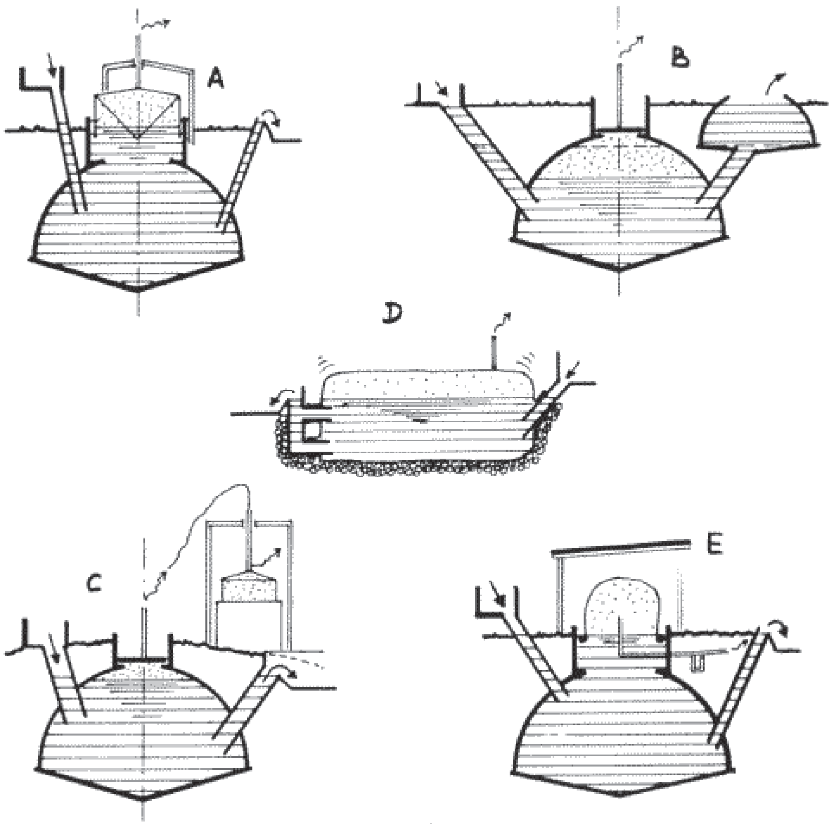


# Biogas Digest

## Volume II

## Biogas - Application and Product Development

isat
Information and Advisory Service
on Appropriate Technology
gtz

## Imprint

This information service on biogas technology has been developed and produced on the order of the GTZ project Information and Advisory Service on Appropriate Technology (ISAT) for the ISAT Website in a collaborative effort of the following institutions and individuals:

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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. Chosing 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 seperatly: 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 equipement
- 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% $CO_2$
- 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 preprocessing 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.

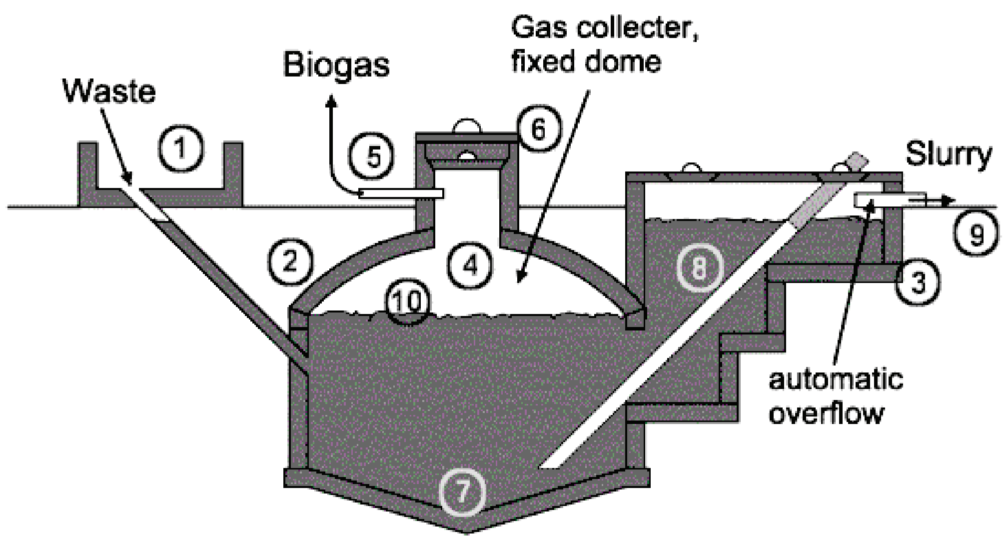


**Figure 1: Fixed dome plant Nicarao design: 1. Mixing tank with inlet pipe and sand trap. 2. Digester. 3. Compensation and removal tank. 4. Gasholder. 5. Gaspipe. 6. Entry hatch, with gastight seal. 7. Accumulation of thick sludge. 8. Outlet pipe. 9. Reference level. 10. Supernatant scum, broken up by varying level.**
*Source: TBW*

### 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.

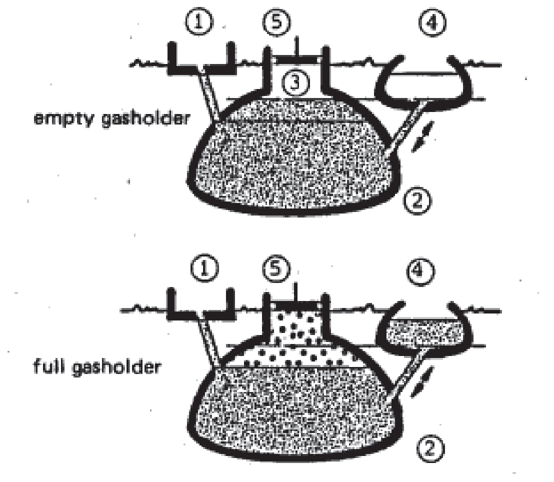


**Figure 2: Basic function of a fixed-dome biogas plant, 1 Mixing pit, 2 Digester, 3 Gasholder, 4 Displacement pit, 5 Gas pipe**
*Source: OEKOTOP*

### 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 Tunesia. The final layers of the masonry structure are being fixed.**
*Photo: gtz/GATE*

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.

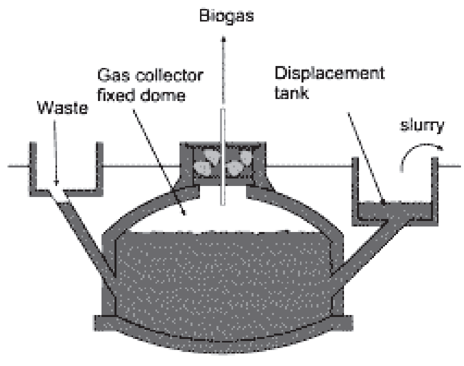


**Figure 4: Chinese fixed dome plant**
*Source: TBW*

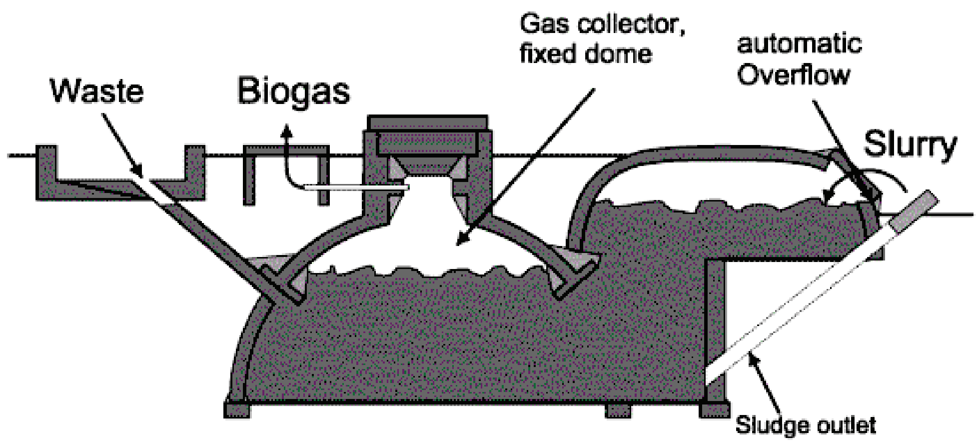


**Figure 5: Fixed dome plant CAMARTEC design**
*Source: TBW*

## 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 $m^3$. Digester volumes up to 200 $m^3$ 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

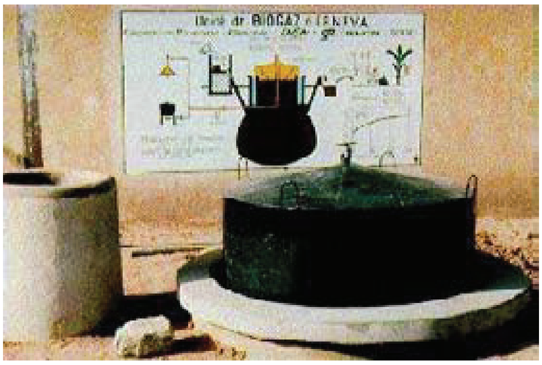

**Figure 7: Floating-drum plant in Mauretania**
*Photo: gtz/GATE*

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: 5-15m$^3$) or in institutions and larger agro-industrial estates (digester size: 20-100m$^3$).

***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.

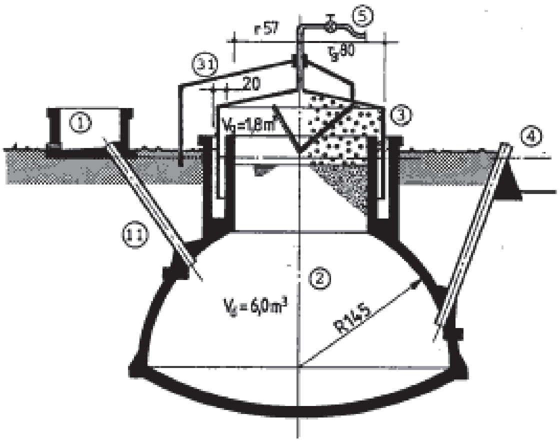


**Figure 8: Water-jacket plant with external guide frame. 1 Mixing pit, 11 Fill pipe, 2 Digester, 3 Gasholder, 31 Guide frame, 4 Slurry store, 5 Gas pipe**
*Source: Sasse, 1984*

## 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 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.

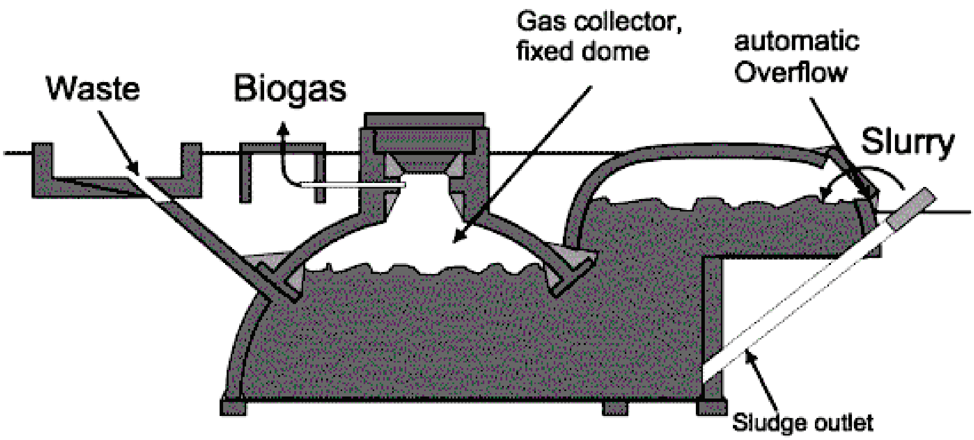


**Figure 10: Fixed dome plant CAMARTEC design**
*Source: TBW*

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# Biogas Plant Types and Design

## Digester types in industrialized countries

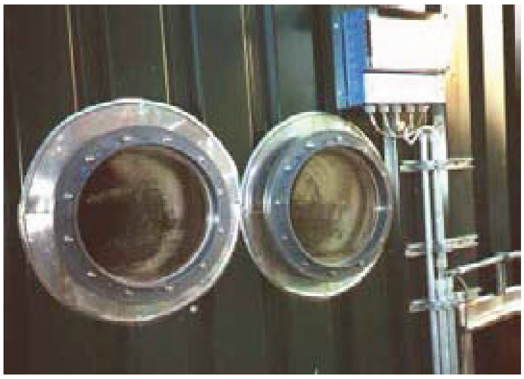

**Figure 11: Control glasses for an industrial digester for solid organic waste, TBW, Germany**

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.

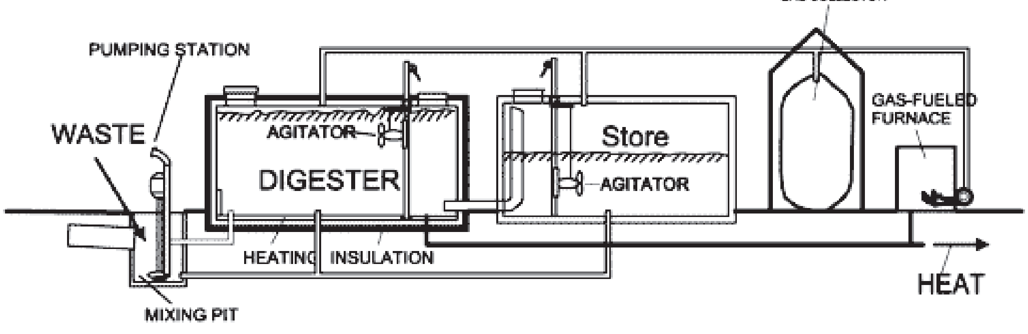


**Figure 12: Concrete digester with two chambers (one heated, one unheated for storage)**
*Source: TBW*

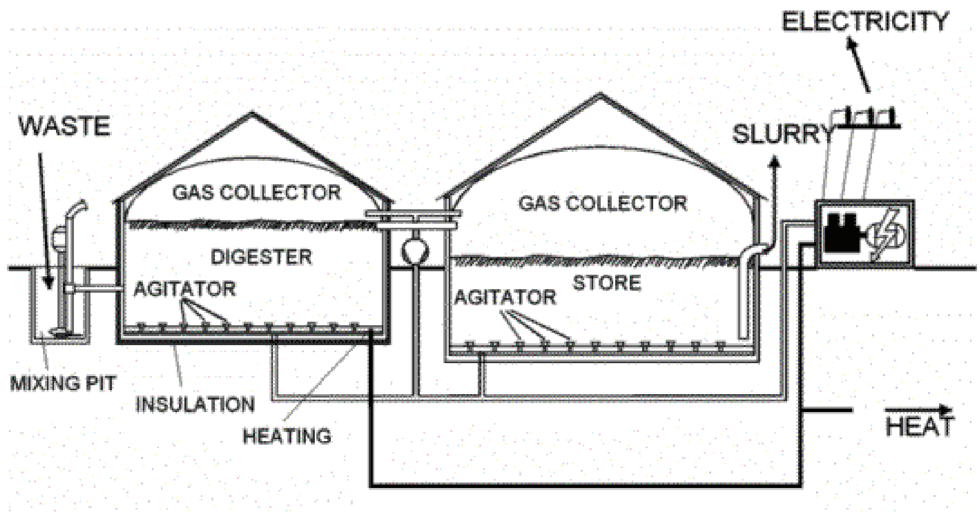


**Figure 13: Concrete digester with integrated plastic gas-holder**
*Photo: TBW*

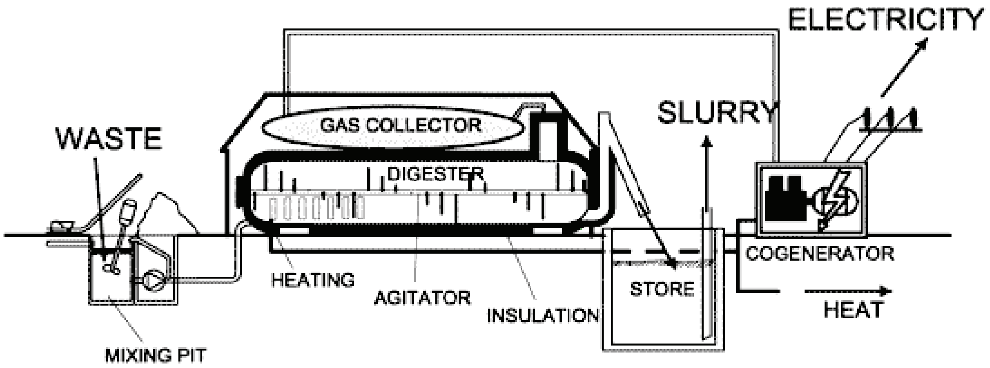


**Figure 14: Steelvessel fermenter with seperate ballon gas-holder**
*Photo: TBW*

## Selection of appropriate design

In developing countries, the design selection is determined largely be 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 theses 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 $m^3$) 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 bio-mass. 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.

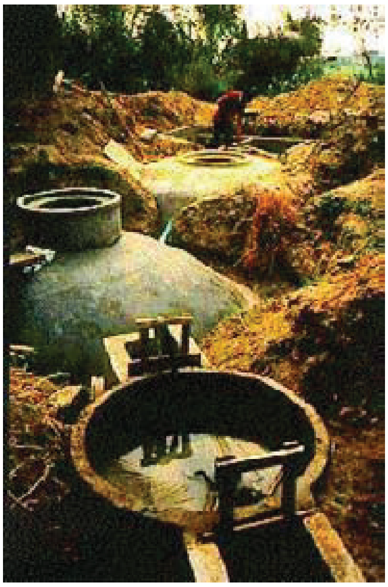

**Figure 15: Installation of a fixed-dome plant in Thailand: The influent collecting tank is in front of the photo, the digester and the outlet are located behind it.**
*Photo: Kossmann (gtz/GATE*

### 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.

### 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 $m^3$ 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 $m^3$ 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 $m^3$ 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 seperate 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

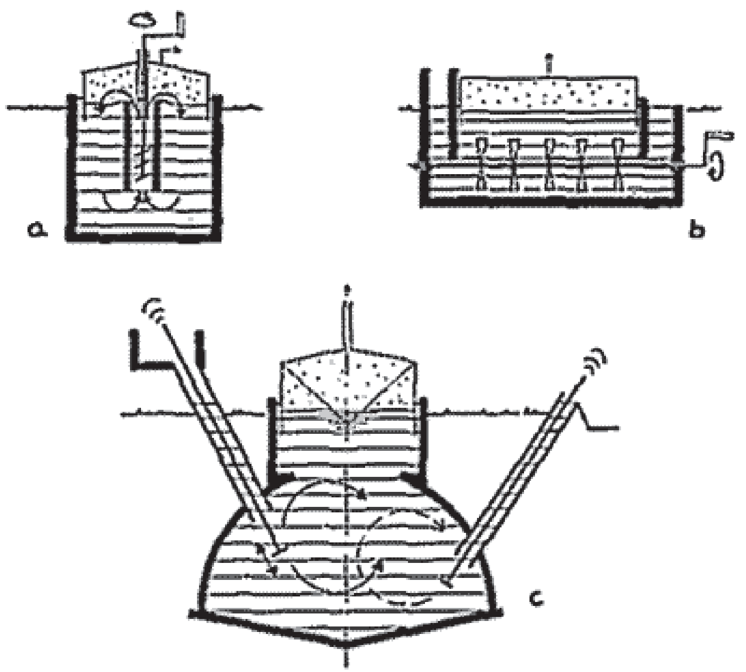


**Figure 20: Stirring facilities in the digester**
*Source: OEKOTOP*

a. The ***impeller stirrer*** has given good results especially in sewage treatment plants.
b. The ***horizontal shaft*** stirs the fermentation channel without mixing up the phases. Both schemes originate from large-scale plant practice.
c. 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