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.

Figure 32: Mixing device in an agricultural digester under construction
Photo: Kraemer

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.

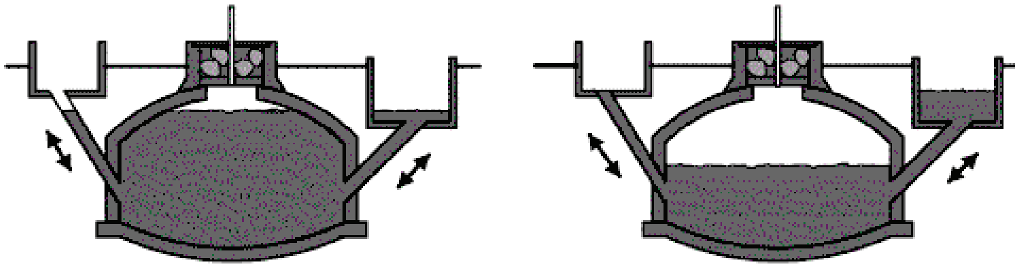

Figure 33: Mixing of substrate through inherent flow in fixed-dome plants
Source: TBW

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.

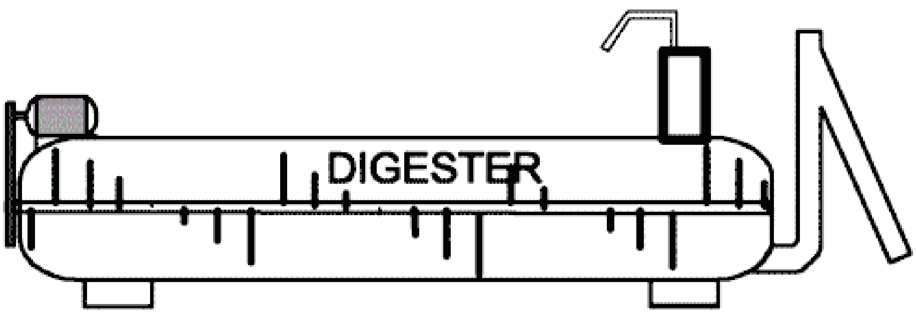

Figure 34: Mechanical paddle rotor
Source: TBW

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

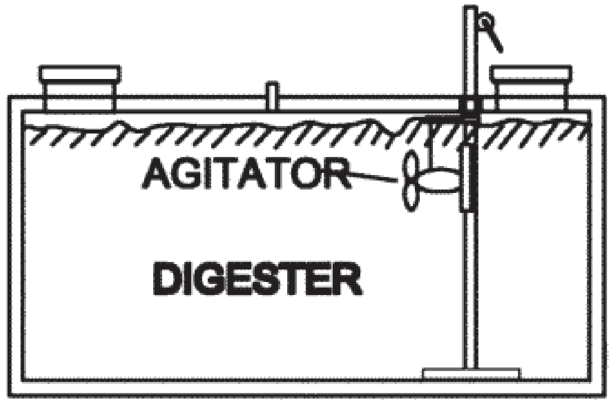

Figure 35: Submerged motor with rotor stirring
Source: TBW

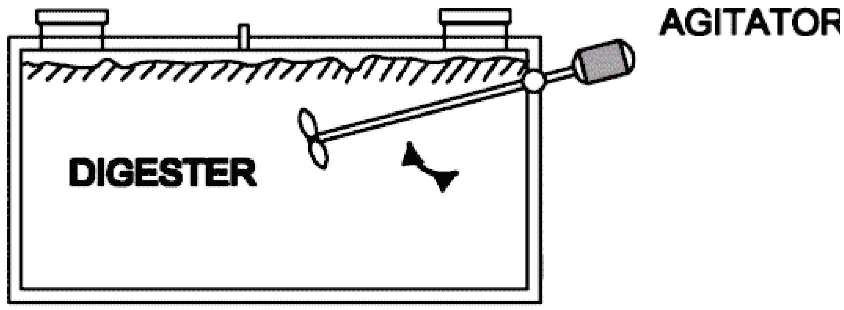

Figure 36: Shaft-driven rotor
Source: TBW

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.

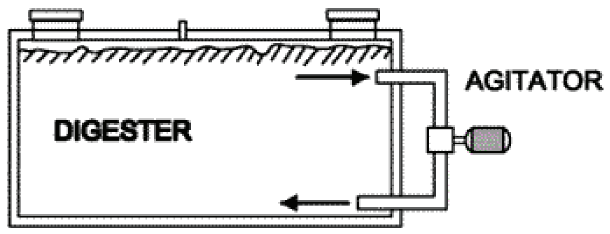

Figure 37: Hydraulic mixing
Source: TBW

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.

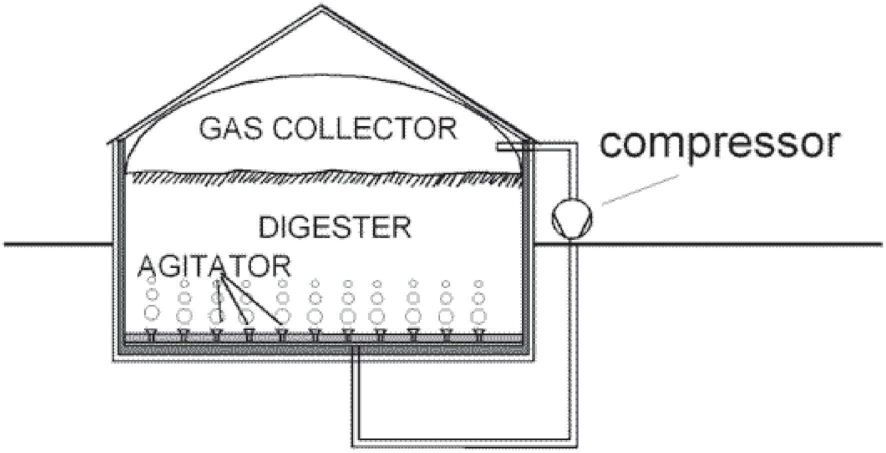

Figure 38: Mixing through injection of biogas
Source: TBW

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 it's 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. It's 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.

Figure 40: Inside plaster of the gastight section of a fixed dome digester
Photo: Kellner (TBW)

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.

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.

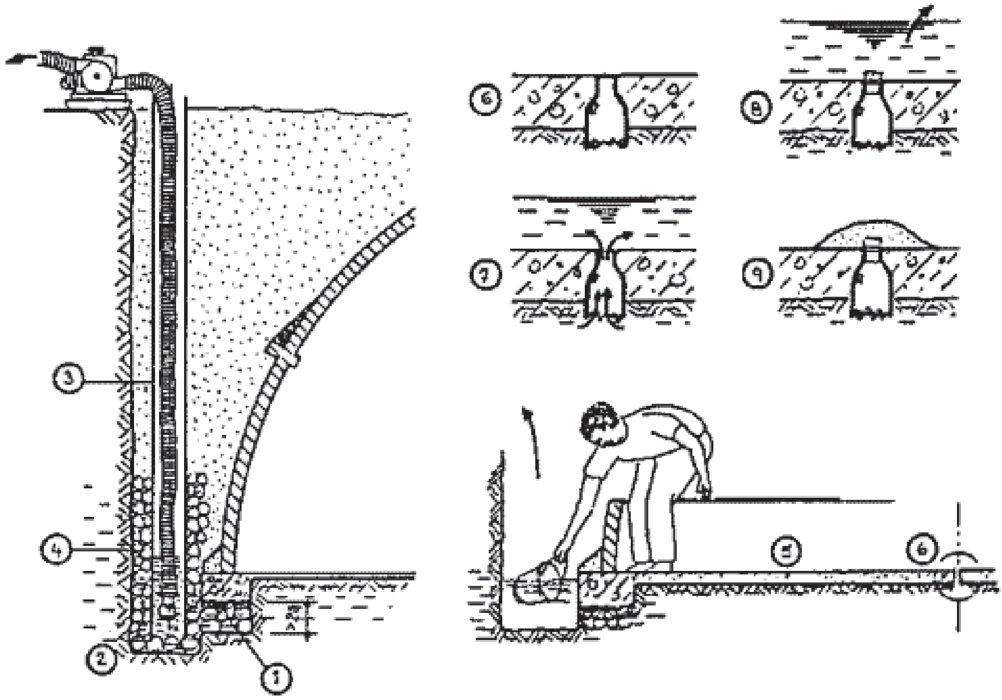

Figure 41: Dealing with ground water during construction: The foundation rests on a stone packing (1) to drain the water into the pump-sink (2). A layer of gravel prevents blockage of the drain. A vertical pipe (3) allows pumping even when back-filling has be done. The lower part of the pipe is surrounded by a stone packing (4). If the ground water is only slightly higher than the digester bottom or if no pump is available, the construction must be flooded. The floor must be of solid concrete (5). Water must be kept away until the outer wall has reached above the ground water table and has been plastered from the outside. Several bottles without bottoms are placed into the concrete (6). When scooping of water has stopped, ground water passes through the bottle and floods the floor (7). After completing the masonry work and covering the dome with soil, the bottle is closed and water might be taken off the digester bottom (8). The cap of the bottle is covered with cement mortar (9). In case of high ground water table a conical or bowl-shaped solid concrete slab is required.

Source: Sasse, Kellner, Kimaro: Improved Biogas Units for Developing Countries, GATE 1991

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 squegee, 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 swimmig 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. it's 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%).

Figure 42: Drying of digested sludge and sludge disposal in Thailand
Photo: Kossmann (gtz/GATE)

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 it's 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.

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 m^3 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/m^3).

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.

Figure 43: Sludge disposal in Thailand

Photo: Kossmann (gtz/GATE)

The phosphate content ("P_2O_5" 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 P_2O_5 and 48 kg K_2O to compensate for an annual yield of 1-1.2 tons of, for example, 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 m^3 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_2O_5 = 1)		
	P_2O_5		K_2O		N	P_2O_5	K_2O
	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

Maintainance, 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;
piping 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 ($Fe(OH)_3$), 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% $Fe(OH)_3$, 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. CO_2 "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.

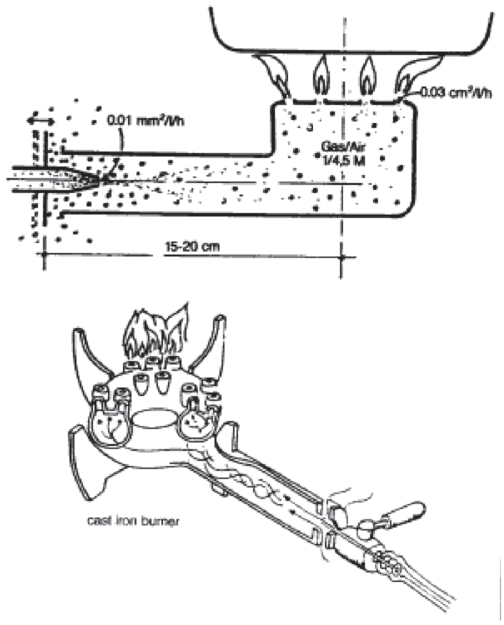

Figure 45: Schematic diagram of a gas burner
Source: Production and Utilization of Biogas in Rural Areas of Industrialized and Developing Countries, Schriftenreihe der gtz No. 97, pg.185

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.

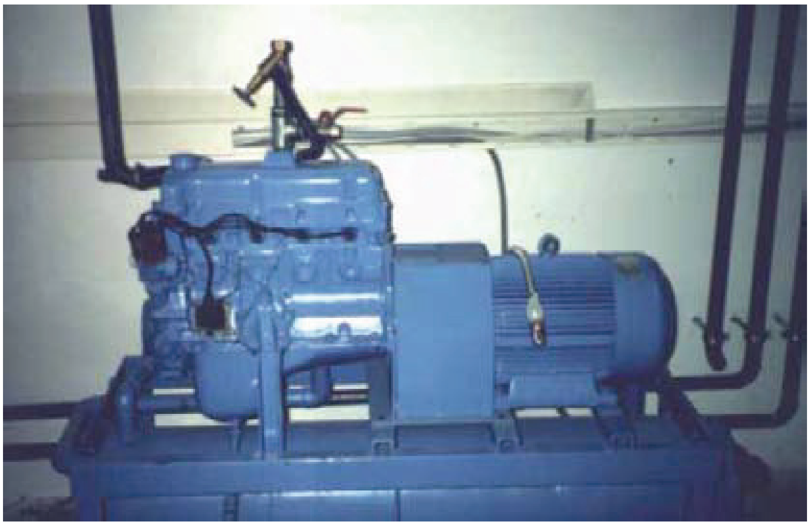

Figure 47: Co-generation unit (electricity and heat utilisation)
Photo: Krämer (TBW)

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 .