Reduction of GHG emission through Promotion of Commercial Biogas Plants

Experimenting digester design book

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UNITS AND ABBREVIATIONS

BTIC	Biogas Technology and Information Centre
GEF	Global Environment Facility
MoE	Ministry of Environment
MAFF	Ministry of Agriculture, Forestry and Fisheries
RUA	Royal University of Agriculture
CO_2	Carbon Dioxide
CH_4	Methane
H_2O	Water
H_2S	Hydrogen Sulphide
HRT	Hydraulic Retention Time
UASB	Upflow Anaerobic Sludge Blanket
"	inch (25.4mm)
h	hour
kg	kilogram
l	liter
m, cm, mm	meter, centimeter (0.01 m), milimeter (0.001m)
m^3	cubic meter

1 INTRODUCTION

The GEF funded project “Reduction of GHG emissions through promotion of commercial biogas plants” is aimed at demonstrating biogas projects, creating an enabling investment environment, improving human and institutional capacity for development, operation and maintenance of commercial biogas projects; and reducing GHG emissions. The project is implemented by UNIDO in close cooperation with the Ministry of Environment (MoE) and the Ministry of Agriculture, Forestry and Fisheries (MAFF) in Cambodia.

Part of the project is the establishment and support of a Biogas Technology and Information Centre (BTIC) that will be hosted by the Royal University of Agriculture (RUA), Cambodia. BTIC is to carry out a range of activities in the field of commercial biogas, during and after the GEF project. These activities include the dissemination of information on biogas and biogas equipment suppliers, providing technical support to (prospective) biogas plant owners, and applied research.

For the research component, BTIC has installed a small ($1m^3$) digester at its premises in Phnom Penh, Cambodia (see Figure 1). The digester can be used for a range of experiments, including testing the methane production potential of feedstocks, high-rate digestion of waste water, the treatment of biogas, and the performance of biogas utilisation equipment. This design book provides a step-by-step guide for the construction of this digester. In addition, it outlines the design for a slightly larger model of $5m^3$ that could be used for institutional biogas production.

Figure 1 Research digester installed at BTIC

2 DESIGN AND DIMENSIONING

2.1 Features

The experimenting digester established at BTIC premises was constructed for the purpose of carrying out a range of research experiments on biogas production and biogas treatment and utilisation. This research can be carried out for generic knowledge development, or as a means of supporting industrial or institutional clients active in the biogas sector in Cambodia. Experiments that are foreseen on the short and medium term include:

1. Biogas / biomethane production potential tests, i.e. determining the amount of biogas that can be produced from particular feedstocks such as animal dung, organic waste, or waste water.
2. Experiments with agitation (recirculation), i.e. determining the extent to which agitation of digester contents affects the capacity of a digester.
3. Experiments with high-rate digestion (UASB, anaerobic film), i.e. determining the suitability or sludge blanket or anaerobic film technology for treating waste water
4. Internal gas treatment (H_2S removal), i.e. determining the operational conditions for removing H_2S by air injection into gas storage
5. External gas treatment (H_2S removal, CO_2 removal, H_2O removal), i.e. testing the effectiveness of external biogas treatment techniques
6. Testing of gas utilisation equipment, i.e. determining the performance (power output , efficiency) of equipment such as stoves and small generators
7. Effluent management, i.e. determining the effectiveness of effluent separation techniques (e.g. sand bed filter)

Different types of digester have been considered (fixed dome, floating dome, batch, bag) and the type that seemed most appropriate is the floating dome digester. The floating dome is to be placed in a water seal around the digester. The features of this type of digester include:

- It can be constructed at appropriate scale (~1m^3)
- All the produced biogas can be captured, no rogue gas emissions from expansion chamber
- It is a continuous digester which can produce and store considerable quantities of biogas for experimentation
- An overhead space in the gas holder can be created to allow internal desulphurisation
- Gas pressure in the storage can be controlled
- It can be reconfigured to support high-rate digestion

A sketch of the floating dome is shown in Figure 2 below.

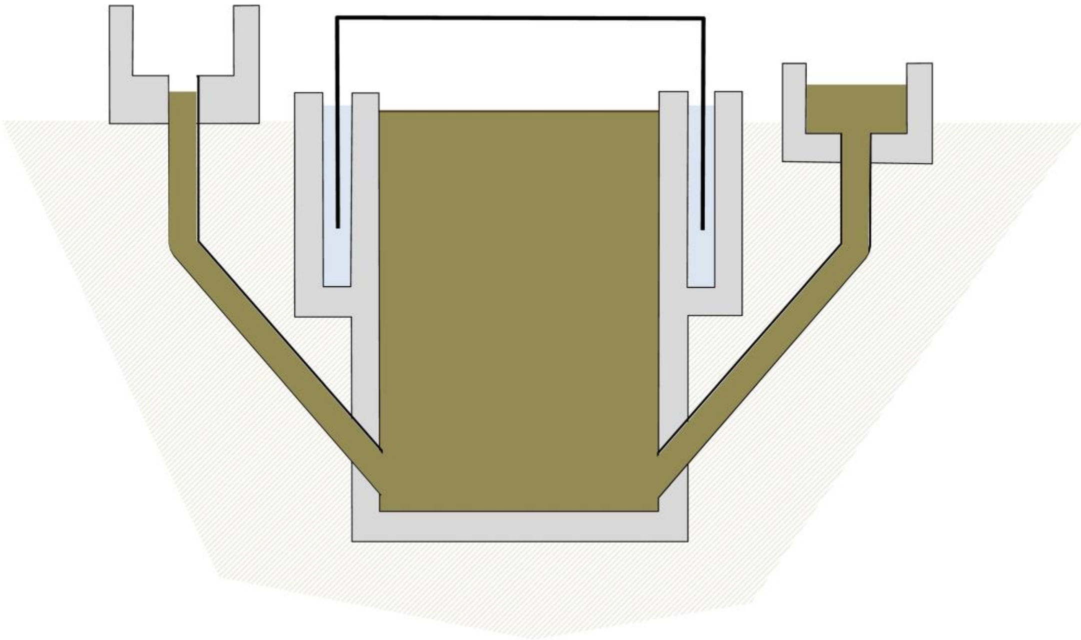

Figure 2 Sketch of floating dome system

2.2 Dimensioning

The capacity of the digester at BTIC has been set at 1m^3, with approx. 1m^3 of gas storage capacity in the gas holder. For the purpose of this manual, a larger model with a capacity of 5m^3 is also presented.

Basic design principles are the following:

- The digester structure and the surrounding water seal are constructed in brick and cement, with concrete foundations
- For the gas holder, a vertical polyethylene water tank has been used as this is gas tight, low weight, low maintenance, and easy to source on local markets.
- The gas holder will move up and down according to the quantity of gas in storage; the gas holder will be supported by guide posts and rollers.
- For the gas piping, PVC pipes will be used as these are low maintenance, low cost, and easy to install (leak-free)

Dimensioning depends to a large extent on the dimensions of the water tanks to be used for the gas holder.

- The gas holder needs to fit over the digester wall, with 2-3 cm of space between the wall and the gas holder to allow free movement of the gas holder. The internal radius of the digester is thus equal to the internal radius of the gas holder, minus the digester wall thickness, minus the distance between wall and the gas holder.
- The bricks to be used wave a width of approx. 8cm; the wall thickness (including plastering) will be approx. 11cm
- A minimum internal digester diameter of approx. 1m should be considered, for facilitating construction; this sets the minimum water tank diameter at approx. 1.3m

- The digester depth follows from the volume and the internal radius
- The gas storage volume should be approx. half of the digester volume. From this follows the height of the gas holder, i.e. the depth of the water seal around the digester.

Table 1 Digester dimensions

Designation	$1m^3$ unit	$5m^3$ unit		Remark
Digester volume	1	5	m^3	Basic design choice
Water tank type	2000LV	5000LV		http://h2o.com.kh/pages/19/339
Gas holder diameter	1.30	1.74	m	As per water tank specification
Digester wall thickness	0.11	0.11	m	Based on brick width of 8cm
Inner diameter digester	1.02	1.46	m	Follows from water tank diameter, wall thickness, space between wall and gas holder
Minimum depth	1.22	2.99	m	Follows from digester diameter and volume
Actual depth	1.40	3.10	m	Slightly more than minimum, to prevent overflowing
Water seal width	0.20	0.20	m	Minimum for construction
Outer diameter	1.86	2.30	m	Follows from digester diameter, wall thickness and water seal width
Min gas holder volume	0.50	2.50	m^3	50% of digester volume
Min gas holder height	0.38	1.05	m	Follows from gas holder diameter and volume
Actual gas holder height	0.70	1.05	m	Could be higher than minimum to allow more gas storage
Actual gas holder vol	0.93	2.50	m^3	Follows from diameter and actual height

For the inlet and outlet dimensions:

- The inlet volume should be minimum 1.5 times the daily feed volume, so that (optionally) mixing can be done in the inlet. At a minimum hydraulic retention time (HRT) of 50 days, daily feed volume would be 20l for the $1m^3$ system and 100l for the $5m^3$ system.
- Outlet volume is less important. Outlet should be big enough to allow easy removal of liquid effluent.

Table 2 Inlet and outlet dimensions

Designation	$1m^3$ unit	$5m^3$ unit		Remark
Daily feed volume	20	100	l	Follows from digester volume and 50d HRT
Min inlet volume	30	150	l	1.5 times daily feed volume
Inlet length / width	0.35	0.60	m	Design choice
Inlet depth	0.25	0.42	m	Follows from inlet volume, length and width
Outlet width	0.35	0.60	m	Equal to inlet
Outlet length	0.60	0.60	m	Design choice
Outlet depth	0.30	0.30	m	Design choice

3 DIGESTER CONSTRUCTION

3.1 Digester construction

3.1.1 Excavation and foundation

The digester should be installed into the ground, extending above ground to some extent: at least 20cm in order to avoid soil to enter the water lock and the outlet, but not more than 50cm in order to avoid the inlet to go too high.

- The depth of the excavation should thus equal the depth of the digester minus the height over ground level plus the thickness of the foundation (10cm).
- The diameter of the lower part should be the external diameter of the digester plus 10cm, allowing the foundation to extend 5 cm around the digester wall.
- The diameter of the higher part of the excavation should be the outer diameter plus 10cm, allowing the foundation of the water lock to extend 5 cm around the outer wall
- The depth of the higher part of the excavation should equal the height of the gas holder minus the height of the digester over ground level plus the thickness of the foundation (10cm).

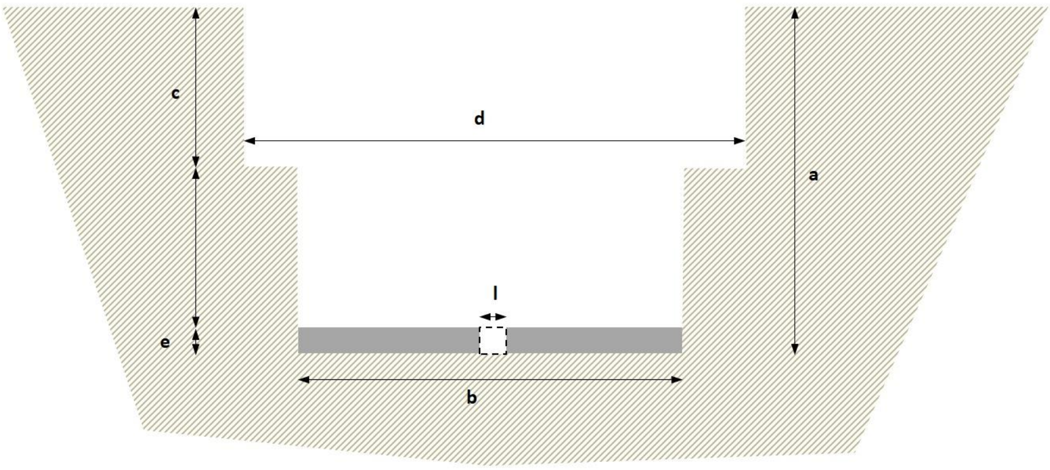

Figure 3 Sketch of excavation (1)

In addition to the main excavation, additional ground work should be done (see figures 3-5):

- For the digester in and outlet piping.
- For (optional) additional piping that could be used for sludge sampling at different heights.
- For the gas holder guide poles, to be placed outside the outer wall.

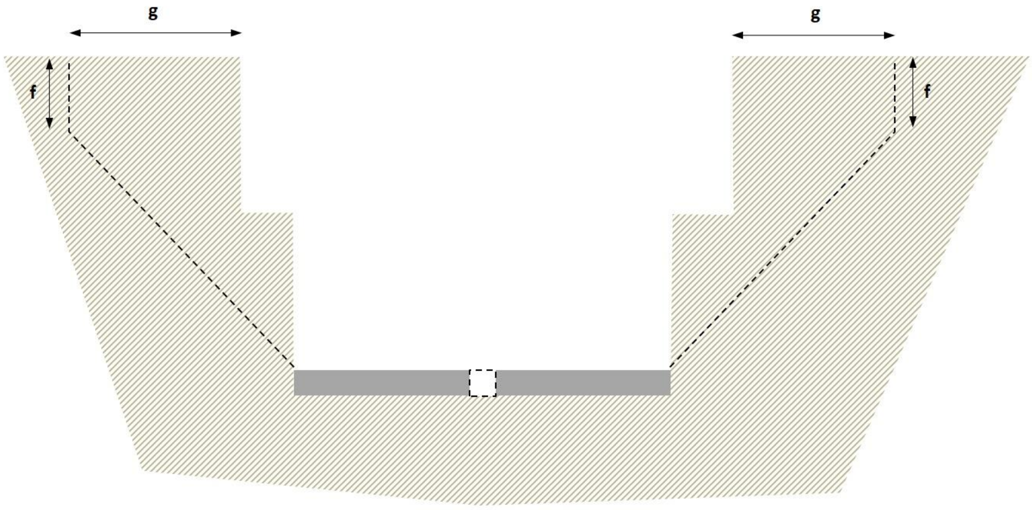

Figure 4 Sketch of excavation (2)

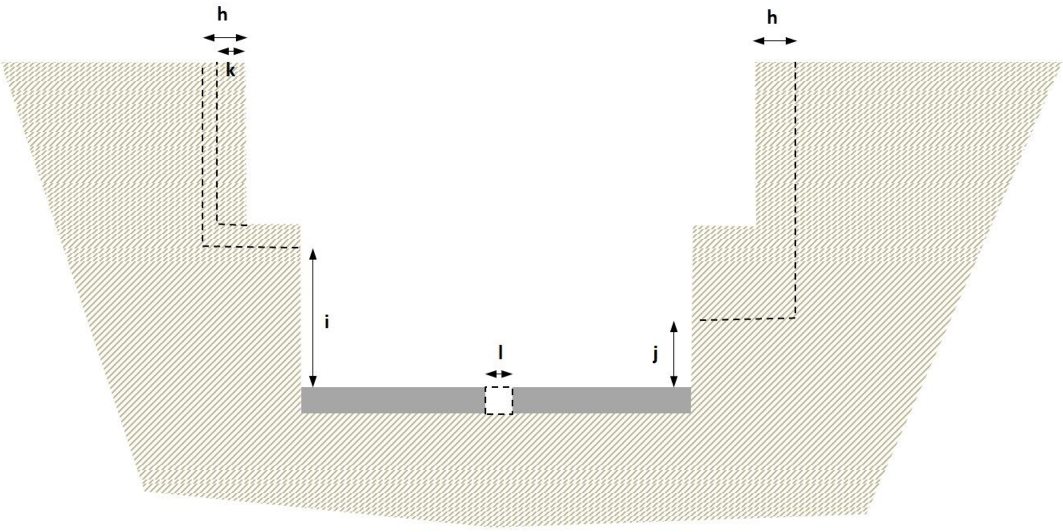

Figure 5 Sketch of excavation (3)

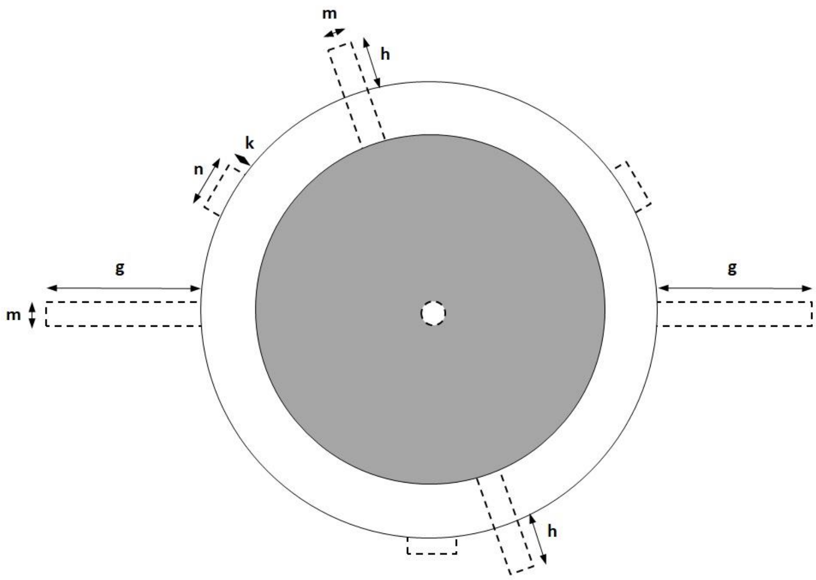

Figure 6 Sketch of excavation (4)

Table 3 Excavation dimensions

Designation	**1m³ unit**	**5m³ unit**		**Remark**
a	1.30	3.00	m	20cm above ground level, 10cm foundation added
b	1.40	1.84	m	Gas holder diameter +10cm
c	0.60	0.95	m	Gas holder height + foundation thickness – digester wall elevation above ground level
d	1.96	2.40	m	Inner digester wall diameter + 4xwall thickness + 2xwater seal width
e	0.10	0.10	m	Design choice
f	0.40	1.00	m	Design choice
g	0.52	1.62	m	Based on 45 degree slope and foundation border
h	0.30	0.30	m	Design choice
i	0.50	1.85	m	Based on depth (a) – (c) – (e) – PVC pipe diameter
j	0.25	0.92	m	Design choice (0.5 x i)
k	0.20	0.20	m	Design choice based on U-bar thickness
l	0.10	0.10	m	PVC pipe diameter
m	0.10	0.10	m	PVC pipe diameter
n	0.30	0.30	m	Design choice based on U-bar width

A foundation with a thickness of 10cm should be poured in the bottom. For small digesters, it can be unarmed concrete; for larger units, reinforcement bar should be included. In the middle of the foundation, a hole should be left out that can be used to mark the centre of the digester. In the hole, a pole can be placed to which the distance of the wall can be measured.

Before pouring the concrete, a sheet of plastic (0.2mm) should be placed on the soil, in order to prevent the concrete from losing water to the soil. After pouring, the concrete should be left to harden for at least 24 hours before continuing with construction works. During this period, the concrete should be kept moist.

Note that all concrete should be made using cement (42.5N), sand (fine or medium grain) and gravel (medium) in a ratio of 1 (50kg sack) : 2 (50l wheelbarrow) : 3 (50l wheelbarrow). The cement for masonry should be made using cement (42.5N) and sand (fine grain) in a ratio of 1 (50kg sack) : 3 (50l wheelbarrow). Cement for plastering should contain a compound for water tightening.

Figure 7 Excavation for a 1m^3 digester

Figure 8 First masonry and piping

3.1.2 Piping

PVC piping for inlet- and outlet should be prepared and put in place during the early stage of digester construction. Normal diameter is 100mm, of heavy duty quality. Straight (90°) elbows should be avoided as these are more prone to blockages. Instead, multiple 135° angle elbows should be used.

It is also important to assure that enlarged pipe endings are in place where needed:

- Inside the digester, the inlet pipe should have an enlarged end, so that that a modified feeding system for high-rate digestion can be installed at a later stage.
- Inside the digester, the outlet pipe have an enlarged end, so that that the pipe can be extended upwards with an elbow and a straight pipe.
- On the outside, the outlet pipe should end on an enlarged end, at the level of the outlet structure bottom, so that a height extension can be placed at a later stage.
- On the outside, the inlet pipe should end on an enlarged end, at the level of the inlet structure bottom, so that the pipe can be easily blocked during operation.

Optional piping for sludge sampling can be smaller, e.g. 75mm. Here also, straight (90°) elbows should be avoided.

All piping should be fixated in place after mounting, while the masonry cement hardens.

3.1.3 Masonry

After the foundation concrete has hardened, the masonry work can start. It is done in different phases, as shown in figures 8 through 12 below. Solid burned clay bricks of 3x8x17cm should be used for masonry, and cement according to the ration described above.

Throughout construction, a central pole is kept in place inside the digester; a steel bar is attached which can be used for placing the bricks at exactly the same distance.

1. Construction of the lower part of the digester inner wall (Figure 9). The masonry is to reach the height of the concrete foundation of the water seal. The different pipes are inserted in the wall during construction.
2. Pouring the foundation for the water seal. After the first masonry has been hardened, the space around it can be backfilled and levelled. Plastic sheeting is placed and a 10cm concrete ring is poured. The concrete should also extend into the 3 cavities where the guide poles are to be set (see points n and k in Figure 6 above).
3. After the concrete ring has hardened, the outer wall can be constructed (see Figure 11) up to the highest level of the digester wall. The precision of this wall is less critical but a spacer and the central pole should be used nevertheless. When the masonry is strong enough, the wall can be plastered, on the inside and the aboveground part of the outside.

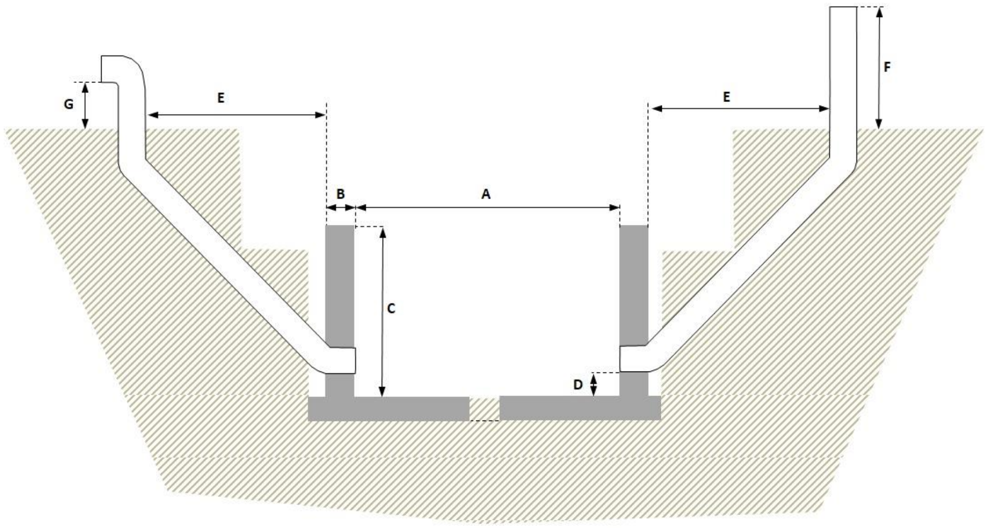

Figure 9 Masonry (1)

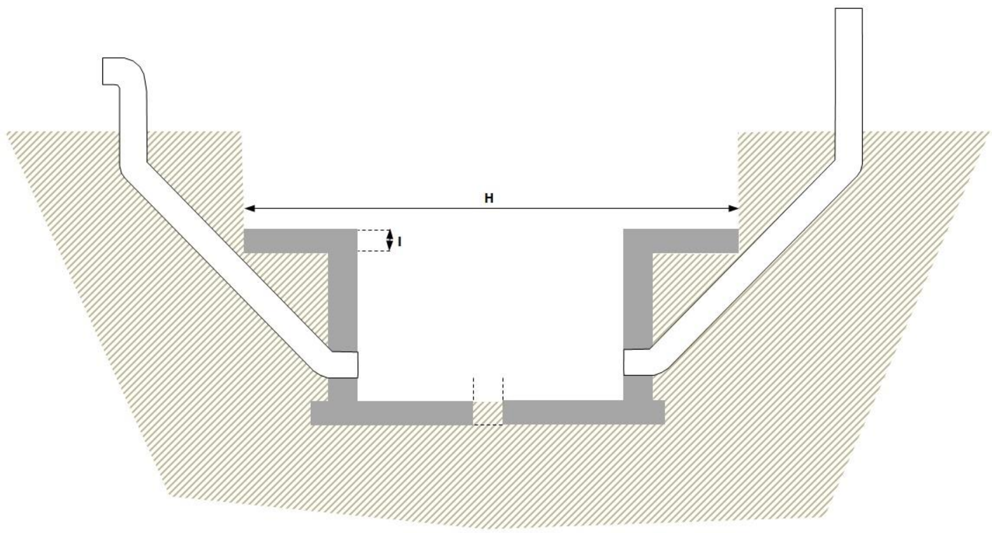

Figure 10 Masonry (2)

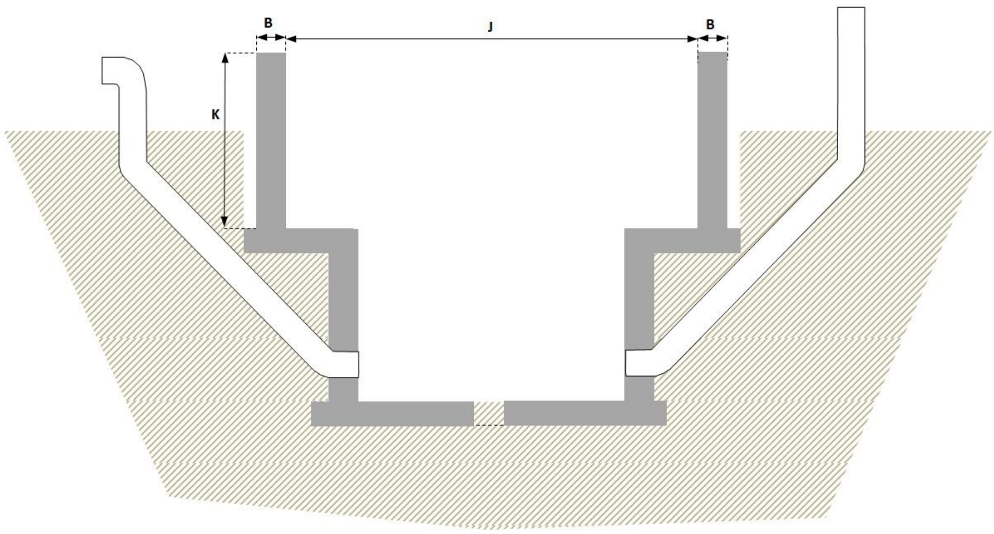

Figure 11 Masonry (3)

4. The next phase is completing the remainder of the inner wall, upto the final level (see Figure 12). Proper diameter and roundness are critical as the gas holder should be able to move freely over this part of the wall. Once it is strong enough, the inner wall can be plastered, on the inside and on the outside. Also, the space around the outer wall can be backfilled, although the casing for the guide pole concrete (see Figure 15) should be placed. The foundations for the inlet and outlet can then be dug and, after applying a layer of plastic, poured. Note that the outlet pipe should be at the same level as the foundation, with an enlarged end extending upwards.

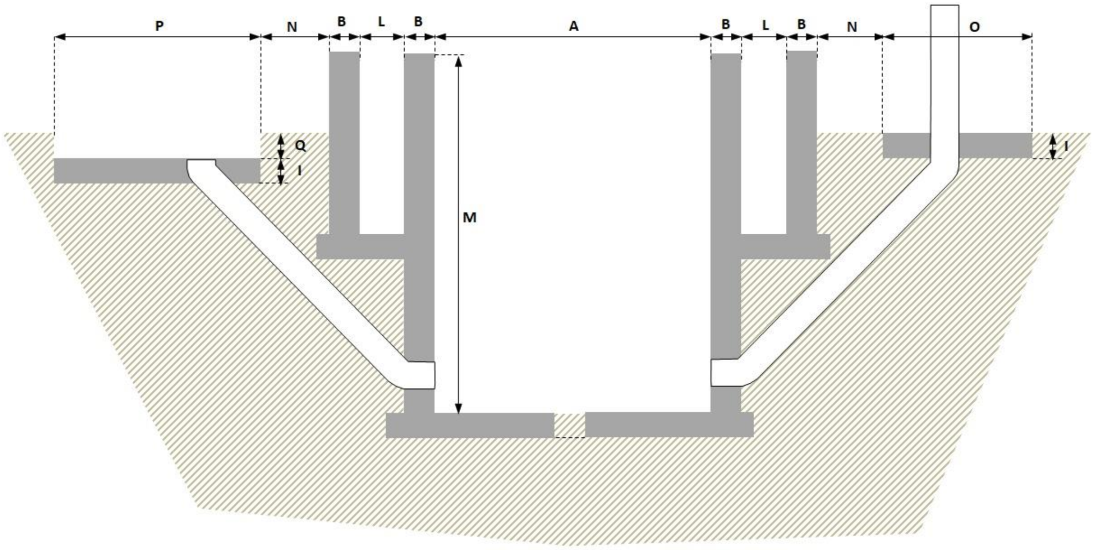

Figure 12 Masonry (4)

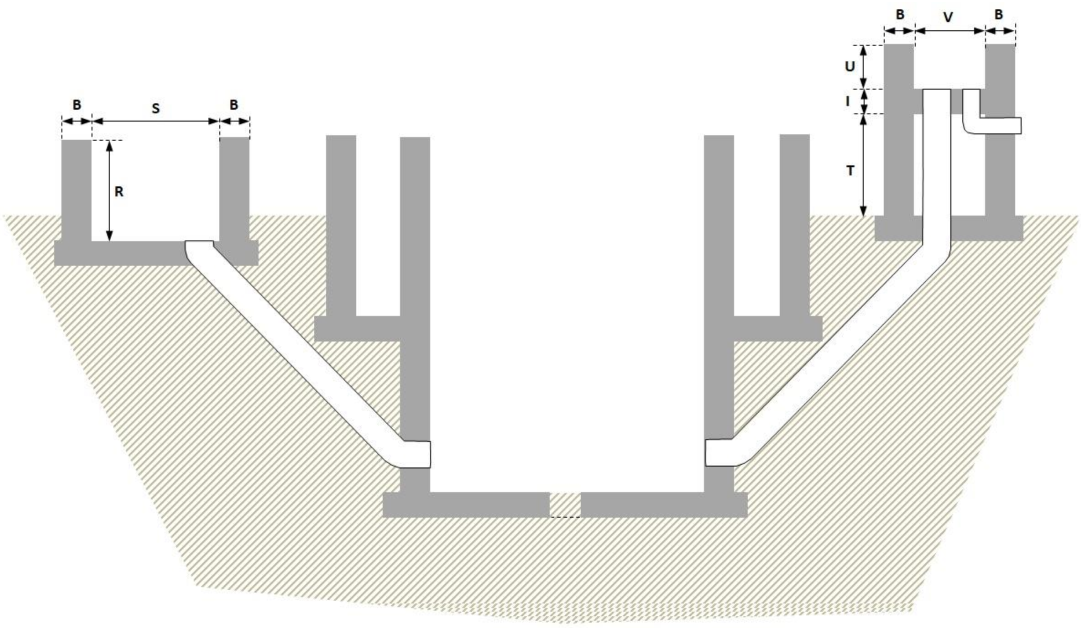

Figure 13 Masonry (5)

Figure 14 Pouring the foundation for water seal

Figure 15 Constructing the inner digester wall

5. The final step in the main digester construction is the finalisation of the inlet and outlet. The outlet should have the same height as the digester wall. The inlet should be higher, allowing the feedstock mix to enter through gravity. A second (smaller) pipe with an elbow should be placed inside the inlet, with an enlarged end extending upwards, that can be used for draining the inlet.

Table 4 Masonry dimensions

Designation	1m^3 unit	5m^3 unit		Remark
A	1.02	1.46	m	Inner digester diameter (table 1)
B	0.11	0.11	m	Digester wall thickness (table 1)
C	0.70	2.05	m	a – c – e (table 3)
D	0.10	0.10	m	Design choice
E	0.78	1.88	m	0.5xd + g – 0.5xA – PVC pipe diameter – B (tables 3, 4)
F	0.50	0.50	m	Digester wall level above ground level + 30cm
G	0.15	0.15	m	Digester wall level above ground level - 5cm
H	1.96	2.40	m	Outer diameter (table 1) + 10cm
I	0.10	0.10	m	Design choice
J	1.64	2.08	m	Outer diameter (table 1) - 2xWall thickness
K	0.70	1.05	m	Actual depth (table 1) - C
L	0.20	0.20	m	Water seal width (table 1)
M	1.40	3.10	m	Actual depth (table 1)
N	0.27	1.37	m	E – B – L – 20cm
O	0.67	0.92	m	Inlet length (table 2) + 2xwall thickness + 2x5cm
P	0.92	0.92	m	Outlet length (table 2) + 2xwall thickness + 2x5cm
Q	0.10	0.10	m	Design choice
R	0.30	0.30	m	Digester wall level above ground level + Q
S	0.60	0.60	m	Outlet length (table 2)
T	0.40	0.40	m	F – foundation thickness
U	0.25	0.42	m	Inlet depth (table 2)
V	0.35	0.60	m	Inlet length (table 2)

Finally, the hole in the centre of the digester foundations must be closed, with cement or concrete. Also, on the inside of the digester, the outlet should be extended by a length of pipe that ends approx. 20cm under the foreseen filling level of the digester, in order to avoid feedstock to move from the inlet to the outlet in a few days. The pipe should be connected to the outlet pipe using an elbow, and be fixed to the inner wall of the digester with a steel brace (see Figure 16).

Figure 16 Outlet pipe extension

Figure 17 Work on guide poles

3.1.4 Gas holder guide poles

In order to prevent the gasholder from toppling over, it will be guided by rollers and guide poles. The steel guide poles are made of 50mm U-profile steel bar. They will be set in concrete just outside the digester outer wall, at exactly the same distance from each other. They will extend to a height of at least the gas holder height, and be interconnected by steel angle bar.

The guide poles should be installed as follows:

1. Before backfilling the space outside the digester outer wall, place concrete casing, from the concrete ring to the top of the digester wall. Dimensions should be 20x20cm.
2. Prepare 3 lengths of U-profile steel bar. Weld 15 cm cross bars on the bottom part, in order to reinforce the concrete in which the guides will be set. Drill 10mm holes in the top and to fix the interconnecting L-profile steel bar.
3. Place the 3 guide poles in the concrete casing, making sure that the distance to the outer wall is the same. The poles should rest on the concrete at the bottom.
4. Adjust the position of the poles such that they are absolutely level (vertically). Keep verifying the distance between the poles, both below and on top, and adjust if required. If all three poles are vertical and at equal distance, fixate them.
5. Prepare concrete and pour into the casing. Directly after pouring, verify the position of each pole and adjust if needed. Let the concrete set.

Table 5 Top view dimensions

Designation	Value	Value	Unit	Remark
i	1.70	2.08	m	To be verified by measuring
ii	0.20	0.20	m	Design choice based on U-bar width
iii	0.32	1.42	m	N (table 4) + 5cm
iv	0.35	0.60	m	Inlet width (table 2)
v	0.57	0.82	m	iv + 2xwall thickness
vi	0.57	0.82	m	v
vii	0.82	0.82	m	Outlet length (table 2)
viii	0.28	0.28	m	h (table 3) – pipe diameter (ix) + 5cm
ix	0.07	0.07	m	Pipe diameter
x	0.90	1.25	m	Actual gas holder height (table 1) + 20cm
xi	0.70	1.05	m	Outer wall height K (table 4)

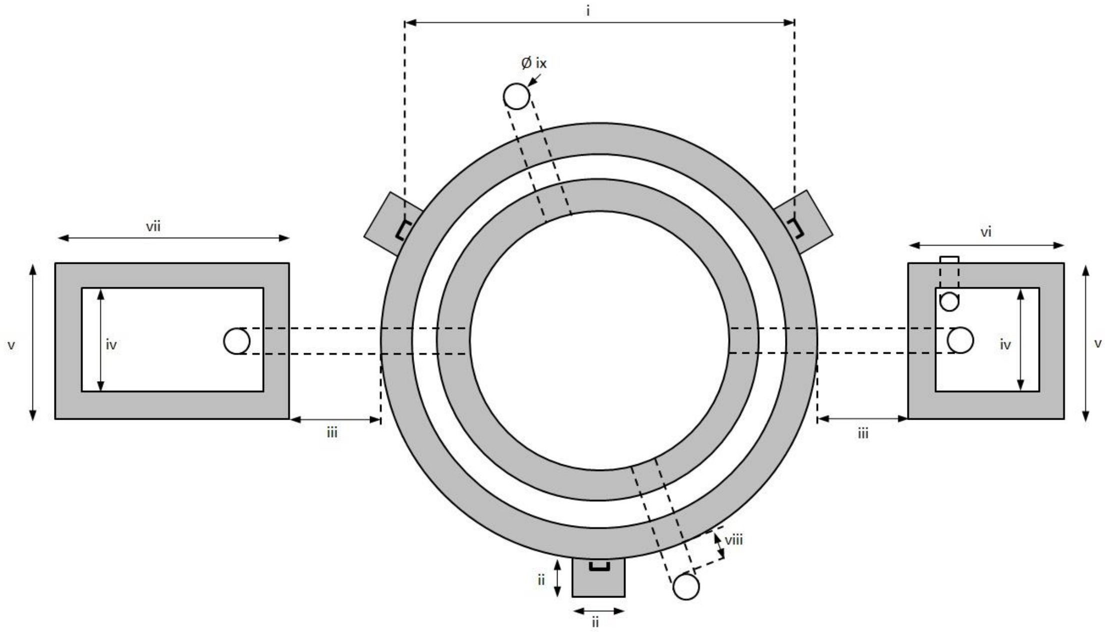

Figure 18 Top view with poles

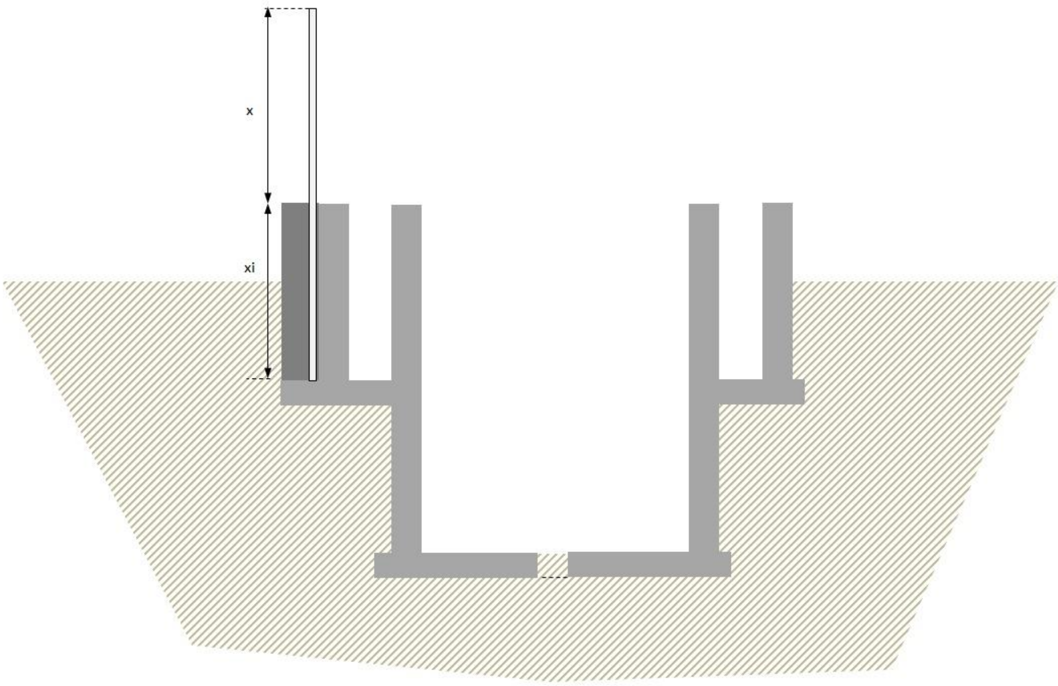

Figure 19 Guide Pole

After the concrete has set, measure the distance between the guide poles at the top end. Prepare angle bars with 60° bends and 10mm holes for mounting at both ends (see Figure 20 and Figure 21). Fix the bars to the guide poles using 10mm bolts and nuts.

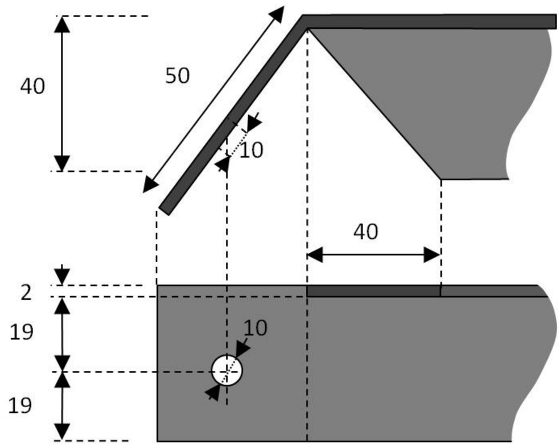

Figure 20 End of angle bars connecting the guide poles

3.2 Gas holder

3.2.1 Cutting

The water tanks used as gas holder will need to be cut to the right height in order to fit the digester (see Table 1 for actual heights). The bottom of the tank will be the top of the gas holder so the top of the tank will need to be cut off. The cut should be made at a height of approx. 10cm above the height indicated in Table 1 (i.e. 0.80m and 1.15m for the small and the large unit, respectively).

The cut needs to be straight, so it is recommended either to follow a ridge around the tank, or to mark the cutting line with a marker. The actual cutting can be done with a disc grinder or a saw.

Figure 21 Angle bars connecting gas holder guides

Figure 22 Gas holder in place

3.2.2 Gas connection

Water tanks tend to have threaded connections at the bottom, and it is recommended to use those for making the gas connection. In case there is more than one connection, it is recommended to use the thread with the diameter closest to the gas piping used, typically between ¾” and 1½”. An elbow should be fitted in the threaded hole (using teflon tape), followed by a valve and an extending piece of pipe (2-3cm) over which a flexible hose can be placed. The flexible hose should be fastened with a metal hose clamp.

Any additional holes in the gas holder should be plugged with an end plug and teflon tape. Check the extent to which the thread extends on the inside of the tank; if this is too much (more than 2 cm) it could cause the tank to hit the digester wall at this point. The extended part should then be sawn off on the inside.

Note that all threaded connections should be made with teflon tape to ensure gas tightness (at least 10 turns, clockwise); non-threaded connections should either be glued with sufficient glue, or made with special connectors with rubber seals.

3.2.3 Guiding rollers and supports

The gas holder will move up and down during operation, and its movements will be guided by rollers that fit into the guide poles (see Figure 23). The rollers are mounted onto a steel band attached to the top of the gas holder.

To prepare the steel band to which the rollers are mounted, follow the following procedure:

- Measure the exact outside circumference of the gas holder on the bottom side.
- Cut 40mm steel band at the measured length (-/- 5cm).
- Drill 10mm holes at both ends, at 15mm from the end. Then bend the last 3cm at an angle of 90°.
- Bend the steel band to a perfect circle using a roller machine.
- Place the band over the top of the gas holder and connect the ends with a 10mm bolt and nut. The bolt should be just at the level of the gas connection. Tighten well.

Put the gas holder over the inner digester wall. Position it such that the distance between the gas holder and the guide poles is equal at all three points, and note the distance. Then prepare the three rollers (see Figure 24). Note that measures depend largely on the size of wheels that can be found on the market, and the distance between gas holder and the guide poles. For wheels it is recommended to choose hard plastic with steel bearings. Their width and diameter should allow them to move freely in the guide pole.

Once the rollers have been prepared, they should be fitted between the gas holder and the guide poles. There should be no more than 2mm of space between the roller and the guide pole; if there is more, a spacer should be placed between the roller suspension and the gas holder band. If there is too little space, some steel should be removed using a disc grinder. If all rollers and their suspension fit, they should be welded to the steel bands. It is recommended to slightly weld them while the gas holder is in place; immediately cool the steel after welding, in order to avoid the plastic of the gas holder to melt. When all three rollers are in place, carefully remove the steel band with the rollers from the gas holder, and reinforce the welding. After this, the suspensions should be painted and the band with rollers can be placed back.

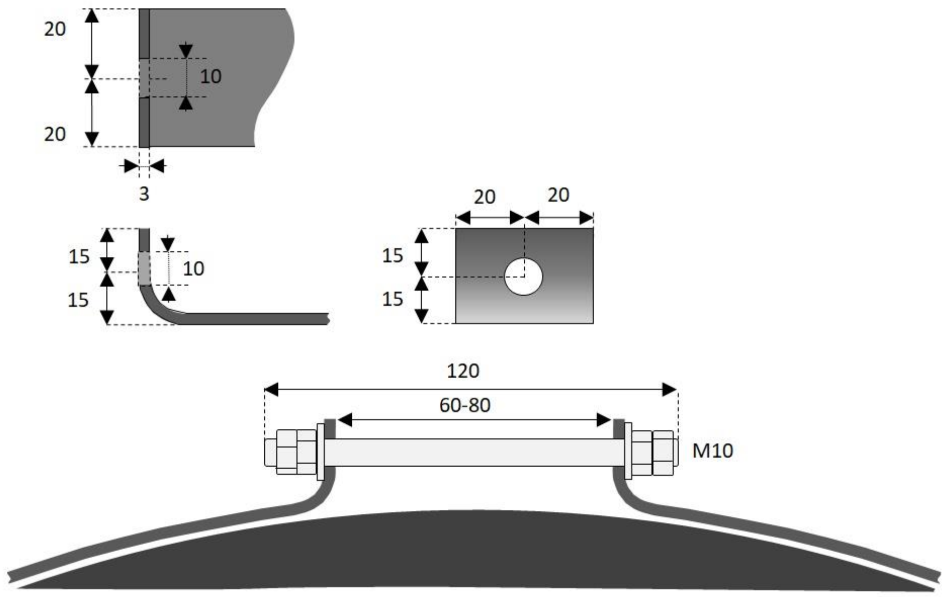

Figure 23 Steel band around the gas holder

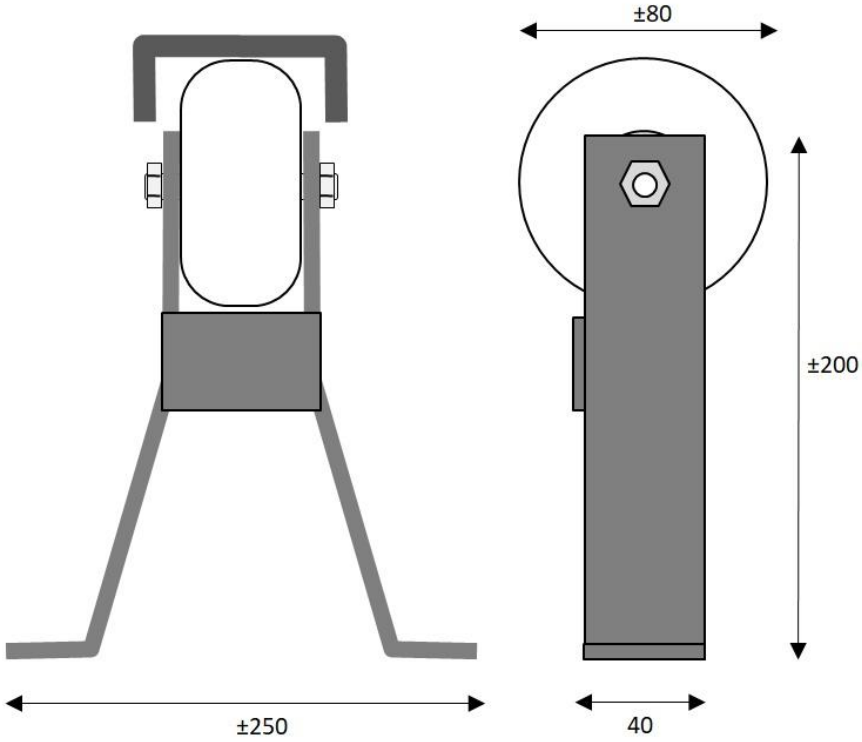

Figure 24 Roller and suspension

Optionally, a steel reinforcement band could be mounted on the bottom (open) side of the gas holder, in order to assure a round shape that will freely move over the digester wall. It should be made of 40mm steel band, and attached on the outside of the gas holder with screws.

- Measure the exact outside circumference of the gas holder on the bottom side.
- Cut 40mm steel band at the measured length and drill 10 holes (5mm) at equal distances.
- Bend the steel band to a perfect circle using a roller machine, and weld the ends together.
- Paint the steel with anti-corrosion paint and place over the bottom end of the gas holder.

- Fasten the steel band to the gas holder with 10 self-tapping screws, avoiding puncturing the gas holder.

Once the gas holder is finished, the water seal (the 20cm space between the inner wall and outer wall) should be filled with water, to 10cm under the edge. The gas holder will float on top; by opening the valve on the gasholder it can be made to descend. Test the free movement of the gas holder once it is in place.

Figure 25 Roller and guide

Figure 26 Gas system

3.3 Gas system

3.3.1 Piping

The gas piping is made of PVC, which is durable, easy to install and low cost. Lengths of pipe can be sawn off with a metal saw, cleaned, roughened with sand paper, and glued together with PVC glue. For good gas-tight connections it is important to apply glue to both ends that need gluing together.

The required diameter of piping depends on foreseen gas flow, the length of the pipes, and the permissible pressure drop. Table 6 shows the minimum pipe diameter required to keep the pressure drop below 1mbar, as a function of gas flow and pipe length. In the case of the experimental digester, the maximum foreseen gas flow is 3m^3/h, and the pipe length is less than 10m. The chosen pipe diameter is ¾”.

Table 6 Minimum pipe diameter (in inches) for a maximum pressure drop of 1mbar

	Pipe length (m)		
Gas flow (m^3/h)	**10**	**20**	**30**
1.0	0.50	0.50	0.75
2.0	0.75	0.75	0.75
3.0	0.75	0.75	1.00
5.0	1.00	1.00	1.00
10.0	1.25	1.25	1.50

The piping system starts on the side of the digester. The first part is usually put underground, allowing the gas temperature to drop slightly so that some water vapour can condense. The pipe end extends above the ground to a height inbetween the highest and lowest point of the gas holder, and has an elbow connected to it pointing towards the gas connection point on the gas holder. The two points are connected by means of a flexible hose that fits tightly over the gas pipe; the length should be sufficient to allow free movement of the gas holder without the hose collapsing and blocking the gas flow. The hose should be fastened on both ends using, hose clamps.

3.3.2 Condense removal

The underground part of the gas pipe should be as long as possible and should slope slightly in the same direction as the gas flow (at least 1%, i.e. 1cm per m pipe) allowing all condense water to flow to one end. At this lowest point, a T piece should be placed, with one end facing downwards; this end should be fitted with a valve which can be opened from time to time to remove condense water. A small pit should be made with brickwork, allowing easy access to the dewatering valve.

Note that if the distance between the digester and the point of gas utilisation is long, multiple condense removal valve may need to be installed; otherwise the required pipe slope would result in the dewatering valve being installed too low for easy access. In this case, multiple lowest points would be created, each time with the T and valve being placed at the lowest point.

3.3.3 Measuring

Most experimental activities require measurements to be carried out; to this end, facilities for measuring are to be installed.

A ***gas counter*** is required for measuring gas volumes. The counter can be used for determining the daily gas production, or for measuring the consumption of a certain equipment that is being tested (e.g. a stove of an engine). For small biogas units, it is recommended to use mechanical diaphragm counters, which are low cost and relatively precise (typically <2% measurement error). Mind the following

- Counter size, indicated with the letter “G”. The size should be chosen such that the expect gas flow range (minimum and maximum) fall within the measuring range of the counter (see Table 7 below).
- Gas flow direction. Usually, the flow direction is indicated with an arrow on top of the counter; this direction must be respected.
- Counter position. The gas counter should be installed such that all produced gas is measured, i.e. before any gas venting or consumption point. It should be installed after the underground passage of gas, so that the internal formation of condensate is minimised. The counter should be shielded from rain.
- Mind the size and type of connections on the counter; most types require bronze adaptors for connecting to standard pipe thread.

Table 7 Gas counter capacities

Capacity indicator	Minimum flow (m^3/h)	Maximum flow (m^3/h)
G1.6	0.016	2.5
G2.5	0.025	4
G4	0.04	6
G6	0.06	10
G10	0.10	16
G16	0.16	25
G25	0.25	40
G40	0.40	65
G65	0.65	100
G100	1.00	160

A ***pressure gauge*** can be installed for measuring gas pressure, for use when experimenting with pressure variations when testing gas consuming equipment (stoves, engines). The pressure gauge can be a mechanical dial gauge, or a manometer made from a transparent U-shaped piece of hose filled with water (see Figure 27).

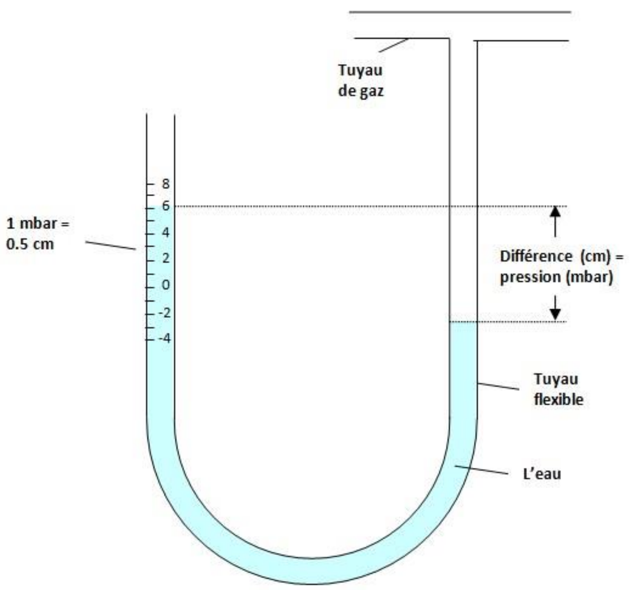

Figure 27 Manometer

Furthermore, it is advisable to create a ***gas sampling port***, a connection in the system from which gas samples can be taken for analysis. This sampling port could be a simple T piece with a valve and a hose pillar for connecting a gas analyser.

3.3.4 Testing

Once the gas system is in place, it should be tested for gas-tightness. This should be done before backfilling the underground pipe.

- A main gas valve should be placed on the far end of the gas pipe, after the measuring equipment. To this point, equipment to be tested with biogas can be connected.
- Close the valve between the gas holder and the flexible hose, and the valve underneath the condensate removal point.

- Pressurise the gas system by blowing hard into the far end of the gas system and closing the main valve.
- Wait for 2 minutes, then open the main valve. If there is still pressure, the gas system can be considered gas tight.
- If there is no pressure after 2 minutes, there is a leak that should be found and fixed. Pressurise the gas system and used a spray bottle to apply soap water to all joints in the gas system. The leak will cause bubbles. Re-attach the tubes at this point and test again.

4 STARTUP, OPERATION AND MAINTENANCE

4.1 General notices

The following general guidelines should be respected:

- It is strongly recommended to construct a fence around the biogas system.
- Access to the digester by unauthorised personnel should be restricted. Only staff and students appointed to attend the digester should be allowed access.
- The site around the digester should be well maintained and kept clean.
- Smoking near the digester or the gas system is strictly prohibited.

4.2 Digester startup

When the brickwork and the plastering of the digester and the inlet and outlet structures are well dried, the digester can be started up. For starting up, the following procedure should be followed:

- The initial charge should consist of a mixture of fresh cattle dung and water, in a mixture of 1:2 to 1:3 by volume. The dung should be as fresh as possible, not older than 1 week. It should originate from animals that are not under treatment with antibiotics.
- Dung and water should be well mixed, either in the inlet and outlet structures, or in an external basin. Once a batch is mixed, it should be left to rest for 2-3 minutes; any floating debris should be removed from the top. When putting the batch into the digester, one should avoid letting any sand and rocks from the bottom flow into the digester.
- Preferably, the digester should be filled to its normal capacity, i.e. the level at which the exit starts to overflow. The minimum feeding is that at which the fluid level is at the same height as the floor of the exit structure.
- The gas holder should be put at its lowest point by manipulating the valves.

The amount of dung required for starting a $1m^3$ digester is approx. 300kg, to be mixed with 700 litres of clean water. For a $5m^3$ digester, the required amount of dung is 1500kg, to be mixed with $3.5m^3$ of clean water.

Note that using digestate from a functional digester is not necessary. However, adding a small quantity will speed up the startup process.

Gas production normally starts after 4-5 weeks. At this time, the gas holder will start to float upwards. The first gas to be produced will be mainly CO_2. Once the gasholder is halfway up, the collected gas can be vented so that the gas holder reaches its lowest point. The gas that is produced after that is normal biogas, containing methane. With this gas, experimenting can begin. From this point onwards, regular daily feeding can commence.

Note that small leaks could cause the gas holder not to rise, as the needed pressure cannot be built up. In such a case, the gas in the overhead space under the gas holder will be biogas, which can be verified with a gas analyser.

4.3 Operation

Daily operation of the digester typically consist of the following steps:

- Visual verification of the digester and the gas system, checking for visible problems with the masonry, the gas holder or its guides. Any problems should be resolved as quickly as possible.
- Digester feeding should be done once per day, every day, at the same time. One should block the inlet pipe in the inlet basin, and put the entrants (feedstock and water) into the basin. After mixing, let the mix stand for 2 minutes, and remove any floating debris. Carefully unblock the pipe so that the mixture can enter the digester, making sure that any sediment (sand or rocks) remain in the bottom of the basin. Block the pipe and clean out the sediment.
- Check that there is some quantity of effluent flowing from the digester outlet.
- Make notes in the digester log book, noting any observations, quantity and type of entrants (feedstock and water), gas production, and any other measurements result.

4.4 Maintenance

Periodic maintenance activities for the digester are as follows:

- Weekly
  - Check all the valves in the system (open and close once).
  - Check free movement of the gas holder.
  - Check the water level in the gas holder water seal and fill if necessary.
- Monthly
  - Remove the gas counter and check if there is condense water inside.
  - Apply oil to the rollers of the gas holder guides.
- Annually
  - Apply fresh paint to the metallic parts.
  - Check gas system for gas tightness.
  - Replace flexible tubing.

4.5 Trouble shooting

<u>No gas output</u>

When there is no gas output (the gas holder does not rise, even when the gas valves are closed) it can mean that there is no gas production or that produced gas is leaking away.

- Note that digester start-up can take several weeks, but at average ambient temperatures above 25°C gas production should start before 5-6 weeks. It may be necessary to wait a bit longer.
- If after 6 weeks there is still no movement in the gas holder, it is possible that start-up was unsuccessful, e.g. due to contamination of dung or water by antibiotics or other inhibitors (e.g. heavy metals, salt, acids). First make sure that the problem is not caused by a leak (see below). Then empty the digester and flush out with clean water, and restart the procedure, making sure that no process inhibitors are present.

- If the digester start-up was successful but there is no movement in the gas holder, gas may be leaking out.
    - Verify the presence of biogas in the overhead space of the gasholder using a gas analyser. If there is biogas, the digester was started up correctly, but there is leak somewhere.
    - Alternatively, the gas hose could be disconnected from the gas holder and replaced by a large thin plastic bag. Even if there are leaks, the plastic bag should be filled with gas within the coarse of a day.
    - Separate the gas system from the gas holder with the valve on the gas holder, to check whether the leak may be in the gas system. If the gas holder then does rise, the leak is in the gas system. The valve on the gas holder should then be opened while 2-4 people move the gas holder upwards, so that the it fills with air. It should then be reconnected to the gas system and weighed down, so that there is some pressure insider the gas holder. All parts of the gas system must then be checked with soap water so that leaks can be spotted where bubbles arise.
    - If the gas holder still doesn't rise with the valve closed, gas could be leaking from other connections to the gas holder, or through the digester inner wall. The first possibility should be checked following the procedure described above, and connections should be checked with soap water. If no leaks are found, leaks through the digester inner wall should be verified by checking gas production with the plastic bag as described above. If there is gas production, the gas holder should be removed altogether, the digester should be emptied until the fluid levels are 30cm below the top of the inner digester wall. The wall should be cleaned thoroughly, dried, and the top of the wall should be painted with epoxy paint or other gas tightening agent.

Be very careful when allowing air to enter the gas holder, as an explosive mixture may be created! After the test, make sure to release the contents of the gas holder.

Inflammable gas

- In case biogas coming from the digester is inflammable, it is possible that its CO_2 level is too high. Note that this is commonly the case in the first stage of digester start-up. In this case, empty the gas holder and wait for it to fill up again. Usually the methane level will have increased.
- Low methane contents can also be caused by digester instability (see below).
- Alternatively, there might be a problem with the burner - too little or too much combustion air. Check the burner and adjust the air admission, if possible.

Digester acidification

Acidification of a digester is usually an indication of unbalance. It can have different causes, but most common are:

- Overfeeding of the digester, causing the build-up of acids surpassing the capacity to convert to methane. In this case, the feeding rate should be reduced.
- Presence of inhibitors (e.g. toxins, antibiotics, salts, ammonium) that inhibit the biological activity of the bacteria. Note that some feedstocks (e.g. high in nitrogen) can cause such inhibitions.
- Micro- and/or macronutrient deficiency, which can limit the biological growth / metabolic rate of bacteria.

- Temperature fluctuations can disturb the microbiology but is not very common in un-heated digesters constructed underground.

In most cases, an acidified digester will need to be emptied and restarted.

Annex A: Materials list

Designation	unit	Unit 1m^3	5m^3 unit
Bricks (3 x 7.5 x 17cm)	pcs	1582	3885
Cement	Bags @ 50kg	8	16
Sand	wheelbarrows	19	40
Gravel	wheelbarrows	13	19
Water tank type	pcs	2000LV	5000LV
Steel U bar 50mm	m	5.76	8.29
Steel L bar 40mm	m	6.11	7.48
Steel strip 40mm	m	7.60	9.26
Bolts M10 120mm	pcs	1	1
Bolts M10 30mm	pcs	3	3
Nuts M10	pcs	7	7
Washers M10	pcs	5	5
Paint	l	0.5	0.5
Rollers r=50mm w = 40mm	pcs	3	3
PVC pipe 100mm	m	6.2	13.4
PVC pipe 50mm	m	3.2	6.6
PVC elbow 135deg 100mm	pcs	4	4
PVC elbow 90deg 100mm	pcs	2	2
PVC elbow 135deg 50mm	pcs	6	6
PVC pipe ¾”	m	10	10
PVC elbow ¾”	pcs	10	10
PVC T ¾”	pcs	2	2
PVC valve ¾”	pcs	3	3
PVC glue	bottle	1	1
Sand paper	sheet	1	1
Flexible hose 20mm	m	4.1	5.5
Hose clamp 40mm	pcs	2	2
Gas meter G4	pcs	1	1