Biogas Plant Construction Manual

Fixed-dome Digester: 4 to 20 Cubic Meters

United States Forces – Afghanistan, Joint Engineer Directorate

Kabul, Afghanistan

April 2011

Forward

In July 2010 United States Forces Afghanistan (USFOR-A) were requested by General David H. Petraeus, Commander International Security and Assistance Force (COMISAF) to investigate the feasibility of biogas technology in Afghanistan. The leading purpose for the rural application of biogas is two-fold: alternative to burning manure and other organic material in the home, and returning nutrient-rich fertilizer to the land. Research show these attributes benefit human health and the environment. USFOR-A Joint Engineer Directorate worked closely with United States Agency for International Development (USAID), Islamic Republic of Afghanistan Ministry of Energy and Water – Renewable Energy Department (Director Amir Mohammad Alamzai), Ministry of Rural Rehabilitation and Development, and Ministry of Agriculture, Irrigation and Livestock to investigate existing biogas technology in Afghanistan, identify competent contractors designing and constructing biogas digesters, and identify facilities and institutions with the potential to incorporate biogas technology.

Director Alamzai provided USFOR-A contacts at the non-profit organization Agency for Rehabilitation & Energy Conservation in Afghanistan (AREA). AREA had demonstrated experience and knowledge in the design, construction and operation of biogas plants in several provinces of Afghanistan, specifically the fix-dome biogas digester made popular in Asia. USFOR-A contracted AREA to design, construct and operate an 8-cubic meter biogas plant at the Renewable Energy Department, Kabul in the winter and spring of 2010-2011. The biogas plant was completed in six weeks and fed dairy cow manure and water. The manual is based on both the Gobar biogas plant and the performance by AREA during the construction of the biogas plant in Kabul.

We sincerely appreciate the support and direction from General Petraeus, Major General Timothy McHale (USFOR-A Deputy Commander for Support), Brigadier General Buckler (Director JENG), Brigadier General Mark Yenter (Director JENG), Brigadier General Mark Martins (Rule of Law Field Force), Colonel Louis Dell'Orco, Lieutenant Colonels Dallas Olson, Butch Welch and Robert Tucker, PhD (JENG), Mr. Abdul Rasool Wardak and the folks with US Agency for International Development. We also appreciate the skill and work of Staff Sergeant Jeffrey Hart for turning rough sketches into professional Engineer designs and the financial process support of Captain Moses Wearing to ensure funding of this project through the Commander's Emergency Response Program. We learned much about the practical design and construction of the biogas plant from Engineer Khail Shah and Engineer Arif Ulla Azimi of AREA and have shared these lessons in this manual. We especially thank Director Alamzai for his support and leadership to guide and direct the project at his facility in Kabul and of course thank the citizens of the United States of America for granting us the resources to accomplish this and many other projects to improve the security and legitimacy of the Government of the Islamic Republic of Afghanistan.

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1. Introduction

A biogas plant is an anaerobic digester of organic material for the purposes of treating waste and concurrently generating biogas fuel. The treated waste is a nutrient-rich, nitrogen-rich fertilizer while the biogas is mostly methane gas with inert gases including carbon dioxide and nitrogen. Biogas plants are a preferred alternative to burning dried animal dung as a fuel and can be used for the treatment of human waste. Other feedstock which can be used includes plant material, non-meat or grease food-wastes, and most types of animal dung. Over a million biogas plants have been constructed in the developing world for treatment of organic wastes, alternative energy supply to direct burning in the home, and overall improvement of human health and the environment. Many factors for selection of feedstock and site location must be researched before deciding to install a biogas plant.

Successful construction of the biogas plant requires a proper design and adherence to follow correct construction methods. The success or failure of any biogas plant primarily depends upon the quality of construction work. The following instructions are based on the step-by-step instructions from the Government of Nepal Biogas Support Program Gobar Gas and Agricultural Equipment Development Company of Nepal has developed the design for model 2047 biogas plant. This biogas plant model has become prolific across Asia and is known as a fixed-dome plant. The advantages of the fixed dome plant include the simplicity of design, few moving parts, low cost to construct and low maintenance. The disadvantages when compared to a floating-dome digester are primarily the inability to store gas for use on demand; gas from the fixed dome digester must be used as generated or expelled to avoid damaging the digester.

2. Determining Plant Size

This manual includes design and construction material quantities for the Gobar biogas plant models of 4, 6, 8, 10, 15 and 20 cubic meters capacity. Design and size of a plant other than mentioned above is feasible and a skilled engineer should be consulted for deviations from the provided designs. The biogas plant size is dependent on the average daily feed stock and expected hydraulic retention time of the material in the biogas system. Generally, 24 kilograms of feedstock complimented with 24 liters of water per day with a hydraulic retention time of 35 days will require a 4-cubic meter plant. Table 2.1 below gives some relevant data about the six different sizes of biogas plants presented in this manual.

Table 2.1. Plant size and average daily feedstock.

Plant Size (m^3)	Daily Feedstock (kilogram)	Daily Water (liters)
4	24	24
6	36	36
8	48	48
10	60	60
15	90	90
20	120	120
Plant size is the sum of digester volumne and gas storage. Based on a hydraulic retention time of 35 days.		

The biogas plant detailed in this manual consists of five main structures or components: 1. Inlet Tank; 2. Digester Vessel; 3. Dome; 4. Outlet Chamber; and 5. Compost Pits. The required quantity of feedstock and water is mixed in the *inlet tank* and the slurry is discharged to the *digester vessel* for digestion. The gas produced through methanogenesis in the digester is collected in the *dome*. The digested slurry flows to the *outlet tank* through the manhole. The slurry then flows through the overflow opening in the outlet tank to the *compost pit*. The gas is supplied from the dome to the point of application through a pipeline.

Photo 2.1: Scale Model of 4 Cubic-Meter Biogas Plant for Training (Camp Nathan Smith, Kandahar, Afghanistan)

When a biogas plant is underfed the gas production will be low; in this case, the pressure of the gas might not be sufficient to fully displace the slurry in the outlet chamber. It is important to design the plant keeping hydrostatic pressure higher at the inlet tank than the outlet tank. The hydrostatic pressure from slurry in the inlet and outlet tanks will pressurize the biogas accumulated in the dome. If too much material is fed into the digester and the volume of gas is consumed, the slurry may enter the gas pipe and to the appliances.

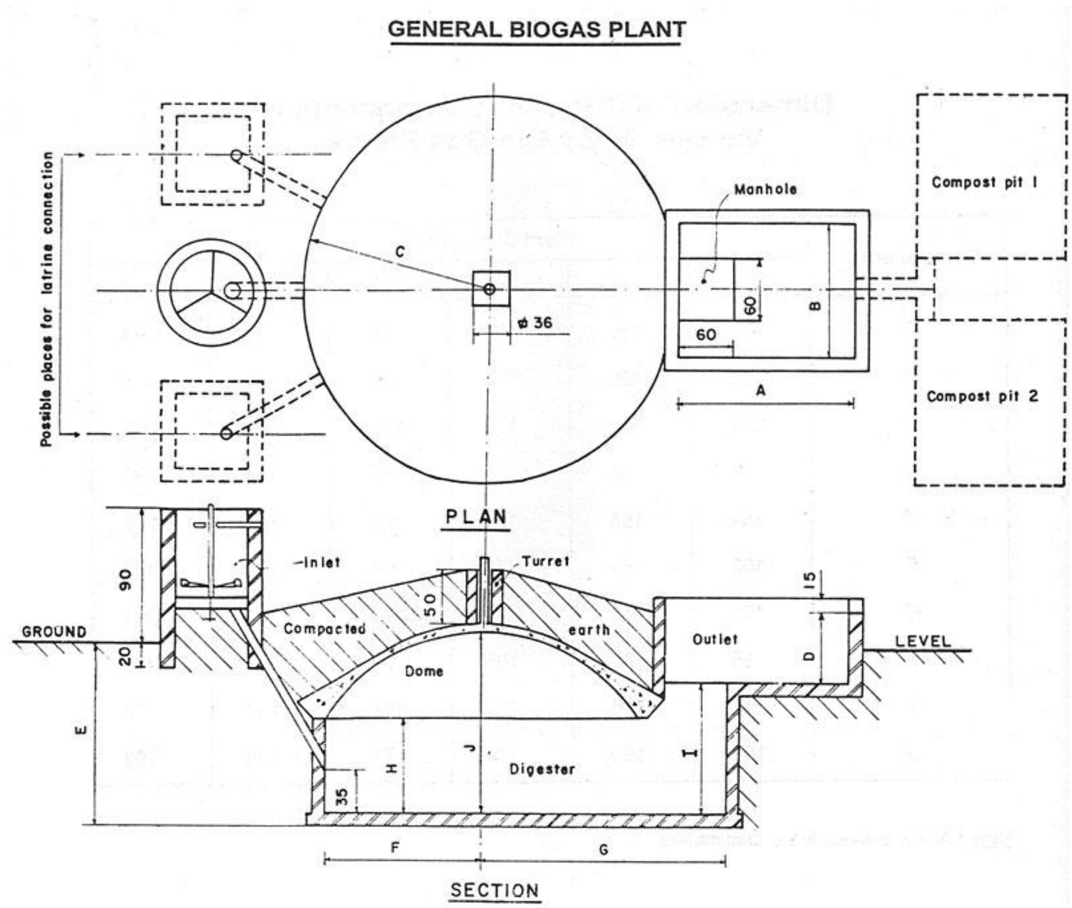

Figure 2.1: Gobar Biogas Plant Design

Components	Plant Size (m^3)					
	4	6	8	10	15	20
A	140	150	170	180	248	264
B	120	120	130	125	125	176
C	135	151	170	183	205	233
D	50	60	65	68	84	86
E	154	155	172	168	180	203
F	102	122	135	154	175	199
G	195	211	230	243	265	293
H	86	92	105	94	115	115
I	112	116	127	124	132	137
J	151	160	175	171	193	203

Note : All dimensions are in centimeters.

Table 2.2: Dimensions for the Various Plant Sizes from the Gobar Gas Design in Figure 2.1

3. Selection of Construction Materials

If the materials used in the plant construction such as cement, sand, aggregate etc. are not of good quality, the quality of the plant will be poor even if the design and workmanship are excellent. A brief description regarding the specifications for some of the construction materials is provided below to assist with selection of the best quality materials. The list of construction materials is given in Table 3.1.

Table 3.1. Biogas Plant Construction Materials

Particular		Unit	4 m^3	6 m^3	8 m^3	10 m^3	15 m^3	20 m^3
1	Building materials:							
*	bricks¯	piece	1200	1400	1700	2000	2400	2800
*	sand	bag	60	70	80	90	110	120
*	gravel	bag	30	35	40	50	60	70
*	cement¯	bag	11	13	16	19	27	34
*	6 mm rod	metre	50	60	70	70	90	100
*	paint	litre	1	1	1	2	3	4
2	Building labour							
*	skilled labour	days	8	8	11	11	13	15
*	unskilled labour	days	20	25	30	35	45	55
3	Pipes & appliances:	piece						
*	vert. mixer device	piece	1	1	1	1	1	-
*	hor. mixer device	piece	-	-	-	-	-	1
*	inlet pipe	piece	2	2	2	2	2	2
*	dome gas pipe	piece	1	1	1	1	1	1
*	GI pipe	piece	12	12	12	12	18	24
*	socket	piece	3	3	3	5	5	6
*	elbow	piece	5	6	8	8	10	12
*	tee	piece	1	2	2	3	4	5
*	union	piece	1	1	1	1	1	1
*	nipple	piece	3	3	4	4	6	6
*	main gas valve	piece	1	1	1	1	1	1
*	water drain	piece	1	1	1	1	1	1
*	rubber hose	metre	1	1	1	2	2	2
*	gas stove	piece	1	1	1	2	2	2
*	gas lamp	piece	-	1	1	1	2	3
*	teflon tape	roll	2	2	2	3	3	4

1. In case of stone masonry : for 4 and 6 m^3, 1 extra bag of cement
for 8 and 10 m^3, 2 extra bag of cement
for 15 and 20 m^3, 3 extra bag of cement

3.1 Cement

The cement to use in the plant construction must be of high quality Portland cement from a brand with a known reputation. It must be fresh, without lumps and stored in a dry place. Bags of cement should never be stacked directly on the floor or against the walls to protect the cement from absorbing moisture before use.

3.2 Sand

Sand for construction purpose must be clean. Dirty sand has a very negative effect on the strength of the structure. If the sand contains 3% or more impurities by volume, it must be washed. The quantity of impurities especially mud in the sand can be determined by a simple test using a bottle and clean water. For the test, the bottle is half-filled with sand, filled with clean water, and then stirred vigorously. Allow the bottle to sit stationary to allow the sand to settle. The particles of sand will settle first while mud particles will settle last. After 20-25 minutes, compare the thickness of the mud layer to the sand inside the bottle are; the percent of mud should be less than 3% of the overall volume. Course and granular sand can be used for concrete work however fine sand is necessary for plastering work.

3.3 Gravel

Gravel size should not be too big or too small. Individual gravel diameter should not be greater than 25% of the thickness of concrete product where it is used. As the slabs and the top of the dome are not greater than 8 cm (3") thick, gravel should not be larger than 2 cm (0.75") in size. Furthermore, the gravel must be clean. If it is dirty, it should be washed with clean water.

3.4 Water

Water is mainly used for preparing the mortar for masonry, concrete and plastering work. It is also used to soak bricks/stones before using them. Water is also used for washing sand and aggregates. It is advised not to use water from ponds and irrigation canals for these purposes, as it is usually too dirty. Dirty water has an adverse effect the strength of the structure; hence, water to be used must be clean.

3.5 Bricks

Bricks must be of the best quality locally available. When hitting two bricks together, the sound must be crisp or clean. They must be well baked and regular in shape. Before use, bricks must be soaked for few minutes in clean water. This will prevent the bricks from soaking moisture from the mortar after laid in place.

3.6 Cobble Stones

If cobble-sized stones, 7.5-30 cm (3-12") in diameter are used for masonry work, they must be clean, solid and of good quality. Cobbles should be washed if they are dirty.

4. Construction Site Selection

The following points should be kept in mind when deciding on a site for biogas plant construction.

- For proper function of the plant, the optimal temperature has to be maintained in the digester. Therefore, a sunny site should be selected to keep the digester near 35 degrees Celsius (95 degrees Fahrenheit). This is more important in the higher elevations year-round while generally a concern in the winter only for the lower elevation sites.
- To make plant operation easier and to avoid wastage of raw feedstock the plant must be as close as possible to the feedstock supply (toilet, animal pen, compost pits, etc.) and water source. If a readily available supply of feedstock or water or both is not available then the biogas plant should not be installed.
- Gas pipe length should be kept as short as possible. A longer pipe increases the risk of gas leaks because of the increased number of joints; the cost of a longer pipe is also a factor. The main gas valve should be opened and closed before and after each use, therefore the plant should be as close as possible to the point of use to facilitate proper operation.
- The edge of the foundation of the plant should be at least two meters away from any other structures to avoid risk of damage during construction.
- The plant should be at least 10 meters away from groundwater wells or surface water bodies to protect water from pollution.

5. Site Layout

After selection of the plant size and site location, the site layout is marked on the ground surface with wooden stakes, rocks, chalk or other materials. To mark the plant a small peg is stuck in the ground at the planned center of the digester. A cord the radius of the digester is attached to the peg (length indicated on the drawing under dimension 'C', Figure 2.1). The circumference can be marked by rotating the end of the cord in circular fashion. A suitable arrangement must then be marked for the inlet tank, inlet-pipe(s), outlet-chamber, compost-pits and gas piping. After the site layout is marked, the engineer should review the selected location again to ensure the best site has been chosen and will not interfere with other activities normally performed at the planned biogas plant.

6. Excavation

The pit depth is indicated on Figure 2.1 under dimension 'E'. The excavation work should only be started after deciding the location of manhole and outlet tank. For safety, the pit wal1s should be vertical and stepped from the ground surface by one meter away from the center of the excavation for each meter in depth excavated.

Photo 6.1: Excavation for Digester. Mechanical or Manual Excavation is Practical.

Excavated soil should be placed at least one meter away from the edge of the dig so it does not fall inside the pit during construction. The pit bottom must be leveled and the earth must be untouched.

Photo 6.2: Excavation for Digester. Mechanical or Manual Excavation is Practical.

If the design depth cannot be achieved because of hard rock or high groundwater, the design will need to be modified to a smaller plant or wider digester or combination of both. It is not recommended to construct the biogas plant at or below the groundwater table elevation. The earth base of the excavation is then compacted using mechanical or manual tools.

Photo 6.3: Earth Base of Excavation is Compacted.

7. Construction of Digester Main Chamber

The digester foundation is placed using cobbles and gravel as aggregate then filled with concrete. The foundation should be 15 cm thick and allowed.

Photo 7.1: Cobbles and Gravel Placed on Compacted Earth Floor.

At the center of the pit, a straight rod or pipe (the 0.5" GI gas pipe) must be placed in an exact vertical position. The vertical pipe will be used during the construction as a field-expedient guide to ensure symmetry of the biogas plant. At ground level, a rigid pole, pipe or cord is placed horizontally across the diameter of the pit. The vertical pipe is secured to the horizontal pipe, pole or cord. After securing, the vertical pipe should be checked to ensure it is still in the plumb/vertical position.

A string or wire is attached to the vertical pipe. The length of this wire can be found on Figure 2.1, dimension 'F'. Add one cm length to this length to allow space for plastering. Every brick or stone that is laid in the round-wall will be exactly F+ 1 cm away from the vertical pipe.

Photo 7.2: Concrete Foundation for Digester. Center Guide Pipe and Horizontal Cord.

After the Foundation has cured for at least two days, the round wall is constructed. The first two rows of bricks must be positioned side by side so that 23 cm (9") wide base is made. It is essential that first row be placed on a firm, untouched and level foundation. Subsequent rows of bricks are positioned on their lengths so that the wall thickness is maintained at 23 cm (9") wide.

Photo 7.3: First Two Courses of Bricks Placed on Top of Foundation.

It is not necessary to build in support columns or pillars in the wall however, the backfilling between wall and pit-side must be compacted with great care. Backfilling should be done no sooner than 12 hours following brick course placement to allow mortar to cure. Earth should be well compacted by adding water and gentle ramming along the circumference of the digester. Poor compaction will lead to cracks in round-wall and dome.

The cement mortar used can be 1 part cement to 4 parts sand (1:4) up to 1 part cement-6 parts sand (1:6) depending on the quality of the sand.

The height of the round-wall is detailed on the drawing in Figure 2.1 under dimension 'H' as measured from the finished floor. The feedstock inlet pipe (and toilet pipe, if installed) must be placed in position when the round-wall is 30-36 cm high. To reduce the risk of blockages, the inlet pipe(s) must be placed as vertical as practically possible.

Photo 7.4: Inlet Pipe Installed in Digester.

Exactly to the opposite of the main feedstock inlet pipe, a 60 cm wide opening must be left in the round-wall that serves as a manhole. The digested slurry will flow to the outlet tank through this opening. Additional inlet pipes should be placed as close as possible to the main feedstock inlet pipe with a maximum distance of 45 degrees from the inlet-center-manhole line.

When the round-wall has reached the correct height, the inside must be plastered with a smooth layer of cement mortar with mix of 1:3 cement-sand.

Photo 7.5: View of Manhole in Main Digester.

8. Dome Construction

When the round wall of the digester is complete, the dome is then constructed. Before filling the pit with earth to make the mould for dome, backside of the round wall should be filled with proper compacted back-fill. If this is not done, the pressure of earth for the mould can lead to cracks in the round-wall.

The dome is constructed using a mould or cast technique. This can be accomplished by constructing a timber frame then placing the earth-cast atop for proper arch design. Once the dome is cast, the timber frame and earth will be removed through the outlet chamber manhole.

Photos 8.1 and 8.2: Interior View of Timber and Plywood Frame Supporting Earth Mould for Dome.

Mark on the vertical center pipe the distance 'J' from the finished floor noted on drawing in Figure 2.1. The vertical pipe should remain in place as the mould is constructed.

A dome arch-guide is made for ensuring the mould is the correct shape. The guide can be manufactured from an iron rod with a loop at one end to ride on the vertical pole of the biogas plant and the other end bent to seat flush to the top of the digester wall. The arch shaped should be an 80 to 90-degree arc from the Mark ‘J’ on the vertical pipe and interior edge of the completed digester wall. The mould is shaped rotating the guide around the central vertical pipe. The top of the round-wall must be clean when the guide is in use.

Photo 8.3: Arch Guide. Loop at Right End for Pivot on Vertical Central Pipe.

It is important that the earth of the mould is well compacted. If the earth is further compressed after casting the dome, by its own weight and that of the concrete, it can lead to cracks in the dome. When the earth mould has the exact shape of the guide, a thin layer of fine sand is spread on the mould-top by gently patting it on the surface. The sand layer will prevent the earth from adhering to the cast. The earth used for the mould needs to be damp to prevent dry earth from soaking up water from freshly casted concrete.

Photo 8.4: Earth Mould with Sand Layer Before Placing Cast.

Before start of the cast work, sufficient labor and construction materials like sand, gravel, cement and water must be staged on the site and ready for use. The casting must be done as quickly as possible and without interruptions as this will negatively affect the quality of the cast. A constant, adequate supply of concrete (mix: 1 cement, 3 sand, 3 gravel – 1:3:3) must be made for the mason. No concrete older than 30 minutes should be used.

Special care should be taken to maintain the thickness of the dome while casting, i.e. the thickness near the outer edge should be greater than the thickness at the center. For the 4, 6, 8 and 10 m3 plant, the thickness at the edge should be 25 cm (10") where as the thickness in the center should be 7 cm (2 ¾"). Similarly, for 15 and 20 m3 plants, the thickness at the edge should be 25 cm (10") and the thickness in the center should be 8 and 9 cm (3 and 3 ½") respectively.

An alternative to concrete cast construction technique is the use of baked clay brick in corbel-arch construction. The compression of the brick and mortar in a spherical shape will support the dome. The clay brick dome will have a near-uniform thickness compared to the cast-concrete dome that thins towards the center. A continuous application of mortar along the sand mould is necessary as the bricks are placed. The brick dome should be placed continuously and use a mortar mix of 1:4 cement to sand. Once the bricks for the dome have all been placed, the exterior is covered with 1:3 cement to sand plaster.

Photo 8.5: Earth Mould with Sand Layer Before Placing Dome (Brick).

During the casting, the concrete has to be protected against strong sunlight by covering it with wetted burlap, jute bags or straw mats. This protection has to be left in place for at least one week. The day after the casting, the turret must be made. The turret is made with brick, 36 cm square and 50 cm tall. The turret is plastered with 1:3 concrete.

Any delays during dome construction can lead to leakage between main gas pipe and dome.

Following completion of the dome, the structure must be sprinkled with water 3 to 4 times a day during the curing period (up to one week).

Photo 8.6: Completed Dome with Turret.

After the dome has cured for approximately one week, the timbers and earth of the mould can be removed through the manhole. When all earth is removed, the inside of the dome has to be thoroughly cleaned with a stiff brush and clean water.

On the clean surface of the dome interior, the following plaster coats must be applied to make the dome gas-tight from first to last coats:

a) Cement and water wash (1:1)
b) 10 mm layer: 1 part cement, 2 parts sand (1:2)
c) 5 mm layer: 1:1
d) Cement/acrylic emulsion paint coating: 1.5 parts paint, 20 parts cement
e) Cement/acrylic emulsion paint coating: 1 part paint, 2 parts cement

Allow at least one day between plaster coats. When a layer of plaster is applied, the work must be executed with great care and without interruptions. The performance of the biogas plant is dependent on the gas tightness of the dome.

For proper insulation during the cold season and as counter weight against the gas pressure inside, a minimum top cover of 40 cm (16”) compacted earth is required on the dome. If the top cover will be prone to erosion due to wind and rain proper protection with gravel, circular wall, or straw matting should be applied.

9. Outlet Chamber Construction

The Outlet Chamber excavation and manhole is completed concurrently with the digester vessel and the manhole shares a common foundation with the digester vessel. The manhole of the Outlet Chamber is near the digester wall. The depth of excavation is less than the digester vessel measured from the top of digester floor by taking the dimension 'I' minus the thickness of the digester floor (will depend upon construction material used but generally ‘I’ + 13 cm (5”). The earth behind the manhole and under the outlet floor must be well compacted to prevent cracks in Outlet Chamber walls.

Photo 9.1: Outlet Chamber Foundation of Brick with Manhole Adjacent to Digester.

The inside dimensions of the outlet can be found on the drawing under A, B and D. The overflow level is at the top of dimension ‘D’ and top of the Outlet Chamber walls is dimension ‘D’ + 15 cm. It is important to use the prescribed dimensions as they determine the useful capacity of the gasholder. For the same reason the outlet floor and the top of the walls must be level. The walls will be vertical and finished with a smooth layer of cement plaster mix: 1 part cement, 3 parts sand. Outside of the walls must be supported with sufficient compacted earth up to the overflow level to avoid cracks. The Outlet Chamber walls should slightly higher elevation than the surrounding ground to reduce chances of surface water entering the outlet during the rainy season.

Photo 9.2: Outlet Chamber Slabs in Casts.

The concrete slabs for the Outlet Chamber should be constructed at the same time of dome casting. It should be easy to make the additional concrete at this time and the slabs will be well cured before they are placed on the outlet. The slabs must be 8 cm (3") thick with proper reinforcement (re-bar) 3 cm (1") from the bottom side. The number of slabs should be designed that they can be handled by four men without great difficulty. Installing re-bar loop handles on the slabs may be useful for the occasional handling of the slabs.

Photo 9.3: Slabs in Place on Outlet Chamber.

When preparing the slab casts use a smoothed, clean sand base and lumber for the frame. Special care must be taken for the placement of the concrete to prevent small holes that can expose the steel reinforcement to corrosive vapor from the slurry in the Outlet Chamber which will cause corrosion and ultimately lead to the slab collapse. If holes form in the slab these should be filled with plaster layer. The Outlet cover slabs are essential to protect people and animals from falling inside and to avoid excessive evaporation of the slurry in dry season.

Photo 9.4: Manhole Inspection of Complete Outlet Chamber.

10. Construction of Inlet Tank

The Inlet Tank is constructed to mix feedstock and water. This can be constructed with or without a mixing device. Installation of a mixing device is preferable because not only it makes plant operation easier but it also improves the quality of mix. When a mixer is installed, it has to be firmly attached to the structure, easy to operate, effective in the mixing process and the steel parts in contact with the feedstock should be galvanized.

The top of the structure should not be more than one meter above ground level and both inside and outside of the tank must be covered with a smooth layer of plaster (Mix: 1:3 cement, sand). The finished bottom of the Inlet Tank must be at least 5 cm above the Outlet Chamber overflow level. The position of the inlet pipe must be such that a pole or rod can be inserted through it to the digester vessel without obstructions. This will allow the operator to clear blockages in the inlet pipe. For the same reason the inlet pipe must be without bends.

Even if a mixing device is not installed, the inlet pit should be round in shape as this is a more economical use of material and easier for hand mixing.

Photo 10.1: Inlet Tank During Masonry Construction.

For plants that receive from a toilet, construct a cleanout valve between the water-trap and digester. The toilet inlet pipe should enter the digester tank no more than 45 degrees from the centerline of the main inlet pipe. Additionally, the toilet pan level should be at least 25 cm above the outlet overflow level.

Photo 10.2: Complete Inlet Tank with Mixer and Ball Valve on Inlet Tube.

11. Lay-out of Pipeline

The gas pipe conveying the gas from the plant to point of user is vulnerable to damages by people, domestic animals and rodents. Therefore, only light quality galvanized iron pipe should be used which must be, where possible, buried 30 cm (1 foot) below ground level. Fittings in the pipeline must be sealed with zinc putty, Teflon tape or jute and paint. Any other sealing agent, like grease, paint only, soap etc. must not be used. The use of fittings, especially unions, should be kept to a minimum to reduce the risk of leakage. No fittings should be placed between the main gas valve and the dome gas pipe. The pipe size, inside diameter should be between .6 and 1 Cm. Pipe size is determined by the size of the digester, (amount of gas produced) and amount of gas required in the house. (Are the stove, heater lights going to be used simultaneously?)

Photo 11.1: Construction of Gas Line Condensate Drain Valve Box.

The biogas generated from the digester is saturated with water vapor. This water vapor will condense on the walls of the pipeline. If the condensate is not removed regularly, it will ultimately clog the pipeline. For this reason, a water drain or trap is installed in the pipeline. The position of the water drain should be vertically below the lowest point of the pipeline so water will flow by gravity to the trap. Water is removed by opening the drain. As this has to be done periodically, the drain must be easily accessible and protected in a well-maintained drain pit.

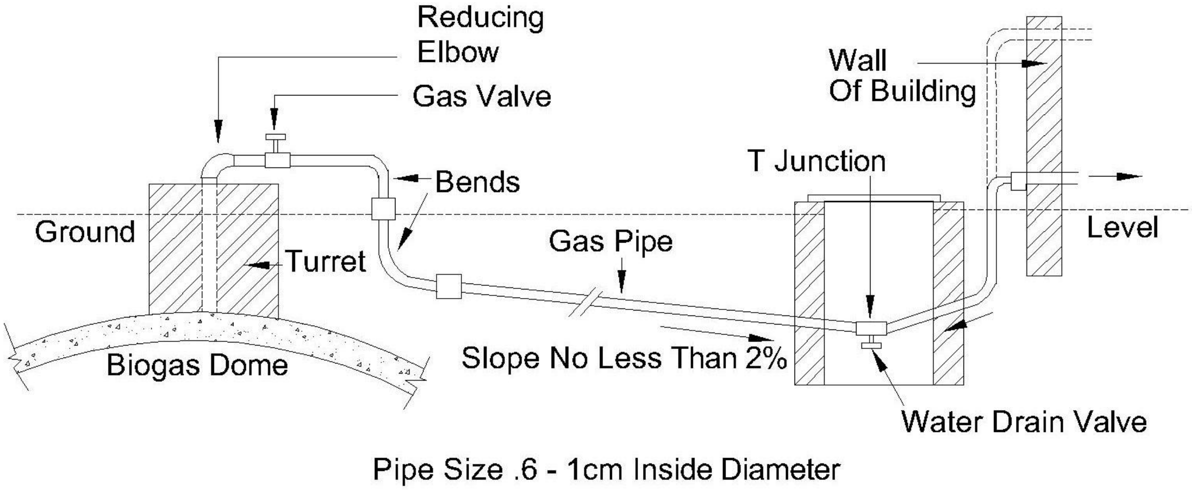

Figure 11.1: Schematic for Condensate Drain Valve in Gas Line.

To connect burners to gas pipelines use of transparent polyethylene hose must be avoided. Only the best quality neoprene, rubber hose should be used. Other biogas appliances should be mounted and connected to the galvanized iron pipe. As soon as there is gas production, all joints and taps must be inspected for leakage by applying a thick soap solution and observing for foam movement.

12. Compost Pits

Compost pits are an integral part of the biogas plant; no plant is complete without them. A minimum of two compost pits must be dug near to the Outlet Chamber overflow in such a way that the slurry can run freely into the pits. Enough earth body must remain however, at least 1 meter, between the pits and the outlet chamber to avoid cracking of the chamber walls. The total volume of the compost pits must be at least equal to the plant volume. The earth excavated from the compost pits is used for backfilling of the inlet and outlet chamber and for top filling on the dome.

Photo 12.1: Compost Pits with Brick Walls for Stability

The compost pits can also be filled with agricultural residues and the slurry from the plant for a nitrogen and nutrient rich fertilizer. Compost Pits are utilized by alternating discharge flow allowing the full pit to evaporate and leach into the soil while the other is being filled. Once the pit material desiccates to the consistency of humus, the material could be removed for agricultural application as fertilizer.

13. Biogas Appliances

The biogas fuel is used for cooking, heating and lighting. Propane and biogas appliances are appropriate for use with biogas.

Photo 13.1 and 13.2: Biogas Lantern and Biogas Double-burner Stove

14. Solar Water Heater:

An optional feature used for biogas plants is a solar water heater. Because Afghanistan has generally strong solar radiation, solar water heaters are a viable accessory for biogas plants. The solar water heater transfers heat from sunshine to the water, which is circulated through a manifold in the digester floor. This is necessary in some climates and higher elevations to raise the temperature of the biomass. The biomass produces its own heat through digestion; however, soil temperate in higher elevations is subject to freezing in winter and inhibiting methanogenesis and reducing efficiency of the biogas plant. The solar water heater can help the digester maintain an optimal temperature to maximize feedstock digestion and gas production.

Photo 14.1: Solar Water Heater for Biogas Plant.

The capacity of the solar water heater system is determined by many factors, specifically the ambient temperatures at the location of the biogas digester, the total volume of the biogas digester vessel, and the temperatures that are to be achieved. The solar water heater system can be closed loop or flow-through. A closed loop system requires a pump to circulate the water since convection alone will not transfer cooler water from the digester to the solar water heater at a higher elevation. A circulation pump will require electricity or photovoltaic solar power supply. The advantage of a PV powered pump. The pump size would depend on the amount of liquid being circulated and the intended rate of circulation.

Photo 14.2: Panoramic View of Plant Interior with Solar Water Heater Manifold on Floor.

The water from a flow-through solar water heater is passed through the digester manifold and discharged at a spigot near the biogas plant. Heated water resides in the manifold and heats the biomass through convection. The water that passes through the manifold in the digester is used in the feedstock and water mix deposited directly into the digester through the Inlet Tank.

Photo 14.3: Spigot from Solar Water Heater

Composting material may also be used on top of the biogas digester dome. The decomposing organic material will both insulate the digester from cool air and give off heat from decomposition.

The biogas plant illustrated thorought this manual is an 8-cubic meter plant constructed by the non-profit firm AREA. The Dimensions of the biogas plant in the photos of the manual are illustrated in Figure 14.1.

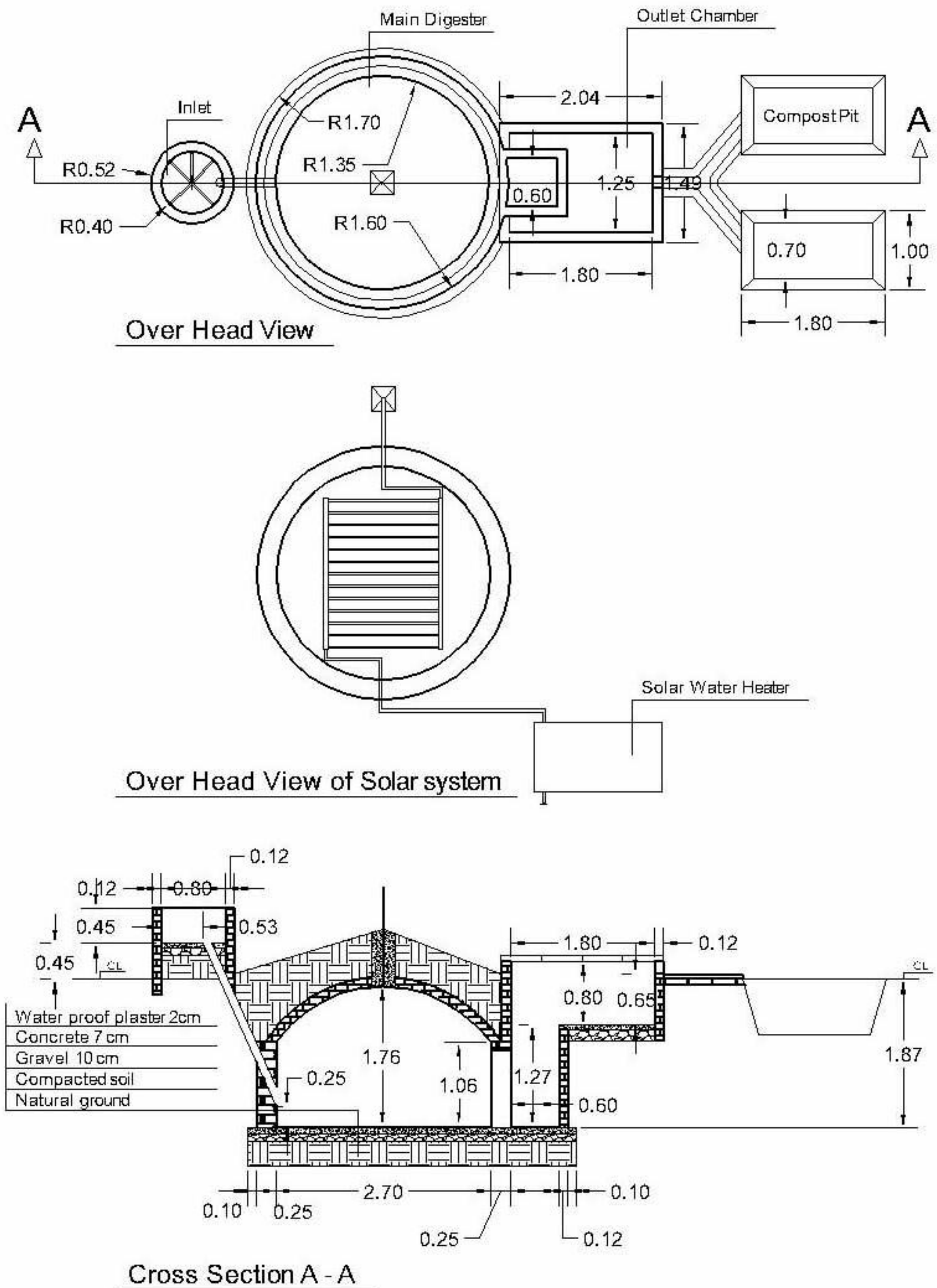

Figure 14.1 AREA Biogas Model Design

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Attachment A

Operation and Maintenance of Biogas Plant

The biogas plant will be a quality system if the engineer, mason and plumber follow the construction manual instructions. A well-planned, constructed and maintained plant will benefit the owner for their investment, ultimately provide positive return and meet their expectations. This may persuade his relatives and neighbors to invest in a biogas plant while a poorly constructed plant will do harm to the reputation of biogas technology. As described in the introduction, this model of biogas plant is designed to be low maintenance system. The biogas plant will last from 20 to 50 years if properly maintained.

The following items are important for the engineer designing and providing services for biogas plant owners. Operators in Afghanistan may not have the education or literacy to comprehend or understand the following O&M guidance for a fixed-dome biogas digester and therefore require training directly by the engineer installing the biogas plant for optimal performance.

1. **Inputs and their characteristics.** Any biodegradable organic material can be used as inputs for processing inside the biodigester. However, for economic and technical reasons, some materials are more preferred as inputs than others. If the inputs are costly or have to be purchased, then the economic benefits of outputs such as gas and slurry will become low. Also, if easily available biodegradable wastes are used as inputs, then the benefits could be of two folds: (a) economic value of biogas and its slurry; and (b) environmental cost avoided in dealing with the biodegradable waste in some other ways such as disposal in landfill.

   One of the main attractions of biogas technology is its ability to generate biogas out of organic wastes that are abundant and freely available. In many countries it is the cattle dung that is most commonly used as an input mainly because of its availability. The potential gas production from some animal dung is given in Table A-1.

Table A-1. Gas Production potential of various types of dung

Types of Dung	Gas Production Per Kg Dung (m3)
Cattle (cows and buffaloes)	0.023 - 0.040
Pig	0.040 - 0.059
Poultry (Chickens)	0.065 - 0.116
Human	0.020 - 0.028

Source: Updated Guidebook on Biogas Development, UN, 1984

In addition to the animal and human wastes, plant materials can also be used to produce biogas and bio-manure. For example, one kg of pre-treated crop waste and water hyacinth has the potential of producing 0.037 and 0.045 m3 of biogas, respectively. Since different organic materials have different bio-chemical characteristics, their potential for gas production also varies. Two or more of such materials can be used together provided some basic requirements for gas production or for normal growth of methanogenesis are met. Some characteristics of these inputs that have significant impact on the level of gas production are described below.

2. **Carbon to Nitrogen (C/N) Ratio.** The relationship between the amount of carbon and nitrogen present in organic materials is expressed in terms of the Carbon/Nitrogen (C/N) ratio. A C/N ratio ranging from 20 to 30 is considered optimum for anaerobic digestion. If the C/N ratio is very high, the nitrogen will be consumed rapidly by methanogens for meeting their protein requirements and will no longer react on the left over carbon content of the material. As a result, gas production will be low. On the other hand, if the C/N ratio is very low, nitrogen will be liberated and accumulated in the form of ammonia (NH4). NH4 will increase the pH value of the content in the digester. A pH higher than 8.5 will start showing toxic effect on methanogen population.

   Animal waste, particularly cattle dung, has an average C/N ratio of about 24. The plant materials such as straw and sawdust contain a higher percentage of carbon. The human excreta has a C/N ratio as low as 8. C/N ratio of some of the commonly used materials are presented in Table A-2 (Karki and Dixit, 1984).

   Materials with high C/N ratio could be mixed with those of low C/N ratio to bring the average ratio of the composite input to a desirable level. In China, as a means to balance C/N ratio, it is customary to load rice straw at the bottom of the digester upon which latrine waste is discharged. Similarly, at Machan Wildlife Resort located in Chitawan district of Nepal, feeding the digester with elephant dung in conjunction with human waste enabled to balance C/N ratio for smooth production of biogas (Karki, Gautam and Karki, 1994).

Table A-2. C/N Ratio of some organic materials

Raw Materials	C/N Ratio
Duck dung	8
Human excreta	8
Chicken dung	10
Goat dung	12
Sheep dung	19
Cow / Buffalo dung	24
Water hyacinth	25
Elephant dung	43
Straw (maize)	60
Straw (rice)	70
Straw (wheat)	90
Saw dust	above 200

3. **Dilution and consistency of inputs**. Before feeding the digester, the feedstock, especially fresh cattle dung, has to be mixed with water at the ratio of 1:1 on a unit volume basis (i.e. same volume of water for a given volume of dung). However, if the dung is in dry form, the quantity of water has to be increased

accordingly to arrive at the desired consistency of the inputs (e.g. ratio could vary from 1:1.25 to even 1:2). The dilution should be made to maintain the total solids from 7 to 10 percent. If the dung is too diluted, the solid particles will settle down into the digester and if it is too thick, the particles impede the flow of gas formed at the lower part of digester. In both cases, gas production will be less than optimum.

For thorough mixing of the cow dung and water (slurry) a steel mixer can be fitted in the inlet tank of a digester. It is also necessary to remove inert materials such as stones from the inlet before feeding the slurry into the digester. Otherwise, the effective volume of the digester will decrease.

Photo A-1: Inlet Tank for Mixing Water and Manure

4. **Slurry management.** Slurry is the residue of inputs that comes out from the outlet after the substrate is acted upon by the methonogenic bacteria in an anaerobic condition inside the digester. After extraction of biogas (energy), the slurry (also known as effluent) comes out of digester as by-product of the anaerobic digestion system. It is an almost pathogen-free stabilized manure that can be used to maintain soil fertility and enhance crop production. Slurry is found in different forms inside the digester as mentioned below:
   i. a light rather solid fraction, mainly fibrous material, which float on the top forming the scum
   ii. a very liquid and watery fraction remaining in the middle layer of the digester
   iii. a viscous fraction below which is the real slurry or sludge
   iv. heavy solids, mainly sand and soils that deposit at the bottom.

There is less separation in the slurry if the feed materials are homogenous. Appropriate ratio of urine, water and excrement and intensive mixing before feeding the digester leads to homogeneous slurry.

5. **pH value.** The optimum biogas production is achieved when the pH value of input mixture in the digester is between 6 and 7. The pH in a biogas digester is also a function of the retention time. In the initial period of fermentation, as large amounts of organic acids are produced by acid forming bacteria, the pH inside the digester can decrease to below 5. This inhibits or even stops the digestion or fermentation process. Methanogenic bacteria are very sensitive to pH and do not thrive below a value of 6.5. Later, as the digestion process continues, concentration of NH4 increases due to digestion of nitrogen, which can increase the pH value to above 8. When the methane production level is stabilized, the pH range remains buffered between 7.2 to 8.2.

6. **Temperature**. The methanogens are inactive in extreme high and low temperatures. The optimum temperature is 35 degrees C. When the ambient temperature goes down to 10 degrees C, gas production virtually stops. Satisfactory gas production takes place in the mesophilic range, between 25 degrees to 30 degrees C. Proper insulation of digester helps to increase gas production in the cold season. When the ambient temperature is 30 degrees C or less, the average temperature within the dome remains about 4 degrees C above the ambient temperature (Lund, Andersen and Torry-Smith, 1996).

7. **Loading rate**. Loading rate is the amount of raw materials fed per unit volume of digester capacity per day. In Nepalese conditions, about 6 kg of dung per m3 volume of digester is recommended in case of a cow dung plant (BSP, 1992). If the plant is overfed, acids will accumulate and methane production will be inhibited. Similarly, if the plant is underfed, the gas production will also be low.

8. **Retention time.** Retention time (also known as detention time) is the average period that a given quantity of input remains in the digester to be acted upon by the methanogens. In a cow dung plant, the retention time is calculated by dividing the total volume of the digester by the volume of inputs added daily. Considering the climatic conditions of Nepal, a retention time of 50 to 60 days seems desirable. Thus, a digester should have a volume of 50 to 60 times the slurry added daily. However, for a night soil biogas digester, a longer retention time (70-80 days) is needed so that the pathogens present in human feces are destroyed. The retention time is also dependent on the temperature and up to 35 degrees C, the higher the temperature, the lower the retention time (Lagrange, 1979).

9. **Toxicity**. Mineral ions, heavy metals and the detergents are some of the toxic materials that inhibit the normal growth of pathogens in the digester. Small quantity of mineral ions (e.g. sodium, potassium, calcium, magnesium, ammonium and sulphur) also stimulates the growth of bacteria, while very heavy concentration of these ions will have toxic effect. For example, presence of NH4 from 50 to 200 mg/l stimulates the growth of microbes, whereas its concentration above 1,500 mg/l produces toxicity. Similarly, heavy metals such as copper, nickel, chromium, zinc, lead, etc. in small quantities are essential for the growth of bacteria but their higher concentration has toxic effects. Likewise, detergents including soap, antibiotics, organic solvents, etc. inhibit the activities of methane producing bacteria and addition of these substances in the digester should be avoided. Although there is a long list of the substances that produce toxicity on bacterial growth, the inhibiting levels of some of the major ones are given in Table A-3.

Table A-3: Toxic level of various inhibitors

Inhibitors	Inhibiting Concentration
Sulphate (SO4- -)	5,000 ppm
Sodium Chloride or Common salt (NaCl)	40,000 ppm
Nitrate (Calculated as N)	0.05 mg/ml
Copper (Cu++)	100 mg/l
Chromium (Cr+++)	200 mg/l
Nickel (Ni+++)	200 - 500 mg/l
Sodium (Na+)	3,500 - 5,500 mg/l
Potassium (K+)	2,500 - 4,500 mg/l
Calcium (Ca++)	2,500 - 4,500 mg/l
Magnesium (Mg++)	1,000 - 1,500 mg/l
Manganese (Mn++)	Above 1,500 mg/l

Source: The Biogas Technology in China, BRTC, China (1989)

10. **Repairs and Services**. The biogas plant may operate normally for several years before a periodic shut down, clean out and inspection of the system is required. When the system is evacuated and inspected, repair any cracks or damage which may allow leaks in the system. The start up of the biogas plant may take as much as two months before it operates normally.

If the biogas plant production of biogas is less than anticipated based on the referenced values listed above and all other parameters are within the normal operating ranges, a specialized biogas engineer familiar with the design, construction, maintenance and operation of the biogas plant may need to inspect the system.