Manual for The Construction

of a Bio Digester,

“LUPO” Design

Edition for Ethiopia

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1. Foreword

Biogas technology is a way of changing organic waste into gas and fertilizer by anaerobic break down (without oxygen). Under warm conditions this technology can be executed in a rather simple manner, whereas in colder areas, with a distinct winter period the technology is executed in a technically complex manner. This booklet deals with the technology for *warm countries* and specifies on Ethiopia. It is based on three years of experience, which was gathered within the framework of an Ethiopian-German development project called LUPO (Land Use Planning and Resource Management, Oromia), supported by GTZ (German Technical Cooperation) and the DED (German Development Service). Heiko Bretternitz, who stayed in Ethiopia within the project as a practitioner from the German consulting firm TBW (naturgerechte Technologien, Bau- und Wirtschaftsberatung) has been of great help to start the job on the book. Most important was also the practical experience we gathered in Ethiopia with 56 costumers, for which we have erected digesters with the help of Yacob Zerom from Fitche, Ethiopia (Zerom Biogas Self Help Group) and David Roeschli and his team from SELAM Technical and Vocational Centre from Addis Abba. Beside the technical and commercial success, a number or rural potentially workless youth have received training in this technology with the support of the German Development Service. I have written this manual for those and all future trainees.

The booklet does not replace the literature, which gives an overall overview on biogas technology, but concentrates after some short introductions on the construction aspect.

2. Introduction, Use, Advantage

Biogas technology has not been very successfully promoted in Africa, contrary to Asia, due to a few social and technical reasons:

- The daily labour input for its operation is in most cases too demanding and
- The technology needs good skill and supervision for reliable operation.

Both aspects can be dealt with, and this booklet shows a successful way.
Another argument for its difficulties in extension is that

- The technology is too expensive for a wider dissemination, especially to low-income target groups.

This argument cannot be ironed out easily and reliably by technical modifications. (except mass production an competition) But the *extension approach* can deal with it: ***Start where the money is. (Just like any other new business).***

These better-off target groups are not only locations of institutions where donors are covering the investment cost, but also certain businesses, which have both, *a waste- and an energy problem*, like larger farms, hotels, people who build modern houses and need a septic tank anyway. If these customers are satisfied, they advertise the technology and the biogas business (extension) can start.

There are enough premises, locations and early adapters who *should have and could afford* but do not have a bio digester. If they get a product, which is in all details convincing, this will create a demand by others. The technology should not be limited to cattle keeping farms alone, but be offered to places with any sort of organic waste and organically loaded wastewater. The digester type introduced here, can deal with all organic waste, as long as the digester temperatures do not fall under 18°C (this is in Ethiopia equivalent to an altitude of more than 3000m above sea level). Otherwise the technology has to be different or the expectations in respect of its performance have to be verified.

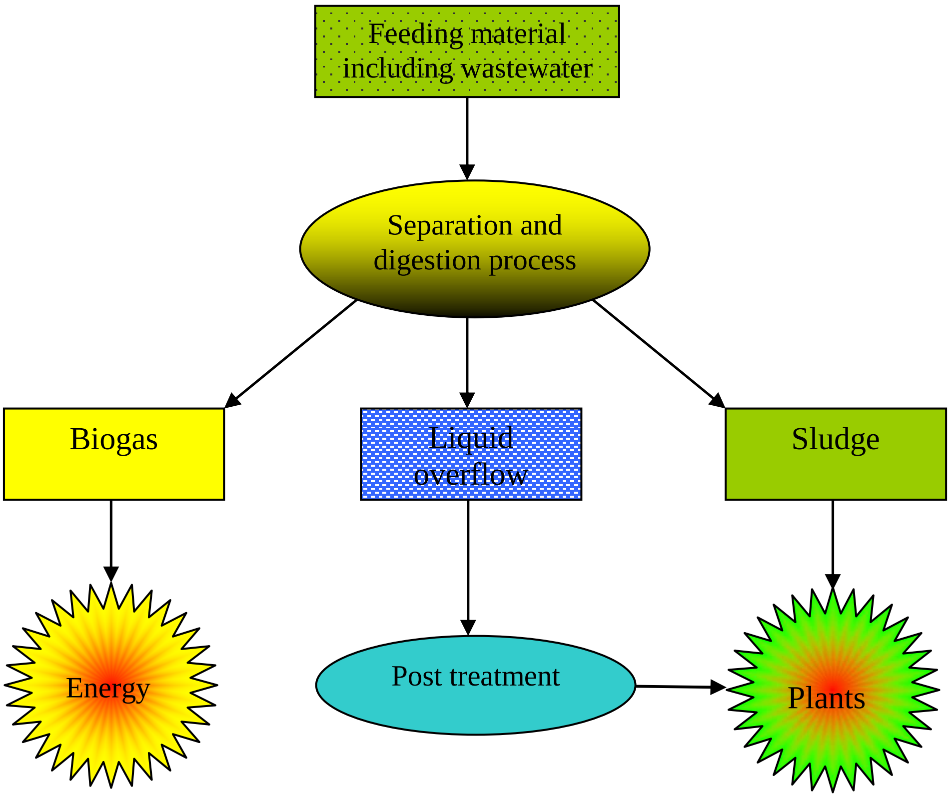
This is the framework under which this booklet was written and the technical design modifications were incorporated. The base of the digester design is taken from the Tanzanian “CAMARTEC” digester. It is a **fixed dome digester** functioning after the so-called *Chinese principle*, with an expansion canal. The *canal* is a speciality which has to do on the one hand with the relatively huge gas storage requirement for the Ethiopian conditions, so that it is easy to make injerra with the stored gas and on the other hand with the objective to ensure a good use of the fertilizer by guiding it to the best location in the vicinity.

Bio digesters are fed with **organic waste** (kitchen waste, toilet waste, cow manure e.g..) and turn these *long carbon chains* by help of natural processes into

- Short carbon chains: *biogas,*
- *Partially cleaned water* (still loaded with nutrients but not with pathogens) and
- *Sludge*, both covered under the term *overflow*.

Furthermore **water** is required for the operation of a digester. To avoid that this is a limiting or cost factor, it is best to use a wastewater stream if it is available. In the farming context this can be urine of animals; in the context of a public toilet this can be hand washing water. In a modern house with bathroom and kitchen with water installations the digester will be installed by replacing the septic tank or soak away pit. Different to other bio digester types it is avoided that mixing of organic matter with water is a necessity. This makes the operation easier and will lead to a primary discharge of the liquid component (water), which does not produce much gas. The solids tend to remain longer in the digester and are fully exploited and are hygiene when they are discharged in small quantities with the water stream. The water discharged is *partially treated*. It can as well be used for irrigation but it is in most cases not free of smell. To remove the smelling components requires an aerobic post treatment. This is best done with a horizontally operating root treatment system. Thus the remaining nutrients in the overflow produce biomass, which can be charged into the digester again. After this second treatment step the water is free of smell.

The material, which has entered the digester, is called: *slurry.*
The material settling at the bottom of the digester and also in the expansion canal is called *sludge.*
Material swimming in the digester on top of the slurry s called *swimming layer.*
If the swimming layer contains gas bubbles it is called *scum.*



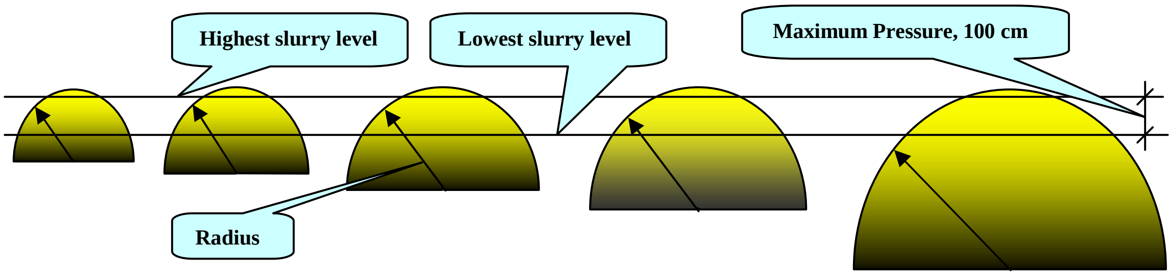
Biogas is a source of energy for cooking, lighting, refrigerator, engines for pumping or generating electricity. The solid material entering turns into a sludge which contains **all nutrients**, which have originally been contained in the feeding material like phosphorus or nitrogen and can be utilized as a fertilizer in farms, nurseries and gardens. No other organic fertilization system can compete with such a favourable form of nutrients conservation and recovery.

The bio digester helps to save conventional fuels (firewood, kerosene, cow dung), will improve the quality of life and save money and time. Proper use of a bio digester is an enormous relief for the environment. Properly designed, executed and utilized the pay back period of a bio digester is less than 4 years. The lifetime of its main structure can easily be more than 20 years.

The precondition for a long term good operation is in the first place a very well execution of the construction work with absolute gas tightness of the digester and of the piping system and unfortunately unavoidable: *regular feeding.*

3. Choosing the Size, Preparation of the Construction Site, Layout

The LUPO designed digesters do all, independent of their size, have the same shape: they are **hemispherical**. And they all generate the same maximum pressure, which is defined as *100 cm water column*.



This has several reasons:

- Particularly the large digesters are limited in gas pressure. A high gas pressure could endanger the structure.
- All digesters can be operated with accessories, which are adapted in a standardized way.
- The gas piping system of all digesters can be interlinked with each other, forming a network. In this manner smaller or less productive digesters store the gas of the more productive ones.

Particularly the last point makes the digesters suited for institution, which have several sources of organic matter or organically loaded waste water. Forming a network for the gas production between several digesters will be the same net of pipes to distribute the gas to different consumption points.

What determines the size of a bio digester to be constructed? The digester sizes available in the LUPO design approach are defined by the different radii, which rise from size to size by 10 cm:

Radius	m	1,6	1,7	1,8	1,9	2	2,1	2,2	2,3	2,4	2,5
Size	m^3	8	9	11	13	16	18	21	24	28	32

The appropriate size and layout of the digester is determined by the average daily input. A minimum of 40 days retention time should be assured. For *toilet digesters* it is preferred to extend the retention time to 100 days to assure the elimination of pathogens. The following table gives a rough indication of which size of digester should be constructed for which kind of feeding material.

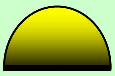
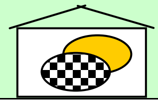
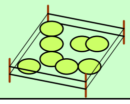
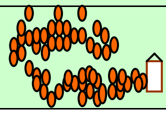
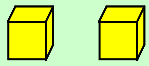
It is limited to either

- Cows kept under 0-grazing conditions,
- Local cows which means they are smaller in size and grazing during the day and confined only at night, or
- Public or community toilets,

In relation to different digester sizes.

These and any other feeding material (organic matter, except wood) can as well mix in one set up. Also a wastewater stream can be added, but would not increase the size of the digester, unless it is a huge stream like from an agro-industrial enterprise.

Table: Examples for the most common digester sizes:

		Approximate alternative feeding conditions			
Main are of application	Size of digester in m^3	No. of cows, 0-grazing	No. of local cows	No. of toilet users	Expected gas yield/per day
small digesters	8	2	8	50	2
					
	9	2	9	60	2.5
	11	3	11	70	3
Family units	13	3	13	80	3.5
	16	4	16	100	4
	18	4	18	130	4.5
	21	5	21	160	5
Institutional digester	30	8	30	200	8
	50	12	50	325	12
	100	25	100	650	25
Note: Each digester can deal with about double the feeding as mentioned above, which means that much more gas is produced but the overflow is not fully exploited or treated. Especially for toilet digesters it is advisable to relate to the figures given above.					Maximum half digester volume gas per day.

The planning parameters for the digester size to be constructed are:

- One upgraded cow under stable feeding conditions produces 1 m³ biogas (1000-litre) per day.
  One person using the toilet produces 40-litre biogas per day, a local cow (grazing) produce 250 l/day.
- The conditions found in Ethiopia allow that a digester produces a maximum of half the digester volume of gas per day (8 m³ gas/day from a 16 m³ volume digester).
- Amount of water entering the digester per day can be tolerated up to ¼ of the digester volume.
- The digester separates liquids from solids. Therefore water is always discharged first.(it has a lower viscosity than sludge or pulp).
- For the construction there is no difference between a digester for sewage than for agricultural waste or for a dry latrine.

If a digester is built instead of a septic tank for a household, the sewage alone will roughly produce 15% of the cooking requirements of the respective person living n the household. If more gas is wanted, organic kitchen and garden waste have to be added on a regular basis. Such a household unit (without having cows or pigs) cannot be sized precisely as its performance as far as gas production is concerned depends on the additional feeding. In order to have at least the chance to produce and/or store enough gas for the entire household cooking, a digester volume of 10 –16 m3 should be provided.

In case the local conditions may opt for a digester size in between the given sizes (e.g.115 toilet users), the cost and readiness of the customer to spend money should decide for the larger or smaller option.

3.1 Preconditions for the Decision for a Digester

None of the following preconditions is an absolute dogma, but it is very important that any digester operates reliably, satisfactorily and economical.

- The foremost condition is that the **customer** has the necessary funds for the investment available.
- The **raw material** for digestion must be conveniently available on a daily basis (minimum 30 kg of cow manure or 15 kg of vegetable waste or any equivalent, otherwise the technology can not be viable).
- There must be a **need for the energy**.
- There must be a **location**, which suits inlet and outlet and the use of the sludge or overflow water, without much transport effort.

3.2 Location of the digester

A bio-digester is in the ideal case completely constructed underground (except inlet and outlet) and the place where it is located can later be used for any purpose except heavy traffic. The operation of the digester should make as little work as possible in its daily operation. Therefore it should be placed on the one hand directly besides the main source of feeding material. In case of a cowshed this is right beside the shed, preferably attached to its lowest point. All dung and urine should enter with less effort than the previous cleaning of the stable (time saving). In case there is no space, it should be considered to shift the stable to a better-suited location.

It is advisable that no compromise as far as the digester location is concerned is made. It is better **not** to construct it at all in one or another case, than risking that the technology will not work properly. A dug hole, already existing on a premise is no argument for a digester location. The responsible planner decides the location, not the customer (otherwise customer is king, of course).

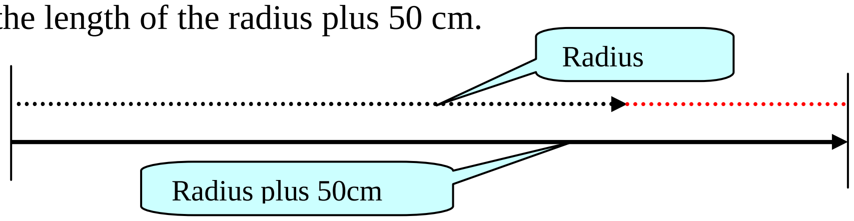
The digester should be built at least 10 m apart from the next water catchments and not too close to trees with a large root system.

4. Construction

For a standardized method of digester set up and the best performance, it is necessary to identify the best location on the respective premises and construct the digester in the right levels. It is aspired that the filling and emptying of the digester takes place by gravity. That means that the premise has to provide a location where the outlet is at least 10 cm lower than the inlet. At the same time the outlet should be high enough to allow the overflowing water to drain off (at grass root level), in order to be guided to an agricultural use or a root treatment system (aerobic post treatment). In case the landscape is rather flat, a discharge area for the slurry has to be dug out to form an artificial slope.

Planning the digester means

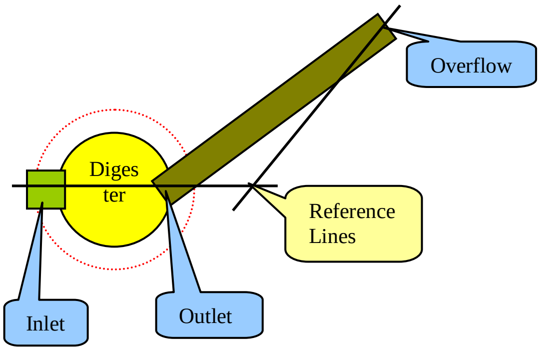
- To define the position of the inlet and the outlet. The two points could be 5 – 15 m apart from each other.
- Mark the position of the digester in a circular shape using a radius string with the length of the radius plus 50 cm.

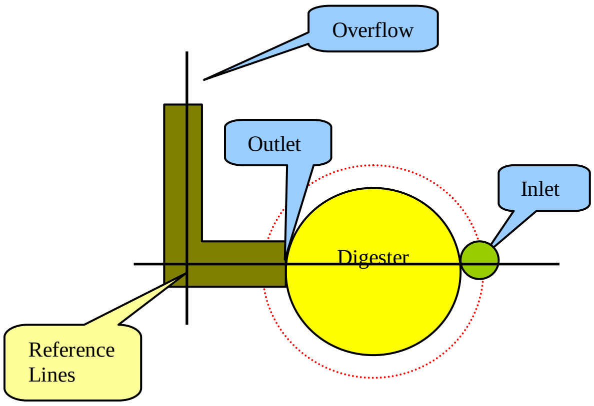


- To place the reference line across the future buildings inlet, centre and outlet. If this is not possible as they are not in one line, use two lines on the same level.

In order to achieve the correct levelling the technical drawings for the LUPO digesters are equipped with a reference line. The reference line has to be transferred to the reality location before the construction starts. It is a thin nylon line, which spans over the building 1 m above the overflow level.

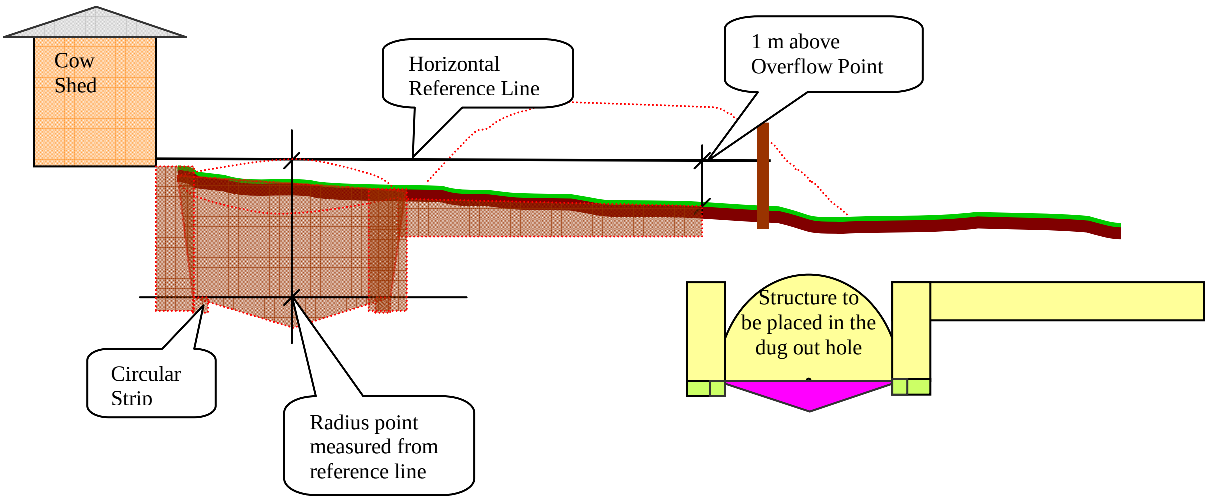
This line is fixed to two nails from where it can be taken off during work and put back to take measurements.





4.1 Digging

The digging has to be done according the layout, which was marked on the construction ground, up to the necessarily depth, measured to the reference line. Additional to the chosen size of the digester space for freely working is needed.
The sides of the pit should be sloped according to the soil properties. Enough space for dumping the soil is also necessary; keep this soil away of the pit edge.

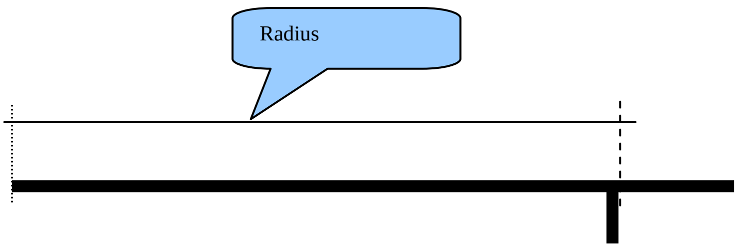


The conical bottom shape is optional and not part of the digester volume calculation. Statically it is not a necessity for the dome. A conical bottom if cast in concrete is more stable than a flat one. The purpose of the slap is to seal the digester against seepage. Usually, if loaded with cow manure the digester seals itself but not to 100%. From the environmental point of view, it is better to construct the digester with a bottom slap. In respect of operation security a conical bottom slab is preferable as this additional volume may hold back sand and sinking particles and make a blockage of the outlet pipe even after may years of operation less likely. This booklet deals in each aspect with the bottom slab, but in practice a flat bottom can be executed, as well. The advantage is that building material is saved. In practice the conical shape can be dug after the construction of the walls has started so that the soil can be used as backfilling material. This may be useful for large digesters where the digging is hard due to depth and size of the heaps with the dug out soil. The shape of the bottom slab should be finalized before mixing of mortar takes place in the digester pit, as the remains can form part of the slab. Particular when the digester is plastered from inside the splashing remains can fall on the soil and form the bottom slab which is compacted by the mason and helpers walking on it. This may lead to a layer of 3 cm thickness only. If an additional layer is added on it or not, can be decided after the plaster is completed. Digesters with a thin bottom slab will need in the start up phase large amounts of water until the manure blocks the likely seepages through capillaries.

4.2 Fixing the central radius point

For the construction of the dome the radius point has to be defined in the middle of the dug hole below the reference line. The distance to the reference line is given in the measurement table. In case the conical bottom slab has been dug, a peg has to be fixed in a temporary construction, which ensures the position of the radius point. It has to be controlled that the centre point is in the middle of the dug out hole. The radius stick gives the measurement from the radius point to the inner wall of the hemispherical digester. For a control of the dug out pit, enough space has to be behind the wall that a layer of wire mash can be fixed and the outside plaster can be applied (25 cm space for thin walls of smaller digesters and 35 cm for large digesters with thicker walls).

The radius stick can be made from wood or for *re-use* a metal pipe with a T-joint can be used.



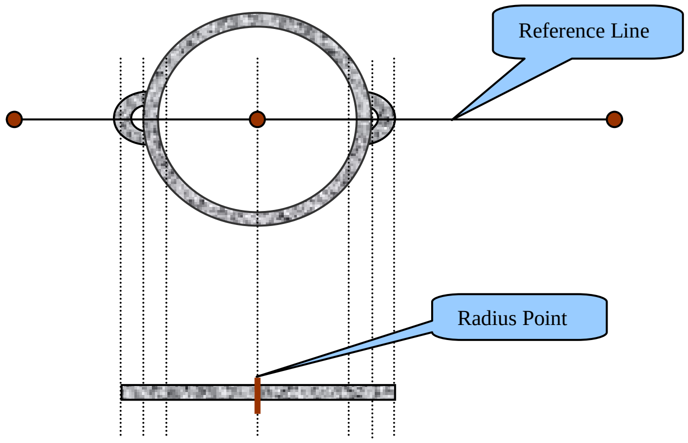
The radius point can be the head of a strong nail attached to a wooden peg. The radius pipe end can spin around the nail head and can be fixed with binding wire.

4.3 Circular Ring Foundation

The foundation ring has to be dug 20 - 30 cm deep and 20 - 30 cm wide below the radius point. The strip foundation should give the hemisphere a firm rest. With the help of a spirit level it has to be placed horizontal. For its construction natural stone

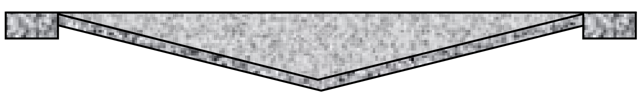
(foundation stone), chopped into geometrical shapes, can be used to minimize the use of concrete. The foundation has to be covered with concrete and has to be firmly rammed.
In case foundation stones are not available, a concrete mixture (*1 cement / 3 sand / 6 aggregates*) has to form the ring foundation. The amount of concrete or mortar to be mixed has to be estimated precisely in advance so that none of the mixture stays for a long time until it is used. The position where the mixing takes place should be in the shade to avoid unnecessary drying. The points where concrete or mortars are applied have to be watered to give a better binding.

For smaller digesters, of less than $16m^3$ digester volume, the inlet and outlet must be designed. They are vertically attached cylindrical openings. The Inlet will allow rough organic material to enter without problem and the outlet is big enough that it cannot block. Both should be big enough to act as manholes for craftsmen to enter the building.
Lay out of foundation for a $16m^3$ digester



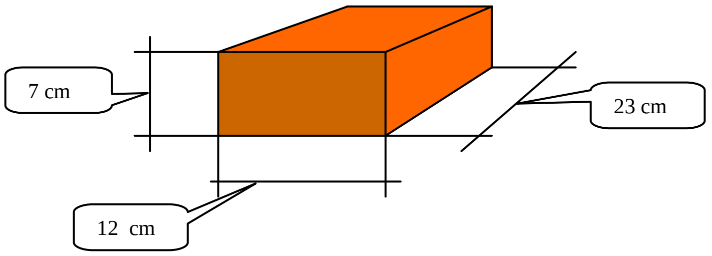
4.4 Conical bottom

The ring foundation and the conical bottom statically fulfil different purposes. While the ring foundation carries the building and the respective earth load (sometimes wet, sometimes dry) on top of it, the bottom slab caries the sludge and the changing gas pressure. As a conical shape for the bottom slab is more stable and provides additional volume, it is preferred to a flat bottom. The drawing gives an approximate measurement of the height of the cone. The bottom slab should be cast with a thickness of 10 cm and a mixture of *1 cement/ 3 sand/ 6 aggregates.*



4.5 Wall of Hemisphere

The first two layers of the hemisphere are built on the same day the foundation is established. For the wall burned bricks of good quality are needed. The approximate size of the bricks is 7 x 12 x 23 cm.

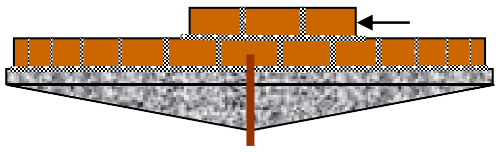


Any other size available can also be used but it means that probably more cement and sand are required.

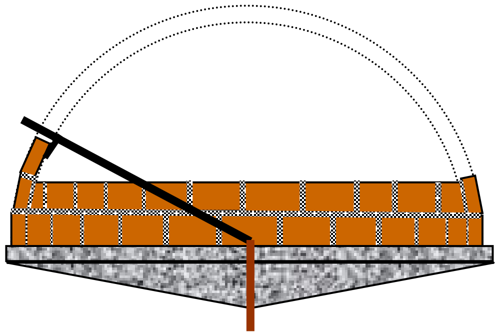
For digester sizes of up to 30 m^3 the bricks can be used as “quarter brick” forming a thickness of the wall of 7 cm only (without inner and outer plaster).

The bricks are laid circular, adjusted in position and angle by the radius stick. The mixture of the mortar is: *1 cement / 3 sand*. At the inlet and outlet *mud mortar* is used. These bricks will be removed later when the structure has strength. During the work the mortar is put below the position of the brick and on the side of a brick before its placement.

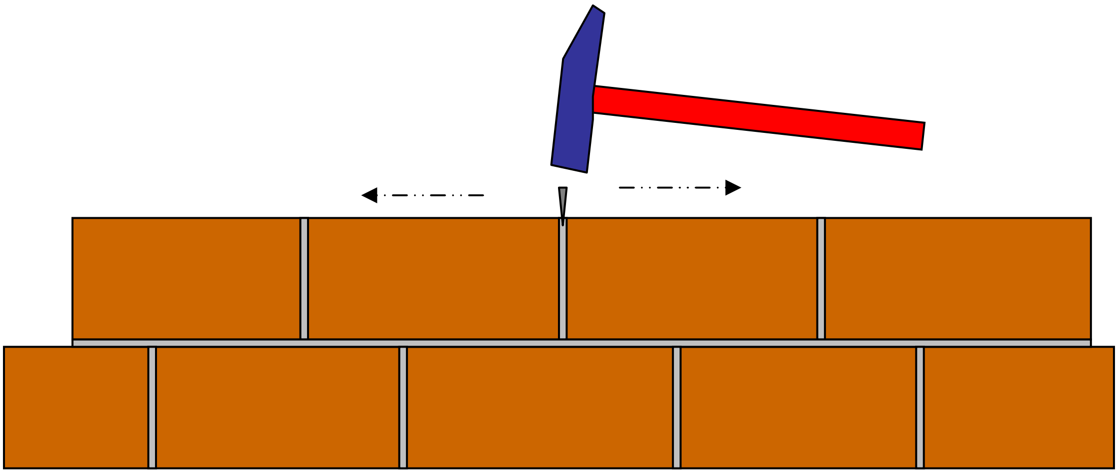
One knock with the trowel will squeeze the mortar and lead to a good strength of the building.



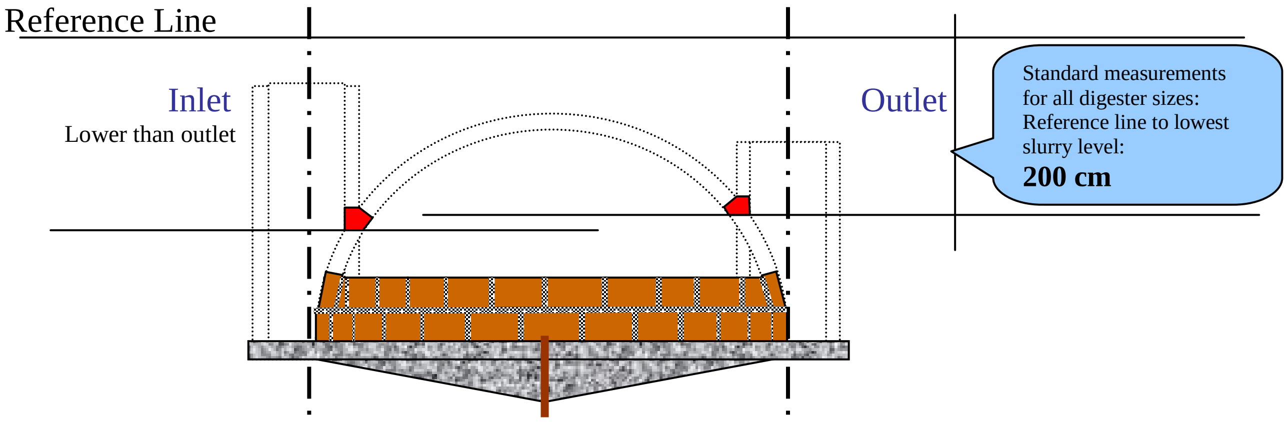
Like this ring after ring is laid. Each ring, which is started, has to be completed in one work unit (no break!).



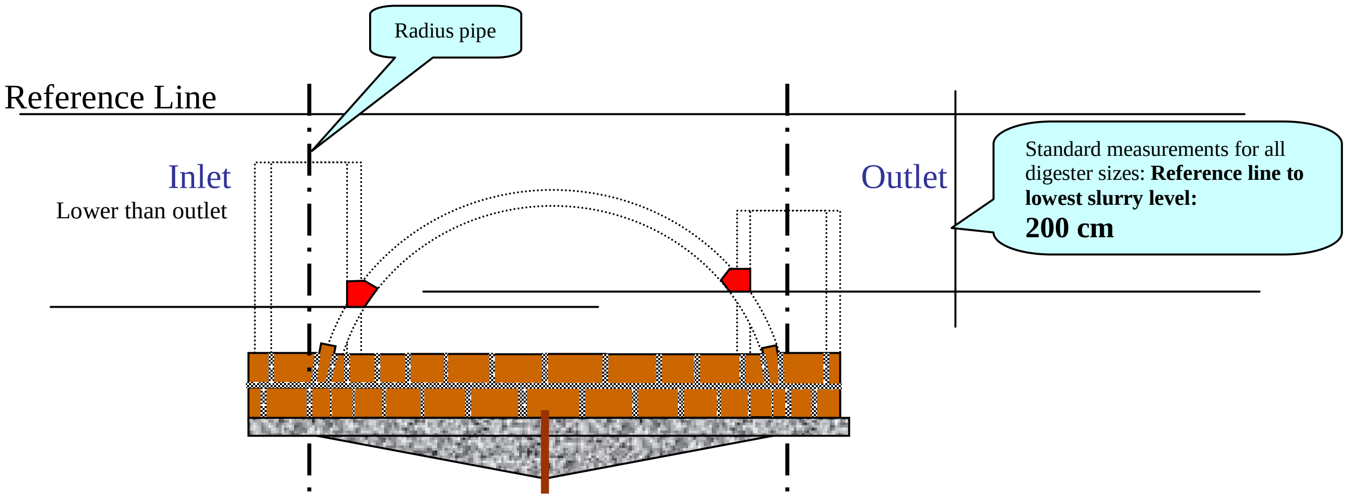
When a ring is completed, small stones will be hammered carefully in the joints as a wedge to put pressure on the joints.



As the structure rises the inlet and outlet have to be constructed. First the measurement between reference line and highest point of inlet has to be measured. The inlet should in any case be slightly lower than the outlet (see table of measurements) side foundation at the respective position of inlet and outlet a vertical centre pipe as a guide for the construction of a cylinder.



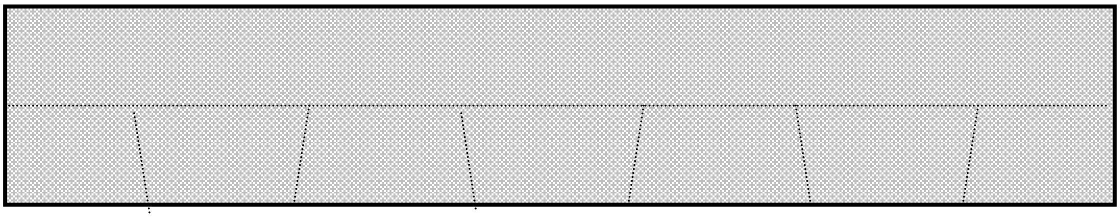
Inlet and outlet are cylinders with an inner radius of 40 cm each. The vertical centre pipe for measuring the brickwork will in case of the outlet be closer to the hemisphere than in the case of the inlet. Where the cylindrical building touches the hemisphere, a large opening is generated. The outlet forms in this way the manhole. The inlet may act as manhole as well, but as it is the lintel is a little lower, it will be less convenient to go in and out. The precise position of the lintels at inlet and outlet opening (where the hemispherical and the cylindrical buildings join), have to be considered when placing the vertical radius pipe for the radius.



4.6 Reinforcement

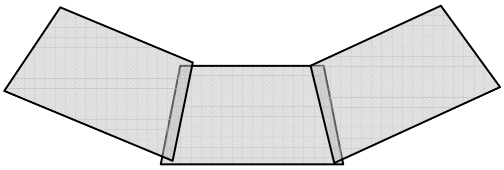
Simultaniously to the brickwork the building receives a reinforcement by wiremesh which is placed outside of the structure, enbedded into an outside plaster. Hexagonal mesh wire (or chicken wire) is cut in trapezoid pieces of about 50 -60 cm hight and 95 –100 cm length. The correct measurement depends on the dimensions of the role in which the wire is available on the market.

In principle the wire is cut in length stripes which than is cut in metre pieces with an angle of 93° (87° respectively) so that the pieces form the trapezoid shapes as indicated before.

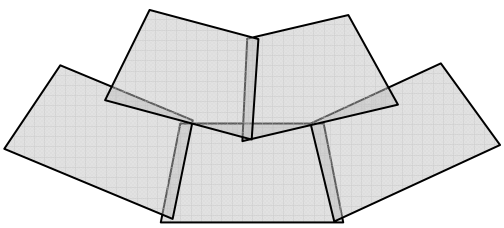


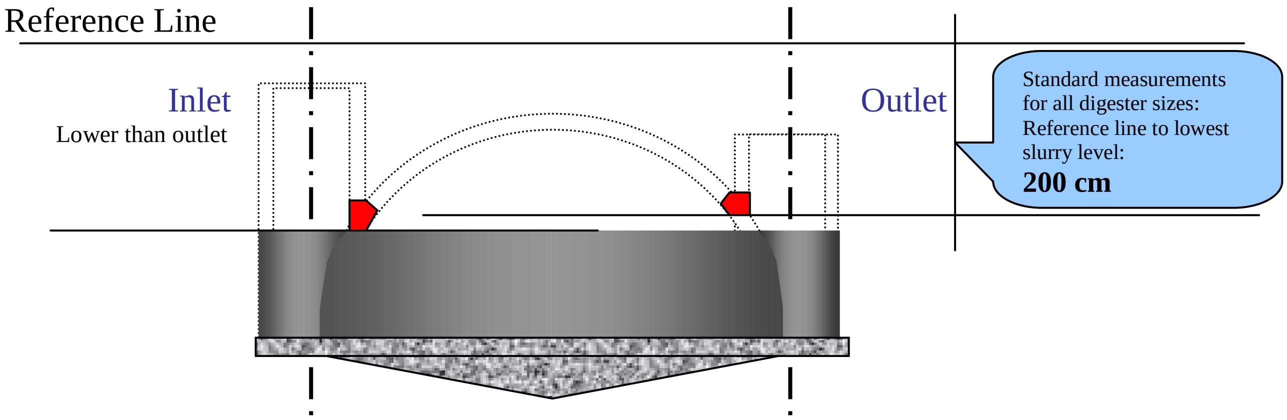
These pieces are placed behind the sphere so that the longer ends are forming the circle of the foundation, whereas the shorter sides will be joint and placed at the higher brick wall section. The pieces are tight with each other with binding wire or loose ends wire.

As soon as the wire layer is tightly spanning around the building, including the inlet and outlet, the outside is plastered is applied with a mixture of *1 cement / 3 sand*.



As the sphere proceeds, the angles in which the wire is cut should become a bit steeper so that the narrower circles can comfortably encompass the hemisphere. At the same time the cylindrical inlet and outlet structures receive a layer of wire mesh to prevent cracking.

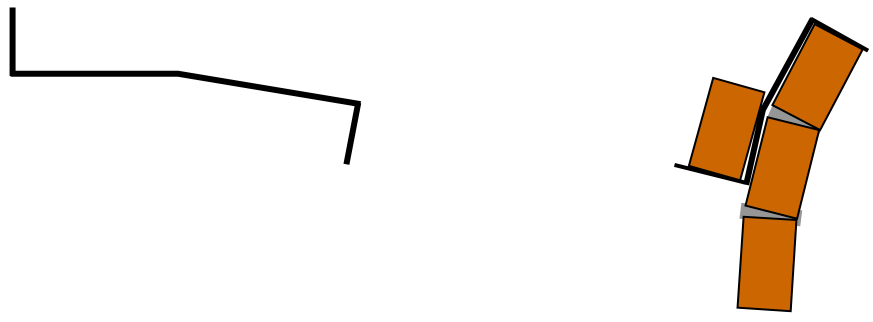




Inlet and outlet have to be well joint with the hemispherical building. Thy rise together at the same speed, when they reach 50 cm in height the first layer of wire mesh is placed behind the brickwork and the outside plaster is applied.

4.7 Upper Part of the Dome

When the spherical building reaches an angle that the bricks tend to fall down, temporary *support hooks* with a little bent in the centre have to be used. 8 mm iron bar of 60 cm length have to be bent 10 cm from each end by 90 ° in opposite direction.

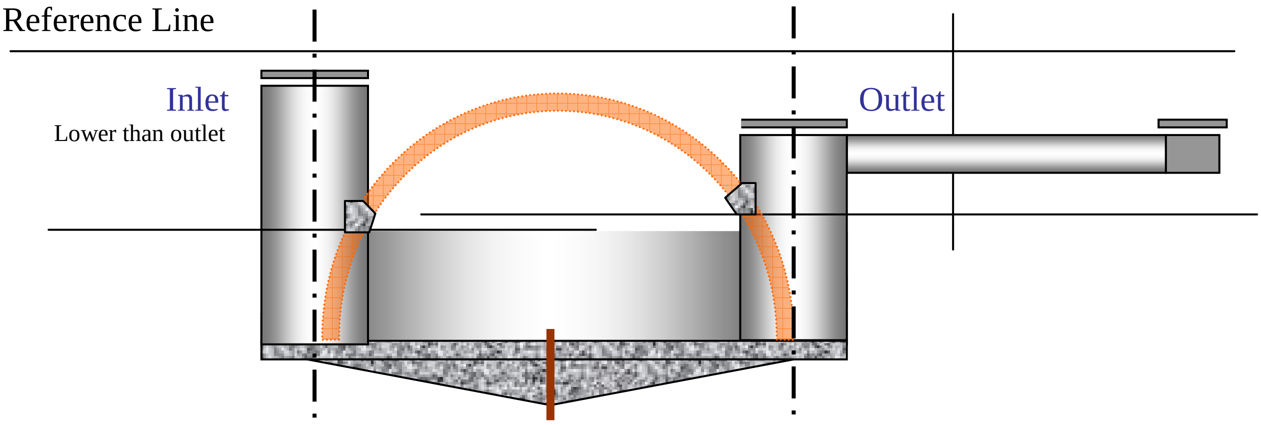


For the construction of a small digester 20 hooks of this shape have to be prepared. For large units 50 hooks should be in place.

A brick is used as a counterweight to keep the freshly placed brick in position. For a beginner it may be useful to use two hooks per brick until the small tricks of the technique are understood.

4.8 Lintels at Inlet and Outlet

When reaching the point where the cylinders from inlet and outlet separate from the hemisphere, a reinforcement bar in form of a lintel has to be placed. The lintels have a length of 50 cm and are reinforced by four bars of 8 mm steel, which are tight together. It is important that the lower part of the lintel at the **outlet** is exactly 200 cm below the reference line and that all steel is entirely covered with mortar to prevent corrosion. The inlet lintel has to be lower than the outlet one so that surplus gas escapes through the outlet rather than through the inlet. The Lintels are forming the foundation for the continuation of both, the cylindrical and the hemispherical building above the opening, which joins them. The ideal shape is a five angular beam. It can be pre-cast, but it may be easier to cast it in place as it also follows the arch shape of the hemisphere.

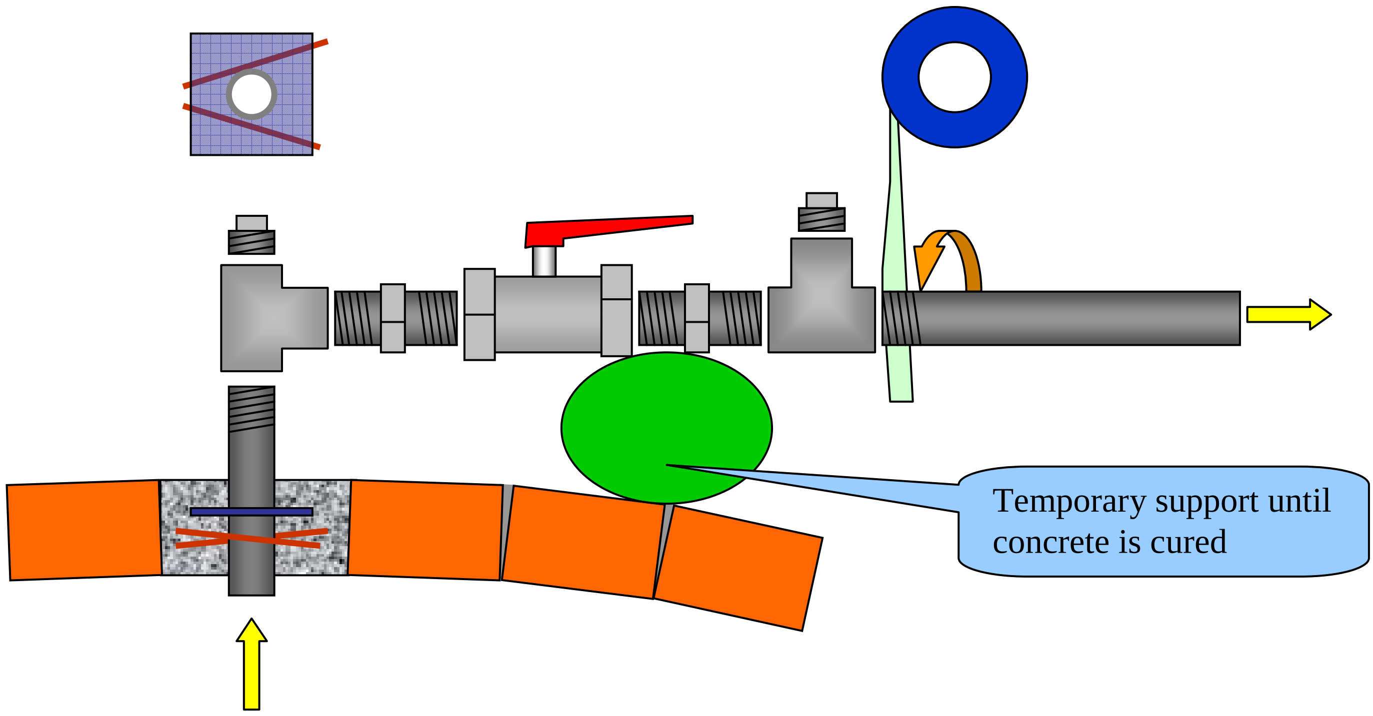


Five- angular reinforced lintels, bent by the radius of the hemisphere, 50 cm long.

Above the beam the hemisphere continues line after with the wire mesh reinforcement. Before it closes completely the gas outlet pipe has to be prepared.

4.9 Gas Outlet Pipe

All digesters will have a galvanized ¾" gas outlet pipe. For large digesters (digester volume of 80 m³ or more) with huge consumers, like community kitchens and engines operating at the same time, a 1" outlet pipe and main piping system should be installed. The gas outlet pipe is formed of a 20 cm piece of pipe to which a disc and some scrap pieces of iron bar are welded. The disk prevents gas escaping along the pipe wall and the iron bars act as an anchor and give additional strength to the pipe fixed in the brickwork. The outside section of the pipe is threaded and a t-joint is mounted on it. It is advisable to grease the thread in advance, to prevent corrosion. This piece of metal should last as long as the concrete structure of the digester, as replacing it is cumbersome. A number of standard fittings should already be mounted on the pipe so that when the piping system is placed stresses and forces as required for the establishment of a steel piping system are avoided on the fresh concrete work. Thus the gas outlet pipe is formed by *t-joint, main valve, and a second t-joint*. This set up is an advisable feature for later maintenance and monitoring of the system. Under normal operation the t-joints are closed with plugs. All threads are joint with seal tape, applied in approximately ten layers.



4.10 Inlet Building

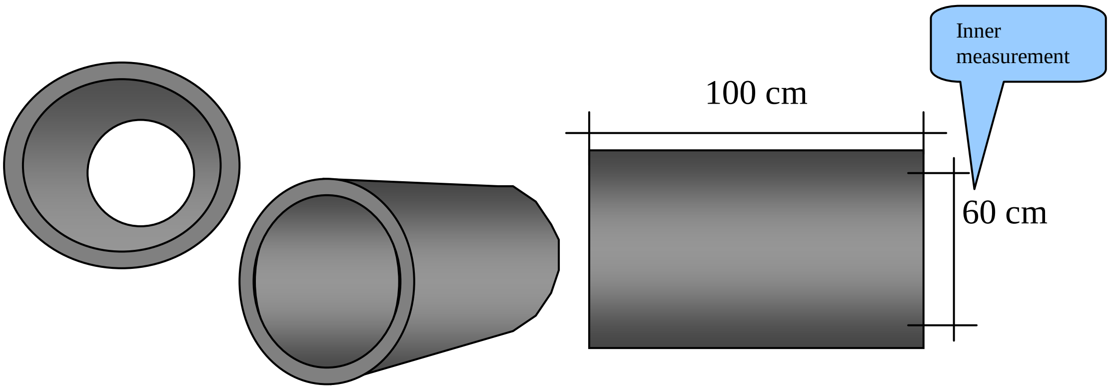
The inlet cylinder continues to a height, which allows convenient feeding. In case a wastewater stream can be guided into the digester, the level where it is entering has to be higher than the overflow point by at least 10 cm. The inlet pipe can as well be the receiving chamber for a dry toilet. In case vegetable waste or dung is arriving by wheelbarrow the inlet Pipe should receive this by tilting. In case the material entering is too dry and the inlet blocks, it should be possible to poke it with a stick. A lid must be provided to close the inlet opening.

4.11 Outlet Building

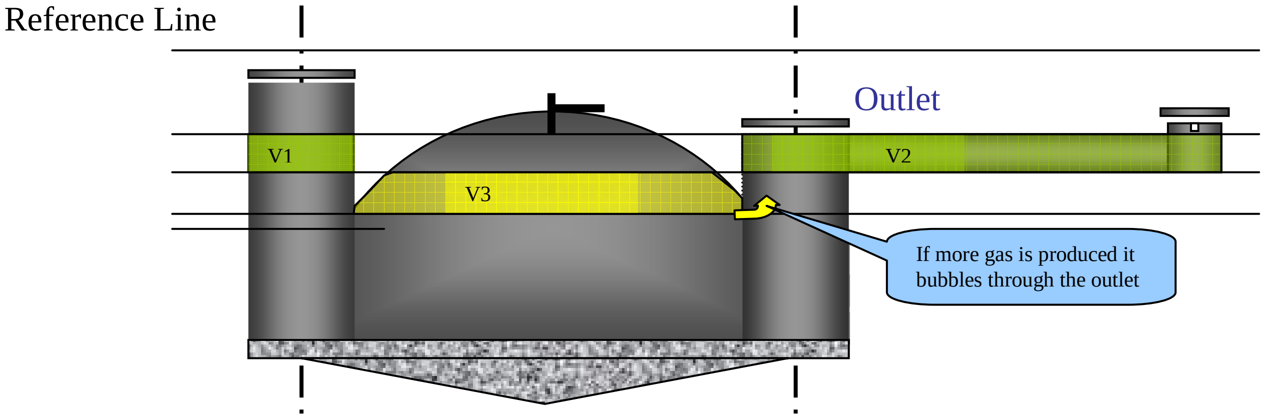
The outlet is at the same time manhole and the connecting pipe between the digester and the expansion canal. On a height of 150 cm a concrete pipes of 60 or more diameter pointing in the direction where the overflow should be joint to the outlet cylinder. The level 150 cm below the reference line is called 0-line. In case the digester had the maximum amount of gas stored and all gas is released, the liquid inside the digester rises and the liquid outside of the digester falls to this level. All brickwork receives the wire mesh as reinforcement, whereas the concrete pipe can stand without the wire mesh. Wherever the outside plaster is applied the soil can be backfilled and compacted evenly and carefully.

4.12 Expansion Canal

The expansion chamber acts as a *displacement tank*. When gas is produced, slurry pushed out of the digester. The displacement tank receives this material, stores it and will allow it to flow back into the digester when the gas is used. In this way the liquid replaces the gas. Therefore the gas storage mechanism taking place in a fixed dome plant does not require any mechanical or moving parts. The expansion chamber can be of any shape, but it has been realized that in the form of a canal it allows at the same time to send the overflow to any point of convenience. The longest expansion canal constructed was 36 m long). The slurry in the canal will not be deeper than 50 cm. That is the niveau on which it is acting to flow back in the digester. It is convenient for the construction to use horizontally placed concrete pipes of a diameter of 60 cm. Any larger size would be possible as well, but be unnecessary expensive. The different volumes of such pipes may be considerable but can be neglected.

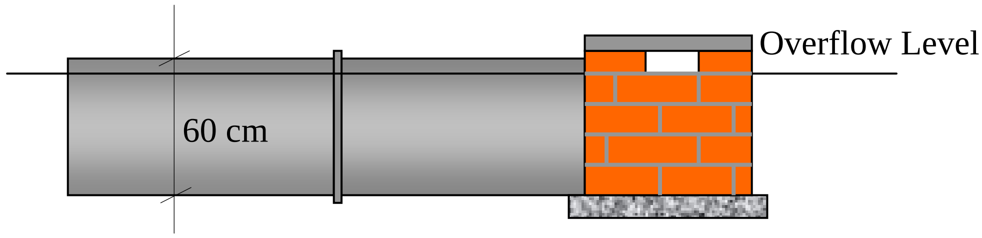


The concrete pipes added have to accommodate the equivalent amount of overflowing water or sludge as the gas storage capacity of the digester. The two volumes as indicated: V1+V2 in the inlet, outlet and expansion canal = V3 which is the volume between 0-line and lowest slurry level.



The level difference between lowest slurry level and 0-line is 50 cm. The height between 0-line and overflow point is as well 50 cm. Together they form the maximum pressure of the digester which equals to 100 cm water column (= 0.1 bar). Under this maximum pressure condition the gas presses with a strength of 1 ton per m² on the inside surface of the entire dome.

At the overflow point a small chamber of 60 cm width is added to the last pipe. It allows to take out digested liquid by bucket. It also deals as checkpoint. It should be equipped with a lid under which the precisely levelled overflow point (100 cm below the reference line)

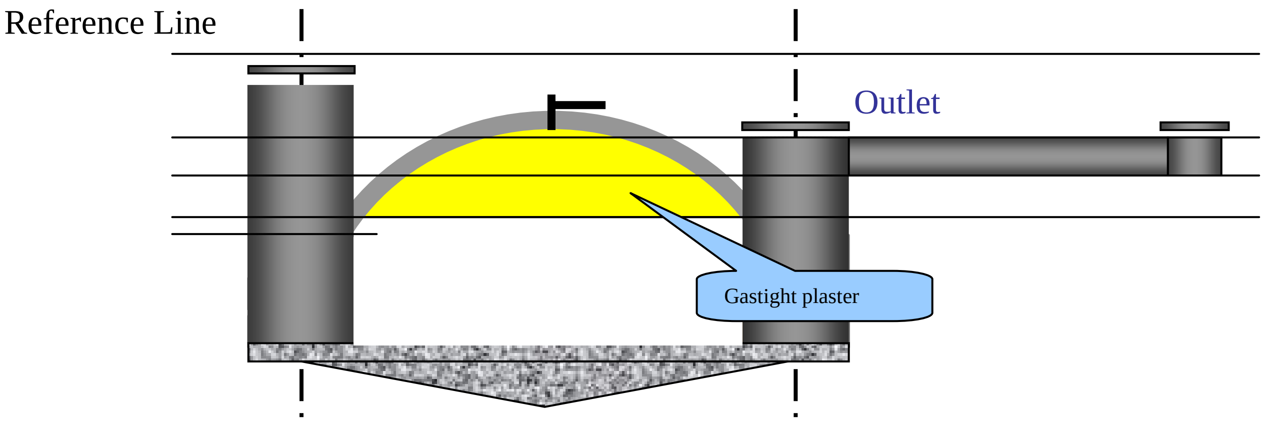


4.13 Inside Plaster of the Digester

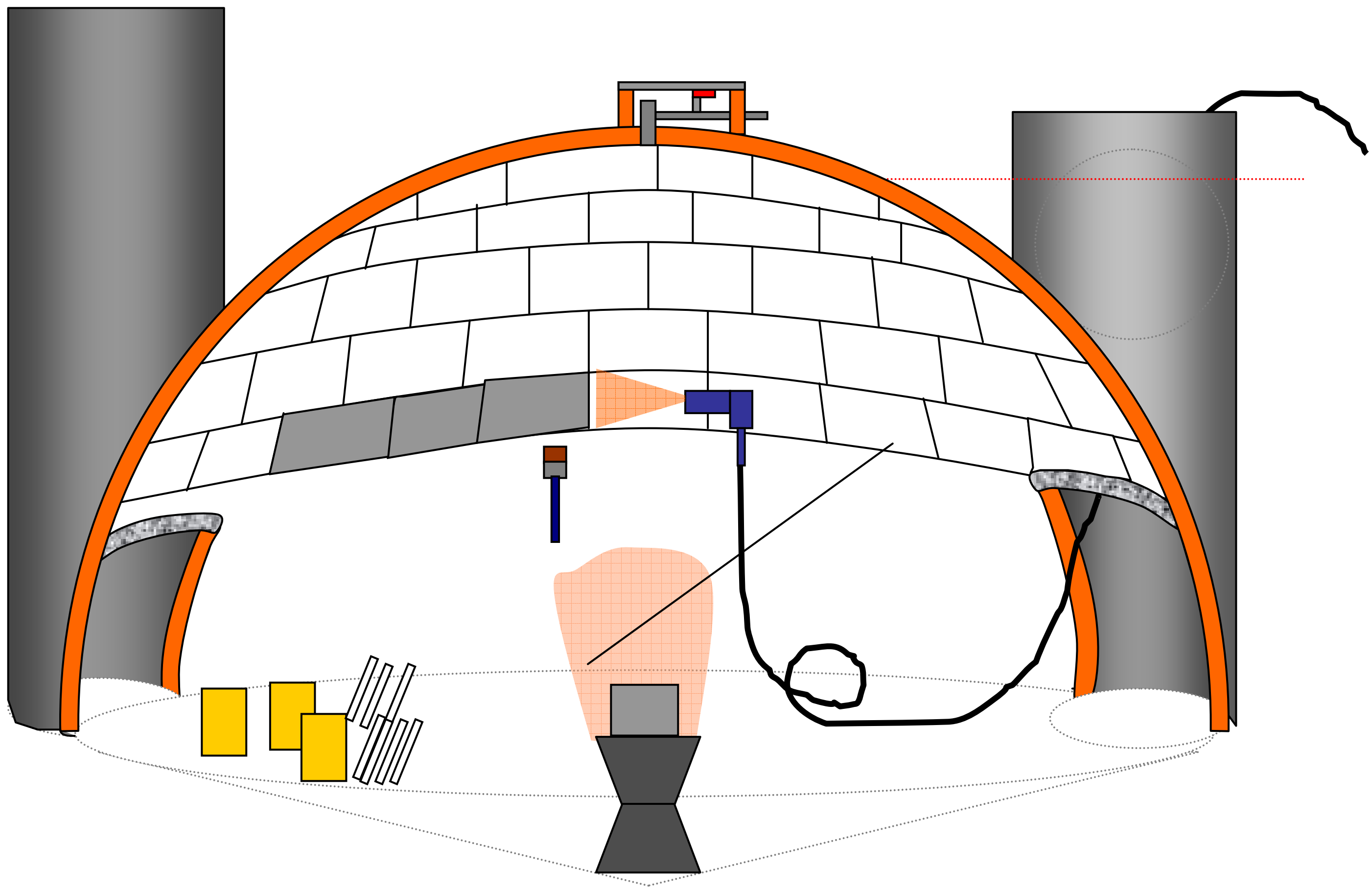
All parts of the building should be watertight, otherwise too much liquid can disappear (to the surrounding soil) and the expansion canal will lose its effect to store the liquid, which replaces the gas when it is used. Furthermore the bio-digester has the function to recycle wastewater for gardening. Therefore the liquid component is a valuable resource.

The entire building, except the pipes of the expansion canal, receives two plaster layers, a rough one to iron out uneven sections and a smooth plaster to establish a smooth surface. The mixture is *1cemnent /3 fine sieved sand*. The thickness is between 1 and 2 cm. Conventional trowels are not being use full to plaster the threedimensional inner curvature of the wall. A wooden trowel with smoothened corners can help to execute a smooth and even surface. All mortar, which splashes down, will used to seal the foundation.

The upper part of the dome has to be plastered gas tight. From the lowest point of the outlet lintel a horizontal charcoal line marks where the gas tight plaster starts. The previous plaster layer receives a brushing with cement water and another smooth layer of plaster. On top of this layer another layer of pure cement plaster is applied with a metal spatula with rounded corners. The outcome should be a plaster surface as even as glass. This surface needs at least ten days to cure, before the final oil/wax layer is put on. Knocking it to test that it is not hollow, before the next step, controls the plaster.



Three parts engine oil and one part candle wax are heated and mixed. In the digester the gastight part is marked with charcoal in sections of 10 * 20 cm. With the help of a *hot air blower* or a *blow torch* a marked section of the wall is heated until it is dry and the hot oil wax mixture is applied by a second person with a brush. It is required to take a charcoal burner down in the digester. The heated plaster will absorb the oil-wax mixture into its capillary and provide long-term gas tightness. This has to be done carefully with the entire surface, which is expected to be gastight.

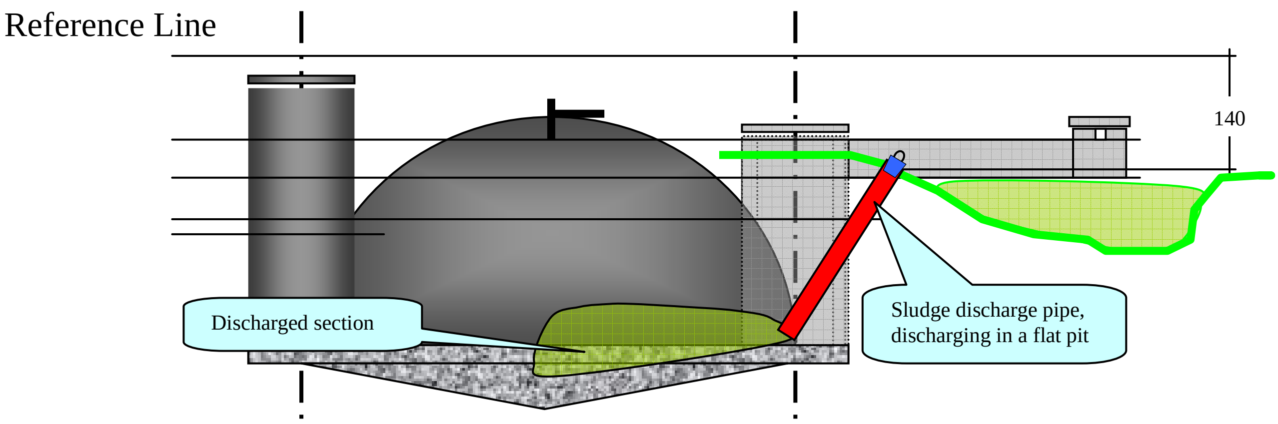


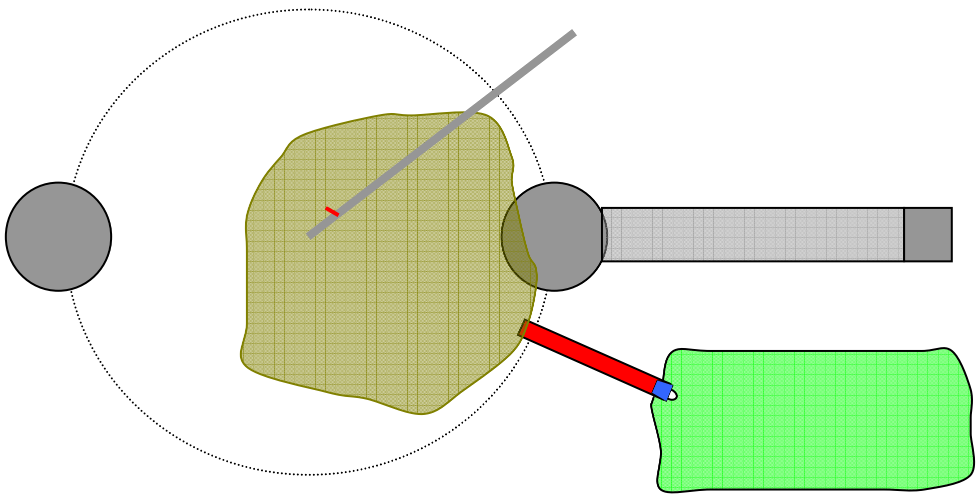
4.14 Sludge Outlet Pipe for Digesters above 30m³

Larger digesters can be equipped with a sludge outlet pipe which discharges once a year the sludge settling at the bottom of the digester. The pipe has a diameter of 15cm and enters near the main outlet into the digester at lowest level. The opening must be at a section of the premises 50cm lover than the main overflow point. If the location does not have such a position, it has to be created by earth movements. The sludge outlet pipe is generally blocked with a plug, which is only removed for sludge discharge and then fixed back in place. The discharge has do be done when the digester is under full pressure. Depending on the size of the digester several m³ sludge and water can be discharged. Most of the material is from the lower part of the digester. It can happen that the pipe has blocked over time and has to be poked free before it discharges.

The sludge being discharged mainly originates in the lower section of the digester, but the middle water layer is likely to be discharged as well.

The discharged sludge will dry and is used as fertilizer or on the compost heap.





4.15 Final touches

A small chamber with a stone or concrete lid protects the gas outlet pipe. Also the inlet, outlet and the overflow point need lids. They can be made from wood or reinforced concrete. If available cast iron manholes with the respective seats can be mounted as well.

4.16 Landscaping

Finally soil is backfilled around the digester and the expansion canal to give a pleasant shape. The surface soil should end at the lid of the gas outlet pipe. The main valve is not meant for daily opening and closing but for occasions when the piping system is maintained or changed. Therefore grass can grow over the lid. The shape of the soil on top of the digester should encourage surface runoff so that no unnecessary amounts of rainwater are surrounding the digester. The underground water has the side effect to cool the digester contend, which leads to less gas production. It has to be taken care that surface water cannot enter any of the openings (inlet, outlet, overflow point), as this could carry uncontrolled amounts of soil inside the digester. The entire building site can be used to develop a flower or vegetable garden.

The dug out soil has to be removed. It may be suited to form terraces or raise a stable floor, if this is necessary to achieve gravity feeding of dung and urine into the digester.

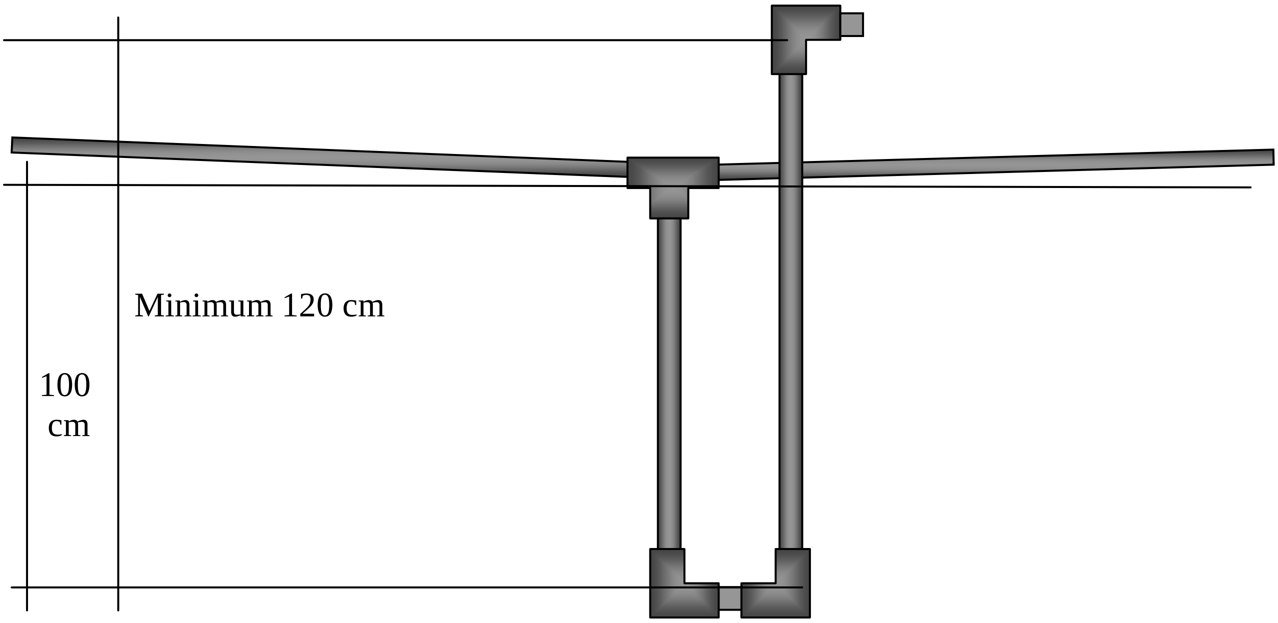
5. Piping System

The piping system is a crucial part of biogas technology. It has to be established with maximum care, otherwise negative reputation of the technology by smell or poor performance can be a hit back for a successful extension of the technology.

All outside piping is done in ¾” galvanized steel pipe. In case a 1” outlet pipe has been constructed the piping system can also be executed in 1”.

The piping system for biogas must always have a slope as the gas contains condensation water. In case the gas consumption points are higher than the digester the slope should guide condensation water back into the digester. In case a continual slope cannot be provided, the piping system should be equipped with a water trap. The most convenient way of executing a water trap is to establish a U-shaped pipe at a t-joint mounted at the (or each) lowest point of a piping system. The open side of the U is closed with a plug. The plug protrudes out of the ground. Under normal conditions there will be times when water gathers in the water trap (when the gas is warmer than the pipe. In other situation the gas will pick up water from the trap to reach saturation (when the pipe is warmer than the gas). It cannot be excluded that the pipe fills up with water completely and the t-joint blocks. In this case the plug has to be opened and the gas pressure provided by the digester will blow out some of the water. It is advisable to operate the digester with the plug in place, as otherwise it can happen that the water dries out faster than it is replaced.

The pipes are laid along buildings. Crossing areas with heavy traffic has to be avoided. Guiding a pipe under a farm road needs a protection pipe for the gas pipe.

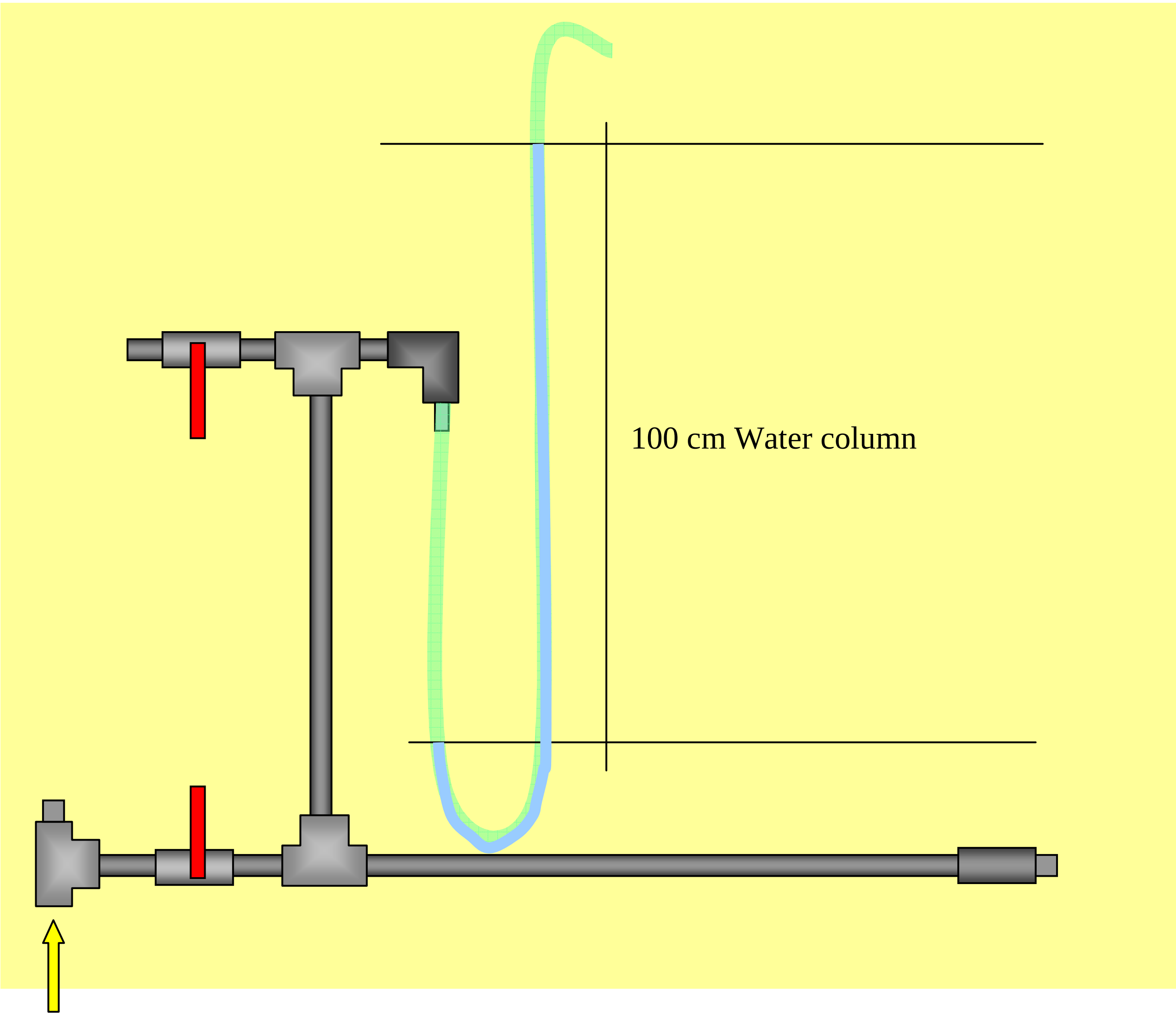


Each section of the piping system has to be pressure tested. For this purpose a *pressure test unit* has to be constructed. It consists of a mouthpiece to blow pressure in the piping system and a transparent plastic U pipe, which has two sides of more than 1 m length. The pipe is filled with water. The set-up is connected to the t-joint of the testing unit, which is at the piping system site of the main valve. All ends of the piping system are closed and air is blown into the mouthpiece until the water in the transparent hosepipe develops to a *level difference* of 1m. If this level difference remains constant, the piping system is tight. When the pressure drops, there is a leakage, which has to be detected first, before the work on the piping system continues. To detect a leakage requires brush and soap water. If soap water is reaching a leakage, a soap bubble is formed. This joint has to be redone. Leakages mainly occur at joints, unions and particularly where hosepipes are connected to the fixed piping system. Such weak points have to be avoided. In rare cases the leakage can also appear in the seam of a pipe.

When the pipes are installed the plumber has to blow through the pipe to detect blockages and to remove dust.

The piping system of a fixed dome digester can be easily several hundred m long. The pressure of the digester is enough to transport the gas required for normal cooking, such a distance. If much gas is required, as for the operation of an engine, a larger diameter, starting from the gas outlet pipe has to be chosen. On long distances it can most likely not be avoided that several water traps are installed. Each water trap has to be placed that it is out of the way, but clearly visible, for instance beside the wall of a building.

When reaching the house, where the gas will be used, the piping system can be reduced to ½”.



6. Loading

When the construction of the digester is completed it can be loaded with digestible material. For best performance the digester should initially be filled with cattle manure and water. If there is not enough manure conveniently available, the remaining volume can be filled with water. The correct filling is to the bottom of the expansion canal, with the gas valve being open. Than the valve is closed. The manure will settle at the bottom of the digester and after some days it will start producing gas and pressure is established. It is not likely that the first gas is burning, as air was trapped in the gastight part of the digester and the newly established biology mainly produces carbon dioxide ($C0_2$). After some days the methane (CH_4) concentration in the gas will naturally increase and when it is reaching 50%, the gas will start burning. After another few days it will reach its final quality of approximately 65% $CH_{4,}$ 34% $C0_2$ and 1%H_2S. During this time small amounts of the routine filling material can enter.

The start of the routine feeding depends on the feeding material. Manure and faeces can enter from the start in full quantity. In case garden waste, grass, straw, citrus waste is the digestion material, the bacteria in the digester have to get adapted to this feeding material. Therefore it is best to start with 1 bucket per day and increase to two to three buckets after a week. Water is excluded from these restrictions. In this start up phase it is necessary to observe the gas quality. In case the burning quality is going down (more $C0_2$ is produced), the feeding should be stopped for some days.

In a later stage, whenever the feeding material is unbalanced and new fodder is provided for the bacteria, it is necessary to give the new digestion material in small dosages first and increase it gradually (e.g. coffee husks during coffee harvest, rotten fruits, spoiled agro-industrial waste…).

7. Using the Gas

The gas can be used for cooking, lighting, operation of engines and gas refrigerators. In principle each accessory, which uses liquid or gaseous fuel, can be modified to operate on biogas. This booklet does not have the purpose to deal with other details than the successful construction of digesters. On the gas use side it is therefore limited to explain the modification of a gas stove.

A decisive part of a gas burner are the

- Jet or nozzle,
- Primary air intake
- Secondary air access of the flame to.
- Exhaust gas, which has to disappear from the flame without hindering the secondary air to reach the flame.

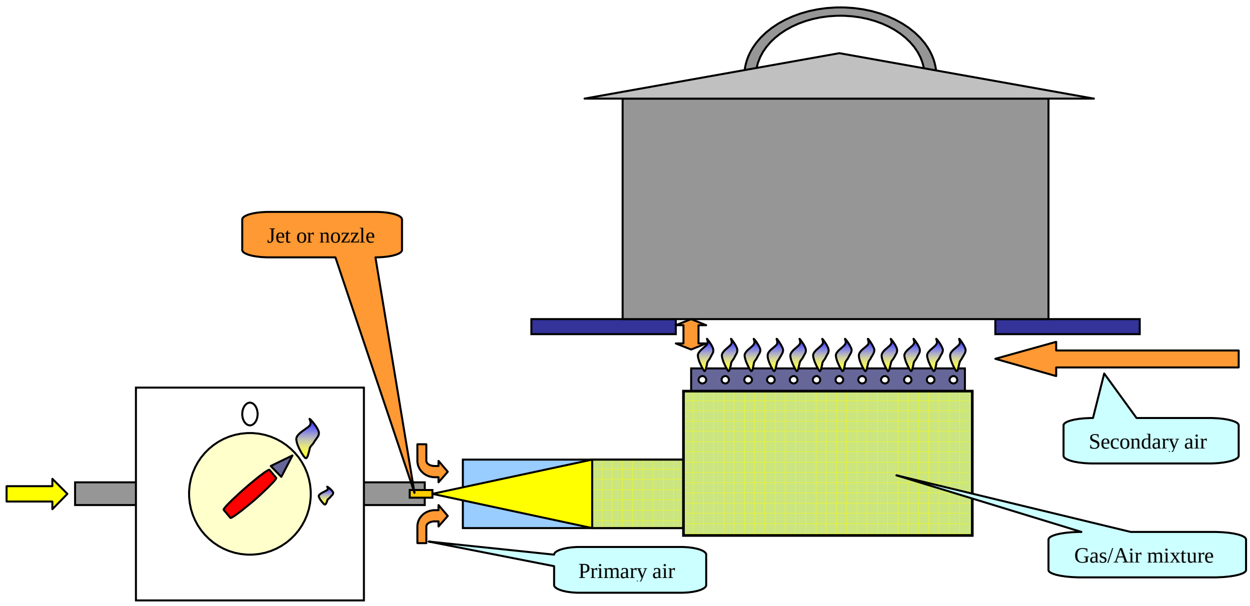
These are the four points to temper with, when a gas stove is to be modified to operate on biogas.
It is achieved that the flame can be adjusted comfortably to be stable and not too wind sensitive under the bottom of the pot. The highest adjustment of the stove knob should not lead to a flame, which licks around the pot and burns the plastic handles. A larger pot rest would have a larger jet drilling than a smaller one. The performance of the flame depends among others on the quality of the gas, the altitude of the location and the gas pressure in the digester. This means that the actual modification is a matter of trial and error.

The first step is to increase the diameter of the jet by drilling it. This should be done in small steps, starting with 1,2 mm, 1,3 … this depends on the size of the pot rest of the stove and the size of pots to be used. For larger stoves the jet can have up to 2.6 mm diameter size.

For the performance tests a pot filled with water has to be at hand. The flame burns better if a pot is sitting on the pot rest (or a bit above).

The next step is to close the primary gas, temporary. This can be done with a piece of aluminium foil. Some stoves also have an adjustable collar to increase or decrease the primary air. No primary air will lead to a large burning flame, which is not very hot (below 700°C). Under such conditions the exhaust gas has a slight smell, as the hydrogen sulphate (H_2S) component contained in the gas does not completely burn. Thus a small amount of primary air is required. Immediately the flame will be smaller, hotter and free of smell. Next the attention is drawn on the crown, which distributes the flame under the pot. An experiment, where the crown is lifted slightly with a knife, while the gas is burning, will show if the openings of the crown should be increased. If the performance of the flame is better (more calm), the crown openings have to be increased by drilling or filing. Finally we deal with the secondary air and the exhaust gas by lifting the pot a bit higher from the pot rest. The flame should continue to burn under all adjustments of the stoves gas valve, when the pot is off. If this cannot be achieved, it is necessary to go back to the primary air adjustment (the gas gets too much air). If necessary the distance under which the pot rests on the stove can probably be adjusted by bending or the application of washers. In most cases this is, however not necessary.

The sketch shows the different parameters on the flame. The example shows the ideal case, small blue flames, completely under the pot … best energy efficiency.



8. Digester Maintenance

The digester design proposed here does not consider the formation of scum or the necessity to check it or remove it. The high and huge designed outlet as well as the up and down movements in the digester regularly encourage small sections of the swimming layer to float out of the digester and accumulate in the expansion canal. They mainly accumulate at the manhole cover. Therefore this cover has to be opened from time to time. This depends on the amount of organic matter which dos not decompose easily entering the digester. These are wooden particles and straw. In case frequent blockage problems occur, after several years of operation, the swimming layer has to be removed by opening the outlet cover. A complete emptying of the digester would only be necessary if several m^3 soil, sand or stones have entered it and reduce the digester volume considerably.

9. Slurry Utilization

10. Dry Toilet Connection

11. Stable Connection

12. Root Treatment System

13. Table of Measurements

14. Technical Drawings

15. Material Lists