BIOGAS PRODUCTION FOR DOMESTIC USE

A FLEXIBLE LEARNING COURSE
Acknowledgements

Course Team

This course was developed as part of the short-course offering from Thika Technical Training Institute, designed to provide skills training to meet the needs of the local community. Thika Technical Training Institute is a partner in the Commonwealth of Learning INVEST Africa partnership.

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Course Introduction

Welcome to this course on biogas production for domestic use. As you well know, energy plays a significant role in all our lives. We use energy for cooking, lighting, drying and warming. For a long time, wood fuel has been the main source of energy, especially in rural African homesteads. However, over reliance on wood fuel has depleted forests and endangered the environment. In addition, smoke inhalation, soot and ash have been found to cause ill health among users of wood fuel. The other alternative source of fuel has been fossil sources such as crude oil, lignite, hard coal, natural gas. These are fossilized remains of dead plants and animals, which have been exposed to heat and pressure in the earth’s crust over hundreds of millions of years. For this reason, fossil fuels are non-renewable resources whose reserves are depleted much faster than new ones are being formed. This has led to a search for other sources of energy such as wind, solar, and biogas. Of all these sources biogas has been found to be the most suitable for domestic use. This is because it is a renewable, simple and cheap to generate.

The aim of this course is to provide you with the knowledge and skills you need to plan, build and operate a biogas plant for domestic purposes. This course is designed for dairy farmers, masons, prospective biogas plan operators and other stakeholders working with this technology. Upon successful completion of this course, you should be able to convert your domestic or farm waste into biogas and bio-manure.

Course Outcomes

On completion of this course you will be able to:

- Explain the meaning of biogas, its uses and benefits
- Outline the components of a biogas system and how they work
- Determine the size and design of a bio-digester
- Describe the steps to follow during the construction of a bio-digester.

Course Content

This course is divided into the following four main units:

- Unit 1: Introduction to biogas technology
- Unit 2: Biogas production process
- Unit 3: Design of a biogas plant
- Unit 4: Construction of a biogas plant
Icons Used in the Units

In the margin of these units, you will find the following icons which tell you what to do:

- **Read the outcomes of the unit.**

- **Complete the Activity.** Activities help you to process and apply what you are learning.

- **Read the summary of what you have covered in the unit.**

Before you begin your study, please watch the following video entitled *Production of Biogas for Domestic Use* via the link below. It will give you a good background and understanding about biogas production. [www.youtube.com/watch?v=SMSr$Kr-As](http://www.youtube.com/watch?v=SMSr$Kr-As)
Unit One: Introduction to Biogas Technology

Introduction

Welcome to the first unit in this course on biogas production. In this unit, we are going to look at the meaning of biogas and the history of biogas technology. We shall also discuss the components of a biogas plant as well as its uses and benefits. The aim of this unit is to give you a foundation on the meaning, origin and components of biogas technology. Let us start by reviewing the outcomes for this unit.

Unit 1 Outcomes

On completion of this unit you will be able to:

• Explain the meaning of the term ‘biogas’;
• Describe the historical development of biogas technology in Africa
• Describe the components of biogas technology
• Uses and benefits of biogas technology.

1.1 What is Biogas?

Biogas is a mixture of gases produced during the anaerobic digestion of biological or organic materials. *Anaerobic* means oxygen free while *aerobic* means with oxygen. In a small farm, biogas can be made from the anaerobic decomposition of organic material such as livestock waste (urine, dung) and waste feeds. Biogas is produced when bacteria known as methanogen bacteria ferment or breakdown the organic material in the absence of oxygen. Methanogen bacteria prefer certain conditions and are sensitive to the microclimate within the digester. Methanogen bacteria develop slowly and are sensitive to sudden changes in temperature. For example, a sudden fall in the slurry temperature by even 2°C may significantly affect their growth and gas production rate.

Biogas consists of methane (40-70%), also known as marsh gas or natural gas (CH4), 30 to 40% carbon dioxide (CO2), and low amounts of other gases such as hydrogen, nitrogen and hydrogen sulphide. Biogas is about 20% lighter than air and has an ignition temperature in the range of 650° to 750° C. It is odourless (after burning) and colourless and it burns with a clear blue flame similar to that of Liquid Petroleum Gas (LPG) gas. Biogas is a renewable fuel because it is produced from waste treatment. Biogas is produced inside a plant known as a bio digester.
What is a bio digester?
This is a covered vessel in which anaerobic digestion of organic or biological matter occurs. It is commonly known as a biogas plant. Since various chemical and microbiological reactions take place inside the bio digester, it is also known as a bio-reactor or anaerobic reactor. The main function of this plant is to provide anaerobic conditions for biogas production. A bio digester should be air and water tight. It comes in different shapes and sizes and can be made of various materials. Figure 1.1 below illustrates a bio digester or biogas plant.

![Figure 1.1: A floating drum bio digester](image)

Activity 1.1

**Biogas Technology**
Which of the following statements is **not** true about biogas technology

a) Biogas is made up of mixture of gases  
b) It is produced during aerobic digestion of organic materials  
c) 40-70% of biogas is made up of methane  
d) It is a renewable fuel

Compare your answer with that given at the end of this unit.

We hope you now understand what biogas is as well as the functions of a bio digester. Next let us examine the history of biogas technology.
1.2 History of Biogas Technology

Biogas technology has been around for a long time and its use has been implemented all over the world. According to Harris (2015), anecdotal evidence indicates that biogas was used for heating bath water in Assyria during the 10th century BC and in Persia during the 16th century AD. In the 12th Century, Marco Polo, the famous merchant from Venice reported the use of covered sewage tanks. In the 18th century, it was determined that flammable gases could evolve from decaying organic matter, and that there was a direct correlation between the amount of decaying organic matter and the amount of flammable gas produced.

In Europe in 1808, Sir Humphrey Davy determined that methane was present in the gases produced during the anaerobic digestion of cattle manure. In 1884, Pasteur researched on biogas from animal residues and proposed the utilization of horse litter to produce biogas for street lighting. In 1890, methane was first recognised as having practical and commercial value in England, where a specially designed septic reservoir was used to generate gas for the purpose of lighting.

In India, the first digestion plant was built at a leper colony in Bombay, in 1859. In the 1950s, the development of simple biogas plants for rural households started. Through strong government backing, a massive increase in the number of biogas plants took place in the 1970s.

In China, biogas plants were built in the 1940s by prosperous families. In the 1970s biogas research and technology developed at a fast rate assisted by the Chinese government. By 2007, China was the biggest biogas producer in the world with around 18 million farm households using biogas and about 3,500 medium to large-scale digester units (DEFRA 2007).

Activity 1.2

Biogas Technology in Kenya
When and how did you first learn about biogas technology in Kenya? Write your answer in the space provided below.

Before you continue reading, complete the following activity.
Whatever your answer to this question, you may be interested to know that biogas technology has been in use in Kenya since mid-1960s. Around this time, the Koru Coffee Research sub-Centre in western Kenya had an elaborate biogas plant which supplied the offices and staff houses with energy for lighting and cooking. In the 1980s, the Ministry of Energy conducted a study on energy demand and supply in Kenya. Thereafter, the Ministry started demonstrating biogas technology all over the country (Karanja et al., 2003).

That was a brief history of biogas technology in the world and in Kenya. Next, let us consider the benefits of biogas technology.

1.3 Benefits of Biogas Technology

One of the main attractions of biogas technology is its ability to generate biogas out of organic waste that is abundant and freely available. The main output of a biogas plant is the methane gas which is valued for its uses in cooking and lighting, and the slurry for its soil nutrients or fertilizing properties. It can also be used as fuel for combustion engines and for absorption fridges. However, fridges are less suitable for domestic biogas as they require large quantities of gas and/or purified gas which is maintained at a constant pressure. Also, contrary to popular believe, it is not feasible to compress biogas into a liquid form and store/transport it in gas cylinders. Biogas has a number of benefits as follows:

- As an Energy source
- Environmental benefits
- Economic benefits
- Benefits to agriculture
- Benefits to women

1.3.1 Biogas as an Energy Source

As we mentioned earlier, biogas is used as a source of energy for cooking, lighting, refrigeration and biofuels. Let us look at each in turn.

**Cooking:**
Cooking with biogas is the most commonly used application and the sturdiest one. It has a number of advantages over traditional cooking with firewood. These are:

- It has 5 times higher stove efficiency than traditional firewood stove
- Cooking with biogas saves the time spent gathering firewood
- It does not produce smoke and therefore women and children are not prone to eye irritations and respiration-problems;
- Unlike firewood stoves, biogas does not soothe the pans and so there is less work to clean them
- It cooks faster and the flame can be regulated
- Cooking can be done in an up-right position
- Cooking can easily be done inside the house
- It is safe to use and there is less chance of children getting burned as is the case with open fire, or stoves.
**Lighting**
In villages without electricity, lighting is a basic need as well as a status symbol. The bright light of a biogas lamp is the result of incandescence, that is, the intense heat-induced brightness of special metals like thorium at temperatures of 1000-2000°C. If the lamp hangs directly below the roof, it can cause a fire hazard. It is therefore important that the gas and air in a biogas lamp are thoroughly mixed before they reach the gas mantle, and that the air space around the mantle is adequately warm. The mantle of a biogas lamp resembles a small net bag. A binding thread made of ceramic fibre thread is provided for tying it onto the ceramic head. When heated at a temperature of more than 1000 o C, the mantle glows brightly in the visible spectrum while emitting little infrared radiation. The fabric of the mantle, when flamed for the first time, burns away, leaving a residue of metal oxide. The mantle shrinks and becomes very fragile after its first use. In general the mantle does not last long because of insect damage and high gas pressure. Therefore, regular maintenance and mantle change is needed. Since thorium is a radioactive material it should be handled with utmost care.

**Refrigeration**
Biogas can be used for the absorption type refrigerating machines which operate on ammonia and water and are equipped with automatic thermo-siphon. Since biogas is the refrigerator’s only external source of heat, the burner itself has to be modified. Refrigerators that run on Kerosene flame can be adapted to run on biogas.

**Biogas fuelled engines**
Raw biogas from a digester cannot be used in that form to fuel engines. It must undergo some purification to upgrade it to the level of natural gas. This process entails removing carbon dioxide, hydrogen sulphide, ammonia, particles, trace components and water so that the gas has a methane content above 95%. A number of biogas upgrading technologies, such as, water absorption, chemical absorption, and Pressure Swing Absorption (PSA) have been developed for the treatment of biogas. The use of biogas as fuel for vehicles such as buses, taxis and communal vehicles makes economic sense and has evident environmental advantages.

**Electricity generation**
Biogas can be used to generate electricity using a reciprocating engine, steam turbine, or gas turbine. When a reciprocating engine is used, the biogas must have condensate and particulates removed. In order to move fuel gas into a gas turbine combustion chamber, the biogas must be free from visible moisture and any particulates and it should also be compressed.
1.3.2 Benefits to the Environment

Biogas production significantly reduces carbon dioxide emission and helps to preserve natural resources such as forests. Biogas production by anaerobic digestion also reduces emissions of greenhouse gases from the storage and utilisation of untreated animal manure as fertilizer. Biogas is a clean source of energy as it does not produce smoke or soot during combustion. Another benefit of biogas technology is its ability to improve management of waste by transforming it into a valuable resource. It also reduces offensive odours which come from overloaded or improperly managed manure storage facilities. These odours impair air quality and may be a nuisance to nearby communities. Lastly, biogas reduces the surface and ground water pollution.

1.3.3 Economic Benefits

Biogas is a cheap source of cooking energy. A two cubic meter biogas plant can produce the equivalent to 26kg of LPG, or 37 litres of kerosene, or 88kg of charcoal, or 210kg of firewood per month. Thus, by producing energy from livestock and farm waste, a farmer saves money that would otherwise have spent on purchasing electric and gas suppliers. It also helps to create jobs related to the design, construction and maintenance of biogas technology.

1.3.4 Benefits of Biogas to Agriculture

A Biogas plant does not only produce fuel, it also produces a high quality and valuable organic soil fertilizer. The fertilizer is rich in nitrogen, phosphorus, potassium and micronutrients which improve the yield of plant production. Organic matter plays an important role because of its beneficial effects in supplying plant nutrients, improving soil aggregation, increasing water holding capacity of soils, stabilizing its humid content and increasing its water holding capacity. Compared to Farm Yard Manure (FYM), the digested slurry has slightly more nutrients, because in FYM, the nutrients are lost due to exposure to heat from the sun as well as by leaching.

![Figure 1.1 Spinach grown with slurry or bio-manure in a rural farm](image-url)
Fertility trials carried out in Nepal and elsewhere have revealed that optimum results can be achieved through the combined application of both chemical and organic fertilizers. In countries like China where biogas technology is well developed, there are evidence that supports the fact that productivity of agricultural land increases remarkably with the use of slurry produced from biogas plant.

1.3.5 Biogas and Forests

Comprehensive data is not available to quantify the overall impact of biogas adoption on forests, however research has shown that:

- The number of animal heads kept by a farming family decreased after installation of a biogas plant, compared to non-adopters.
- Biogas technology led to the adoption of stall-feeding practices which reduced the pressure on nearby forest and pasture land by animals grazing there.
- Biogas replaces 80% to 85% of firewood consumption of a family.

These findings show the positive impact of biogas installation on forests and pasture lands along with the qualitative improvement in animal husbandry.

1.3.6 Benefits of Biogas to Women

It is worth mentioning that the first design of the biogas plant developed in 1956 in India by Jashu Bhai Patel was named “Greeha Laxmi” (housewife). This shows its relevance to the well-being of women. In view of the traditional role that a female member plays in a family, the following are some of the prominent aspects of biogas that help women in particular:

- Reduction of in-house pollution in general and that of kitchen in particular. The Biogas flame does not leave black soot on pots. Cleaning is easy, cleaning time is reduced while the life of the pots is prolonged.
- It reduces the time required for cooking as well as time spent fetching firewood. The time saved can be used for other useful purposes.
- It contributes to a healthy environment free from flies and mosquitoes. Most of the pathogens are destroyed in the process of anaerobic digestion.
- In remote villages where there is no electricity, biogas lighting facilitates education and income generating activities.

Generally, it is the housewife who is more involved in operating and maintaining a biogas plant. This has forced all development workers in the biogas sector to focus their activities to the female members of a family. In other words, use of biogas technology has been instrumental in enhancing the role of women not only in matters of family decisions but also in planning and implementation of other development activities.
We hope you are impressed by the many benefits and uses of biogas at the domestic level. As a way of reflecting on what you have read in this section, complete the following activity.

**Activity 1.3**

**Benefits of Biogas Technology**
Which of the following are potential benefits of biogas technology at the domestic level? Tick the correct answers.

- [ ] Used as an energy source for cooking and lighting
- [ ] Causes in-house pollution and destruction of forests
- [ ] Converts plant and livestock waste into high quality manure
- [ ] Saves money that would have been used to purchase kerosene or gas for cooking
- [ ] Contributes to a healthy environment free of flies and mosquitoes
- [ ] It is not women friendly

Compare your answers with those given at the end of this unit.

That brings us to the end of our first unit on introduction to biogas technology. Let us review what you have learnt.

**What have we learnt?**

In this unit we have learnt that biogas is a mixture of gases produced when bacteria known as methanogen bacteria ferment or breakdown biological or organic material in the absence of oxygen. This process takes place in a covered vessel known as a biodigester. Next we explored the history of biogas technology and saw that it dates back to 10th Century BC where it was used to heat bath water in Assyria. Since then it has spread all over the world with China being the biggest biogas producer in the world. Lastly, we learnt about the uses and benefits of biogas technology. These included its use as a source of energy for cooking, lighting, refrigeration and biofuels. In addition it has benefits to the environment, economy, women, forests and agriculture.

In the next unit you will learn how a biogas production system works.
Unit 2: Biogas Production Process

Introduction

Welcome to the second unit in our module on biogas production. In the last unit we learnt about the meaning of biogas, the historical background, uses and benefits of this technology. We saw that domestic biogas plants convert livestock manure, night soil or other organic material into biogas and fermented manure, known as slurry. In this unit we shall discuss how biogas is produced. In the first section we shall consider the process of biogas production. We shall start by looking at the various components of a biogas system. Then we shall discuss the key inputs that go into biogas production. Next, we shall consider the aerobic digestion process that produces biogas, and finally we shall look at the by-product of this process known as slurry.

Let us start by reviewing the main outcomes of this unit.

Unit 2 Outcomes

On completion of this unit you will be able to:
- Describe the components of a biogas system
- Identify the key inputs that go into a bio-digester
- Explain the stages of anaerobic digestion and the factors that hinder or facilitate this process
- Describe the different forms of slurry.

2.1: Components of a Biogas System

A biogas production plant normally has five major components. The required quantity of substrate or feedstock is mixed with water and fed to the digester through the inlet tank. Once the mixture is digested, gas is produced and collected in the dome, also known as the gasholder. The digested slurry flows to the outlet tank through the manhole and eventually ends up in the compost pit where it is collected and composted. The gas is supplied to the point of application through the pipeline. Figure 2.2 below illustrates the components of a biogas system.
The following are the main components of a biogas plant:

- **Inlet pipe**: a system used to collect and transport waste or substrate to the digester. It consists of a receptacle for the raw/fresh organic waste and a pipe of at least 10 cm diameter leading to the digester. The connection between the inlet pipe and the digester must be airtight.
- **A digester**: this is the reservoir of organic wastes in which the substrate is acted on by anaerobic microorganisms to produce biogas.
- **Biogas holder**: a system to collect the gas produced: this may be simply an empty but enclosed space above the slurry in the digester.
- **A gas pipe or a system to distribute the gas to the end user**: this system is connected to a special lighting lamp or a modified cooking burner, see Figure 2.1 below.

![Gas pipe connected to a simple kitchen stove](image)

- **An outlet discharge pipe**: this system collects and distributes the digested slurry to the end user. It consists of a pipe of similar size to the inlet pipe, which is connected to the digester at a slightly lower level than the inlet pipe. It facilitates the outflow of exhausted slurry.

You now know the components of a biogas plant. As a way of reflecting on what you have learnt in this section, complete the following activity.
Next, let us discuss the inputs that go into a biogas system.

### 2.2: Inputs for Biogas Production

In principle, any biodegradable organic material can be used as substrate for processing inside the bio digester. If you purchase or transport the inputs for biogas production over a large distance, then the economic benefits of biogas production would be adversely affected. If however, the inputs are easily available within the homestead, then biogas production has great economic value.

#### Activity 2.2

**Components of a Biogas Plant**

Draw a line to match each component of a biogas plant with its correct function.

<table>
<thead>
<tr>
<th>Component</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet Pipe</td>
<td>Collects the gas produced</td>
</tr>
<tr>
<td>Digester</td>
<td>Connects to a lamp or gas burner</td>
</tr>
<tr>
<td>Gas holder</td>
<td>Facilitates outflow of exhausted slurry</td>
</tr>
<tr>
<td>Gas pipe</td>
<td>Transports organic waste to the digester</td>
</tr>
<tr>
<td>Outlet pipe</td>
<td>Reservoir in which anaerobic digestion takes place</td>
</tr>
</tbody>
</table>

#### Activity 2.3

**Inputs for Biogas Production**

What input materials are used for biogas production in your community? List them in the space provided below.

______________________________________________________________

Compare what you have written with what you read in the following section.
In domestic settings, the input material or substrate for biogas production includes:

- Remains of agriculture or food production such as feed remains, chaff from rice and wheat
- Organic household waste
- Fresh plant material such as maize, grass, water hyacinth. 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
- Human excrements or night soil
- Animal excrements such as slurry or manure. The potential gas production from animal dung is given in Table 2.1 below.

**Table 2.1: Gas production potential of various types of Animal Dung**

<table>
<thead>
<tr>
<th>Type of Dung</th>
<th>Gas Production Per Kg (M3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cattle (cows and buffaloes)</td>
<td>0.023 - 0.040</td>
</tr>
<tr>
<td>Pig</td>
<td>0.040 - 0.059</td>
</tr>
<tr>
<td>Poultry (Chickens)</td>
<td>0.065 - 0.116</td>
</tr>
<tr>
<td>Human</td>
<td>0.030 - 0.050</td>
</tr>
</tbody>
</table>

Since different organic materials have different bio-chemical characteristics, their potential for gas production also varies. You can use two or more of such materials together, provided that some basic requirements for gas production or for normal growth of methanogens are met.

**Take Note:**
Do not install a biogas plant if you do not have a supply of substrate or water or both.

You now know the components and inputs of a biogas system. Before you move on to the next section, complete the following activity. Next, let us find out how biogas is produced.

### 2.3 The Anaerobic Digestion Process

Can you remember how we defined anaerobic digestion? We said that it is the process of decomposition of biological matter in the absence of oxygen. Inside the bio-digester, the process of aerobic digestion takes place in various stages, in which the initial material is continuously broken down into smaller units. Specific groups of micro-organisms are involved in each individual stage. These organisms successively decompose the products of the previous stage.

**Stages of Biogas Production**
The process of biogas production can be divided into three main stages. These are:
• **Hydrolysis**
  During hydrolysis, the microorganisms excrete extracellular enzymes which break down the organic matter into simpler and soluble compounds.

• **Acidogenesis**
  During this stage, acid-producing bacteria reduce compounds with a low molecular weight into acetic acid (CH₃COOH), hydrogen (H₂) and carbon dioxide (CO₂). To produce acetic acid, these bacteria need oxygen and carbon. For this, they use the oxygen found in the solution. Thereby, the acid-producing bacteria create an anaerobic (oxygen free) condition, which is essential for the methane producing microorganisms.

• **Methanogenesis**
  During this stage, the methanogenic bacteria processes the principle acids produced in Stage 2 to produce methane. The reaction that takes place in the process of methane production is called Methanization.

**Factors that Facilitate or Hinder Anaerobic Digestion**
There are a number of factors that hinder or facilitate anaerobic digestion. These factors are:

- Carbon/Nitrogen Ratio
- Dilution and Consistency of Inputs
- Volatile Solids
- Temperature
- Loading rate
- pH Value
- Retention time
- Toxicity.

Let us examine each factor in turn and how it affects gas production.

**Carbon/Nitrogen 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. Microorganisms need both nitrogen and carbon for assimilation into their cell structures. 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 the bacteria or methanogens and will no longer react on the leftover 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 accumulate in the form of ammonia (NH₄). This will increase the pH value of the content in the digester, thus producing a toxic effect on the methanogen population. Therefore the C/N ratio of the substrate used in a biogas plant is important. Cattle, pig and poultry manures have a good C/N ratio.

**Dilution and Consistency of Inputs**
Most biogas plants are designed for a total solids content of about 8%. A change of this ratio affects the proper functioning of the plant. Before feeding the digester, the excreta, especially fresh cattle dung, should be mixed with water at the ratio of 1:1, that is, same volume of water for a given volume of dung.
However, if the dung is in a dry form, one should increase the quantity of water accordingly in order to arrive at the desired consistency of the substrate. For example, the ratio could vary from 1:1.25 to even 1:2. You should ensure that the dilution maintains a total solid content of 7 to 10%. If the dung is too diluted or too thick, this will lower gas production. This is because in the case of over diluted dung, the solid particles tend to settle down into the digester. While in the case of thick dung, the particles impede the flow of gas formed at the lower part of digester. There is also a higher risk of scum formation at the top of the slurry layer if the mixture is too thick.

**Volatile Solids:**
Volatile solids are the part of the total solids contents of the substrate that can be converted into biogas. Biomass that is completely dried and then heated to about 550° C, will gasify. The weight of the dried biomass minus the weight of the remaining ash after gasification will be the weight of the volatile solids. The biogas production potential of different organic materials can also be calculated on the basis of their volatile solid content.

**Temperature:**
The methanogens are inactive in extreme high and low temperatures. The Optimum temperature for these bacteria is 35° C. When the ambient temperature goes down to 10° C, gas production virtually stops. To increase gas production during the cold season, one can place a haystack on top of the digester in order to provide proper insulation. When the ambient temperature is 30°C or less, the average temperature within the dome remains 4° C above the ambient temperature (Lund, Andersen, Tony-Smith, 1996). The process of bio-methanation is very sensitive to changes in temperature. The degree of sensitivity, in turn, is dependent on the temperature range. Brief fluctuations not exceeding ± 1°C/h do not inhibit the process of fermentation. The temperature fluctuations between day and night are not a great problem for plants built underground, since the temperature of the earth below a depth of one meter is practically constant.

**Loading Rate**
This refers to the amount of substrate or raw materials fed in the digester per day. If the plant is overfed, acids will accumulate and methane production will be inhibited. Similarly, if the plant is underfed, the gas production will be low.

**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 can inhibit or even stop 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 - 8.2
Retention Time:
Retention time, also known as hydraulic retention Time (HRT) is the average period that a given quantity of input or substrate remains in the digester to be acted upon by the methanogens. The theoretical retention time is calculated by dividing the average slurry holding volume of the digester by the volume of the substrate added daily. Depending on the vessel geometry and the means of mixing, the effective retention time may vary widely for the individual substrate constituents. Selection of a suitable retention time thus depends not only on the process temperature, but also on the type of substrate used. In general the optimum retention time can vary between 30 and 100 days. For night soil biogas digesters, the retention time is extended by 10 days so that the pathogens present in human faeces are largely destroyed.

Toxicity:
Mineral ions, heavy metals, antibiotics and detergents are some of the toxic materials that inhibit the normal growth of microbes in the digester. Small quantities of mineral ions (e.g. sodium, potassium, calcium, magnesium, ammonium and sulphur) stimulate the growth of bacteria, while very heavy concentration of these ions has a toxic effect. For example, the presence of Ammonia (NH4) from 50 to 200 mg/l stimulates the growth of microbes, whereas concentration above 1,500 mg/l results in toxicity. Similarly, small quantities of heavy metals such as copper, nickel, chromium, and zinc are essential for the growth of bacteria, while higher concentration have toxic effects. Detergents including soap, antibiotics and organic solvents inhibit the activities of methane producing bacteria and should not be added to the digester. However, small domestic amounts of natural soap used to clean a toilet, usually do not cause major problems.

Activity 2.4
Input Factors that hinder biogas production
Tick the factors that hinder the process of biogas production

- A carbon/nitrogen ratio ranging from 20 to 30
- Extremely high and low temperatures
- Mixing cow dung with water at a ratio of 1:1
- When pH value in the digester is less than 5
- A total solid content of 8%
- Presence of heavy metals and detergents

Compare your answers with those given at the end of this unit.

2.4: Biogas Slurry
This is what comes out through the outlet chamber after methanogenic bacteria act upon the substrate inside the digester. After extraction of biogas (energy), the slurry (also known as effluent) comes out of the digester as a by-product of the anaerobic digestion system. It is almost pathogen-free stabilized manure that can be used to maintain soil fertility and enhance crop production. When fully digested, the slurry from a biogas plant is odourless and does not attract insects or flies.
Slurry is found in the following different forms inside the digester:

- A light rather solid fraction, mainly fibrous material, which float to the top forming scum;
- A very liquid and watery fraction which remains in the middle layer of the digester;
- A viscous fraction below which is the real slurry or sludge; and
- Heavy solids, mainly sand and soils that deposit at the bottom.

When the feed materials or substrate are homogenous, there is less separation in the slurry. If you want to achieve homogeneous slurry, you should use the appropriate ratio of urine, water and excrement and mix the slurry intensively before feeding the digester.

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.

That brings us to the end of this unit on the biogas production system. We hope you have found it interesting and useful. Let us now review what we have learnt.

**What have we learnt?**

In this unit we have learnt that a biogas system has 5 major components, namely: the inlet pipe, a digester, gas holding system, gas pipe and outlet discharge pipe. We also considered the inputs that go into a biogas system. We noted that most organic or biodegradable material can be used as substrate for processing inside a bio digester. The common inputs at domestic level come from livestock excrements, human waste, fresh plants and household waste. We discussed the anaerobic digestion process of a biogas system. We saw that it has three main stages during which bacteria continuously break down the substrate into smaller units until methane is produced. These stages are hydrolysis, acidification, and methanization. Lastly, we looked at slurry which is a by-product of a biogas system. We hope you still remember that slurry is a useful organic fertiliser.

In the next unit you will learn how to design and construct a bio digester.
Unit 3:
Design of a Biogas Plant

Introduction

In this unit we are going to learn about the design of bio digesters. In the last unit, we looked at the entire biogas production system, from its components, inputs and processes, to its by-product. In this unit we shall start by discussing the different types of bio digesters and the factors you should consider when choosing one. We shall also consider the technical aspects of plant design such as how to calculate the size of the digester. As usual, let us start by reviewing our unit outcomes.

Unit 3 Outcomes

On completion of this unit you should be able to:

- Identify the different types of digesters;
- Describe the factors that one should consider when selecting a biogas plant;
- Calculate the size of a biogas digester and the average substrate.

3.1: Types of Bio digester Designs

In the first unit of this course we described what a bio digester is. Can you remember what we said? Find out by completing the following activity.

Activity 3.1

Meaning of bio digester

Briefly describe a bio digester in the space provided below.

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

Well done! Now compare your answer with our description below.
At the beginning of this course, we described a bio digester as a physical structure that provides anaerobic conditions needed for biogas production. It comes in different shapes and sizes and can be built with various construction materials. The following are some of the commonly used bio digester designs for domestic use:

- Floating drum digester
- Fixed dome digester
- The plastic bag digester

Let us look at each type of design in turn starting with the floating drum digester.

### 3.1.1 Floating Drum Digester

The floating drum biogas plant was introduced in India in 1956. In this design, the digester chamber is made of brick masonry in cement mortar. A mild steel drum is placed on top of the digester to collect the biogas produced from the digester. Thus, there are two separate structures: for gas production and gas collection as shown in figure 3.1 below.

The advantage of the floating drum design is the constant gas pressure, which is equal to the gasholder’s weight divided by its surface. This means that lamps, stoves and other appliances don’t need any further adjustments ones they have been correctly set. Another advantage is that the level the gasholder has risen above the digester pit, is a clear indication of the available gas.

Its main disadvantage is the high installation and maintenance costs. This has made this design obsolete for domestic use.

---

*Figure 3.1: The floating drum biogas plant*
3.1.2: The Fixed Dome Digester or Chinese Model Digester

The fixed dome biogas plant was designed and developed in China in 1936. Since then the design has been adapted in various countries in the world. A fixed dome biogas plant comprises of a closed, dome-shaped digester. It has an immovable, rigid gas-holder and a displacement pit, also known as compensation tank. The gas is stored in the upper part of the digester. The plant is constructed underground, protecting it from physical damage and saving space. The underground digester is protected from temperature fluctuations which has a positive influence on the bacteriological process.

The cost of constructing a fixed dome plant is relatively low. It is also simple as it does not have moving parts. There are also no rusting steel parts and hence it has a long life of 20 years or more. The construction of fixed dome plants is labor-intensive, thus creating local employment.

One of its disadvantages is that it is not easy to build. It requires the services of experienced biogas technicians to ensure that the plant is gas tight and does not have porosity or cracks.

There are various types of the fixed dome digester:

- **The Chinese fixed dome plant**: this is the original design on which all the others are based. It consists of a cylinder with a round bottom and top and is widely used in China. See figure 1.5 below.

![Figure 3.2: Chinese fixed dome plant](image)

**The Deenbandhu model**: this model was developed in 1984 by the Action for Food production in New Delhi, India. It is made entirely of brick masonry work with a spherical shaped gas holder at the top and a concave bottom. It proved to be 45% cheaper than the floating drum plant of equal size. It is the most commonly used plant in India with over 3 million plants constructed. Figure 1.5 shows a typical design of the Deenbandhu plant.
3.1.3: The Plastic Bag Digester

The plastic bag digester consists of a trench lined with a plastic tube. The trench length has to be considerably greater than the width and depth. This plant is easy and cheap to construct, especially in areas with a high water table. It’s main weakness is its vulnerability. It is easily damaged by cattle and playing children. Also the UV rays in sunlight make the plastic gets brittle. Figure 1.6 gives an illustration of the plastic bag digester.

We hope you now understand the main plant designs which are suitable for domestic production of biogas. Before you move on to the next section, complete the following activity.
In the next section we shall discuss the factors that you should consider when selecting a bio digester.

3.2: Factors to Consider When Selecting a Bio digester

There are various factors that you should consider when deciding on the type of bio digester to use. Before you continue reading, take a minute to think about them and then complete the following activity.

Activity 3.2

Bio-digester Designs
Indicate whether the following statements are True or False.

<table>
<thead>
<tr>
<th>Statement</th>
<th>True</th>
<th>False</th>
</tr>
</thead>
<tbody>
<tr>
<td>The floating drum digester has two separate structures for gas production and gas collection.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The floating drum digester has low maintenance and installation costs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A fixed dome biogas plant comprises of a closed, dome-shaped digester</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The underground fixed dome digester is protected from temperature fluctuations which has a positive influence on the bacteriological process</td>
<td></td>
<td></td>
</tr>
<tr>
<td>In a fixed dome digester the gas is stored in the lower part of the digester</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Deenbandhu model is 45% cheaper than the floating drum plant of equal size</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The plastic bag digester is not suitable for places with a high water table</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Compare your answers with those given at the end of this unit.

Activity 3.3

Factors to consider in selecting a bio digester
What factors would you consider when selecting a bio digester? List at least 2 factors in the space provided below.

1. ________________________________________________________
2. ________________________________________________________
Well, we hope your list included the following factors:

- Investment
- Utilization of Local Materials
- Durability
- Type of Inputs
- Soil conditions and water table
- Gas consumption pattern of the average household

Let us examine each factor in further detail.

**Investment:**
An ideal plant should be as low-cost as possible in terms of the initial investment and the long-term operation and maintenance cost.

**Utilization of Local Materials:**
A biogas plant should make use of local materials during the construction. This is an important consideration, particularly in areas where transportation systems are often expensive. Furthermore, provision of service such as construction and repair work, can be hampered by the use of exotic materials.

**Durability:**
Construction of a biogas plant requires a certain degree of specialized skill which may not be easily available. Therefore, when constructing a biogas plant, you should consider designs that are durable. This is because a plant with a short lifespan, though cheap in the short term, may not be reconstructed once its useful life ends. This is so especially in situations where the adoption of this technology is low and the necessary skill and materials are not readily available. Furthermore, if an adequate follow-up to a complaint on the functioning of a plant cannot be guaranteed, it will be better to opt for a more reliable but usually also more costly design.

**Type of Inputs:**
The design should be compatible with the type of inputs, popularly known as feeding materials that are used. If plant materials such as rice straw, maize straw or similar agricultural wastes are used, then the batch feeding design or discontinuous system should be used instead of a design for continuous or semi-continuous feeding.

**The Soil condition and water table:**
Unstable soil conditions, such as black cotton soil, as well as high water tables require a structure that is able to cope with these conditions. Conical or sphere shaped floors are recommended in such conditions instead of flat bottoms.

**Gas consumption pattern of the household:**
If the daily gas use is most commonly ended early in the evening, a relatively larger gas storage capacity of the plant will be needed to hold the gas that is generated overnight.

We hope you are now able to make an informed decision when selecting a biogas digester design. In the next section we shall discuss technical details of plant design.
3.3: Biogas Plant Size Analysis

The size of a biogas digester depends on the quantity, quality, and kind of available biomass, digesting temperatures and biogas requirements.

When designing your biogas digester, you should consider the following factors:

- the size of the digester
- daily gas production
- the plant parameters;
- the size of the gas holder
- average daily feedstock

Let us examine each of these factors in further detail.

Size of the Digester

The size of the digester, also known as the *digester volume* \( V_d \), is determined by the *daily substrate input quantity* \( S_d \) and the chosen *retention time* \( RT \), using the following formula:

\[
V_d = S_d \times RT \quad [\text{in cubic metres (M}^3\text{) /day x number of days}]
\]

Where:

- Digester volume \( V_d \) is in cubic metres (m\(^3\));
- Daily substrate input quantity in cubic meters (m\(^3\)) per day or litres per day (L/day)
- Retention time \( RT \) is in days
- Biomass or organic material in Kg; and
- Water is in litres (L)

*The Retention Time* is determined by the chosen biomass and given digestion temperature. For an unheated biogas plant, the temperature prevailing in the digester may be assumed to be 1-2\(^\circ\) centigrade above the prevailing soil temperature. However, seasonal variations must be given due considerations.

For a plant of simple design, the retention time should amount to at least 40 days. However, practical experience shows that the retention time can range from 60 to 80 days or even 100 days when there is a shortage of substrate. On the other hand, extra-long retention times can increase gas yield by 40%.

*The Substrate input* depends on how much water has to be added to the substrate in order to arrive at a solids content of 4-8%. It is calculated using the following formula:

\[
\text{Substrate input (SD)} = \text{Biomass (B)} + \text{Water (W)} \text{ m}^3 /\text{Day.}
\]

In most agricultural biogas plants the mixing ratio for dung (cattle and/or pig) and water \( (B:W) \) is normally between 1:3 and 2:1. For cow dung the ratio for dung and water is normally 1:1.
Determining Daily Gas Production (G)
The amount of biogas generated each day $G$ (m$^3$ gas / day), is calculated on the basis of the specific gas yield $G_y$ of the substrate and the daily substrate input $S_d$. The calculation may be based on the following:

- Volatile solids content:
  \[ G = V_s \times G_y \quad \text{m}^3 / \text{day} = \text{kg} \times \text{m}^3 / \text{day} \text{kg} \]

- Weight of moist mass $B$
  \[ G = B \times G_y \quad \text{m}^3 / \text{day} = \text{kg} \times \text{m}^3 / \text{day} \text{kg} \]

- Standard gas yield values per Livestock Unit (LSU)
  \[ G = \text{Number of LSU} \times G_y \quad \text{m}^3 / \text{day} = \text{number} \times \text{m}^3 = \text{day number} \]

As a rule it is advisable to calculate according to several different methods, since the available basic data are usually very imprecise. A higher degree of sizing certainty can be achieved by comparing and averaging the results.

Biogas Plant Parameters

The degree of safe sizing certainty can be increased by defining a number of plant parameters namely:

1. **Specific gas production $G_p$**: this is the daily gas generation rate per m$^3$ of digester volume $V_d$. It is calculated in m$^3$ / day using the following equation:
   \[ G_p = G \div V_d \quad \text{m}^3 / \text{day} \div \text{m}^3 \]

2. **Digester loading ($L_d$)**: this is calculated from the daily total solids input $T_S/d$ and the digester volume ($V_d$) using the following equation:
   \[ L_d = T_S/d \div V_d \quad \text{kg} / \text{day} \text{ or m}^3 / \text{day} \]

Sizing the Gas Holder

The size of the gasholder that is the gasholder volume ($V_g$) depends on the relative rates of gas generation and gas consumption. The gasholder must be designed to:

- Cover the peak consumption rate ($G_{c_{\text{max}}}$), $V_g1$
- Hold the gas produced during the longest zero consumption period ($t_{z_{\text{max}}}$), $V_g2$

   \[ V_g1 = G_{c_{\text{max}}} \times t_{c_{\text{max}}} = V_{c_{\text{max}}} \]
   \[ V_g2 = (G_h) \times t_{z_{\text{max}}} \]

Where
- $G_{c_{\text{max}}}$ = maximum hourly gas consumption, (m$^3$ / hr)
- $T_{c_{\text{max}}}$ = time for maximum consumption, (hrs)
- $V_{c_{\text{max}}}$ = maximum gas consumption, (m$^3$)
- $G_h$ = hourly gas production, (m$^3$ / hr)
- $t_{z_{\text{max}}}$ = maximum zero consumption time, (hr)
The larger Vg-value (Vg1 or Vg2) determines the size of the gas holder. However, a safety margin of 10 – 20% should be added since practical experience show that 40 – 60% of the daily gas production has normally has to be stored.

The ratio Vd : Vg (digester volume : gasholder volume) is a major factor with regard to the basic design of a biogas plant. For a typical agricultural biogas plant, the ratio is between 3:1 and 10:1, with 5:1 to 6:1 occurring most frequently.

**Average Daily Feedstock**

Generally, a 4-cubic meter biogas plant can take 24 to 40 kilograms of substrate combined with 24 to 40 liters of water per day with a hydraulic retention time of 40 days. Table 3.1 below gives you information about the four different sizes of biogas plants and the average daily feedstock or substrate in kilograms.

**Table 3.1. Plant size and average daily feedstock or substrate**

<table>
<thead>
<tr>
<th>Plant Size (m³)</th>
<th>Daily Feedstock (kilogram)</th>
<th>Daily Water (liters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>24 - 40</td>
<td>24 - 40</td>
</tr>
<tr>
<td>6</td>
<td>40 - 60</td>
<td>40 - 60</td>
</tr>
<tr>
<td>8</td>
<td>60 - 80</td>
<td>60 - 80</td>
</tr>
<tr>
<td>10</td>
<td>80 - 100</td>
<td>80 - 100</td>
</tr>
</tbody>
</table>

*Note: Plant size is the sum of digester volume and gas storage based on a hydraulic retention time of 40 days.*

**Take Note**

Before deciding the size of the plant, it is necessary to collect dung for several days to determine what is the average daily.

We hope you are able to calculate the size of a biogas digester and the average daily feedstock. That brings us to the end of this unit on how to design a biogas plant. Let us now review what you have learnt.

**What have we learnt?**

In this unit we have learnt about three types of biogas digester designs, namely the floating drum, fixed dome, and plastic bag digesters. We also considered their advantages and disadvantages. Next we examined the factors that you should consider when selecting a biogas plant. These were factors such as durability, gas consumption, and investment to mention just a few. Lastly, we learnt how to estimate the size of a biogas digester and the average daily feedstock or substrate.

In the next unit we shall discuss how to construct and install a biogas plant.
Unit 4: Construction of a Biogas Plant

Introduction

Welcome to the last unit in our course on biogas production. In the last unit you learnt about the different designs of biogas plants and the factors to consider when designing a plant. In this last unit we shall discuss the construction of a biogas plant. We shall start by looking at the responsibilities of a biogas plant builder. Then we shall discuss the materials you need for the construction of a biogas plant. Lastly, we shall consider the steps involved in the construction of a biogas plant. The success or failure of any biogas plant primarily depends upon the quality of construction work. In this unit we shall focus on the construction of the fixed dome type of plant. As usual, let us start by reviewing our unit outcomes.

Unit 4 Outcomes

On completion of this unit you will be able to:
- Explain the responsibilities of a biogas plant builder
- Identify the materials you need for the construction of a biogas plant
- Describe the steps involved in the construction of a biogas plant.

4.1: Responsibilities of a Biogas Plant Builder

The role of a biogas plant builder is vital in the successful installation of a biodigesters. The following are some of the main responsibilities of a biogas plant builder:
- Provide necessary information on benefits of bio-digester to the users and motivate them for bio-digester installation
- Select proper size of bio-digester based upon the availability of feeding materials
- Ensure that the quality standards of construction materials and appliances are properly complied with.
- Follow strictly the design and drawing as provided to them during construction of bio-digesters
- Comply with the construction manuals while installing the bio-digesters
- Provide the users with knowledge and skill on how to operate various components of bio-digester
- Ensure timely completion of the work
- Report progress and difficulties, if any, to supervisors regularly
• Work as extension worker and promoter of the technology in their areas of influences
• Provide regular follow-up and after-sales services to the users to ensure trouble-free functioning of completed plants

As a way of reflecting on what you have just read, complete the following activity.

**Activity 4.1**

**Responsibilities of a Biogas Builder**
Which of the following are NOT the responsibilities of a hired biogas plant builder?

- [ ] Providing information on the benefits of a bio-digester
- [ ] Providing finances for the construction of a biogas plant
- [ ] Selecting the correct size based upon availability of substrate of feeding stock
- [ ] Carefully implement the design and drawings of the bio-digester
- [ ] Deciding whether or not to build a bio-digester
- [ ] Providing follow-up and after sales service

Compare your answers with those given at the end of this unit.

**4.2 Materials for Construction of a Biogas Plant**

The construction of a biogas plant requires a variety of materials. The domestic fixed dome plant is constructed with a round wall made of stone, a dome with plain concrete and slabs with reinforced concrete. The inlet can be built with stones or bricks. It is important to note that the quality of your plant will depend on the materials you use. If you use materials of poor quality, the plant will be poor even if the design and workmanship are excellent. Before you read on complete the following activity.

**Activity 4.2**

**Materials for construction of a biogas plant**  *(Time: 10 mins)*

1. What type of materials would you need for the construction of your biogas plant?

Now compare your list with the materials we discuss in the following section.
The following are some of the construction materials used to build a biogas plant:

- Cement,
- Sand
- Gravel
- Water
- Bricks
- Cobblestones.

We shall consider each type of material in detail looking so that you can learn how to select the best quality.

**Cement**

The cement used in the plant construction must be of high quality. 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.

**Sand**

The sand must be clean. Dirty sand has a 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 still 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. The percent of mud should be less than 3% of the overall volume. Coarse and granular sand can be used for concrete work while fine sand is necessary for plastering work.

**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 7 cm thick, gravel should not be larger than 2 cm in size. Furthermore, the gravel must be clean. If it is dirty, it should be washed with clean water.

**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. You should not use water from ponds and irrigation canals for these purposes, as it is usually too dirty. Dirty water has an adverse effect on the strength of the structure; hence, make sure you use clean water.
Bricks
Use the best quality bricks available in your locality. To know if the bricks are of good quality, hit two bricks together. If they make a crisp or clean sound then they are good. Make sure they are well baked and regular in shape. Before use, soak the bricks in clean water for a few minutes. This helps to prevent the bricks from soaking moisture from the mortar after being laid in place.

Cobblestones
If you use cobblestones which are 7.5-3.0 cm (3-12”) in diameter, make sure that they are clean, solid and of good quality. Cobblestones should be washed if they are dirty.

In addition to these you will require PVC pipes, galvanised pipes, binding wire, glue, paint and steel rods among others. Once you gather all your materials together you are ready for the next step which is the actual construction.

4.3: Construction of a Biogas Plant

The following are the main steps in the construction of a biogas plant:
• Selection of a construction site
• Plant layout
• Excavation
• Construction of the digester chamber
• Dome construction
• Construction of the outlet chamber
• Construction of inlet tank
• Layout of gas pipes

Let us consider each step in further detail starting with selection of the construction site.

Selection of a Construction Site
When selecting the site of construction, you should keep the following points in mind. Please note that it will not be possible to meet all the requirements as stated below, however, you should ensure that as many points as possible are considered:
• The site should facilitate easy construction work
• The selected site should be such that the construction cost is minimized
• The selected site should ensure easy operation and maintenance activities like feeding of the plant, use of the main gas valve, composting and use of slurry, checking of gas leakages, draining condensed water from the pipeline, etc.
• The site should guarantee plant safety
• Select a sunny site to keep the digester near 35 degrees Celsius (95 degrees Fahrenheit). This helps to maintain the optimal temperature in the digester for proper function of the digester.
• The area to construct the plant should have an even surface
• The site should be in a slightly higher elevation than the surrounding. This helps in avoiding water logging. This also ensures free flow of slurry from the outlet overflow to the composting pit.

• There should be enough space for compost pit(s) as these are an integral part of the bio-digester.

• The site should be at sufficient distance from trees to avoid damage of the bio-digester from roots.

• The plant should be as close as possible to the feedstock supply (toilet, animal pen, compost pits, etc.) and water source in order to make the plant operation easier and avoid wastage of raw feedstock.

• Keep the gas pipe length 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 plant should be as close as possible to the point of use to facilitate proper operation, such as opening and closing the main gas valve before and after each use.

• 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.

### Plant Layout

Construction work starts with marking the dimensions of the plant on the ground in order to start digging. After selecting the plant size and site location and layout, you should mark on the ground surface with wooden stakes, rocks, chalk or other materials. Then you should stick a small peg in the ground at the centre of where digester will be and proceed as follows:

• level the ground and determine the centre line of the digester, outlet tank and inlet pit (generally called hart-line);

• define the reference level. It is better to assume the levelled ground as the reference level. The top of the dome (outer) should exactly be at this level;

• select the outer radius of the pit (digester diameter plus wall thickness and a space for a footing projection of at least 10 cm);

• Attach a cord for the radius of the digester is attached to the peg;

• Mark the circumference by rotating the end of the cord in circular fashion;

• Mark where the inlet tank, inlet pipe(s), outlet-chamber, compost-pits and gas piping will be placed;

*Figure 4.1: Planning the plant layout (Source: RURA, 2012)*
Insert a stick or wooden peg in the levelled ground at the centre of the proposed digester pit. With the help of the pole and chord prepared earlier, make a circle, which indicates the area to dig.

Mark the manhole ensuring that the inner size is 60 cm x 60 cm;

Draw horizontal parallel lines from the points in either side in the tangent, which will meet the dome.

From the central point where the central line meets with the perimeter line, measure the length of the outlet plus the wall thickness to define the outer dimension of the outlet;

Check the size diagonally to ensure that the corners are exactly at 90 degrees;

Use coloured powder to mark the dimensions;

Decide on the location of slurry pits while laying out plant digester and outlet;

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.

**Excavation**

Once you complete the layout work, you can now start digging of the pit. You will need tools such as the crow-bar, picks, spade, shovel and basket. You should then continue as follows:

- Start the excavation work only after deciding the location of the manhole and outlet tank.
- Ensure the digging is done as per the dimensions fixed during layout;
- Ensure the cutting in the ground is vertical, however, if the soil is cohesionless and the angle of repose needs more slope cutting, scaffolding may be needed.
- If the water table is high and digging to the required depth is difficult, construct a deeper pit near the digester pit;
- Drain all water that has accumulated in the digester pit through underground pipes;
- Ensure that you have dug up to the correct dimension and then start levelling and ramming the base;
- the pit bottom must be levelled and the earth must be untouched;
- be careful to avoid accidents while digging near the sides as soil may collapse;
- dig the foundation for the manhole (first step of outlet tank) along with the foundation for the digester as per the dimensions in the drawing during the layout;
- horizontal poles have to be placed in the ground level crossing each other at 90 degree in the centre;
- ensure that the poles rest on levelled ground;
- for safety, ensure that the pit walls are vertical and stepped from the ground surface by one meter away from the center of the excavation for each meter in depth excavated;
- place excavated soil at least one meter away from the edge of the dig so that it does not fall inside the pit during construction;
if you cannot achieve the design depth because of hard rock or high groundwater, you may need to modify the design to a smaller plant or wider digester or combination of both;

one should not construct the biogas plant at or below the groundwater table elevation. You can compact the earth base using mechanical or manual tools. Figure 4.2 shows excavation works.

![Excavation works](image)

**Figure 4.2: Excavation works (Source: RURA, 2012)**

**Construction of Digester Chamber**

Place the foundation of the digester using cobblestones and/or gravel as aggregate, and then fill with concrete or pain cement as shown in Figure 4.3. The foundation should be 15 cm thick.

![Cobblestones and gravel placed on compacted floor](image)

**Figure 4.3: Cobblestones and gravel placed on compacted floor (Source: RURA, 2012)**

- place a straight rod or pipe at the centre of the pit (the 0.5" GI gas pipe) in an exact vertical position. The vertical pipe will be used during the construction as a guide to ensure symmetry of the biogas plant.
- at ground level, place a rigid pole, pipe or cord horizontally across the diameter of the pit. Secure the vertical pipe to the horizontal pipe, pole or cord. After securing, the vertical pipe check to ensure that it is still in the plumb/vertical position;
- attach a string or wire to the vertical pipe.
- add one cm length to this length to allow space for plastering. Every stone that is laid in the round-wall will be exactly F+ 1 cm away from the vertical pipe. See Figure 4.4 for a picture showing the foundation of a digester with the centre guide pipe and horizontal cord.
• after the foundation has cured for at least two days, you can start the construction of the round wall.
• ensure that the first two rows of bricks are positioned side by side so that 23 cm (9") wide base is made.
• it is essential that the first row be placed on a firm, untouched and level foundation. Subsequent rows of bricks should be positioned on their lengths so that the wall thickness is maintained at 23 cm (9") wide;
• it is not necessary to build support columns or pillars in the wall however, the backfilling between the wall and pit-side must be compacted with great care;
• ensure that backfilling is done no sooner than 12 hours following brick course placement to allow mortar to cure;
• ensure the earth is well compacted by adding water and gentle ramming along the circumference of the digester. Poor compaction will lead to cracks in the round-wall and dome;
• depending on the quality of the sand, the cement mortar you use can be 1 part cement to 4 parts sand (1:4) up to 1 part cement-5 parts sand (1:5);
• place the feedstock inlet pipe (and toilet pipe, if installed) in position when the round-wall is 30-36 cm high;
• to reduce the risk of blockages, place the inlet pipe(s) as vertical as practically possible;
• leave a 60cm wide opening in the round-wall that serves as a manhole just opposite the main feedstock inlet pipe. The digested slurry will flow to the outlet tank through this opening, see Figure 4.5 showing the position of the manhole;
• place additional inlet pipes as close as possible to the main feedstock inlet pipe with a maximum distance of 45 degrees from the inlet-centre-manhole line;
• when the round-wall has reached the correct height, plaster the inside with a smooth layer of cement mortar with mix of 1:3 cement-sand.
Dome Construction

Once you complete the construction of the round as we described above, then the next thing to build is the spherical or dome-shaped gasholder. The gasholder is constructed with plain cement concrete with the help of an earthen mould prepared by filling excavated earth. The following are the main steps to follow:

- before you fill the pit with earth to make the mould for the dome, fill the backside of the round wall with properly compacted earth. If this is not done, the pressure of the earth for the mould can lead to cracks in the round wall;
- on the vertical centre pipe which is used for constructing the round wall, make a mark from the finished floor and fill in the finished digester up to the marked height;
- once the earth filling is completed, remove the vertical pipe by pulling it upwards. It has to be replaced by a shorter 0.5” diameter pipe, approximately 0.5 m length, in the earth exactly at the same spot.

Making the Shape of the dome using a template

Use a template to make the shape of the dome, as shown in Figure 4.6. Make sure that the top of the round wall is clean when the template is in use. Check the template by making sure that the top is horizontal and the side is exactly vertical. Furthermore, the part of the template that touches the round-wall must be in the same position all over the round wall. Any excess sand or soil that falls on the round wall must be removed.

Figure 4.5: View of manhole in main digester (Source: RURA, 2012)

Figure 4.6: Using a template to make the shape of the dome (Source: RURA, 2012)
Once you make the shape of the dome using a template, you should proceed as follows:

- ensure 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;
- spread a thin layer of fine sand on top of the mould by gently patting it on the surface. This is done when the earth mould has the exact shape of the guide. The sand layer prevents the earth from adhering to the cast. Figure 4.7 shows an earth mould with a sand layer before placing the cast;
- ensure that the earth used for the mould is damp to prevent dry earth from soaking up water from freshly casted concrete.

![Figure 4.7 Earth mould with sand layer before placing the cast (Source: RURA, 2012)](image)

- before you start the cast work, make sure that you have sufficient labour and construction materials like sand, gravel, cement and water on the site and ready for use;
- complete the casting as quickly as possible and without interruptions as this can negatively affect the quality of the cast;
- ensure there is a constant, adequate supply of concrete (mix: 1 cement, 3 sand, 3 gravel – 1:3:3) for the mason;
- do not use concrete older than 30 minutes;
- take special care 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;
- ensure that for 4 and 6 m³ plants, the thickness in the edge should be 15 cm whereas the thickness in the centre should be 7 cm;
- similarly, for 8 & 10 m³ plants, the thickness in the edge should be 20 cm whereas the thickness in the centre should be 7 cm;
- ensure that there is a continuous application of mortar along the sand mould 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, cover the exterior with 1:3 cement to sand plaster. Figure 4.8 below shows the earth mould with the sand layer before placing the dome.
leaving the small pipe on top of the mould in place until the main gas pipe is installed. This is to make sure that the main gas pipe is exactly in the centre;

- during the casting, protect the concrete against strong sunlight by covering it with wetted burlap, jute bags or straw mats. Leave this protection in place for at least one week;

- the day after the casting, make the turret. The turret is made with bricks, 36 cm square and 50 cm tall;

- plaster the turret with 1:3 concrete. Any delays during dome construction can lead to leakage between main gas pipe and dome;

- following completion of the dome (from the day after the casting onwards), sprinkle the structure with water 3 to 4 times a day during the curing period (up to one week). Figure 4.9 shows a completed dome with turret.

The gas-tightness of the gasholder is very important for the effective functioning of any bio-digester. If the gas stored in the gasholder escapes through the minute pores, the users will not be able to get gas at the point of application. The whole investment will therefore be wasted if the gasholder is not made perfectly gas-tight.

After approximately one week, depending on the temperature, remove the earth of the mould through the manhole. When all the earth is removed, scrub the surface of the gasholder clean using water and an iron brush.
Make sure you clean the entire surface of the concrete dome before you start plastering on the clean surface of the dome interior. The following 5 layers of plaster have to be applied to make the gasholder perfectly gas-tight:

- **Layer-1:** Plain cement-water flush (1 part cement and 3-5 parts of water), applied with the help of a broom;
- **Layer-2:** 10 mm thick plastering with cement sand mortar (1 part of cement and 3 parts of sand) applied with a plastering trowel;
- **Layer-3:** 3-5 mm thick cement - sand punning (1 part of cement and 2 parts of sand) with a plastering trowel;
- **Layer-4:** Plastering with cement and acrylic emulsion paint mix (1 part paint and 10 parts cement) 3 mm thick applied with a plastering trowel;
- **Layer-5:** Painting with thick layer of cement- acrylic emulsion paint (1 part of paint and two parts of cement) applied with a painting brush (10 cm wide).

While plastering the surface of the dome interior you should also consider the following points:

- a plaster coat must be well set before applying the next layer;
- allow an interval of one day between the third and fourth coat in order to achieve good gas-tightness;
- while applying the plaster layers, the work must be executed with the greatest care and without interruption in between;
- each layer must be smooth and fine;
- ensure curing of each layer before applying another layer;
- the well functioning of the plant is very much dependent upon the gas tightness of the dome and hence, the work of plastering each layer has to be done very carefully and as per the set quality standards. Figure 4.10 shows people plastering the digester and gas holder.

*Figure 4.10 Plastering of the digester and gas holder (Source: RURA, 2012)*

- 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, you should apply proper protection with gravel, circular wall, or straw matting.
Construction of the Outlet Chamber (Tank)

To construct the outlet tank also known as the displacement chamber, you should excavate just behind the manhole. You should complete the excavation of outlet chamber and manhole concurrently with the digester vessel as they share a common foundation with the digester vessel. It is important to accurately comply with the dimensions of the tank, as it determines the useful capacity of the gasholder. You should consider the following points when constructing the tank:

- the depth of excavation should be the inner depth of outlet plus the thickness of plaster plus the thickness of flooring (D+2+7.5 cm) from the ground level;
- when excavated at this depth, the top level of flooring should be exactly at the top of the manhole;
- the earth in the base of the outlet, behind the manhole, has to be well compacted, otherwise cracks will appear in the outlet floor later on;
- the length and breadth of digging should be the inner dimension plus the wall thickness plus the plaster layer;
- once the excavation is completed, compact the floor and lay broken stones or brick bats (broken bricks) on the floor;
- after properly compacting the stone or brick floor, lay a thick layer of course cement-sand mortar (1:4);
- the finished surface should be levelled and smooth. In this surface, once the mortar is set, start the construction of the outlet walls;
- while fixing the dimensions, allow at least 2 cm for plastering (in each side). Lay a first layer of mortar (1 cement: 3 sand) and start constructing the wall;
- first, place the bricks/stones in the four corners of the tank wall and fix a rope to guide the brick/stone work by tying it with the bricks/stones in either side;
- the walls should be vertical and finished with a smooth layer of cement plaster (1 cement: 3 sand);
- the outer part of the wall should be compacted well to avoid cracks due to slurry pressure from inside;
- there is no need of plastering the outside of the outlet tank walls;
- it is better to orient the outlet in such a manner that the length is parallel to the hart-line;
- always construct the overflow in the longer wall;
- the overflow level in the outlet wall should be at least 5 cm higher in elevation than the natural ground level. This is done to avoid the surface run-off from the surrounding areas to enter into the outlet, especially in the rainy season;
- support the outside of the walls with sufficient compacted earth up to the overflow level in order to avoid cracks.

Construction of Inlet Tank

Usually the inlet tank is constructed after completion of the outlet tank. However, it can be constructed simultaneously. If the feeding material is cattle dung, then an inlet tank is necessary. This tank is constructed to mix dung and water and make the required paste with solid content about 8-10% in the mix.
If you are going to use pig manure as your substrate, then a collection channel and maturation chamber must be constructed. The following are some of the facts that need to be considered while constructing an inlet tank to feed cattle dung into the digester:

- the foundation of the inlet pit should be placed in well rammed, hard and levelled surface;
- in the rammed surface, a rectangular portion of the inlet tank has to be constructed;
- the height of the base should be decided in such a manner that the floor of inlet tank is at least 15 cm above the outlet overflow level. Figure 4.11 below shows construction of an inlet tank.

![Figure 4.11 Construction of an inlet tank (Source: RURA, 2012)](image)

- once the base is constructed, the circular portion of the inlet tank has to be constructed where the dung and water will be mixed;
- prior to the commencement of the construction of the round wall for the inlet, you should make provisions in the base to house the mixing device if a mixing device is to be installed;
- to fix the mixing device in position, a pivot should be placed at the centre of the base of inlet, before the floor of the inlet tank is made.
- in the finished surface, you should make a circular mark with the help of a thread or cord of 30 cm radius to decide the inner circumference of the tank.
- the round wall of the inlet tank should now be constructed with the brick placed in circular fashion following the mark already made. See Figure 4.12 below.

![Figure 4.12: Inlet tank during masonry construction (Source: RURA, 2012)](image)
when the height of circular pit reaches to 45 cm, an iron bracket should be fixed to tighten the mixing device, if it is to be installed;  
the mixing device should be firmly attached to the structure, so that it can be easy to operate, effective in the mixing process and rust-proof;  
the steel parts in contact with the slurry need to be galvanized properly;  
the height of the inlet from the ground level including the base should be at least 90 cm or not more than 100 cm;  
once the round wall is constructed, enough time should be allowed to set the mortar properly;  
even if a mixing device is not installed, the inlet pit should be round in shape as this easier for hand mixing and facilitates a more economical use of material  
both the inside and outside of the tank should be plastered with cement mortar (1 part of cement to 3 parts of sand);  
the bottom of the tank must be at least 15 cm above the overflow level in the outlet wall;  
the position of the inlet pipe in the floor must be such that a pole or rod could be entered through it without obstructions if any de-blocking is needed;  
if the inlet pipe is not positioned properly, the inlet walls have to be dismantled to insert a rod or pole through it. Figure 4.13 shows a complete inlet tank with a mixing device.

*Figure 4.13: Complete inlet pipe with a mixing device (Source: RURA, 2012)*

**Layout of Gas Pipes**  
The gas pipe carries gas from the biogas plant to the point of use. It is vulnerable to damages by people, domestic animals and rodents. Therefore during its construction you should consider the following points:  
use light quality PVC pipe only and where possible it should be buried 30 cm below ground level;  
seal the fittings in the pipeline with zinc putty, Teflon tape or jute and paint;  
do not use any other sealing agent, like grease, paint only, soap etc.;  
avoid the use of fittings, especially unions, in order to reduce the risk of leakage;
• do not place fittings between the main gas valve and the dome gas pipe;
• ensure the inside diameter of the pipe is between 6 and 1 cm;
• the pipe size is determined by the size of the digester, (amount of gas produced) and amount of gas required in the house.
• Install a water drain or trap in the pipeline. The position of the water drain should be vertical below the lowest point of the pipeline so that water can flow by gravity to the trap;
• ensure the drain is easily accessible and protected in a well-maintained drain pit since water will be removed periodically by opening the drain. Figure 4.14 shows the layout of gas pipes.

![Diagram of gas pipeline layout](image)

**Figure 4.14: Layout of condensate drain valve in gas line**

Connecting gas burners and other appliances to gas pipeline
When connecting burners and other appliances to the gas pipeline you should take note of the following:
• do not connect burners to gas pipelines with transparent polyethylene hose;
• use only the best quality neoprene, rubber hose. Other biogas appliances should be mounted and connected to the galvanized iron pipe;
• inspect all the joints and taps for leakage by applying a thick soap solution and observing for foam movement.

Figure 4.15 below shows a picture of an installed biogas plant.

![Diagram of biogas plant](image)

**Figure 4.15: Installed biogas plant**
You have now come to the end of this section on construction of a biogas plant. To help you remember what you have learnt, complete the following activity.

**Activity 4.3**

**Construction of a biogas site**
1. Tick the factors that you would consider when selecting the site for constructing your biogas plant.
   - Site that guarantees plant safety
   - Site with an uneven surface
   - Site that provides easy operation and maintenance of biogas plant
   - A site with temperatures below 35° C
   - A site with enough space for compost pits
   - A site near trees
   - A site in a slightly higher elevation than the surrounding

2. Arrange the steps of biogas plant construction in column A in the correct order in column B

<table>
<thead>
<tr>
<th>COLUMN A</th>
<th>COLUMN B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excavation</td>
<td></td>
</tr>
<tr>
<td>Plant layout</td>
<td></td>
</tr>
<tr>
<td>Construction of inlet tank</td>
<td></td>
</tr>
<tr>
<td>Construction of the digester chamber</td>
<td></td>
</tr>
<tr>
<td>Dome construction</td>
<td></td>
</tr>
<tr>
<td>Construction of the outlet chamber</td>
<td></td>
</tr>
<tr>
<td>Selection of the site</td>
<td></td>
</tr>
<tr>
<td>Laying of gas pipes</td>
<td></td>
</tr>
</tbody>
</table>

Compare your answers with those given at the end of this unit.

That brings us to the end of this unit. Let us now review what you have learnt.

**What have we learnt?**

In this unit we have discussed the responsibilities of a biogas constructor and the materials you need for the construction of a biogas plant. We also looked at the construction of the various components of a biogas plant, from excavation to the construction of the digester chamber, dome, inlet tank and outlet chamber, among others.

Congratulations! You have now come to the end of this course on biogas production for domestic use. We hope that you are now well equipped to supervise the construction of your plant and produce biogas for domestic use. Appendix 1 gives you quotations for the construction of different sizes of fixed dome digesters to help you choose the one that fits your budget. Good luck!
Answers to Learning Activities

Activity 1.1: Statement B is not true about biogas technology. Biogas is produced during anaerobic (without oxygen) digestion of organic matter.

Activity 1.3: Benefits of Biogas Technology
Which of the following are potential benefits of biogas technology at the domestic level? Tick the correct answers.

- It is an important energy source for cooking and lighting
- Causes in-house pollution and destruction of forests
- Converts plant and livestock waste into high quality manure
- Saves money that would have been used to purchase kerosene or gas for cooking
- Contributes to a healthy environment free of flies and mosquitoes
- It is not women-friendly

Activity 2.1: Components of a Biogas Plant
Draw a line to match each component of a biogas plant with its correct function.

<table>
<thead>
<tr>
<th>Component</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet Pipe</td>
<td>Collects the gas produced</td>
</tr>
<tr>
<td>Digester</td>
<td>Connects to a lamp or gas burner</td>
</tr>
<tr>
<td>Gas holder</td>
<td>Facilitates outflow of exhausted slurry</td>
</tr>
<tr>
<td>Gas pipe</td>
<td>Transports organic waste to the digester</td>
</tr>
<tr>
<td>Outlet pipe</td>
<td>Reservoir in which anaerobic digestion takes place</td>
</tr>
</tbody>
</table>

Activity 2.2: Input Factors that hinder biogas production
Tick the factors that hinder the process of biogas production

- A carbon/nitrogen ratio ranging from 20 to 30
- Extremely high and low temperatures
- Mixing cow dung with water at a ratio of 1:1
- When pH value in the digester is less than 5
- A total solid content of 8%
- Presence of heavy metals and detergents

Activity 3.1: Bio digester Designs
- The floating drum digester has two separate structures for gas production and gas collection. [True]
- The floating drum digester has low maintenance and installation costs [False]
- A fixed dome biogas plant comprises of a closed, dome-shaped digester [True]
- The underground fixed dome digester is protected from temperature fluctuations which has a positive influence on the bacteriological process. [True]
- In a fixed dome digester the gas is stored in the lower part of the digester [False]
• The Deenbandhu model is 45% cheaper than the floating drum plant of equal size [True]
• The plastic bag digester is not suitable for places with a high water table [False]

Activity 4.1: Responsibilities of a Biogas Constructor
Which of the following are NOT the responsibility of a biogas contractor?

☐ Providing information on benefits of a bio-digester
☑ Providing finances for the construction of a biogas plant
☐ Selecting the correct size based upon availability of substrate of feeding stock
☑ Deciding whether or not to build a bio-digester
☐ Provide follow-up and after sales service

Compare your answers with those given at the end of this unit.

Activity 4.2: Materials for construction of a biogas plant  (Time: 10 mins)
1. What type of materials would you need for the construction of your biogas plant?
   • Cement,
   • Sand
   • Gravel
   • Water
   • Bricks
   • Cobblestones.

Activity 4.3: Selection of a construction site.
1. Tick the factors that you would consider when selecting the site for the construction of a biogas plant.

☑ Site that guarantees plant safety
☐ Site with an uneven surface
☑ Site that provides easy operation and maintenance of biogas plant
☐ A site with temperatures below 35° C
☑ A site with enough space for compost pits
☐ A site near trees
☑ A site with a slightly higher elevation than the surroundings

2. Arrange the steps of biogas plant construction listed in Column A in the correct order in Column B

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</tr>
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<td>Construction of inlet tank</td>
<td>Excavation</td>
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<td>Construction of the digester chamber</td>
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<tr>
<td>Dome construction</td>
<td>Dome construction</td>
</tr>
<tr>
<td>Construction of the outlet chamber</td>
<td>Construction of the outlet chamber</td>
</tr>
<tr>
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<td>Construction of inlet tank</td>
</tr>
<tr>
<td>Laying of gas pipes</td>
<td>Laying of gas pipes</td>
</tr>
</tbody>
</table>
APPENDIX 1: QUOTATIONS FOR DIFFERENT SIZES OF FIXED DOME DIGESTERS IN KENYA AS AT JANUARY, 2015. (Obtained courtesy of Kenya National Domestic Biogas Programme (KENDBIP))

<table>
<thead>
<tr>
<th>ITEM</th>
<th>Approx. cost (Ksh)</th>
<th>Quantity per given size and approximate cost of materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td></td>
<td>4m3 6m3 8m3 10m3 12m3</td>
</tr>
<tr>
<td>No. of cows</td>
<td>1-2</td>
<td>3-4 5-6 7-8 9-12</td>
</tr>
<tr>
<td>Cement 50kg bags</td>
<td>700</td>
<td>12(8,400) 15(10,500) 18(12,600) 22(15,400) 25(17,500)</td>
</tr>
<tr>
<td>River sand in tonnes</td>
<td>1200</td>
<td>3 (3,600) 5 (6,000) 6 (7,200) 7 (8,400) 7(8,400)</td>
</tr>
<tr>
<td>Gravel/Ballast in tonnes</td>
<td>700</td>
<td>1(700) 2(1,400) 3(2,100) 4(2,800) 4(2800)</td>
</tr>
<tr>
<td>Quarry stones 6” x 9”</td>
<td>30</td>
<td>200(600) 250 (7,500) 250 (7,500) 300 (9000) 420(12600)</td>
</tr>
<tr>
<td>Bricks pcs</td>
<td></td>
<td>10 150(1,500) 200(2,000) 300(3,000) 350(3,500) 400(4,000)</td>
</tr>
<tr>
<td>Round bars 3/8” (Y8)</td>
<td>480</td>
<td>4(1,600) 4(1,600) 4(1,600) 4(1,600) 4(1,600)</td>
</tr>
<tr>
<td>Round bars 1/4” (R6)</td>
<td>180</td>
<td>1(180) 1(180) 1(180) 1(180) 1(180)</td>
</tr>
<tr>
<td>PVC pipe 4”</td>
<td>780</td>
<td>1(780) 1(780) 1(780) 1(780) 1(780)</td>
</tr>
<tr>
<td>PVC elbow 4” 45 degrees</td>
<td>250</td>
<td>1(250) 1(250) 1(250) 1(250) 1(250)</td>
</tr>
<tr>
<td>Dome pipe</td>
<td>2500</td>
<td>1(2,500) 1(2,500) 1(2,500) 1(2,500) 1(2,500)</td>
</tr>
<tr>
<td>Binding wire in kgs</td>
<td>150</td>
<td>1(150) 1(150) 1(150) 1(150) 1(150)</td>
</tr>
<tr>
<td>Water proof additive</td>
<td>300</td>
<td>3(900) 5(1,500) 5(1,500) 7(2100) 10(3000)</td>
</tr>
<tr>
<td>Plumbing / piping fee</td>
<td></td>
<td>5000 5000 5000 5000 5000</td>
</tr>
<tr>
<td>Technical fee (Ksh)</td>
<td>25000</td>
<td>25000 25000 25000 25000 25000</td>
</tr>
<tr>
<td>Total cost (Ksh)</td>
<td></td>
<td>51,160/= 64360/= 69360/= 76660/= 83760/=</td>
</tr>
</tbody>
</table>

NB: The farmer should be able to select the size of the proposed digester depending on the number of his cows.
References

3. ISAT/GTZ (undated). *Biogas Digest Volume I*. ISAT, Eschborn, Germany.
4. ISAT/GTZ (undated). *Biogas Digest Volume II*. ISAT, Eschborn, Germany.