Operation & Maintenance Guideline for Bio-Digesters

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1 BIOGAS AND ANAEROBIC DIGESTION

Anaerobic Digestion (AD) is the conversion of organic non-woody material (organic matter) in the absence of oxygen into stable and commercially useful compounds. AD feedstock can be biodegradable materials such as biomass, manure or sewage, municipal waste, green waste etc. Besides the process of anaerobic digestion takes place in the intestines of humans and animals.

Digestion process

The digestion process consists of 4 stages: hydrolysis, acidification, acetogenesis and methanogenesis.

In the first phase anaerobic bacteria use enzymes to decompose high molecular organic substances such as proteins, carbohydrates, cellulose and fats into low molecular compounds. During the second phase acid forming bacteria continue the decomposition process into organic acids, carbon dioxide, hydrogen sulphide and ammonia. Acid bacteria form acetate, carbon dioxide and hydrogen during the acetogenesis phase. The methanogenesis phase involves methane forming bacteria producing methane, carbon dioxide and alkaline water.

Use of anaerobic digestion

AD is widely used to treat wastewater sludge and organic waste because it provides volume and mass reduction of the input material. Anaerobic digestion is widely used as a renewable energy source because the process produces a methane and carbon dioxide rich biogas suitable for energy production helping replace fossil fuels. Also, the nutrient-rich digestate can be used as fertiliser.

System options

Although the process of AD is relatively simple there are several system options which will be determined by feedstock type, output requirements, space and infrastructure. System options are as follows:

- <u>Mesophilic</u> (25 – 45°C) or <u>thermophilic</u> (50 - 60°C)

  <u>Mesophilic Digestion</u>: The digester is heated to 30 – 35°C and the feedstock remains in the digester typically for 15 to 30 days. Mesophilic digestion tends to be more robust and tolerant than the thermophilic process but gas production is less, larger digestion tanks are required and sanitisation, if required, is a separate process stage. Mesophilic digestion is the most common approach since it is more reliable and plant management is easier.

  <u>Thermophilic Digestion</u>: The digester is heated to 55°C and the residence time is typically 12 to 14 days. Thermophilic digestion systems offer higher methane production, faster throughput, better pathogen and virus 'kill', but require more expensive technology, greater energy input and a higher degree of operation and monitoring.

During this process 30 to 60 % of the digestible solids are converted into biogas.

- Wet (5 – 15 % dry matter) or dry systems (over 15 % dry matter)
- Continuous or batch flow
- Single, double or multiple digesters
- Vertical tank or horizontal plug flow

2 THE BIO-DIGESTER

A bio-digester is a tank that facilitates anaerobic digestion (☞ Chapter 1). It is an anaerobic treatment technology that produces (a) a digested slurry and (b) biogas. Often, a bio-digester is used as an alternative to a conventional septic tank, since it offers a similar level of treatment, but with the added benefit of biogas.

A bio-digester can come in different shapes and sizes, depending on the general requirements, the needs and the local possibilities in building materials.

A bio-digester or biogas system is a waste-management solution that traps methane as it is produced, making it available for heating, cooking or even electricity generation. By preventing methane from venting freely into the atmosphere, the system can help reduce emissions that contribute to climate change. Biogas is a sustainable substitute for the propane, kerosene, and firewood often used in Kenya for energy needs.

Outputs from the digestion process

The outputs from the digestion process are:

1. **Biogas** – a mixture of ~ 60 % methane (C_2H_4), ~ 40 % carbon dioxide (CO_2), hydrogen sulphide (less than 1 %) and traces of other 'contaminant' gases. This biogas is then combusted to generate heat, power or road fuel.
2. **Digestate (slurry)** – an inert and sterile wet product with valuable plant nutrients and organic humus. This product can be separated into 'liquor' and fibre for application to land or secondary processing.

Biogas

The valuable component of Biogas is methane (CH_4) which typically makes up 60 %, with the balance being carbon dioxide (CO_2) and small percentages of other gases. The proportion of methane depends on the feedstock and the efficiency of the process, with the range for methane content being 40 % to 70 %. Biogas is saturated and contains hydrogen sulphide (H_2S) that is partially responsible for the foul odour of rotten eggs and flatulence.

Use of biogas

In developing countries the most common use is where biogas is used with suitable designed burners for cooking. It gives a clean, smokeless blue flame. Where biogas replaces firewood as a fuel for cooking, this technology helps to reduce deforestation. Also, as biogas burns much cleaner than traditional wood stoves, it helps to reduce eye- and respiratory diseases caused by smoke in unventilated houses (the World Health Organisation estimates that exposure to indoor air pollution may be responsible for nearly 2 million excess deaths in developing countries).

Besides, biogas can fuel an internal combustion gas engine in a Combined Heat and Power (CHP) unit to produce electricity and heat.

In Sweden the compressed gas is used as a vehicle fuel and there are a number of biogas filling stations for cars and buses. The gas can also be upgraded and used in gas supply networks. The use of biogas in solid oxide fuel cells is being researched

Slurry

Only a small proportion of the total mass of the feedstock is converted into biogas. The slurry that is produced is rich in organics and nutrients, but almost odourless and partly disinfected (complete pathogen destruction would require thermophilic conditions).

Use of slurry

The slurry is rich in various plant nutrients such as Nitrogen, phosphorus and potash. Nutrients are conserved with more than 90 % of nutrients entering anaerobic digesters conserved through the digestion process. Well fermented biogas slurry improves the physical, chemical and biological properties of the soil resulting to qualitative as well as quantitative yield of food crops. Other uses of slurry include putting into ponds as feed for algae, water hyacinth, fish or ducks, mushroom cultivation.

Feeding material

In theory, any organic material can be decomposed anaerobically to produce biogas, but some materials work better than others. In general, materials need to be rich in energy and easily digestible. Manure works very well, coming from cows, pigs, or horses. Bio-digesters can be fashioned from septic tanks, but the waste production is often not enough to produce enough biogas, and cleaning agents (bleach etc.) kill the anaerobic bacteria necessary for digestion. Plant material can be used, but acidic matter should be avoided, for they disturb the anaerobic processes. Plant matter is also often low-energy and slow to digest, creating a number of difficulties for digesters relying solely on such material.

Production capacity

It is very difficult to estimate the production capacity of a bio-digester for the following reasons:

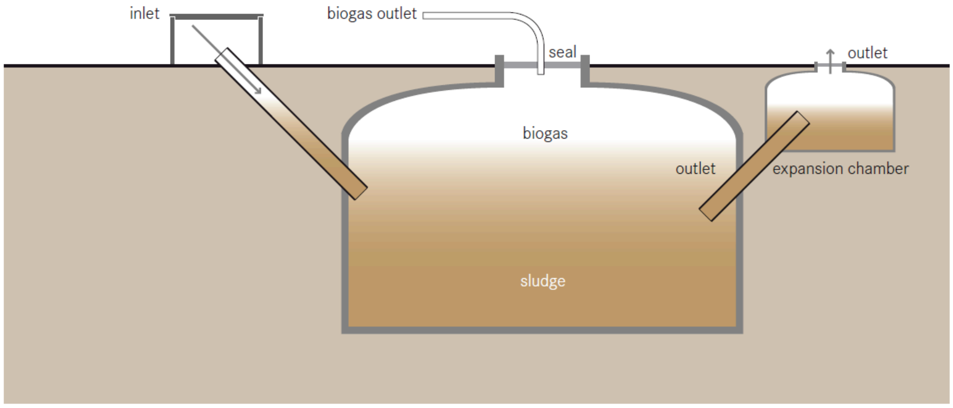
- Biogas production is best measured by scientific processes.
- Biogas production varies with the type of material used to feed the bio-digester.
- Biogas production varies with the temperature of the mixture inside the tank.
- Biogas production varies with the acidity or alkalinity of the mixture inside the tank.
- Other factors, such as defects in construction, can make true measurements of biogas production very difficult.

Layout

A bio-digester is a chamber or vault that facilitates the anaerobic degradation of blackwater, sludge, and/or biodegradable waste. It also facilitates the separation and collection of the biogas that is produced.

The tanks can be built above or below ground. Prefabricated tanks or brick-constructed chambers can be built depending on space, resources and the volume of waste generated. Figure 1 displays the rough layout of a bio-digester.

Figure 1: Layout of a bio-digester (example)



Hydraulic retention time (HRT)

The hydraulic retention time (HRT) in the reactor should be a minimum of 15 days in hot climates and 25 days in temperate climates. For highly pathogenic inputs, a HRT of 60 days should be considered. Normally, bio-digesters are not heated, but to ensure pathogen destruction (i.e. a sustained temperature over 50°C) the reactor should be heated (although in practice, this is only found in the most industrialized countries).

Gas utilisation

Once waste products enter the digestion chamber, gases are formed through fermentation. The gas forms in the sludge but collects at the top of the reactor, mixing the slurry as it rises.

Bio-digesters can be built as fixed dome or floating dome reactors. In the fixed dome reactor the volume of the reactor is constant. As gas is generated it exerts a pressure and displaces the slurry upward into an expansion chamber. When the gas is removed, the slurry will flow back down into the digestion chamber. The pressure generated can be used to transport the biogas through pipes. In a floating dome reactor, the dome will rise and fall with the production and withdrawal of gas. Alternatively, the dome can expand (like a balloon).

Size

Most often bio-digesters are directly connected to indoor (private or public) toilets with an additional access point for organic materials. At the household level, reactors can be made out of plastic containers or bricks and can be built behind the house or buried underground. Sizes can vary from 1 m^3 for a single family up to 100 m^3 for institutional or public toilet facilities.

Emptying

Depending on the design and the inputs, the reactor should be emptied once every 6 months to 10 years.

Efficiency

If the bio-digester is connected to (sanitation) facilities and also receives a lot of water (e.g. greywater form showers and sinks) the efficiency of the reactor can be improved significantly by also adding animal manure and biodegradable organic waste.

Location

Depending on the soil, location, and size required, the reactor can be built above or below ground (even below roads). For more urban applications, small biogas reactors can be installed on the rooftops or in a courtyard.

To minimize distribution losses, the reactors should be installed close to where the gas can be used.

Climate aspects

Bio-digesters are less appropriate for colder climates as gas production is not economically feasible below 15°C.

Health Aspects / Acceptance

The digested slurry is not completely sanitized and still carries a risk of infection. There are also dangers associated with the flammable gases that, if mismanaged, could be harmful to human health.

The bio-digester must be well built and gas tight for safety. If the reactor is properly designed, repairs should be minimal. To start the reactor, active sludge (e.g. from a septic tank) should be used as a seed. The tank is essentially self-mixing, but it should be manually stirred once a week to prevent uneven reactions.

Gas equipment should be cleaned carefully and regularly so that corrosion and leaks are prevented.

Grit and sand that has settled to the bottom should be removed once every year.

3 ADVANTAGES AND DISADVANTAGES OF BIO-DIGESTER TECHNOLOGY

Advantages

Processing organic waste anaerobically to create biogas is a sustainable, renewable waste to energy solution. While waste needs to be added and effluent removed on a daily basis, bio-digesters are typically very reliable systems that require little maintenance. The process offers numerous advantages over conventional technologies / wastewater treatment options:

+ Reducing the transport of wastewater and waste as it is treated on-site;
+ Reduce contamination of surface water, groundwater and other resources;
+ Reduce odours and pathogens (closed vessel processing confines odorous compounds which are converted to other chemicals);[1]
+ Generation of a clean, renewable, valuable energy source;
+ Preventing the uncontrolled emissions of CH_4;

[1] Bio-digesting sewage can reduce the parasitic and pathogenic bacterial counts by over 90%. The product of digestion has no more odour than compost.

+ Reduce greenhouse gas emissions;[2]
+ No electrical energy required;
+ Low capital and operating costs;
+ Underground construction minimizes land use;
+ Long life span;
+ Can be built and repaired with locally available materials;
+ Bio-fertiliser produced displaces mineral fertilisers;
+ Improvement in slurry characteristics such as: fluidity, crop compatibility, homogeneity, reduction of weed germs.
+ Can accommodate a wide variety of organic wastes including animal manure, night soil, crop stalks, straw, slaughterhouse wastes, biodegradable garbage and wastewater.
+ Production of electricity and heat provides valuable income.
+ Positive use of organic waste materials reduces land and water pollution.

Disadvantages

Bio-digesters function poorly in colder climates unless an external heat source is applied. The methanogenic bacteria responsible for generating biogas require temperatures well above freezing (optimal temperature ranges - mesophilic: 30 to 40°C; thermophilic: 50 to 60°C), so bio-digesters are not ideal in cooler areas.

In order to keep the anaerobic digestion process going continually, bio-digesters require a daily amount of work and a consistent source of organic materials:

- If organic waste and not only wastewater is fed into the digester, each day, the waste to be added needs to be mixed with water and/or ground to a liquid state. Manure and wastewater from sanitation facilities are water-soluble, but kitchen scraps, such as banana and orange peels need to be ground into smaller which can be time consuming.
- Each day, the bio-digester effluent needs to be removed from the effluent tank.
- Biogas provides much less energy compared to fuels such as propane and natural gas.
- Requires expert design and skilled construction.
- Gas production below 15°C is not economically feasible.
- Digested sludge and effluent still requires treatment.

[2] Since anaerobic digestion operates in a closed system, substantial reductions in greenhouse gas emissions are achieved. Ammonia losses, while not of direct GHG concern, are also reduced.

4 TECHNICAL DESIGN

The technical design (drawings and bill of quantities) of a bio-digester are presented in Module 6 of this toolkit.

5 OPERATION AND MAINTENANCE REQUIREMENTS OF DIGESTERS AND BIOGAS PLANTS

Factors affecting the biogas plant

To ensure a sufficient treatment process while at the same time increasing the biogas conditions such as air tightness, suitable temperature, necessary nutrients, water contents, and maintaining suitable pH balance must be maintained. The following factors affecting the digestion process have to be optimised and observed during operation:

1. Temperature

   The optimum temperature for methane producing bacteria is about 35°C. When the slurry temperature is low gas production is greatly reduced. At 10°C (slurry temperature) the production of biogas more or less stops.

2. Retention time

   The retention time is temperature dependent. The higher the temperature, the faster the bacteria use the food from the slurry and sooner it needs replacing.

3. Air

   Methane producing bacteria are anaerobic. So air should be excluded in the plant interior.

4. Bacterial concentration

   It is greatly affected with methanogenic bacteria. If they are less in number, gas production is greatly reduced. The fermentation process involves in two stages. Firstly bacteria breakdown complex organic materials and secondly the breakdown of organic materials to produce methane by a kind of bacteria known as methanogenic microorganism. If this type of bacteria is not developed to attack cellular materials in the dung, methane cannot be formed.

5. Carbon-Nitrogen ratio (C:N ratio)

   The elements of carbon and nitrogen are the main nutrients for anaerobic bacteria. Carbon is utilized for energy and nitrogen for the building of cell structures. Bacteria use carbon 25 – 30 times faster than they use nitrogen. So the ratio seems 25-30:1. If the carbon nitrogen ratio is not appropriate, we can increase or decrease the ratio by adding certain amount of urea or gypsum.

6. pH

pH for bacteria is usually 7-8, but can go up or down further by 0.5. pH can be checked either with universal indicator or pH paper or pH meter. It is quite easy to find out the pH with the help of pH paper.

7. Gobar water ratio

The ratio is dependent upon the feeding materials (dry matter). However, there should not be any stratification in the digester. In other words, mixing of gobar should be properly done, which can be easily observed by calculating the percentage of dry matter (DM %). If there is a great change in DM % of the top as well as bottom, there will be stratification. Generally, gobar water ratio should be 1:1. If the amount of water is more the gas production is less. The slurry should be neither too thick (more than 14 %) nor too thin (less than 6 %) but should be 8 – 10 % of total solids.

8. Solid contents

The solid contents of the slurry should be 8-10%.

The table below describes standard operating procedures for the bio-digester with respective intervals.

Table 1: Standard operating procedures for the bio-digester

Procedure	Description	Interval
Feeding of bio-digester	Feed the digester regularly with the right material. If the plant is fixed to toilets, they should be under constant use to guarantee regular feeding to ensure continuous gas production.	Daily
Increasing the micro-bacterial activity by addition of cow dung	The concentration of the anaerobic bacteria can be increased by first putting fresh cow dung into the digester which already contains bacteria. Cow dung has got methanogen bacteria which are of the same type as the ones in the digester.	If required
Slurry analysis	Slurry analysis should be done at least once a year and whenever need arises especially when gas production has reduced.	annually
pH-testing	The pH of the slurry should be tested regularly and whenever need arises especially when gas production has reduced.	monthly
No use of gas	Valve at the neck should always be closed when gas is not used.	
Inspection of gas pipes	Check for the leakages along the pipes and the accessories. Teflon tape must be used in pipe fittings to avoid leakage from pipe fittings.	Annually
Water traps and moisture control	Check and remove the accumulated water in the water traps once every week. The water trap or water drain at the lowest part of the piping line should be checked regularly for its functionality. Water drain must be made at the lowest level of the fittings. Excess overflow of water in this device may increase the moisture content in the gas	Weekly

Procedure	Description	Interval
	rendering it inflammable.	
Replace the gas valves and taps anytime they start to leak	Biogas has a tendency of corroding GI pipe fittings. During piping, these components should be avoided but in case they are used, they should be replaced regularly in a spun of two years.	Every two years
De-sludging of decomposed waste from the digester plant.	This is the process of manual or mechanical removal of the settled decomposed waste at the bottom of the plant. During anaerobic decomposition of waste gases are produced and the remains settle down after some time. This continuous process accumulates some solids which affect the performance of the plant with time. De-sludging therefore becomes necessary after a period of 18 months depending on the type of waste digested. During de-sludging, an exhauster can be used through the de-sludging down pipe. Manual removal of waste where no exhauster services can be applied but with caution. All the gas produced must first be released to the air or used up. The sealed neck can then be removed slowly beginning with wedges. The waste can be removed till everything is emptied to the floor.	Every 18 months
Cleaning of the gadgets connected to biogas as fuel	Biogas contains other gases such as carbon dioxide and sulphur dioxide as a result of decay. During combustion, these gases disintegrate producing other solid components as Carbon and sulphur oxides that are dissipated on the surfaces of the stoves, lamps, generators and all the equipments used. This causes blockages when they have accumulated to reasonable level. It is advisable to clean off all these particles for higher equipment efficiencies.	If required

Low gas yield especially in the winter seasons, underfeeding of the plants, no commercial use of gas as well as slurry, no choice of other design, size and feeding materials are some of the technical problems.

The following table highlights the most common problems in digester operation and corresponding operating procedures:

Table 2: Problems and procedures

Problem	Reason	Procedure
Biogas does not burn	The first gas coming from the plant may not burn	Remove the gas from dome once or twice. If the problem persists, check the water traps and empty them well.
Plenty of gas in the dome but won't come to the stove	Main valve may be closed	Open main gas valve.
	Gas tap or gas jet may be blocked	Clean the gas tap and gas jet.
	May be blocked in the pipe line	Open main gas valve and water drain. Remove the water or slurry through the water outlet.
Less gas production	Irregular feeding	Feed the digester as recommended.
	Low outside temperature	Insulate the plant
	Too much water in the digester	Put less water in the toilet and add water as recommended.
	Toxic substances entered the digester	Use clean water only for cleaning the toilets. Minimize use of disinfectants.
	Leakage from the pipe line	Check joints and fittings with the help of soap water. If bubbles occur repair the leakage.
The flame is weak and red	Impurities in the gas tap and/or stove	Clean the gas tap and stove weekly.
	Insufficient amounts of gas inside the plant	Close the valve to allow more gas collection. Check for any leakages along the pipes and fittings with soapy water.
Gas burns with long flame	There may be blockage in the air regulating hole and ring	Clean the hole and the ring.
Slurry comes through the pipe line	Inadequate feeding	Feed the plant adequately.
	Gas using frequently	Close the valve for about 10 hrs.
	Gas leakage	Check the main gas valve and other fittings with soap water and repair the leakage. If the problem is not solved contact the concerned company.
Gas leakage	Leakages around the neck and on the Lid	Gas leakages can be very dangerous and harmful to the environment. The sealed neck is kept under water film in the neck so as to detect any leakages if any. Check for any leakages on the dome, if applicable and around the neck. This can be done by use of soapy water on top of the sealed lid.

6 ECONOMICS

Economics

The viability of a bio-digester will depend on:

- The availability of waste to give a feedstock of zero cost;
- Whether the electricity generated (if applicable) is displacing existing demand;
- Whether gas generated is displacing existing demand (e.g. cooking);
- Whether value is derived from surplus heat and the bio-fertiliser produced;
- Scale and location of the digester.

Capital costs for gas transmission infrastructure can increase the project cost. Depending on the quality of the output, the gas transmission capital costs can be offset by long-term energy savings.