditions in order to arrive at a locally practical solution. By no means is this planning guide intended to relieve the agricultural extension officer of the responsibility to thoroughly familiarize himself with the on-the-spot situation and to judge the overall value of a given location on the basis of the knowledge thus gained.

Detailed planning guide for biogas plants		
0. Initial situation	Data	Rating
Addresses/project characterization Plant acronym: Address of operator/customer: Place/region/country: Indigenous proj. org./executing org.: Extension officer/advisor: General user data Household structure and number of persons: User's economic situation: Crops: types, areas, manner of cultivation: Non-agricultural activity: Household/farm income: Cultural and social characteristics of user: Problems leading to the "biogas approach" Energy-supply bottlenecks: Workload for prior source of energy: Poor soil structure/yields: Erosion/deforestation: Poor hygiene and other factors: Objectives of the measure "biogas plant" User interests: Project interests: Other interests:		

1. Natural / Agricultural conditions	Data	Rating
Natural conditions Mean annual temperature: Seasonal fluctuations: Diurnal variation: Rating:		- 0 +
Subsoil Type of soil: Groundwater table, potable water catchment area: Rating:		- 0 +
Water conditions Climatic zone: Annual precipitation: Dry season (months): Distance to source of water: Rating:		- 0 +
Livestock inventory (useful for biogas production) Animals: kind and quantity: Type of stable: Use of dung: Persons responsible for animals: Rating:		- 0 +
Vegetable waste (useful for biogas production) Types and quantities: Prior use: Rating:		- 0 +
Fertilization Customary types and quantities of fertilizer/areas fertilized: Organic fertilizer familiar/in use: Rating:		- 0 +
Potential sites for biogas plant Combined stable/biogas plant possible: Distance between biogas plant and livestock stable: Distance between biogas plant and place of gas consumption: Rating:		- 0 +
Overall rating 1		- 0 +
2. Balancing the energy demand with the biogas production	Data	Rating
Prior energy supply Uses, source of energy,		

consumption: Anticipated biogas demand (kwh/day or l/d) for cooking: for lighting: for cooling: for engines: Total gas demand a) percentage that <i>must</i> be provided by the biogas plant: b) desired demand coverage: Available biomass (kg/d) and potential gas production (l/d) from animal husbandry pigs: poultry: cattle: Night soil Vegetable waste (quantities and potential gas yield) 1. 2. Totals: biomass and potential gas production a) easy to procure: b) less easy to procure: Balancing Gas production clearly greater than gas demand -> positive rating (+) Gas demand larger than gas production -> negative rating (-); but review of results in order regarding: a) possible reduction of gas demand by the following measures -> b) possible increase in biogas production by the following measures -> If the measures take hold: -> qualified positive rating for the plant location (o)		
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If the measures do not take hold: -> site rating remains negative (-)		
Overall rating 2		- o +
3. Plant Design and Construction	Data	Rating
Selection of plant design Locally customary type of plant: Arguments in favor of floating-drum plant: Arguments in favor of fixe-dome plant: Arguments in favor of other plant(s): Type of plant chosen: Selection of site Availability of building materials Bricks/blocks/stone: Cement: Metal: Sand: Piping/fittings: Miscellaneous: Availability of gas appliances Cookers: Lamps:		
Overall rating 3		- o +
4. Plant operation / maintenance / repair	Data	Rating
Assessment of plant operation Incidental work: Work expenditure in h: Persons responsible: Rating with regard to anticipated implementation:		- o +
Plant maintenance Maintenance-intensive components: Maintenance work by user: Maintenance work by external assistance: Rating with regard too anticipated implementation:		- o +
Plant repair Components liable to need repair: Repairs that can be made by the user: Repairs requiring external assistance:		- o +

Requisite materials and spare parts: Rating with regard to expected repair services:		
Overall rating 4		- o +
5. Economic analysis	Data	Rating
Time-expenditure accounting Time saved with biogas plant Time lost due to biogas plant Rating:		- o +
Microeconomic analysis Initial investment: Cost of operation/maintenance/repair: Return on investment: energy, fertilizer, otherwise: Payback time (static): Productiveness (static): Rating:		- o +
Quality factors, useful socioeconomic effects and costs Useful effects: hygiene, autonomous energy, better lighting, better working conditions, prestige: Drawbacks: need to handle night soil, negative social impact: Rating:		- o +
Overall rating 5		- o +
6. Social acceptance and potential for dissemination	Data	Rating
Anticipated acceptance Participation in planning and construction Integration into agricultural setting: Integration into household: Sociocultural acceptance: Rating:		- o +
Establishing a dissemination strategy Conditions for and chances of the professional-craftsman approach: Conditions for and chances of the self-help oriented approach:		- o + - o +
General conditions for dissemination Project-executing		- o +

organization and its staffing: orgnaizational structure: interest and prior experience in biogas technology: Regional infrastructure for transportation: communication: material procurement: Craftsman involvement, i.e. which acitivities: minimum qualifications: tools and machines: Training for engineers, craftsman and users: Proprietary capital, subsidy/credit requirement on the part of user: craftsmen: Rating:		
Overall rating 6		- o +
7. Summarization		
Siting conditions	No.	Rating
Natural/agricultural conditions	1.	- o +
Balancing the energy demand and the biogas production	2.	- o +
Plant design and construction	3.	- o +
Plant operation/maintenance/repair	4.	- o +
Economic analysis	5.	- o +
Social acceptance and potential for dissemination	6.	- o +
Overall rating of siting conditions		- o +

Step-by-Step Planning Checklist for Biogas Plants

The following table 2 gives an overview of all the steps required to build a biogas unit. The order follows a usual time-line. There are steps which can be combined. However, to skip any of them might lead to future problems.

Customer	Contractor
	organizes advertisement, awareness creation
hears about biogas, develops interest, get's in contact with the contractor	
	gives first overview over costs
	writes letter to the customer
writes a request	
	starts file
	makes a side visit, including: discussion and calculations
	makes a quantity survey,
	does object planning
	writes invoice explains warranty performances
makes first payment (50%)	organizes a customer and constructor sign contract
	hands over a list of building material to be delivered by the customer
prepares the material he agreed to deliver	
	organizes material delivery, reference line, main construction work, finishing, landscaping, slurry component, piping.
starts to fill the plant second payment (50%)	
	finishes piping installation of gas consumption accessories
discusses handing over	
makes an agreement on co-operation regarding fertiliser utilisation	
	makes a follow up on fertiliser utilisation
	does customer monitoring
	conducts technical and agricultural service visits

Sizing a biogas plant

The size of the biogas plant depends on the quantity, quality and kind of available biomass and on the digesting temperature. The following points should be considered

Sizing the digester

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

$$\mathbf{Vd} = \mathbf{Sd} \times \mathbf{RT} \text{ [m}^3 = \text{m}^3/\text{day} \times \text{number of days]}$$

The retention time, in turn, is determined by the chosen/given digesting temperature. For an unheated biogas plant, the temperature prevailing in the digester can be assumed as 1-2 Kelvin above the soil temperature. Seasonal variation must be given due consideration, however, i.e. the digester must be sized for the least favorable season of the year. For a plant of simple design, the retention time should amount to at least 40 days. Practical experience shows that retention times of 60-80 days, or even 100 days or more, are no rarity when there is a shortage of substrate. On the other hand, extra-long retention times can increase the gas yield by as much as 40%.

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

$$\text{Substrate input (Sd)} = \text{biomass (B)} + \text{water (W)} \text{ [m}^3/\text{d]}$$

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

Calculating the *daily gas production* **G**

The amount of *biogas generated each day* **G** [m³ gas/d], is calculated on the basis of the *specific gas yield* **Gy** of the substrate and the daily substrate input **Sd**.

The calculation can be based on:

10. The *volatile solids content* **VS**

$$\mathbf{G} = \mathbf{VS} \times \mathbf{Gy}(\text{solids}) \text{ [m}^3/\text{d} = \text{kg} \times \text{m}^3/(\text{d} \times \text{kg}) \text{]}$$

11. the weight of the moist mass **B**

$$\mathbf{G} = \mathbf{B} \times \mathbf{Gy}(\text{moist mass}) \text{ [m}^3/\text{d} = \text{kg} \times \text{m}^3/(\text{d} \times \text{kg}) \text{]}$$

12. standard gas-yield values per livestock unit **LSU**

$$\mathbf{G} = \text{number of LSU} \times \mathbf{Gy}(\text{species}) \text{ [m}^3/\text{d} = \text{number} \times \text{m}^3/(\text{d} \times \text{number}) \text{]}$$

The temperature dependency is given by:

$$\mathbf{Gy(T,RT)} = \mathbf{mGy} \times \mathbf{f(T,RT)}$$

where

Gy(T,RT) = *gas yield as a function of digester temperature and retention time*

mGy = *average specific gas yield, e.g. l/kg volatile solids content*

f(T,RT) = *multiplier for the gas yield as a function of digester temperature T and retention time RT*

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

Establishing the plant parameters

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

Specific gas production G_p

i.e. the daily gas generation rate per m^3 digester volume V_d , is calculated according to the following equation

$$G_p = G \div V_d \text{ [(m}^3\text{/d) / m}^3 \text{]}$$

Digester loading L_d

The digester loading L_d is calculated from the *daily total solids input* TS/d or the *daily volatile solids input* VS/d and the *digester volume* V_d :

$$L_{dT} = TS/d \div V_d \text{ [kg/(m}^3\text{ d)]}$$

$$L_{dV} = VS/d \div V_d \text{ [kg/(m}^3\text{ d)]}$$

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

Sizing the gasholder

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

- cover the *peak consumption rate* gc_{max} ($\rightarrow V_{g1}$) and
- hold the gas produced during the longest *zero-consumption period* tz_{max} ($\rightarrow V_{g2}$)

$$V_{g1} = gc_{max} \times tc_{max} = vc_{max}$$

$$V_{g2} = G_h \times tz_{max}$$

with

$$gc_{max} = \text{maximum hourly gas consumption [m}^3\text{/h]}$$

$$tc_{max} = \text{time of maximum consumption [h]}$$

$$vc_{max} = \text{maximum gas consumption [m}^3\text{]}$$

$$G_h = \text{hourly gas production [m}^3\text{/h]} = G \div 24 \text{ h/d}$$

$$tz_{max} = \text{maximum zero-consumption time [h]}$$

The larger V_g -value (V_{g1} or V_{g2}) determines the size of the gasholder. A safety margin of 10-20% should be added:

$$V_g = 1.15 (\pm 0.5) \times \max(V_{g1}, V_{g2})$$

Practical experience shows that 40-60% of the daily gas production normally has to be stored.

The ratio $V_d \div V_g$ (digester volume $\div$ gasholder volume) is a major factor with regard to the basic design of the biogas plant. For a typical agricultural biogas plant, the V_d/V_g -ratio amounts to somewhere between 3:1 and 10:1, with 5:1 - 6:1 occurring most frequently.

Siting of the Biogas Unit

Stable

- The stable should be built on an elevated position. This makes it possible to use gravity to collect urine and dung for feeding into the biogas plant. An elevated site on the farm also facilitates the distribution of slurry by gravity onto the farm land.
- For security reasons, the stable often is situated near the house.
- For easy access the feeding trough should be directed towards the area where fodder is grown.
- The milking place has to be at the higher end of the sloping stable floor. The milking should take place under clean conditions, away from the dung alley.
- roofed. If it is totally roofed, sun should still enter and ventilation should be assured.
- The position of the stable should allow for later extension.
- The animals need constant access to clean and fresh water and feeds.
- If the present position of the stable is unsuitable as a place for the biogas unit, it is usually better to shift the stable to the optimal position on the farm.



Figure 22: A digester should be as close as possible to the source of dung.



Figure 23: Cowshed, directly connected to the plant: A urine chamber to the right collects the liquid which can be used to wash the dung into the digester.

Photo: Kellner (TBW)

Biogas plant

- A golden rule is: the plant belongs to the stable rather than to the kitchen. Preferably, the mixing chamber and inlet are directly connected to a concrete stable floor. A few meters of piping are more economic than the daily transport of dung from the stable to the biogas plant.
- The roof of the stable should neither drain on the digester nor on the soil covering the plant. Large amounts of water entering the ground around the plant weaken the soil and cause static instability. Excess rain water may cool down the slurry in the plant and cause the gas production to drop.
- The overflow point should guide into farmland owned by the plant user. It has been observed that plants which overflow on public or foreign land can cause social problems. A promise of the owner to remove the slurry daily should not convince the planner.
- Water traps in the piping are a constant source of trouble. If the site allows, the plant and its piping should be laid out in a way that a water trap in the piping can be avoided. This is only possible if the pipes are sloping all the way back to the plant.
- The piping is a major cost factor. It should not be unnecessarily long. This criterion, however, is given less priority than having the stable close to the inlet and the outlet directed towards the farm land.
- A fixed dome plant should not be located in an area required for tractor or heavy machinery movements.
- Trees should not be too close to the plant. The roots may destroy the digester or the expansion chamber. In addition older trees may fall and destroy parts of the plant. If the position of the biogas plant is too shady, the soil temperature around the plant will be low in general. This leads to a decrease in gas production.
- The area around a biogas plant should not be a playground for children. This is less important for underground fixed dome plants, more important for floating drum plants and essential for balloon plants.



Figure 24: A model of an agricultural digester in Germany with two horizontal steel tanks, a gas storage bag and a co-generation unit in a container.

Photo: Krämer (TBW)

Substrate types and management

- Cattle dung and manure
- Pig dung and manure
- Goat dung
- Chicken droppings
- Human excrements
- Manure yield of animal excrements
- The problem of scum

Cattle dung and manure

Cattle dung is the most suitable material for biogas plants because of the methane-producing bacteria already contained in the stomach of ruminants. The specific gas production, however, is lower and the proportion of methane is around 65% because of pre-fermentation in the stomach. Its homogenous consistency is favourable for use in continuous plants as long as it is mixed with equal quantities of water.

Fresh cattle dung is usually collected and carried to the system in buckets or baskets. Upon arrival it is hand-mixed with about an equal amount of water before being fed into the digester. Straw and leftover fodder or hay is removed by hand in order to prevent clogging and reduce scum formation. Since most simple cow-sheds have dirt floors, the urine is usually not collected. When it is, it usually runs along the manure gutter and into a pail standing in a recess at the end of the gutter. The pail is emptied into the mixing pit - thereby replacing some of the mixing water - in preparation for charging the digester. Urine can considerably increase the gas production. A cemented stable floor, directly attached to the mixing pit, is the best solution to make optimum use of dung and urine and to save time for charging the digester.

Liquid cattle manure, a mixture of dung and urine, requires no extra water. However, the simple animal housing found on most farms in developing countries normally does not allow the collection of all animal excrement. Hence, most of the urine with its valuable plant nutrients is lost.

Pig dung and manure

When pigs are kept in unpaved areas or pens, only the dung can be collected. It must be diluted with water to the requisite consistency for charging the digester. This could result in considerable amounts of sand being fed into the digester, unless it is allowed to settle in the mixing vessel. Once inside the digester, sand and soil accumulates at the bottom and has to be removed periodically. Some form of mechanical mixer should be used to dilute the dung with water, since the odor nuisance makes manual mixing so repulsive that it is usually neglected. Similar to cow stables, a cemented floor, sloping towards the mixing pit, is a preferable solution.

Compared to cattle, pigs are more frequently kept on concrete floors. The water used for washing out the pens yields **liquid manure** with a low solids content. Thus, whenever the topography allows, the liquid manure should be allowed to flow by gravity into the digester. Wash-water should be used as sparingly as possible in order to minimize the necessary digester volume. Very frequently, the pig manure is collected in pails, which is advantageous, even though a sand trap should be provided to prevent sand from entering the digester.

Goat dung

For goats kept on unpaved floors, the situation is comparable to that described for pigdung. Since a goat farm is practically the only place where any substantial amount of goat dung can accumulate, and then only if the animals are kept on straw bedding, the available feed-stock for a biogas system will usually consist of a mixture of dung and straw bedding. Most

such systems are batch-fed versions into which the dung and an appropriate quantity of water are loaded without being pre-mixed. The feed-stock is usually hauled to and from the digester in wheelbarrows or baskets.

Chicken droppings

Chicken droppings can only be used if the chickens roost above a suitable dung collecting area of limited size. Otherwise, the sand or sawdust fraction would be disproportionately high. Chicken droppings can be fed into plants which are primarily filled with cow dung without any problem. There is a latent danger of high ammoniac concentration with pure chicken dung, but despite this there are many well functioning biogas plants combined with egg or meat producing factories. The collected droppings are hard and dry, so that they have to be pulverized and mixed with water before they can be loaded into the digester. Mechanical mixing is advisable. The proportion of methane in biogas from chicken excrement is up to 60%.

Human excrements

In most cultures, handling human excrement is loaded with taboos. Thus, if night soil is to be used in a biogas system, the toilets in question should drain directly into the system so that the night soil is fermented without pretreatment. The amount of water accompanying the night soil should be minimized by ensuring that no water taps or other external sources drain into the toilet bowls, and cleaning/flushing should be limited to rinsing out with about 0.5 - 1 liter water from a bowl. Western-style flush tanks should not be used in connection with small-size biogas plants.

In areas subject to frequent or seasonal water shortages, sand traps are a must, since wiping with stones is often the only means of cleaning after using the toilet.

The problem of scum

If there is heavy gas release from the inlet but not enough gas available for use, a thick scum layer is most likely the reason. Often the gas pressure does not build up because of the continuous gas release through the inlet for weeks. There is a danger of blocking the gas pipe by rising scum because of daily feeding without equivalent discharge. The lid (or man-hole) must be opened or the floating drum removed and scum is to be taken out by hand.

Separation of material

Straw, grass, stalks and even already dried dung tends to float to the surface. Solid and mineral material tends to sink to the bottom and, in the course of time, may block the outlet pipe or reduce the active digester volume. In properly mixed substrate with not too high water contents, there is no such separation because of sufficient friction within the paste-like substance.

Substrate

With pure and fresh cattle dung there is usually no scum problem. Floating layers will become a problem when e.g. undigestible husks are part of the fodder. This is often the case in pig feeds. Before installing a biogas plant at a piggery, the kind of fodder and consequently the kind of dung, must be checked to ensure that it is suitable for a biogas plant. It might be necessary to grind the fodder into fine powder. The user must be aware of the additional costs before deciding on a biogas unit. The problem is even bigger with poultry droppings. The kind of fodder, the sand the chicken pick up, and the feathers falling to the ground make

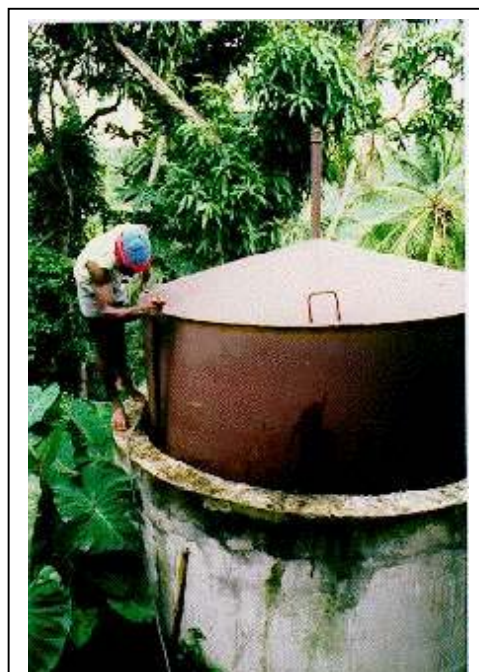


Figure 25: Destruction of the scum in a floating-drum plant in the Carribean
Photo: gtz/GATE

poultry dung a difficult substrate. In case of serious doubt, the building of a biogas plant should be re-assessed.

Scum can be avoided by stirring, but...

Scum is not brittle but very filthy and tough. Scum can become so solid after only a short time, that it needs heavy equipment to break it. It remains at the surface after being broken up. To destroy it by fermentation, it must be kept wet. Either the scum must be watered from the top or pushed down into the liquid. Both operations demand costly apparatus. For simple biogas plants, stirring is not a viable solution for breaking the scum.

The only solution for simple biogas plants to avoid scum is by selecting suitable feed material and by sufficient mixing of the dung with liquid before entering the plant.

Construction Details of Biogas Plants

This section provides detailed information on materials and devices used in the construction of biogas plants:

- Checklist for construction
- Agitation
- Heating
- Piping systems
- Plasters and Coats
- Pumps
- Slurry equipment
- Underground water

Checklist for building a biogas plant

1. **Finishing the planning**, i.e. site evaluation, determination of energy demand and biomass supply / biogas yield, plant sizing, selection of plant design, how and where to use the biogas, etc., in accordance with the planning guide
2. **Stipulate the plant's location and elaborate a site plan**, including all buildings, gas pipes, gas appliances and fields to be fertilized with digested slurry
3. **Draft a technical drawing showing all plant components**, i.e. mixing pit, connection to stabling, inlet / outlet, digester, gas-holder, gas pipes, slurry storage
4. **Preparation of material / personnel requirements list and procurement of materials needed for the chosen plant:**
 - bricks / stones / blocks for walls and foundation
 - sand, gravel
 - inlet / outlet pipes
 - metal parts (sheet metal, angle irons, etc.)
 - gas pipes and fittings
 - paint and sealants
 - gas appliances
 - tools
 - mason and helper
 - unskilled labor
 - workshop for metal (gas-holder) and pipe installation
5. **Material / personnel assignment planning**, i.e. procedural planning and execution of:
 - excavation
 - foundation slab
 - digester masonry
 - gasholder
 - rendering and sealing the masonry
 - mixing pit - slurry storage pit
 - drying out the plant
 - installing the gas pipe
 - acceptance inspection
6. **Regular building supervision**

7. Commissioning

- functional inspection of the biogas plant and its components
- starting the plant

8. Filling the plant

9. Training the user

Piping Systems

The piping system connects the biogas plant with the gas appliances. It has to be safe, economic and should allow the required gas-flow for the specific gas appliance. Galvanized steel (G.I.) pipes or PVC-pipes are most commonly used for this purpose. Most prominently, the piping system has to be reliably gas-tight during the life-span of the biogas unit. In the past, faulty piping systems were the most frequent reason for gas losses in biogas units.

PVC piping

PVC pipes and fittings have a relatively low price and can be easily installed. They are available in different qualities with adhesive joints or screw couplings (pressure water pipes). PVC pipes are susceptible to UV radiation and can easily be damaged by playing children. Wherever possible, PVC pipes should be placed underground.



Figure 26: Final touches on a piping system with PVC pipes
Photo: Krämer (TBW)

Galvanized steel piping

Galvanized steel pipes are reliable and durable alternatives to PVC pipes. They can be disconnected and reused if necessary. They resist shocks and other mechanical impacts. However, galvanized steel pipes are costly and the installation is labor intensive, therefore they are only suitable for places where PVC is unavailable or should not be used.

Pipe diameters

The necessary pipe diameter depends on the required flow-rate of biogas through the pipe and the distance between biogas digester and gas appliances. Long distances and high flow-rates lead to a decrease of the gas pressure. The longer the distance and the higher the flow rate, the higher the pressure drops due to friction. Bends and fittings increase the pressure losses. G.I. pipes show higher pressure losses than PVC pipes. The table below gives some values for appropriate pipe diameters. Using these pipe diameters for the specified length and flow rate, the pressure losses will not exceed 5 mbar.

Table 3: Appropriate pipe diameter for different pipe lengths and flow-rate (maximum pressure loss < 5 mbar)

	Galvanized steel pipe			PVC pipe		
Length [m]:	20	60	100	20	60	100
Flow-rate [m ³ /h]						
0.1	1/2"	1/2"	1/2"	1/2"	1/2"	1/2"
0.2	1/2"	1/2"	1/2"	1/2"	1/2"	1/2"
0.3	1/2"	1/2"	1/2"	1/2"	1/2"	1/2"
0.4	1/2"	1/2"	1/2"	1/2"	1/2"	1/2"
0.5	1/2"	1/2"	3/4"	1/2"	1/2"	1/2"
1.0	3/4"	3/4"	3/4"	1/2"	3/4"	3/4"
1.5	3/4"	3/4"	1"	1/2"	3/4"	3/4"
2.0	3/4"	1"	1"	3/4"	3/4"	1"

The values in this table show that a pipe diameter of 3/4" is suitable for flow rates up to 1.5 m³/h and distances up to 100 m (PVC pipe). Therefore one could select the diameter of 3/4" as single size for the hole piping system of small biogas plants. Another option is to select the diameter of 1" for the main gas pipe and 1/2" for all distribution pipes to the gas appliances.

Lay-out of the piping system

PVC can be used for all underground pipes or pipes that are protected against sun light and out of the reach of children. For all parts of the piping system that are above ground one should install galvanized steel pipes. Therefore it is recommended to use 1" G.I. steel pipes for the visible part of the piping system around the biogas digester. For the main pipe one uses 1" PVC pipe placed underground. The distribution pipes should be 1/2" G.I. steel pipes or PVC pipes, depending whether they are installed above or under the wall plastering. But even though G.I. pipes are less susceptible to damage, placing them underground should always be the preferred solution.

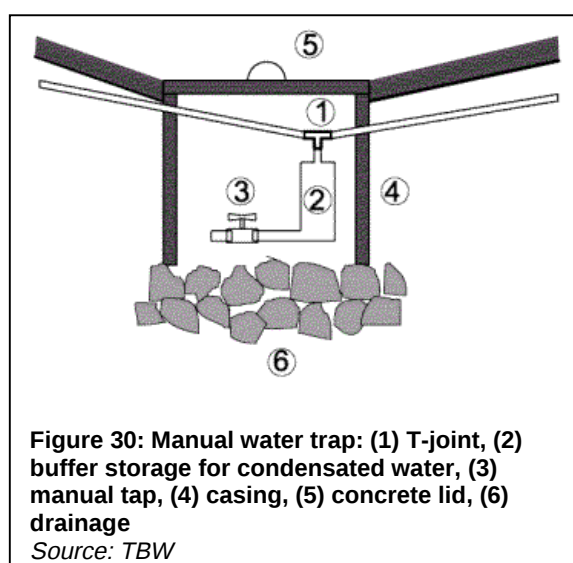
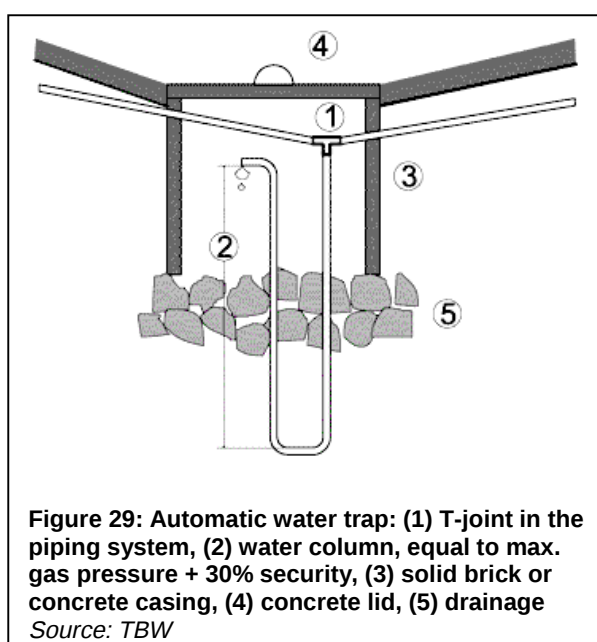
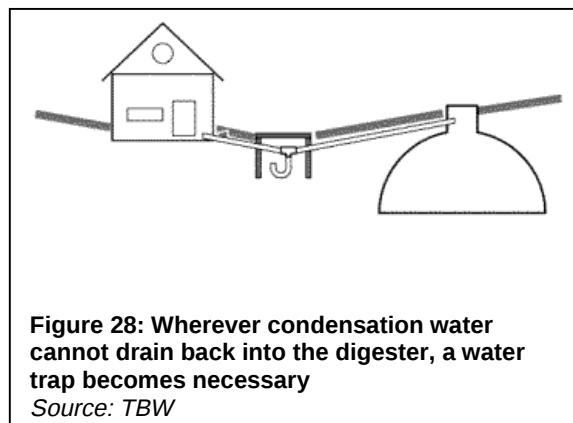
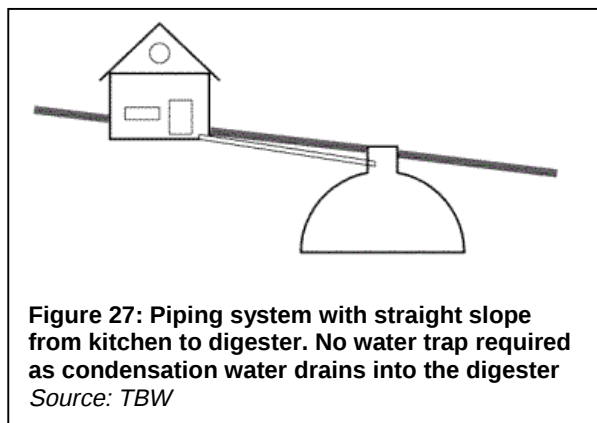
PVC pipes have to be laid at least 25 cm deep underground. They should be placed in a sand bed and be covered with sand or fine earth. One should carefully back-fill the ditches in order to avoid stones lying directly above the pipe.

When the piping is installed - and before refilling the ditches - it has to be tested for possible gas leakage. This can be done by pumping air into the closed piping system up to a pressure that is 2.5 times the maximum gas pressure of the biogas plant. If pressure loss occurs within few hours, every joint of the piping system has to be checked with soap water. Soap-bubbles indicate any leakage of gas.

Water traps

Due to temperature changes, the moisture-saturated biogas will form inevitably condensation water in the piping system. Ideally, the piping system should be laid out in a way that allows a free flow of condensation water back into the digester. If depressions in the piping system can not be avoided, one or several water traps have to be installed at the lowest point of the depressions. Inclination should not be less than 1%.

Often, water traps cannot be avoided. One has to decide then, if an 'automatic' trap or a manually operated trap is more suitable. Automatic traps have the advantage that emptying - which is easily forgotten - is not necessary. But if they dry up or blow empty, they may cause heavy and extended gas losses. In addition, they are not easily understood. Manual traps are simple and easy to understand, but if they are not emptied regularly, the accumulated condensation water will eventually block the piping system. Both kinds of traps have to be installed in a solid chamber, covered by a lid to prevent an eventual filling up by soil.



Valves

To the extent possible, ball valves or cock valves suitable for gas installations should be used as shutoff and isolating elements. The most reliable valves are chrome-plated ball valves. Gate valves of the type normally used for water pipes are not suitable. Any water valves exceptionally used must first be checked for gas-tightness. They have to be greased regularly. A U-tube pressure gauge is quick and easy to make and can normally be expected to meet the requirements of a biogas plant.

The main gas valve has to be installed close to the biogas digester. Sealed T-joints should be connected before and after the main valve. With these T-joints it is possible to test the digester and the piping system separately for their gas-tightness. Ball valves as shutoff devices should be installed at all gas appliances. With shutoff valves, cleaning and maintenance work can be carried out without closing the main gas valve.

Pumps for Biogas Plants

Pumps are required to bridge differences in height between the levels of slurry-flow through the biogas unit. They can also be required to mix the substrate or to speed up slow flowing substrates. If substrates have a high solids content and do not flow at all, but cannot be diluted, pumps or transport belts are essential.

Pumps are driven by engines, are exposed to wear and tear and can be damaged. They are costly, consume energy and can disrupt the filling process. For these reasons, pumps should be avoided where possible and methods of dilution and use of the natural gradient be utilized instead.

If pumps cannot be avoided, they can be installed in two ways:

- Dry installation: the pump is connected in line with the pipe. The substrate flows freely up to the pump and is accelerated while passing through the pump.
- Wet installation: the pump is installed with an electric engine inside the substrate. The electric engine is sealed in a watertight container. Alternatively, the pump in the substrate is driven by a shaft, the engine is outside the substrate.

Types of pumps

Rotary pumps

Rotary pumps operate with a rotor which presses the liquid against the outside wall of the rotor chamber. Due to the geometry of the chamber the liquid is pushed into the outlet pipe. Rotary pumps are very common in liquid manure technology. They are simple and robust and used mainly for substrates of less than 8% solids content. The quantity conveyed per time unit depends largely on the height of lift or the conveying pressure. The maximum conveying pressure is between 0,8 and 3.5 bar. The quantity that can be conveyed varies from 2 to 6 m³per min. at a power input of 3 - 15 kW. Rotary pumps cannot, usually, be used as a sucking device. As a special form of rotary pumps, the chopper pump deserves mentioning. It's rotor is equipped with blades to chop substrates with long fibers like straw and other fodder parts before pumping them up. Both wet and dry installation is possible with rotary pumps.

Positive displacement pumps

Positive displacement pumps are normally used for substrates with higher solids content. They pump and suck at the same time. Their potential quantity conveyed is less dependent on the conveying pressure than with rotary pumps. The direction of pumping / sucking can be changed into the opposite direction by changing the sense of rotation. In biogas units, mainly the eccentric spiral pump and the rotary piston pump (both positive displacement pumps) are used. For better access, a dry installation is the preferred option.

Eccentric spiral pump

This pump has a stainless steel rotor, similar to a cork screw, which turns in an elastic casing. Eccentric spiral pumps can suck from a depth of up to 8.5m and can produce a pressure of up to 24 bar. They are, however, more susceptible to obstructive, alien elements than rotary pumps. Of disadvantage is further the danger of fibrous material wrapping round the spiral.

Rotary piston pump

Rotary piston pumps operate on counter-rotating winged pistons in an oval casing. They can pump and suck as well and achieve pressures of up to 10 bar. The potential quantity conveyed ranges from 0.5 to 4 m³/min. They allow for larger alien objects and more fibrous material than eccentric spiral pumps.

Table 4: Types of pumps in comparison

	rotary pumps	chopper pumps	eccentric spiral pump	rotary piston pump
solids content	< 8 %	< 8 %	< 15 %	< 15 %
energy input	3 - 15 kW	3 - 15 kW	3 - 22 kW	3 - 20 kW
quantity conveyed	2 - 6 m ³ /min	2 - 6 m ³ /min	0,3 - 3,5 m ³ /min	0,5 - 4 m ³ /min
pressure	0,8 - 3,5 bar	0,8 - 3,5 bar	< 25 bar	< 10 bar
structure of substrate	medium long fibers	long fibers	short fibers	medium long fibers
max. size of obstructive elements	approx. 5 cm	depending on choppers	approx. 4 cm	approx. 6 cm
intake	not sucking	not sucking	sucking	sucking
suitability	suitable for large quantities; simple and robust built	suitable for long-fiber substrates which need to be chopped up.	Suitable for high pressures, but susceptible to obstructive bodies	higher pressures than rotary pumps, but higher wear and tear
price comparison	cheaper than positive displacement pumps	depending on choppers	similar to rotary piston pump	similar to eccentric spiral pump

Heating

To achieve the optimum biogas yield, the anaerobic digestion needs constant environmental conditions, preferably close to the process optimum. The digester temperature is of prime importance. In temperate areas, a heating system and an insulation of the digester is necessary. Hence, the needed temperature for digestion can be reached and a loss of energy by transmission is compensated.

Because of the high costs for material and installation of a heating system, a low-cost biogas plant, as needed in developing countries, can only be built without heating. To boost the biogas yield for those plants, the building of a bigger digester to increase the retention time would be cheaper. A bigger digester reduces the required maintenance, while a heating system, increases maintenance requirements. A bigger digester serves also as a buffer for sediments, pH-variations and gas storage. For example, a fixed dome plant sized 50% bigger, is only 10% more expensive.

The mean surrounding temperature and its seasonal variations are very important. Biogas plants without heating system work, therefore, only in warmer regions for the whole year. In regions with extreme temperature variations, for instance in Turkey (hot summer, cold winter), the biogas plant should be built under the stable. Hence the biogas yield would be lower in summer, but constant over the year and at the end higher. Before implementation, at least an approximated average temperature profile and expected extremes over the year should be available for the site.

A biogas plant with heating system and co-generation can be operated with process energy. Nevertheless the dimensioning of such a heating system is difficult, as the substrate, which has to be heated up, is not homogenous.

A guiding figure for a digester with a hydraulic retention time of 20 days is 270 W/m^3 digester volume. The increasing of the hydraulic retention time makes it possible to reduce the heating power per volume. With a hydraulic retention time of 40 days the digester needs only 150 W/m^3 .

Following figures are for heating systems with a heating water temperature difference of 20 K:

hydr. retention time	40 days	30 days	20 days
temperature difference	20 K	20 K	20 K
heating power	150 kW/m^3	210 kW/m^3	270 kW/m^3

A heating system located in the digester produces a thermal circulation, which is, especially for non-agitated digesters, very important.

An indirect energy transfer by heat exchanger is most common. Exceptions are steam injection, liquefying of solid manure with heated water and the heating by pre-aeration.

Internal and external heating systems

External heating systems have a forced flow on both sides. Due to the turbulent flow patterns of both media, a very good heat transportation can be reached. Therefore, the surface of the heat exchanger can be comparatively small. Nevertheless those systems cannot be recommended for non-agitated digesters.



Figure 31: Heating system for a biodigester under construction (Germany)

Photo: Krieg (TBW)

The proper dimensioning of an internal heating system seems to be more difficult because of the different currents due to pumping, agitation, thermo-convection and the inflow of bio-mass.

Under-floor heating systems have been very popular, as they have no disturbing parts in the digester itself. Due to sedimentation and the resulting worsening of heat transportation into the digester, under-floor heating is no longer recommended. With the growth of digester volumes and the need of bigger heating systems, it is also more difficult to build under-floor heating big enough to provide the necessary heat.

Heating coils installed at the inner wall of the digester are a rather new practice. Heating coils made out of steel are much more expensive than heating coils out of plastic material (PE). Materials developed during the last years make such a system more stable while not increasing the costs of the heating system.

Another option is to construct two digesters connected in series, the first heated, the second unheated. The first digester can be used as sedimentation tank , in which the substrate is heated up. The second digester is well isolated to reduce loss of heat.

Agitation

The term 'agitation' subsumes different ways of homogenising the substrate or mixing it with water and co-substrate:

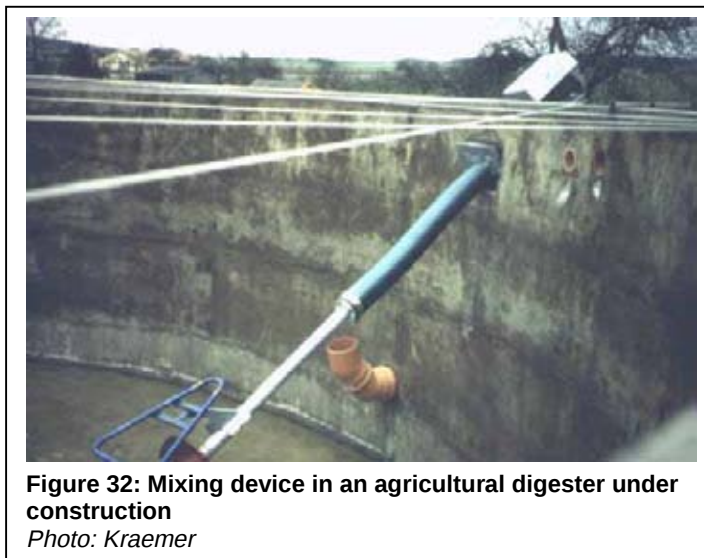
- Mixing and homogenizing the substrate in the mixing chamber
- Agitation inside the digester
- Poking through the in- and outlet pipes (small scale plants)

Agitation of the digester contents is important for the trouble-free performance of a biogas-plant. For the following reasons agitation is recommended several times a day:

- to avoid and destroy swimming and sinking layers
- to improve the activity of bacteria through release of biogas and provision of fresh nutrients
- to mix fresh and fermenting substrate in order to inoculate the former
- to arrive at an even distribution of temperature thus providing uniform conditions inside the digester

Even without mixing device, there is a certain agitation through the raising gas, through the movement of substrates with different temperatures and by the inflow of fresh substrate. This agitation, however, is usually insufficient. A well agitated substrate can, leaving other parameters constant, increase it's biogas production by 50%.

Agitation, as a general rule, should be performed *as much as necessary but as little as possible*. Too frequent mixing with fast rotating, mechanical agitation devices can disturb the biological processes in the fermenting substrate. In addition, an all-too thorough mixing of the whole digester contents may lead to half-digested substrate leaving the digester prematurely.



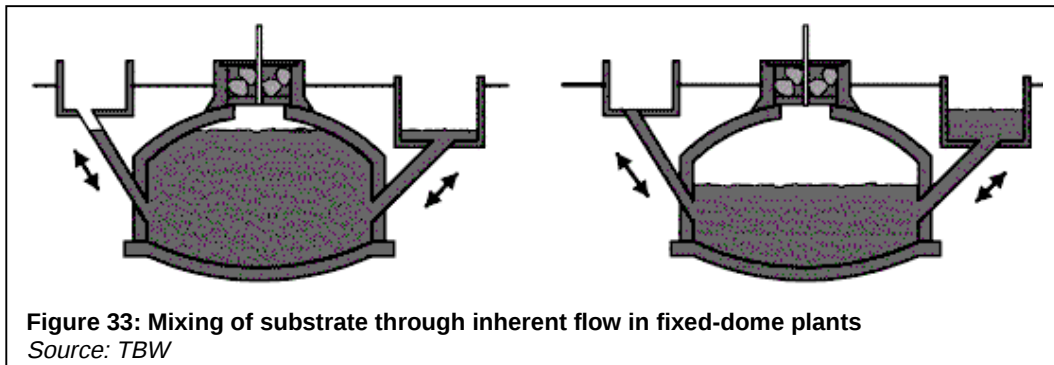
Mixing methods

Simple mixing methods have been installed mainly in developing countries:

- tangential inlet and outlet pipes
- separation walls
- forced substrate flow
- vertical hand-operated rotors
- horizontal, hand-operated paddle rotors
- poking through inlet and outlet

Mixing through inherent flow

In fixed dome plants, frequently found in developing countries, a certain mixing of the substrate is provided by the substrate being pushed up in the compensation tank with gas accumulation. When the stored gas is used, the substrate flows back into the digester.

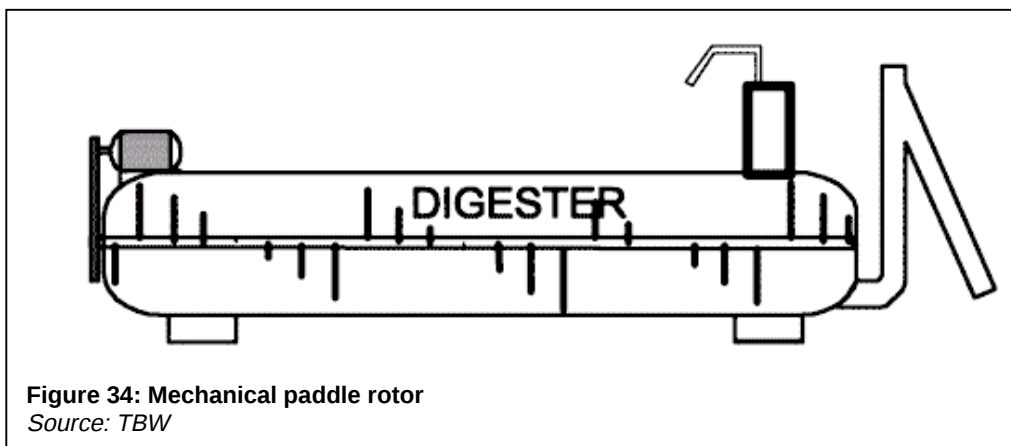


The company "VSP-Anlagen" further developed and patented this principle:

Through the pressure of the biogas, the substrate is pushed from the main digester into the subsidiary digester, resulting in a difference of levels between the two digesters. By reaching a certain difference in levels, a gas valve opens between main and subsidiary digester which equalizes the height difference. The flow-back of the substrate is guided in a way that destroys sinking and swimming layers.

Mechanical paddle rotor

Mechanical paddle rotors are predominantly used in horizontal steel vessels. A horizontal shaft in hardwood bearings runs through the whole vessel. Attached are paddles or loop-shaped pipes. By turning the shaft the vessel contents are mixed, the swimming layer is broken up and sediments are pushed towards a drainage opening. The loop-shaped pipes can also be used as heat exchangers to warm up the substrate.



Submerged motor with rotor stirring

A sealed, submerged electric engine directly drives a rotor. The rotor mixes the substrate by creating a strong current. These stirring devices can usually be adjusted in height and in angle.

Shaft-driven rotors

The mode of operation of a shaft-driven rotor is comparable to that of a submerged engine with rotor, only that the rotor is driven via shaft by an engine or by hand. The shaft should be movable in height and in angle to allow a mixing throughout the digester. The shaft should be long enough to reach both swimming and sinking layers.

The rotor shaft can be inserted in two principle ways:

- Through the digester wall below the slurry level with water-tight sealing
- Through the gas-holder with gas-tight sealing

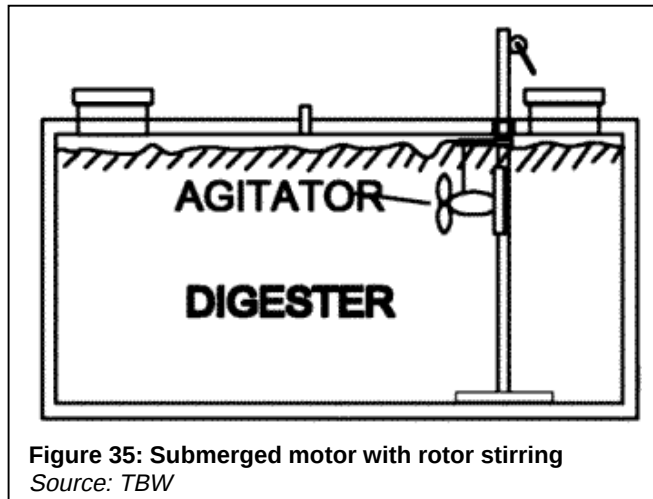


Figure 35: Submerged motor with rotor stirring
Source: TBW

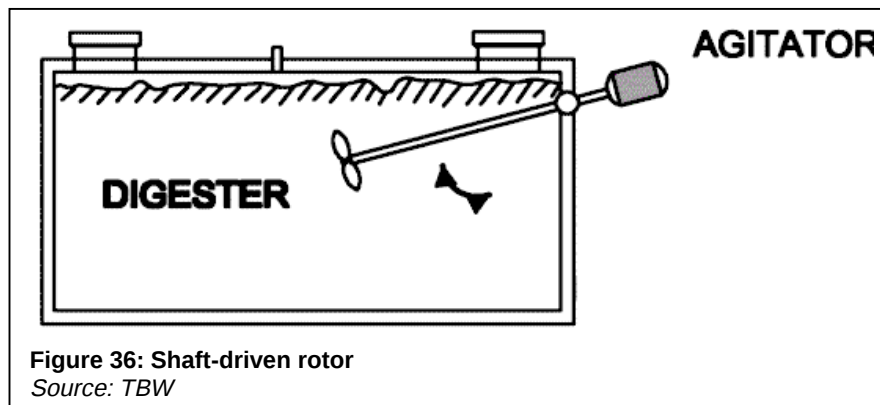


Figure 36: Shaft-driven rotor
Source: TBW

Hydraulic mixing

With a strong pump the whole substrate can be put in motion, provided the intake and outlet of the pump are placed in a way that corresponds with the digester shape. These pumps are often placed in a central position to cater for other tasks.

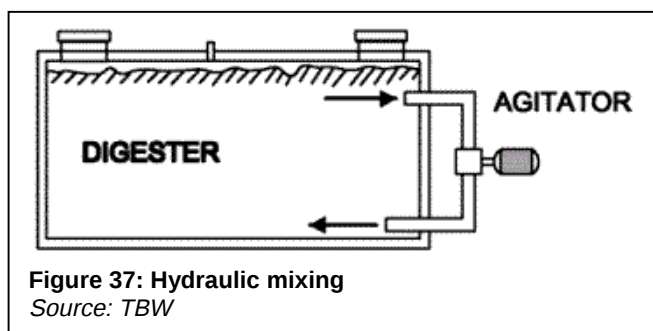
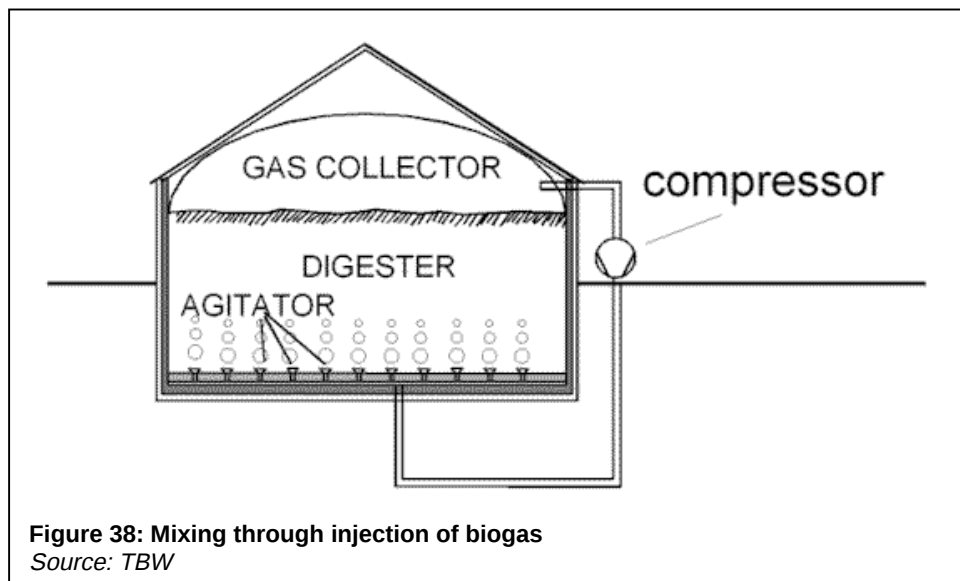


Figure 37: Hydraulic mixing
Source: TBW

Mixing through injection of biogas

A piping system with gas-jets is installed at the bottom of the digester. The raising biogas bubbles provide a gentle mixing of the substrate. The main problem with these systems is slurry entering into the piping system. This can be avoided by fixing pieces of elastic hose-pipe with stainless steel hose coupling to the jets.

Hydraulic mixing by injecting biogas should not be used if the formation of swimming layers is a prevailing problem. Gas bubbles attach themselves to larger fibrous particles and lift them upwards, thus speeding up the formation of a swimming layer. Chopping up the substrate by means of chopper pumps or chopper rotors can only partly solve this problem.



Slurry-Use Equipment

For the use of biogas slurry, a multitude of tools and technologies have been developed. They differ mainly according to the quantities of digested material. Big differences exist as well between developing and industrialized countries, depending on the technological development and the cost of labor. Slurry use technologies range from hand-application with the help of a bucket to mechanized distribution, supported by GPS (global positioning system) and a computer on board of the liquid manure spreader. The choice of technology essentially depends on the amount of slurry and the area to be fertilized as well as on the financial means and the opportunity cost of labor.

On **small farms in developing countries**, simple but effective tools are used. They include buckets, scoops, containers with straps, wooden wheelbarrows with lids, barrels on wheels and others. These tools allow a precise application of slurry. The most economic way to apply slurry is by means of gravity, either by a network of small slurry furrows or by mixing slurry in the irrigation system. Both options require a gradient of at least 1% (for irrigation water) and 2% (for slurry distribution), sloping from the biogas plant's overflow point to the fields.

Making best and least labor-intensive use of the slurry is an important planning parameter. Especially where gravity distribution is feasible, the positioning of the biogas plant and the expansion chamber and the level of the expansion chamber overflow are of high importance. In rather flat areas, it should be considered to raise both the stable and the biogas-plant in order to allow a slurry distribution by gravity.



Figure 39: Device for slurry distribution by tractor.
Photo: Krämer (TBW)

In **industrialized countries** and for **large plants in developing countries** two methods of mechanized distribution systems have evolved:

Distribution via piping systems

The slurry is pumped directly from the slurry storage tank onto the field and is distributed there. If the pump is rather small and the pressure and transported amounts are low, the distribution can be done by hand. With increasing pressure and transported amounts, the distribution system is attached to a tractor. The tractor does not have to be very powerful as there is no need to pull a heavy tanker. The main advantage of this method is the low ground pressure and the ability to enter into fields of steep slope, of fragile soil structure and during bad weather.

The biogas slurry, if it is not too viscous, can be applied with a liquid manure rainer. The disadvantages are the costly pump and the expensive piping system. Therefore, this method is only economic for fields close to the slurry storage container.

Distribution via tanker

The tanker is filled at the slurry storage and pulled to the field for distribution. Below are the principal distribution systems ex-tanker:

With reflection plate

The slurry is squirted through a nozzle against a reflection plate which, by its special form, diverts and broadens the squirt. An improvement of the simple reflection-plate-distribution is a swiveling plate which leads to a more even distribution.

Direct application through sliding hoses

The slurry is pumped into a distribution system which feeds a number of hoses which move closely to the ground. The slurry is applied directly on the soil surface, therefore reducing nutrient losses. Distances between the hoses can be adjusted to suit different plant cultures.

Hoses with drill coulters

The soil is opened with two disks (drill coulters) in a v-shape. The slurry is applied with sliding hoses into the v-furrows, which are closed behind the hose. This application method could be labeled 'sub-surface application'. It is the most advanced in terms of avoiding nutrient losses. Similar to the hose application, distances between application rows are adjustable. Alternatively to the hose application, the slurry can be positioned by a metal injector.

The application methods close to the soil surface, in contrast to the broadcasting methods, have the advantage of a higher degree of exactness and less nutrient losses to the atmosphere. Fertilization can be better adjusted to plant needs. In contrast to broadcast-spraying, direct application is possible even at later stages of plant growth without damaging the leaves. Disadvantages are the rather sophisticated machinery necessary and the high costs involved. Direct application methods are, therefore, mostly used as inter-farm operation.

Separation of slurry and drying of the moist sludge

In industrialized countries, the slurry is usually separated by means of separators and sieves. The water is re-fed into the digestion process or distributed as liquid manure while the moist sludge is dried or composted. As a simple technology for separation, slow sand-filters can be used.

The moist sludge can be heaped on drying beds, filled in flat pits or simply placed on paved surfaces near the biogas plant for drying. Depending on climatic conditions, large drying areas may be necessary. Drying times and nutrient losses can be reduced by mixing dry substances with the moist sludge. A disadvantage of all drying methods, again depending on the climate, is the high loss of nutrients. In particular heavy rains can wash out the soluble nutrients. Losses of nitrogen, for example, can amount to 50% of the overall nitrogen and up to 90% of the mineral nitrogen. Drying of the moist sludge can only be recommended where long distances and difficult terrain hampers transport to the fields or if composting is difficult for lack of manpower and lack of dry biomass.

Composting of slurry

Dry plant material is heaped in rows and the liquid slurry is poured over the rows. Ideally, plant material and slurry are mixed. The mixing ration depends on the dry matter content of plant material and slurry. The main advantage is the low nutrient loss. Compost, containing plant nutrients in a mainly biologically fixed form, is a fertilizer with long-term effects. Its value for improving soil structure is an additional positive effect of importance.

Plasters and Coats for Digester and Gas-Holder

In industrialized countries, most of the new digesters are built of gas-tight concrete or steel. Additives are mixed into the concrete to render it gas-tight. If existing concrete vessels are used, their gas-tightness has to be checked. Often, they have not been built from gas-tight concrete or cracks have formed over time which allow the gas to escape.

It is important to check the digester and piping system for gas-tightness prior to putting the biogas unit in service. If leakage is detected only during operation, the digester has to be emptied, cleaned and plastered again. Rectifying a leakage before the initial filling is a lot cheaper.

In developing countries, digesters are usually masonry structures. The plastering has to be watertight up to the lowest slurry level and gas-tight from the lowest gas level upwards (gas-holder). The plaster has to resist moisture and temperatures up to 60°C reliably. The plaster must be resistant to organic acid, ammonia and hydrogen sulfide. The undercoat must be absolutely clean and dry.



Figure 40: Inside plaster of the gastight section of a fixed dome digester

Photo: Kellner (TBW)

Cement plaster with special additives

Good results in water- and gas-tightness have been achieved by adding 'water-proofer' to the cement plaster. For gas-tightness, double the amount of water-proofer is required as compared to the amount necessary for water-tightness. The time between the applications of the layers of plaster should not exceed one day, as the plaster becomes water-tight after one day and the new plaster cannot adhere to the old plaster. The following 'recipe' from Tanzania guarantees gas-tightness, provided the masonry structure has no cracks:

1. layer: cement-water brushing;
2. layer: 1 cm cement : sand plaster 1 : 2.5;
3. layer: cement-water brushing;
4. layer: cement : lime : sand plaster 1 : 0.25 : 2.5;
5. layer: cement-water brushing with water-proofer;
6. layer: cement : lime : sand plaster with water proofer and fine, sieved sand 1 : 0.25 : 2.5;
7. layer: cement screed (cement-water paste) with water-proofer.

The seven courses of plaster should be applied within 24 hours.

A disadvantage of cement plaster is their inability to bridge small cracks in the masonry structure as, for example, bituminous coats can do.

Bitumen (several layers)

Bitumen coats can be applied easily and remain elastic over long periods of time. Problems arise in the application as the solvents are inflammable (danger of explosion inside the digester) and a health hazard. Bitumen coats cannot be applied on wet surfaces. The drying of masonry structures requires several weeks, unless some heating device (e.g. a charcoal stove) is placed inside the digester for two to three days. Furthermore, the bituminous coat can be damaged by the up-and-down movement of the slurry.

Bitumen coat with aluminum foil

On the first still sticky bitumen coat, aluminum foil is mounted with generous overlaps. A second layer of bitumen is applied on the aluminum foil. Gas-tightness is usually higher compared to the several layers of bitumen without foil.

Water-thinnable dispersion paint

These paints are free from fire- or health hazards. Most of them, however are not gas-tight and not resistant to moisture. Only those dispersion paints should be used which are explicitly recommended for underwater use and which form a gas-tight film.

Single- and dual component synthetic resin paints

Synthetic resin paints form elastic, gas-tight coats which can resist rather high physical load. They are comparably expensive, their use seems only justified if the coating has to resist mechanical stress. This is usually the case with fixed dome plants. Measurements have given evidence that the masonry structure of a fixed dome stretches, though minimally, after filling and under gas pressure.

Paraffin

Paraffin, diluted with new engine oil, is warmed up to 100 -150°C and applied on the plaster which has been heated up with a flame-thrower. The paraffin enters into the plaster and effects a 'deep-sealing'. If paraffin is not available, simple candles can be melted and diluted with engine oil.

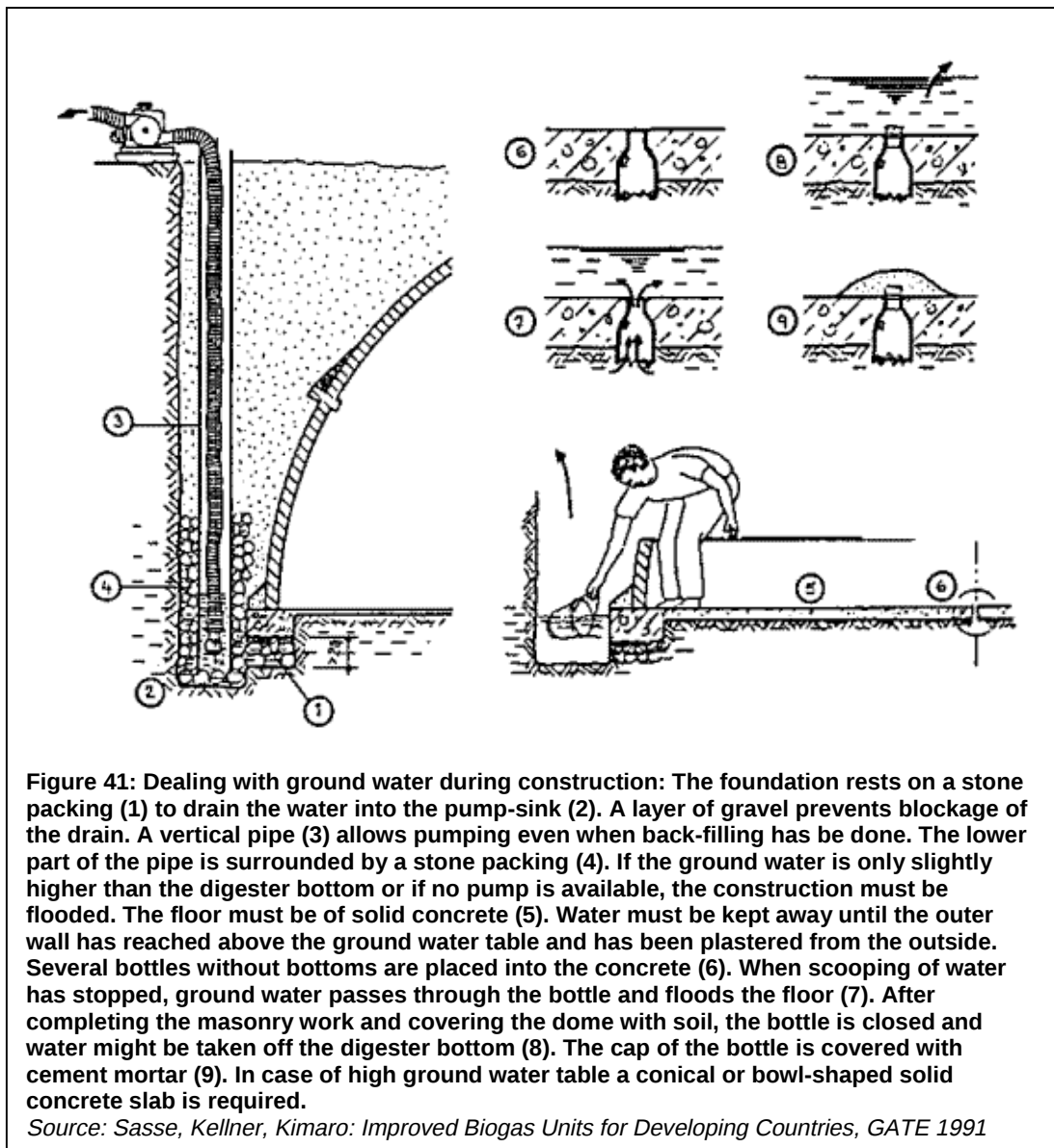
Underground Water

Underground water features in all three steps of biogas implementation:

- During planning, the site selection and design of the digester can eliminate most of the problems caused by groundwater and threats to groundwater.
- During construction, groundwater can be a nuisance, effecting additional costs. But it is during construction, that serious leakage can be avoided.
- During operation, little can be done but to monitor the quality of water and to avoid surface spilling.

By positioning the biogas plant and the well, a great deal of drinking water safety can be achieved. First, the distance should be at least 30 m, second, the biogas plant should be downstream of surface- and groundwater flows and third, the well should be above the biogas unit to avoid contamination through surface spilling.

During construction, ground water must be drained. An empty biogas digester can develop such buoyancy, if surrounded by water, that the whole shell is lifted. The figure below illustrates some simple techniques how to deal with ground water during construction of small biogas plants.



During the operation of the biogas plant further attention has to be paid to keeping the groundwater clean. Seeping biogas digesters and unprotected slurry storage can pollute water sources chemically (nitrate poisoning can be fatal for infants) and biologically (mainly with toilet biogas plants). Reasons may be wrong configuration of security devices like the pressure relief valves or because of leakage in lower parts of the digester. Smaller cracks, however, close up in the course of time through particles in the slurry.

Trace metals applied to natural systems do not pose a threat to groundwater quality because trace metals are usually removed from the percolating water by adsorption or chemical precipitation within the first few meters of soil, even in rapid infiltration systems with high hydraulic-loading rates.

Bacterial removal from effluents passing through fine soils is quite complete. It may be less complete in the coarse, sandy soil used for rapid infiltration systems. Fractured rock or limestone cavities may provide a passage for bacteria that can travel several hundred meters from the point of application. This danger can be avoided by proper geological investigations during site selection.

Operation and Use

The day-to day operation of a biogas unit requires a high level of discipline and routine to maintain a high gas production and to ensure a long life-span of the biogas unit. Many problems in the performance of biogas plants occur due to user mistakes or operational neglect. Often, these problems can be reduced,

- by less complicated designs that are adapted to the substrate, the climatic conditions and the technical competence of the user,
- by high-quality and user-friendly appliances,
- by design and lay-out of the biogas for convenient work routine,
- by proper training and easy access to advice on operation problems.

During design selection, planning, construction, handing over and follow-up, the biogas extension program should emphasize further on a reduction of the users' workload for operating the biogas unit and using the gas and the slurry. In particular during work peaks for farm work, it is important that the biogas unit relieves the user from work rather than adding to the workload. As a general rule, the farming family should have *less work with a biogas unit than without it*, while enjoying the additional benefits in terms of a clean fuel and high quality fertilizer.

Daily operation

Feeding of the digester

In larger biogas units, the dung, urine and other substrate usually enter the plant by pipes, channels, belts or pumps. The available substrate has to enter the digester as soon as it is available to avoid pre-digestion outside the digester. The functioning of the feeding mechanisms has to be checked daily. Separators for unsuitable material have to be checked and emptied. The amounts of substrate fed into the digester may be recorded to monitor the performance of the biogas plant.

Smaller plants in developing countries are fed by hand. The substrates, often dung and urine, should be thoroughly mixed, plant residues should be chopped, if necessary. Obstructive materials like stones and sand should be removed from the mixing chamber. Simple tools like a rubber squeegee, a dipper, forks to fish out fibrous material, proper buckets and shovels greatly facilitate this work. Filling work is further made easier by smooth concrete stable-floors and a minimized distance between the stable and the plant.

Agitation

In industrialized countries and for large plants in developing countries, engine driven stirring devices are the norm. Usually, but not always, they are operated automatically. The user, however, should check the operation of the stirring device daily.

Small size biogas plants have manual stirring devices that have to be turned by hand as recommended. If there is no stirring device, poking with sticks through the inlet and outlet is recommended. The stick should be strong, long enough but not too heavy. It should have a plate fixed at the end (small enough to fit in the inlet-/outlet pipes) to produce a movement of the slurry. Regular poking also ensures that the inlet/outlet pipes do not clog up. The drums of floating drum plants should be turned several times a day.

Experience shows that stirring and poking is hardly ever done as frequently as it should be. Farmers should be encouraged to run a trial on gas production with and without stirring. The higher gas production will convince the user more than any advice.

Controlling the overflow

A special problem of small scale fixed dome plants is the clogging up of the overflow point. This can lead to over-pressure (the hydraulic pressure increases with the slurry level in the expansion chamber) and to clogging of the gas outlet if too much slurry flows back into the digester. The overflow point should, therefore, be checked and cleaned daily.

Slurry distribution

If the slurry distribution is done directly by gravity, the slurry furrows need to be checked and slurry diverted accordingly. Slurry may be applied from the furrows directly to the plant with the help of dippers or shovels.

Weekly / monthly operation

- Controlling of the water separator
- Renewing the agents of the gas purification system (if existing)
- Mixing the swimming and sinking layers of in the expansion chamber of fixed dome plants
- The water sealing of the lid in the man hole of a fixed dome plant should be checked and filled up
- Gentle cleaning of the drum of a floating drum plant
- Checking and filling up the water jacket of water jacket plants
- Flexible pipes above ground should be checked for porosity
- Slurry storage tanks should be checked and emptied, if required and slurry flows diverted accordingly

Annual operation

- Swimming layers should be removed from the digester
- The whole plant and digester should be exposed to a pressure test once a year to detect lesser leakages

Security

When operating a biogas plant special attention has to be paid to the following dangers:

- Breathing in biogas in a high concentration and over longer periods of time can cause poisoning and death from suffocation. The hydrogen sulfide contents of biogas is highly poisonous. Unpurified biogas has the typical smell of rotten eggs. Purified biogas is odorless and neutral. Therefore, all areas with biogas operating appliances should be well ventilated. Gas pipes and fittings should be checked regularly for their gas-tightness and be protected from damage. Gas appliances should always be under supervision during operation. Everybody dealing with biogas, in particular children, should be instructed well and made aware of the potential dangers of biogas.
- After emptying biogas plants for repair, they have to be sufficiently ventilated before being entered. Here the danger of fire and explosion is very big (gas/air mixture!). The so-called chicken test (a chicken in a basket enters the plant before the person) guarantees sufficient ventilation.
- Biogas in form of a gas-air mixture with a share of 5 to 12 % biogas and a source of ignition of 600°C or more can easily explode. Danger of fire is given if the gas-air mixture contains more than 12 % of biogas. Smoking and open fire must therefore be prohibited in and around the biogas plant.
- The initial filling of a biogas plant poses a particular danger, when biogas mixes with large empty air-spaces. A farmer may want to check with an open flame how full the plant is already and cause an explosion.
- The digester of a biogas plant and the slurry storage facilities should be built in such a way that neither persons nor animals are in danger of falling into them.
- Moved and movable parts should have a protective casing to avoid catching persons or animals.

- Appliances operating on biogas normally have high surface temperatures. The danger of burning is high, in particular for children and strangers. A casing of non-heat-conducting material is advisable.
- The mantle of the gas lamp is radioactive. The mantle has to be changed with utmost caution. Especially the inhalation of crumbling particles must be avoided. Hands should be washed immediately afterwards.
- The piping system can form traps on the farm compound. As much as possible, pipes should be laid some 30 cm underground. Pits for water traps, gas meters, main valves or test-units should be cased by a concrete frame and covered with a heavy concrete lid.

Biogas - Sludge Management

Sludge storage

To retain the maximum fertilizing quality of digested slurry, i.e. its nitrogen content, it should be stored only briefly in liquid form in a closed pit or tank and then applied on the fields. Preferably, it should be dug into the soil to prevent losses on the field.

Sludge storage is normally effected according to one or the other of the following three techniques

- Liquid storage
- Drying
- Composting

Liquid storage

The effluent outlet of the biogas system leads directly to a collecting tank. Loss of liquid due to evaporation or seepage must be avoided. Just before the sludge is needed, the contents of the tank is thoroughly agitated and then filled into a liquid manure spreader or, if it is liquid and homogenous enough, spread by irrigation sprinklers. The main advantage of liquid storage is that little nitrogen is lost. On the other hand, liquid storage requires a large, waterproof storage facility entailing a high initial capital investment.

The practice of spreading liquid slurry also presents problems in that not only storage tanks are needed, but transport vessels as well. The amount of work involved depends also on the distance over which the slurry has to be transported. For example, loading and transporting one ton of slurry over a distance of 500 m in an oxcart (200 kg per trip) takes about five hours. Distributing one ton of slurry on the fields requires another three hours.

Drying

It is only possible to dry digested sludge as long as the rate of evaporation is substantially higher than the rate of precipitation. The main advantage of drying is the resultant reduction in volume and weight. Drying can also make the manual spreading easier. The cost of constructing shallow earthen drying basins is modest. On the other hand, drying results in a near-total loss of inorganic nitrogen (up to 90%) and heavy losses of the total nitrogen content (approx. 50%).

Composting

Nitrogen losses can be reduced by mixing the digested sludge with organic material. As an additive to crop residues for composting, biogas sludge provides a good source of nitrogen for speeding up the process. At the same time it enriches the compost in nitrogen, phosphorus and other plant nutrients. Furthermore, the aerobic composting process, by its temperature, effectively destroys pathogens and parasites that have survived the anaerobic digestion treatment. The ready-made compost is moist, compact and can be spread out by simple tools. With most available transport facilities in developing countries, it is easier to transport than liquid manure.

Composition of sludge

Process of biomethanation

Anaerobic digestion draws carbon, hydrogen and oxygen from the substrate. The essential plant nutrients (N,P,K) remain largely in the slurry. The composition of fertilizing agents in digested slurry depends on the fermented substrate and can, therefore, vary within certain limits.



Figure 42: Drying of digested sludge and sludge disposal in Thailand

Photo: Kossmann (gtz/GATE)

For an average daily substrate feed rate of 50 kg per livestock unit (LSU = 500 kg live weight) and a daily gas yield of 1 m³ biogas/LSU, the mass of the influent substrate will be reduced by some 2% through the process of bio-methanation (volumetric weight of biogas: 1.2 kg/m³).

Viscosity

The viscosity of the slurry decreases significantly, because the amount of volatile solids is reduced by about 50% in the course of a stable process of fermentation. In addition, the long carbon chains (cellulose, alcohol and organic acids) are converted into short carbon chains.

Odor

The effluent sludge is much less odorous than the influent substrate (dung, urine). Given sufficient retention time, nearly all odorous substances are completely digested.

Nutrients

The fertilizing properties of digested slurry are determined by how much mineral substances and trace elements it contains. In tropical soil, the nitrogen content is not necessarily of prime importance - lateritic soils, for example, are more likely to suffer from a lack of phosphorus. All plant nutrients such as nitrogen, phosphorous, potassium and magnesium, as well as the trace elements essential to plant growth, are preserved in the substrate. The C/N ratio is reduced by the simultaneous loss of carbon, thus generally improving the fertilizing effect of the digested sludge, since a lower C/N ratio (ca. 1:15) has a favorable phytophysiological effect. Table 5 below lists the approximate nutrient contents of various substrates, whereby it should be remembered that the actual values may vary considerably, depending on fodder eaten by the animals.

The phosphate content ("P₂O₅" is the form of phosphorous available for plants) is not affected by fermentation. Some 50% of the total phosphorous content is available for plants in the form of phosphate. Similarly, anaerobic fermentation does not alter the rate of plant-available potassium (75 to 100% of the total potassium).

Nitrogen compounds

In contrast to the above nutrients, however, some nitrogen compounds undergo modification during anaerobic digestion. About 75% of the nitrogen contained in fresh manure is built into organic macromolecules, and 25% is available in mineral form as ammonium. The effluent sludge contains roughly 50% organic nitrogen and 50% mineral nitrogen. The stated levels can only be taken as approximate values, since they vary widely, depending on the type of animal involved, the fodder composition, the retention time, etc. Mineral nitrogen can be directly assimilated by plants, while organic nitrogen compounds must first be mineralized by microorganisms in the soil.

Fertilizing effect of effluent sludge

Digested slurry is most effective when it is spread on the fields shortly before the beginning of the vegetation period. Additional doses can be given periodically during the growth phase, with the amounts and timing depending on the crop in question. For reasons of hygiene, however, leafy vegetables should not be top-dressed.

Assuming that the soil should receive enough fertilizer to replace the nutrients that were extracted at harvesting time, each hectare will require an average dose of about 33 kg N, 11 kg P₂O₅ and 48 kg K₂O to compensate for an annual yield of 1-1.2 tons of, for example,



Figure 43: Sludge disposal in Thailand

Photo: Kossmann (gtz/GATE)

sorghum or peanuts. Depending on the nutritive content of the digested slurry, 3-6 t of solid substance per hectare will be required to cover the deficit. For supply with a moisture content of 90%, the required quantity comes to 30-60 t per hectare and year. That roughly corresponds to the annual capacity of a 6-8 m³ biogas plant.



Figure 44: Field experiments with sludge in Thailand
Photo: Kossmann (gtz/GATE)

Caustic effect on grassland

Digested sludge has much less caustic effect on grassland than does fresh liquid manure. Effluent sludge is also very suitable for use as a "top-dressing" whenever its application is deemed to have the best fertilizing effect.

Eutrophication

Serious ecological damage can be done by applying fertilizing sludge in excessive amounts or at the wrong time, namely when the assimilative capacity of the plants is low. Nitrogen "washout" can cause over-fertilization (eutrophication) of ground and surface water.

Annual Manure Yield and Nutrient Content of Animal Excrements

Table 5: Annual manure yield and nutrient content of cow, pig and chicken excrements; compiled from various sources

Total annual yield [kg/LSU/a] and percentage shares							
	Total Wt.	TS		VS		N	
	kg/a	kg/a	[%]	kg/a	[%]	kg/a	[%]
Cow	16,100	1850	11.6	1400	8.7	77	0.5
Pig	13,500	1130	8.4	900	6.7	102	0.8
Chicken (fresh droppings)	18,250	4020	22.0	3170	17.4	232	1.3
Chicken (dry droppings)	4,230	3390	80	2560	60	146	3.5

Total annual yield [kg/LSU/a] and percentage shares					Nutritive ratio (P ₂ O ₅ = 1)		
	P ₂ O ₅		K ₂ O		N	P ₂ O ₅	K ₂ O
	kg/a	[%]	kg/a	[%]			
Cow	34	0.2	84	0.5	2.3	1	2.5
Pig	56	0.4	35	0.3	1.8	1	0.6
Chicken (fresh droppings)	194	1.0	108	0.6	1.2	1	0.6
Chicken (dry droppings)	193	4.6	106	2.5	0.8	1	0.6

Source: Production and Utilization of Biogas in Rural Areas of Industrialized and Developing Countries, Schriftenreihe der gtz, No. 97, pp. 71-72; after: Rager, K. Th.: Abwassertechnische und wasserwirtschaftliche Probleme der Massentierhaltung; Darmstadt, FRG, 1971, p. 38

LSU = livestock unit (= 500 kg live weight)

TS = Total solids

VS = Volatile solids

Maintenance, Monitoring and Repair

The maintenance of a biogas plant comprises all work which is necessary to guarantee trouble-free operation and a long working life of the plant. Repair reacts to breakdowns of the biogas system. Maintenance services should be carried out by the manager or main operator of the biogas plant or a well-trained biogas technician. One has to bear in mind that measurements indicating problems may be wrong. All doubtful measurements have to be verified. Often, one symptom has a variety of possible reasons.

Daily maintenance work

Control	Mistakes	Removal
gas pressure	gas pressure too high; (gas pressure rises, if gas consumption is lower than the production and if the gas storage is full)	The pressure relief valve malfunctions - it should be cleaned or renewed;
	gas pressure too low; (gas pressure falls, if the consumption (including leakage!) is higher than the production and if the gas storage is empty);	leakage in gas conducting parts: find out the leakage and seal; gas production has fallen: check the sludge's quality;
substrate temperature (heated plants) (bacteria are very sensitive to temperature extremes and fluctuations);	temperature too high;	defective heating control system. Check control system and repair or exchange part(s) concerned;
	temperature too low;	defective heating control system. Check control system and other concerned part(s), repair or exchange; sediment layer on the heating surface: remove layer;
gas production	gas production clearly under normal levels;	biological reasons: temperature, substrate, antibiotics, change of pH-value; leakage in digester or piping system; blocked gas pipes due to water or alien elements; identify problem and act accordingly;
strong sludge odor	plant is overloaded or fermenting conditions are sub-optimal;	reduce substrate intake; correct pH-value with adequate means;

Weekly/monthly (prophylactic) maintenance work

- clean gas appliances;
- lubricate movable parts (slides, guiding frame of floating drum plants, taps etc.);
- servicing of biogas-driven engines within the prescribed time intervals;
- maintenance of pressure relief valves and under pressure valves;
- maintenance of slurry agitator / mixer;
- control gas appliances and fittings on tightness and function

Control of functions

Control	Mistakes	Removal
water separator	non-automatic water separator is full;	empty the water separator;
pipng system	no water is collected in the water separator; gradient of the pipes is wrong;	Reinstall pipes in a way that condensation flow leads to the water separator;
pressure relief and under pressure valves	non-functioning	clean valves or renew them

Annual maintenance work

- Check the plant in respect of corrosion and, if necessary, renew protective coating material;
- Check the gas pipes for gas tightness (pressure check). If necessary, search the leakage and repair the parts concerned. Note: minor gas leakage is usually undetected during normal operation as it is 'compensated' by gas production

Monitoring

Monitoring subsumes all activities of data collection regarding an individual biogas unit or biogas programs. Collecting data on the performance of biogas units is necessary to

- detect problems in the unit's performance;
- to have a base for economic evaluation;
- to have a base for comparing different models and different modes of operation

Measurements and other data which become necessary for the optimization of the existing biogas unit should be recorded by the owner or by a person appointed by him/her. The records should include the following data:

- The amount and type of substrate, incl. the amounts of mixing water.
- The substrate temperature, if necessary at various stages of the substrate flow (heated plants). By measuring the substrate temperature, faults in the heating system can be detected.
- Gas production: measurements are carried out with a gas meter between the digester and the gas-holder (gas production) or between the gas-holder and the points of consumption (gas consumption). In simple plants, the gas production can be estimated during times of no consumption. Changes in gas production and the speed by which these changes occur give valuable hints on the nature of the problem.
- Electricity and heat production from co-generation units;
- pH-value (monthly); recorded substrate intake;
- content of hydrogen sulfide in the gas (monthly);
- analysis of the fertilizing value of biogas slurry (annually or seasonally) to determine the optimal amount of slurry to be spread on the fields.

- Records on breakdowns and their causes. By means of previously recorded breakdowns it is easier to compare the breakdowns and detect the reasons for failure.

Beyond this, there are various institutions, associations and companies which carry out series of measurements for different kinds of biogas plants. These series of measurements, records and evaluations analyze errors with the objective to disseminate and optimize biogas technology as well as to avoid mistakes of the past.

Repair

Breakdowns which might appear when operating biogas plants are described in the following. The most frequently occurring disturbance is insufficient gas production which can have a variety of different reasons. Sometimes observations and experiments might take weeks until a perfect solution is found.

Disturbances	Possible reasons	Measures to be taken
blocked inlet/outlet pipe	fibrous material inside the pipe or sinking layer blocking the lower end of the pipe	cleaning up the pipe with a pole; removing sinking layer by frequent 'poking' through inlet and outlet pipe.
floating drum is stuck	swimming layer	turn the dome more frequently; if turning not possible, take off the dome and remove the swimming layer
	broken guiding frame	weld, repair and grease guiding frame
sinking sludge level	digester not water-tight	if cracks in the digester do not self-seal within weeks, empty digester and seal cracks;
insufficient gas storage	gas store not gas-tight due to cracks or corrosion	seal cracks, replace corroded parts;
blocked taps	corrosion	open and close several times, grease or replace taps;
gas pipe is not tight	corrosion or porosity; insufficient sealing of connections;	identify leaking parts; replace corroded or porous parts; re-seal connections
sudden gas loss	8. crack in the gas pipe 9. automatic water trap blown empty 10. open gas tap	4. repair or replace 5. add/refill water, detect reason for over-pressure; check dimensioning of the water-trap 6. close tap
throbbing gas pressure	1. water in the gas pipe 2. blocked gas pipe	1. check functioning of water trap; install water traps in depressions of piping system or eliminate these depressions; 2. identify the blocked parts (start with gas outlet, connections to appliances and bends); clean the respective parts;

Repair measures are being taken in case of acute disturbances or during routine maintenance work. Repair measures which go beyond routine maintenance work have to be carried out by specialists, since the biogas plant owner in most cases does not have the required tools and the necessary technical know-how. In any case, annual maintenance service should be carried out by a skilled biogas technician.

In industrialized countries with large plants and good infrastructure, a professional biogas service can cover a large area. In developing countries with scattered small scale biogas units, logistical problems can severely hamper the evolution of a professional and commercial biogas service. To ensure that built biogas units are maintained and, if necessary, repaired, the following approaches are conceivable:

- ***The farmer technician approach:*** out of a group of biogas farmers, an outstanding individual is encouraged to undergo maintenance and repair training to take this up as a side job. Emphasis has to be placed on management training. To make his enterprise sustainable, the farmer technician should gain a reasonable income.
- ***The cluster approach:*** if the demand for biogas plants is high, the biogas project or the biogas company can attempt to install biogas units in a regional clustering to minimize distances for the maintenance service.
- ***The subsidized transport approach:*** a professional biogas technician is supported with transport by the biogas project or government departments (e.g. agricultural extension, veterinary service). The technician can also receive a bicycle or small motorbike as an initial input, running costs can either initially be shared by the biogas project or directly be charged to the farmers.

However the logistical problems may be solved, the critical ingredient for the evolution of a professional and commercial biogas service is the training of the technicians-to-be both in technical and managerial terms. Experience shows, that this can take several years. Biogas projects should, therefore, plan with a not too narrow time horizon.

Biogas Utilization

Gas production

If the daily amount of available dung (fresh weight) is known, gas production per day in warm tropical countries will approximately correspond to the following values:

- 1 kg cattle dung 40 liters biogas
- 1 kg buffalo dung 30 liter biogas
- 1 kg pig dung 60 liter biogas
- 1 kg chicken droppings 70 liter biogas

If the live weight of all animals whose dung is put into the biogas plant is known, the daily gas production will correspond approximately to the following values:

- cattle, buffalo and chicken: 1,5 liters biogas per day per 1 kg live weight
- pigs, humans: 30 liters biogas per day per 1 kg weight

Conditioning of biogas

Sometimes the biogas must be treated/conditioned before utilization. The predominant forms of treatment aim at removing either **water**, **hydrogen sulfide** or **carbon dioxide** from the raw gas:

Reduction of the moisture content

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

Reduction of the hydrogen-sulfide content

The hydrogen sulfide in the biogas combines with condensing water and forms corrosive acids. Water-heating appliances, engines and refrigerators are particularly at risk. The reduction of the hydrogen sulfide content may be necessary if the biogas contains an excessive amount, i.e. more than 2% H_2S . Since most biogas contains less than 1% H_2S , de-sulfurization is normally not necessary.

For small- to mid-size systems, de-sulfurization can be effected by absorption onto ferric hydrate ($\text{Fe}(\text{OH})_3$), also referred to as bog iron, a porous form of limonite. The porous, granular purifying mass can be regenerated by exposure to air.

The absorptive capacity of the purifying mass depends on its iron-hydrate content: bog iron, containing 5-10% $\text{Fe}(\text{OH})_3$, can absorb about 15 g sulfur per kg without being regenerated and approximately 150 g/kg through repetitive regeneration. It is noteworthy that many types of tropical soils (laterite) are naturally ferriferous and suitable for use as purifying mass.

Another de-sulfurization process showing good results has been developed in Ivory Coast and is applied successfully since 1987. Air is pumped into the gas store at a ratio of 2% to 5 % of the biogas production. The minimum air intake for complete de-sulfurization has to be established by trials. Aquarium pumps are cheap and reliable implements for pumping air against the gas pressure into the gas holder. The oxygen of the air leads to a bio-catalytic, stabilized separation of the sulfur on the surface of the sludge. This simple method works best, where the gas holder is above the slurry, as the necessary bacteria require moisture, warmth (opt. 37°C) and nutrients.

In industrialized countries and for large plants, this process has meanwhile reached satisfactory standard. For small scale plants in developing countries, however, using an electric pump becomes problematic due to missing or unreliable electricity supply. Pumping in air with a bicycle pump works in principle, but is a cumbersome method that will be abandoned sooner or later.

Avoiding de-sulfurization altogether is possible, if only stainless steel appliances are used. But even if they are available, their costs are prohibitive for small scale users.

Reduction of the carbon-dioxide content

The reduction of the carbon-dioxide content is complicated and expensive. In principle, carbon-dioxide can be removed by absorption onto lime milk, but that practice produces "seas" of lime paste and must therefore be ruled out, particularly in connection with large-scale plants, for which only high-tech processes like micro-screening are worthy of consideration. CO₂ "scrubbing" is rarely advisable, except in order to increase the individual bottling capacity for high-pressure storage.

Biogas burners

In developing countries, the main prerequisite of biogas utilization is the availability of specially designed biogas burners or modified consumer appliances. The relatively large differences in gas quality from different plants, and even from one and the same plant (gas pressure, temperature, caloric value, etc.) must be given due consideration.

The heart of most gas appliances is a biogas burner. In most cases, atmospheric-type burners operating on premixed air/gas fuel are preferable. Due to complex conditions of flow and reaction kinetics, gas burners defy precise calculation, so that the final design and adjustments must be arrived at experimentally. Compared to other gases, biogas needs less air for combustion. Therefore, conventional gas appliances need larger gas jets when they are used for biogas combustion. About 5.7 liters of air are required for the complete combustion of one liter of biogas, while for butane 30.9 liters and for propane 23.8 liters are required.

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

- Butane/propane gas has up to three times the caloric value of biogas and almost twice its flame-propagation rate.
- Conversion to biogas always results in lower performance values.

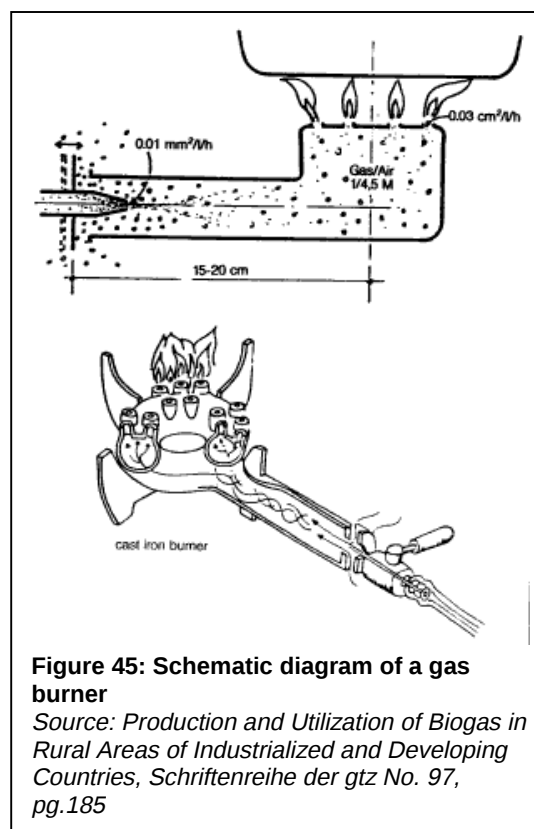
Practical modification measures include:

- expanding the injector cross section by factor 2-4 in order to increase the flow of gas;
- modifying the combustion-air supply, particularly if a combustion-air controller is provided;
- increasing the size of the jet openings (avoid if possible).

The aim of all such measures is to obtain a stable, compact, slightly bluish flame.

Efficiency

The calorific efficiency of using biogas is 55% in stoves, 24% in engines, but only 3% in lamps. A biogas lamp is only half as efficient as a kerosene lamp. The most efficient way of using biogas is in a heat-power combination where 88% efficiency can be reached. But this is only valid for larger installations and under the condition that the exhaust heat is used



profitably. The use of biogas in stoves is the best way of exploiting biogas energy for farm households in developing countries.

appliances	gas lamps	engines	gas stoves	power-heat
efficiency [%]	3	24	55	88



Figure 46: Different types of Biogas burners at an agricultural exhibition in Beijing/China

Photo: Grosch (gtz/GATE)

For the utilization of biogas, the following consumption rates in liters per hour (l/h) can be assumed:

- household burners: 200-450 l/h
- industrial burners: 1000-3000 l/h
- refrigerator (100 l) depending on outside temperature: 30-75 l/h
- gas lamp, equiv. to 60 W bulb: 120-150 l/h
- biogas / diesel engine per bhp: 420 l/h
- generation of 1 kWh of electricity with biogas/diesel mixture: 700 l/h
- plastics molding press (15 g, 100 units) with biogas/diesel mixture: 140 l/h

Biogas can also be used for various other energy requirements in the project region. Refrigerators and chicken heaters are the most common applications. In some cases biogas is also used for roasting coffee, baking bread or sterilizing instruments.



Figure 47: Co-generation unit (electricity and heat utilisation)

Photo: Krämer (TBW)

Gas demand

In developing countries, the household energy demand is greatly influenced by eating and cooking habits. Gas demand for cooking is low in regions where the diet consists of vegetables, meat, milk products and small grain. The gas demand is higher in cultures with complicated cuisine and where whole grain maize or beans are part of the daily nourishment. As a rule of thumb, the cooking energy demand is higher for well-to-do families than for poor families. Energy demand is also a function of the energy price. Expensive or scarce energy is used more carefully than energy that is effluent and free of charge.

The gas consumption for cooking per person lies between 300 and 900 liter per day, the gas consumption per 5-member family for 2 cooked meals between 1500 and 2400 liter per day.

In industrialized countries, biogas almost always replaces existing energy sources like electricity, diesel or other gases. The objective of biogas production may be less to satisfy a certain demand, but to produce biogas as much and as cheap as possible. Whatever surplus is available can be fed as electricity into the grid. The gas demand is market-driven, while in developing countries, the gas demand is needs-driven.

Gas Yields and Methane Contents for Various Substrates

Table 6: Gas yields and methane contents for various substrates at the end of a 10-20 day retention time at a process temperature of roughly 30°C.

Substrate	Gas yield (l/kg VS*)	Methane content (%)
Pig manure	340-550	65-70
Cow manure	90-310	65
Poultry droppings	310-620	60
Horse manure	200-300	
Sheep manure	90-310	
Barnyard dung	175-280	
Wheat straw	200-300	50-60
Rye straw	200-300	59
Barley straw	250-300	59
Oats straw	290-310	59
Corn straw	380-460	59
Rape straw	200	
Rice straw	170-280	
Rice seed coat	105	
Flax	360	59
Hemp	360	59
Grass	280-550	70
Elephant grass	430-560	60
Cane trash (bagasse)	165	
Broom	405	
Reed	170	
Clover	430-490	
Vegetables residue	330-360	
Potato tops/greens	280-490	
Field/sugar beet greens	400-500	
Sunflower leaves	300	59
Agricultural waste	310-430	60-70
Seeds	620	
Peanut shells	365	
Fallen leaves	210-290	58
Water hyacinth	375	
Algae	420-500	63
Sewage sludge	310-740	

Source: Production and Utilization of Biogas in Rural Areas of Industrialized and Developing Countries, Schriftenreihe der gtz, No. 97, pg. 63, after: Felix Maramba, Biogas and Waste Recycling - The Phillipine Experience; Metro Manila, Phillipines, 1978

* VS = Total volatile solids, e.g. ca. 9% of total liquid manure mass for cows .