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FROM DOCUMENTED EXPERIENCE

Nº2

Comprehensive Overview of Biogas for Sanitation Options – Training of Trainers

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Comprehensive Overview of Biogas for Sanitation Options – Training of Trainers

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The findings and conclusions contained within are those of the authors and do not necessarily reflect
positions or policies of the Bill & Melinda Gates Foundation or other above mentioned institutions.

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Abbreviations & Acronyms

% vol Volume percent
ABR Anaerobic Baffle Reactor
AD Anaerobic Digestion
AF Anaerobic Filter
ASBR Anaerobic Sequencing Batch Reactor
BAU Bangladesh Agricultural University (Bangladesh)
Biol Bio-liquid: liquid fraction of / from bio-slurry after liquid-solid separation
Biosol Bio-solid: solids fraction of / from bio slurry after liquid-solid separation
BOD Biological Oxygen Demand
BRAC Building Resources Across Community (Bangladesh NGO)
BSERT Bureau of Socio-Economic Research and Training (Bangladesh)
C/N ratio ratio of Carbon to Nitrogen in organic material
Ca Calcium
Cd Cadmium
CD Cow dung
CH_4 Methane
cm centimeter
CO_2 Carbon Dioxide
COD Chemical Oxygen Demand
Cr Chromium
CSES Center for Sustainable Environmental Sanitation (China)
Cu Copper
d day
DAE Department of Agricultural Extension (Bangladesh)
DM Dry Matter
e.g. for example (from Latin: *exempli gratia*)
Fe Iron
FRP Fiber Glass Reinforced Plastic
FYM Farm Yard Manure
g gram
h hour(s)
H2 Hydrogen
H_2O Water
H_2S Hydrogen Sulfide
HCO_3 Bicarbonate
HRT Hydraulic Retention Time
IDCOL Infrastructure Development Company Limited (Bangladesh)
incl. including
Index of Wobbe an indicator of the interchangeability of fuel gases such as natural gas, liquefied petroleum gas (LPG), and town gas and is frequently defined in the specifications of gas supply and transport utilities.
K Potassium
K_2O Potassium Oxide
kg Kilogram
kg/m^3 Kilogram per cubic meter
kPa Kilopascal
kW Kilo Watt
kWh/m^3 Kilo Watt hour per cubic meter

Abbreviations & Acronyms

l	liter
l/d	liter per day
l/p/d	liter per person per day
LPG	Liquefied Petroleum Gas
mbar	millibar
m	meter
m^3	cubic meter
mg	milligram
Mg	Magnesium
mg/l	milligram per liter
mg/m^3	milligram per cubic meter
MJ/m^3	Megajoule per cubic meter
min	minutes
mm	millimeter(s)
Mn	Manganese
N	Nitrogen
N2	Di-Nitrogen
NH3	Ammonia
O2	Oxygen
°C	Celsius Degree
ODM	Organic Dry Matter
°K	Kelvin Degree
P	Phosphorus
Pb	Lead
P_2O_5	Di-Phosphorus Pentoxide
PAHs	Polycyclic Aromatic Hydrocarbons
PCI	Pouvoir Calorifique Inférieur = Lower heating value
PCS	Pouvoir Calorifique Supérieur = Higher heating value
pH	measure of the acidity or alkalinity of a solution
PL	Poultry litter
ppm	Parts per million
Prefab FRP digester	Prefabricated fiber glass reinforced plastic digester
RD	recommended doses
SRT	Sludge Retention Time
SWOT	Strengths - Weaknesses - Opportunities - Threats
tons/ha	tons per hectare
TS	Total Solids
U places	flexible pipe forming a “U” when hanging
UASB	Upflow Anaerobic Sludge Blanket digester
UPM	Umwelt-Projekt-Management GmbH
USTB	University of Science and Technology Beijing (China)
VS	Volatile Solids
WHO	World Health Organization
Zn	Zinc

Preface

This publication is the result of the technical assistance provided by UPM Umwelt-Projekt-Management GmbH (UPM) and its partners, the Centre for Sustainable and Ecological Sanitation (CSES) of the University of Science & Technology Beijing (USTB), and the Bureau of Socioeconomic Research and Training (BSERT) of the Bangladesh University of Agriculture (BAU) to the United Nations High Commissioner for Refugees (UNHCR), the Department of Public Health Engineering (DPHE) and the local WASH sector in Cox's Bazar, Bangladesh, in cooperation with the Bill & Melinda Gates Foundation.

The goal of this technical assistance assignment was to provide support to the emergency WASH sector and local administration, regarding sanitation and faecal sludge management, with focus on value—recovery in emergency settings, in order to sustainably improve the living conditions of displaced populations and their hosting communities.

The present manual "Comprehensive Overview of Biogas for Sanitation Options- Training of Trainers" has been elaborated after a three-days training on "Biogas Sanitation Systems for Rohingya Refugee Camps" organised with engineers and technicians of BRAC working in the area in December 2018.


brac
BILL & MELINDA GATES foundation
BIOGAS PLANT
বায়োগ্যাস প্ল্যান্ট
Camp-22 • Block-D
Latitude: 21.088916
Longitude: 92.196925
INFORMATION
- 2 biogas plants
- 22 latrines
- 440 latrine users
- 4.8 cubic metre gas
- 12 to 16 cooking hours
- Community kitchen
- 100 beneficiaries
Operation started: 28/07/2018

Introduction

In the past, many biogas support programmes in developing countries focused on rural families with cattle, pig or poultry, using mainly animal manure as feedstock. The main goals were to reduce the use of firewood by providing people with biogas, improve soil fertility and reduce indoor air pollution. A lot of experience was gained in optimizing the biogas technology and the efficiency of anaerobic digestion processes that lead to biogas generation. Nowadays, anaerobic digestion plays an important role as climate friendly waste and wastewater treatment option for sanitation, converting predominantly toilet, kitchen and/or market wastes in energy and soil improver.

The present manual focuses on the systems treating black water, brown water, excreta, faecal sludge, wastewater from low or no flush toilets, and organic kitchen waste - biogas sanitation systems for short.

The main advantages of the anaerobic treatment process compared to the aerobic treatment process are not only the generation of biogas and significantly less sludge production. The fact that the plant nutrients, phosphorus and potassium, are not removed during the treatment is an additional advantage: it allows for the application of the sanitized nutrient- rich effluent and digestate from biogas systems in gardening and agriculture to replace chemical fertilizer. However, it is important to guarantee that the effluent would never be discharged directly into water bodies without further treatment.

Biogas is a mixture of carbon dioxide (CO_2) and methane (CH_4). It can be used as a renewable energy source for cooking or for generating electricity, thereby replacing other fuel sources.

Treatment concepts for brown water, black water, faecal sludge or excreta based on anaerobic technology have advantages in terms of nutrient recycling, energy balance and CO_2-emission reduction compared to conventional aerobic wastewater treatment systems.

The construction design of biogas sanitation units depends on the way how active bacteria would be retained, and the time required to degrade and sanitize the input material.

Glossary

Anal cleansing water

is water collected after it has been used to cleanse oneself after defecating and/or urinating. It is only the water generated by the user for anal cleansing and does not include dry materials. The volume of water collected during anal cleansing ranges from 0.5 l to 3 l per cleaning.

Biogas

is the common name for the mixture of gases generated through anaerobic digestion. In conventional septic tanks, Imhoff tanks (combined settler and sludge treatment units) and anaerobic lagoons this biogas is vented out, creating climate critical emissions due to its methane content. The rate of methane production depends on the rate of removed COD and the temperature. It is also common to relate the production to the dry matter (DM) or organic dry matter (ODM) of the input material. In human faeces organic matter makes up to 86% of dry matter. Depending of the reactor type, retention time and biodegradability, about 40% to 90% of organic matter could be converted to biogas.

Biogas sanitation systems

are usually designed as:

- Primary treatment for removal of settleable and digestible solids and digestion of organic matter (biogas settler, biogas septic tank), the primary treatment could be divided in multiple anaerobic steps i.e. as “biogas settler followed by anaerobic baffled reactor”, or “biogas tank followed by septic tank”.
- Secondary treatment for nutrient removal (nitrogen), partly hygienization, and reduction of chemical oxygen demand (COD) and biological oxygen demand (BOD) occurs in anaerobic filter or upflow anaerobic sludge blanket reactor. Secondary (and even tertiary) treatment could further be carried out in a separate aerobic treatment process with natural aerated trickling filters, constructed wetlands, French Drains or aerobic polishing pond systems (Refer to Post-treatment Manual).

Biosolids

See *Treated sludge*

Blackwater

is the mixture of urine, faeces and flush water with anal cleansing water and/or dry cleansing material, such as toilet paper. Black water contains all of the pathogens of faeces and all of the nutrients of urine diluted in flush water or anal cleansing water. A research project in Freiburg, Germany, revealed that anaerobic digestion of brown water yields higher biogas production than from black water. This is due to the high nitrogen concentrations in the black water: urea is cleaved by the enzyme urease to CO_2 and ammonia, which is one of the most powerful cell poisons. Fermentation process can come to a halt (auto-intoxification). Remedy: separation of urine, or solid / liquid separation of black water and digestion of the solid (brown water or sludge) phase.

Brown water

consists of faeces and flush water; in practice there is always some urine contained, as only 70–85% of the urine could be diverted. Brown water is generated in urine diversion (flush) toilets. The amount finally depends on the volume of the flush water used. If urine is strictly separated, the nutrient content is reduced. The pathogen load of faeces is not reduced, only diluted by flush water and anal cleansing water.

Digestate

See *Treated sludge*.

Effluent

is the general term for liquid that has undergone some level of treatment and/or separation from solids. It originates from either collection, storage and treatment or a (semi-)centralized treatment technology. Depending on the type of treatment, the effluent may be completely sanitized or may require further treatment before it can be reused or finally disposed.

Excreta

consists of urine and faeces that are not mixed with any (flushing) water. Excreta is small in volume but concentrated in nutrients and pathogens. Depending on the faeces fraction it is solid, soft or fluid.

Faecal sludge

also known as *Night soil*, is the general term for the raw or partially digested slurry or solid that results from the storage of black water or excreta. The composition of faecal sludge varies significantly depending on the location, the water content, and the storage. For example, ammonium (NH_4-N) can range from 300–3,000 mg/l while helminth eggs can amount to 60,000 eggs/l. The composition determines the appropriate type of treatment and reuse.

Faeces

Refers to semi-solid excreta without urine or water. Each person produces approximately 50l faecal matter per year. Of the total nutrients excreted, faeces contain about 10% N, 30% P, 12% K and 107–109 faecal coliforms /100 ml.

Flush water

is the water that is used to transport excreta from the user interface —toilet— to the storage or treatment point. Freshwater, rainwater, recycled greywater, or any combination of the three can be used as flush water source.

Night soil

See *Faecal sludge*.

Organics

refers here to biodegradable organic material also called biomass or green organic waste (including kitchen waste). Organic degradable material or soft organic material could include leaves, grass and market wastes.

Treated sludge

also named *digestate* or *biosolids*, is the general term for pre-thickened partially digested or fully stabilized faecal sludge. The USA Environmental Protection Agency has strict criteria to differentiate between degrees of treatment and how the different types of sludges can be used. “Treated sludge” is used as a general term to indicate that the sludge has undergone some level of treatment, although it should not be assumed that treated sludge is fully treated or that it is safe for reuse. It indicates only that the sludge is no longer raw. Anaerobically treated sludge should be post-treated again to achieve a higher sanitization degree. To separate remaining water it could be by dried in leachate beds, sludge soilisation units, through composting, or mechanical processes.

Even traditional sludge methods could provide an effective barrier to the occupational health risks associated with untreated fecal sludge reuse in agriculture.[1]

[1] Source: Razak, 2010.

Objectives of the Biogas Training Manual

This Biogas Training Manual serves multiple purposes:

→ It presents an outline for an introductory training in biogas sanitation technology. This outline will guide trainers through the training sessions ensuring that none of the broad range of topics related to biogas sanitation technology will be missed.

→ It provides standardized proceedings for trainees. These proceedings will help trainees to recap the training lessons, and to understand the flow of the lessons.

This Biogas Sanitation Training Manual does not replace an intensive theoretical education and practical training for design, construction, operation and maintenance of a well-performing biogas system.

Nevertheless, this standardized Biogas Sanitation Training Manual intends to raise interest and motivate trainees to follow-up their capacity building on biogas technology and to update their knowledge on further developments and innovations in the sector.

Objectives and expectations for the trainees could be:

→ Learn to include a reference line in drawings and on construction sites.

→ Learn about the importance of gravity feeding, including co-digestion of animal urine and manure wherever possible

→ Gain skills on gas tight plumbing and about the fittings.

→ Gain knowledge on the relation between pressure and liquid level in the digester tank.

→ Gain skills on leakage checking in gas piping systems.

→ Gain knowledge of condensed water or foam in pipes and its effect on pressure and gas flow.

→ Gain knowledge on pressure indicator reading and flow meter reading.

→ Gain knowledge on how to encourage operators to make best use of slurry as fertilizer.

→ Gain knowledge on environmental aspects of biogas and digestate.

→ Gain knowledge on siting of a biogas sanitation plant and its proper management.

Elements for a Participatory Interactive Training Approach

The methodology applied to conduct the training should consist of a blended approach and a variety of modern training techniques and tools, thus promoting a participatory interactive learning experience.

Some of the elements for a participatory interactive training approach are:

Opening session

- → Welcome words on behalf of the trainers team, donor(s) and organizers.
- → Presentation of the trainers team.
- → Introduction of the program of the training event including objectives, logistics and rules.

Initial discussion

- → Introduction of participants including short personal knowledge and experience with the topic.
- → Brainstorm session to gather the participants' expectations and their current knowledge on biogas technology. Possible guiding questions:
  - What are sanitation challenges in your country?
  - What do you know about small and large scale biogas technology?

Classroom work

- → Short lectures with projector and flip-charts.
- → Input presentations on theoretical aspects of biogas systems.
- → Brainstorming visualization and clustering.
- → SWOT Analysis.
- → Discussion of concept variations.
- → Display of required spare parts and monitoring measurement devices (if available).
- → World café.
- → Parking lot.
- → Questions & Answers.
- → Share conclusions with the trainees.
- → Assessment game or quiz as closure of the training event:
  - A game is played to test the knowledge of the participants.
  - A quiz at the end of training provides a measurement of the training efficacy to the trainers and sets success benchmarks to the learner. Bear in mind that this kind of assessment must not be too technical or mathematically challenging.
  - A reasonable passing test score implies that the learner has a robust understanding that will allow her/him to apply the lessons learned.
- → Get Feedback – either through an evaluation questionnaire or through a "round table of opinions":
  - Although you already know how to conduct a training, ensure that your training material / presentation / lecture is proofread by another team member. By obtaining a fresh perspective, you will be able to single out typo errors and ensure that the content is accurate, clear and comprehensive. Usability test will allow you to identify system bugs that will otherwise be a blind spot.

Field work

- → During a 2–4 days workshop, at least 1 day should be reserved for on-site visits for practical understanding and application of lessons learned.

Schedule

- An essential tool of any training is a clear schedule. It helps trainers to step forward in time from topic to topic, and it helps trainees to follow the flow of the training session.
- Every day, before closing the workshop, at least 30 minutes should be given to Questions & Answers; examples are given in the table below.
- Each workshop day should start with a 30 minute session called "review of the previous day". During this session, participants can ask to clarify issues they have not yet understood. This is an important step into the next training day, because trainers want to make sure that the trainees have fully understood the content discussed on the previous day(s).

TRAINING METHODOLOGIES, TECHNIQUES & TOOLS

Examples for Questions & Answers

TABLE 1: Examples for Questions & Answers.

Query	Trainer response / Answer
If there are two digesters near each other, why linking them together?	If it is found that some of the stoves are used more than others, joining two digester gas outlets will level the operational pressure in both. The digester which stores less gas will help to store the gas of the one which produces more.
What is the appropriate *jet size* for a burner?	Bigger size bigger flow and smaller size smaller flow of gas - hence the opening is preferred to be 1.2mm for small stove flames and 1.5mm for bigger stove flames. Gas consumption between 1.2mm Ø and 1.5mm Ø is up to four times more - at same pressure. For flexible bag gas storage with very low pressure, jet sizes of 3.5mm Ø are used. Too large injectors lead to poor combustion and toxic CO production.
Why does water occur in pipes?	Condensation water always occurs if the outside temperature is less than the temperature of the gas inside the digester. In Bangladesh, this is a problem in winter, and it may also happen during the night. When water particles, usually saturated with sulphur, reach the stove corrosion of the stove burner is accelerated. Furthermore, it may block the flow of gas in the pipe.
What is a *water trap*?	It is used to drain the condensed water and foam from pipes. It should be installed in the lowest part of the pipe or most probable place of water accumulation in the pipe. An automatic water trap can also be used.
What are commonly used piping systems for household biogas?	Piping systems can be installed underground or above ground. In Bangladesh, most of the biogas piping are laid above ground with flexible hose pipes, always with a risk to have hanging U bends in the pipe where condensation water accumulates.

How to remove swimming particles?	After digestion, organic residues, like structure material of plants, which is not totally digested, becomes lighter and floats on the surface of the fermenting substrate. It usually presses through the outlet and forms a layer in the hydraulic chamber. It can be removed by using local tools like a scoop bucket.
How to read the gas meter?	If the counter is in a metric system it counts in m^3 and provides 3 digits after the comma which then reads the gas production as 0091,772 liter = 91 m^3 + 772 liter.
How to read the pressure indicator?	The minimum count of a pressure meter is 1 kPa (kiloPascal). A pressure gauge showing 5 kPa is read as 50 cm water column. This indicates that the water level in the digester is 50 cm lower than in the displacement tank. Roughly 25 cm height of liquid in the displacement tank replaces roughly 25 cm height of gas in the digester.
What is *black water*? What is *grey water*?	Black water is the water from toilets (mix of faeces, brown water and urine). Grey water is from showers and kitchens. In many cases, we can combine the two to produce biogas. At least wastewater passing near the biogas plant can be fed into the biogas plant. Stormwater and rainwater should never enter the biogas plant.
What is *inoculation*?	It is the process of introducing methanogenesis bacteria in the system. Usually, as initial feeding, the plant is fed with cow dung to start up the anaerobic processes. For sanitation plants, where cow dung is not available, inoculum can be effluent or digestate slurry from nearby operating biogas plants or wastewater from septic tanks nearby.
What different feeding materials can be used?	All "soft" organic matter can be used.
What is the relation between the number of people and size of digester in case of a sanitation biogas plant?	The size of a biogas plant depends on the inflow quantity and hydraulic retention time. Current quantity of liquid waste inflow parameter of low flush toilet pans is estimated at 1.9 to 2.75l/p/d. However, this needs always to be verified before detailed design and construction planning. Hydraulic retention time (HRT) for single sanitation digesters is usually 50–90 days; settleable sludge retention time (SRT) should be at least 90 days. In a 2-step system this HRT will be extended to 10 to 20 days for each step, also depending of the planned post- treatment systems for hygienization and handling restrictions of the effluent.
What is faecal sludge and what is the difference with sewage sludge?	Faecal sludge is generated onsite (e.g., discharge to toilet/ latrine pits and septic tanks). It is difficult to be transported through sewer pipes without additional water or air flush. It has different physical-chemical characteristics than settled or activated sludge generated at a (semi-)centralized treatment plant. The service chain for faecal sludge management shows a potential for increased human health risk associated with pathogen exposure during the collection of the material and subsequent transport to a treatment or disposal facility. Thus, design, operation and management of any sanitation system must consider safe collection and transport of faecal matter.

Training Schedule (Example)

TABLE 2: Example of schedule for the training.

Time	Topic	Place within training	Responsible
0.5 h	Introduction to the training: presentation of objectives, trainers, schedule, logistics, rules...	1	
0.5 h	Introduction of participants	2	
0.5 h	Discussion of expectations	3	
2 * 0.5 h	Review of previous day(s)	4 From 2nd day onwards, first rank of the schedule	
2 * 0.5 h	Questions & Answers	5 Every day at least one session in the afternoon before closing the day	
1.2 h	What are challenges for sanitation in your place?	6	
1.2 h	What do you know about biogas technology?	7	
1.2 h	Biogas technology: principles and practices	8	
1.2 h	Potential strengths and weaknesses of biogas technology in your place	9	
3 h	Field visit: Analysis of gas distribution system(s), stoves and user friendliness	10	
3 h	Practical work: improvements / repair work	11	
1.2 h	How can biogas technology improve sanitation in a camp of large scale?	12	
1.2 h	Biogas technology and feeding materials: What is important to know?	13	
1.2 h	Design of a biogas plant, intermediate settlers and mode of calculation	14	
1.2 h	Gas production	15	
1.2 h	Digester sizes: in-situ or prefab designs?	16	
1.2 h	How to fit digesters in the landscape?	17	
1.2 h	Effluent Management	18	
1.2 h	Test of Knowledge / Right-Or-Wrong Game	19	
1.2 h	Training Evaluation	20	

N.B.: Example for 3 days of classroom training + 1 field day = 18 hours net + 6 h net = 1080 Minutes / 15 + 360 Minutes = 72 Minutes * 15 + 180 Minutes * 2.

→ Ask for praying breaks if needed.

→ Do not forget coffee/tea breaks in the morning and in the afternoon, and sufficient time for lunch.

What are challenges for sanitation in your place?

The provision of sanitation is a key development intervention; without it, illness dominates a life without dignity. Having access to safe sanitation increases health, well-being and economic productivity. Inadequate sanitation impacts on individuals, households, communities and countries. Despite its importance, achieving real gains in sanitation coverage has been slow. Scaling up and increasing the effectiveness of investments in sanitation need to be accelerated. [2]

For households having flush toilets with septic tanks and other not connected to a sewer network, the sludge is collected once in two or three years depending on the size of the septic tank. This could be done either manually or mechanically (suction through pipe attached to pump and tanker. The collected sludge is carried by cistern trucks and disposed off in the open land (uncontrolled dumping sites) into rivers or on land fill sites. Apart from removal of sludge from septic tanks, sludge is also collected from pit latrines on more or less regular intervals and disposed of as mentioned above. In a number of locations (cities, towns, and villages), untreated wastewater is flowing through open drains and disposed of into water bodies. Open defecation and pit latrines are major threats for water pollution and pose severe risks to public health.

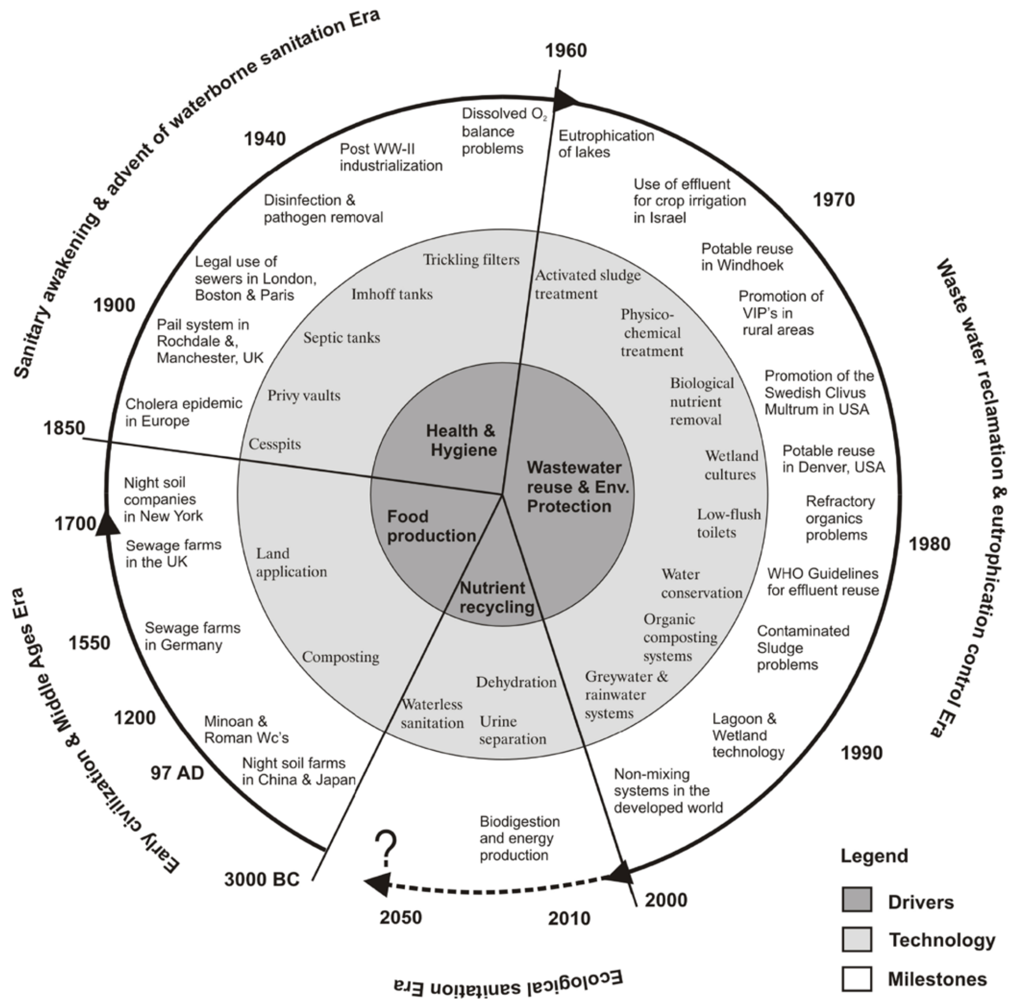


FIGURE 1: Timeline for sanitation developments.

[2] Source: The sanitation challenge: turning commitment into reality, WHO, 2004.

What do you know about biogas technology?

What is biogas?

Biogas originates from bacteria in the process of bio-degradation of organic material under anaerobic (without air) conditions. The natural generation of biogas is an important part of the biogeochemical carbon cycle.

Methanogens, methane producing bacteria, represent the last element in a chain of micro-organisms which degrade organic material and return the decomposition products to the environment. In this process, biogas is generated as a source of renewable energy composed by of a range of gases. Its main components are methane (CH_4) and carbon dioxide (CO_2).

Biogas and the global carbon cycle

Each year, 590–880 million tons of methane are released worldwide into the atmosphere through microbial activity. About 90% of the emitted methane derives from biogenic sources, i.e. from the decomposition of biomass. The remainder is of fossil origin (e.g. petrochemical processes). In the northern hemisphere, the present tropospheric methane concentration amounts to about 1.65 ppm.

Biology of methanogenesis

Knowledge of the fundamental processes involved in methane fermentation is necessary for planning, building and operating biogas plants. Anaerobic fermentation involves the activities of three different bacterial communities. The process of biogas-production depends on various parameters such as changes in ambient temperature. This could have a negative effect on bacterial activity.

Substrate and material balance of biogas production

Any organic material can be anaerobically digested. However, only homogeneous and liquid substrates can be considered for low-tech biogas plants, such as faeces and wastewater from toilets. Solids have to be diluted with about the same quantity of liquid - if possible, urine should be used. Waste and wastewater from food-processing industries are best suitable for low-tech biogas plants if they are homogeneous and in liquid form. The maximum of gas-production from a given amount of raw material depends on the type of substrate.

Policy

The Bangladesh National Renewable Energy Policy (2008) promotes the production of biogas and other green energy from waste and also provides incentives such as Clean Development Mechanism (CDM) to promote renewable energy projects.

TRAINING TOPICS

Potential strengths and weaknesses of biogas technology in your place

A bioreactor based on human waste as fermentation substrate (biogas septic tank) can be used by families who neither have access to electricity nor livestock manure. In addition, a household-sized system can be built without sophisticated construction equipment. It could be installed in areas where the electrical grid is not available. The biogas sanitation system would be especially useful in places where there is no sewer system, and people are extremely exposed to waste- and wastewater borne illnesses, also due to high-density population environment. Human faeces carry parasites and cause diseases such as cholera and giardia.

Anyone building a household- or community-based sanitation system should analyze its potential to spread disease. Safely operating a biogas sanitation system in such a context requires to take special caution before reusing the digested effluent or sludge. It still needs to be post-treated either by composting, liming, drying, gasification, or other methods of sanitization.

A biogas sanitation system has a clear potential to mitigate methane emissions. The Greenhouse Gas CH_4 has a global warming potential 21 times higher than CO_2.

Operators of biogas sanitation systems have to focus on safety and maintenance in the daily operation. Failure in biogas plant operation could be owed to various reasons, e.g., poor quality of construction and construction materials, non-availability of repair and maintenance services.

The following considerations influence the decision making on whether, and where, to use which kind of biogas interceptor tanks, what construction type, and/or to develop alternative designs as “bio-solid filter”:

- → Desludging frequency: often seems to extend beyond the design frequency implying significant digestion or washout of hydrolyzed or re- suspended material.
- → Accessibility for manual or mechanical desludging: health authorities may require tank emptying at prescribed intervals, while others leave it up to the decision of an inspector.
- → Assessment of skills, knowledge and capacity of local residents: they should / would / could be able to operate the interceptor tanks with minimal external support.
- → Level of interest of residents in biogas: for cooking, electricity production, soil improver; appreciation of biogas leads to remuneration of one staff / responsible operator per system.

Biogas Technology: Principles and Practices

Anaerobic digestion (AD) is a chemical process with four steps, during which complex biodegradable organic matter is broken down by groups of co- and interdependent bacteria in the absence of free oxygen to form methane and carbon dioxide.

The final product is called biogas. In any of these steps - hydrolysis, acidogenesis (production of Volatile Fatty Acids), acetogenesis (acetate formation) and methanogenesis (methane formation), different bacteria, micro-organisms and enzymes are involved. Digestion is not completed until the substrate has passed through all stages. In well- working biogas systems, the different degrading processes take place in parallel.

Biogas sanitation systems are defined as ‘‘engineered systems designed and constructed to utilize biological processes which break down solids and soluble organics in the liquid by anaerobic bacterial action under exclusion of free oxygen in treating organically loaded sludge, excreta or wastewater’’.

Figure 2 shows the complex process, while the following table gives a summarized overview of the main stages of what is happening in a biogas system.

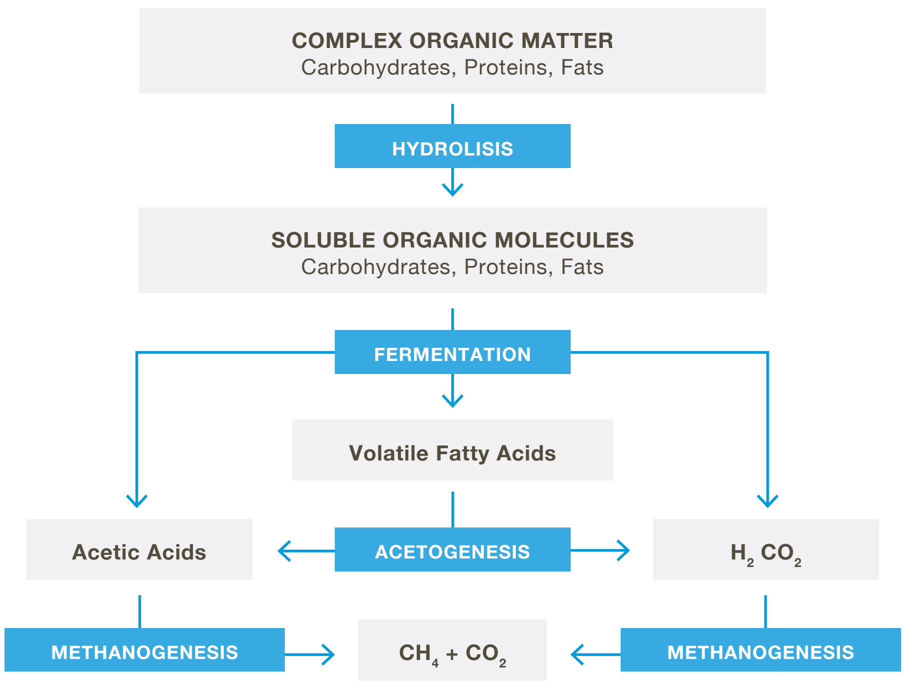


FIGURE 2: Process of biogas formation.

1 Hydrolysis	2 Acetogenesis	3 Methanogenesis
→ The organic matter is hydrolyzed by extracellular enzymes; → Bacteria decompose the long chains of complex to simpler substances, for example polysaccharide to monosaccharide;	→ Acid producing bacteria convert intermediate fermentation products into acetic acid, H2 and CO_2; → Acid producing bacteria create anaerobic condition for CH_4 (methane) producing bacteria;	→ Methanogens, methane producing bacteria; acetic acid and/or hydrogen is used to form methane. Sulphate reduction leads to the formation of hydrogen sulphide.

A clear differentiation between the treatment of wastewater and solids has to be made. For the treatment of wastewater, bacteria have to be accumulated and kept in the system. For the treatment of solids they are first hydrolyzed and then converted into biogas. Anaerobic wastewater treatment and biogas sanitation are using the same biological process, but the goal of anaerobic wastewater treatment is to purify wastewater, rather than to prepare it for fertilizing reuse and to produce biogas. The purification is the result of the breakdown which occurs in the absence of oxygen (anaerobic conditions).

The main advantages of the anaerobic treatment process of faecal sludge compared to the aerobic treatment process are the generation of biogas and up to 20 times less sludge (or bio-slurry) production. The fact that the plant nutrients phosphorus and potassium are not removed in the AD treatment process, could also be an advantage for the application of the effluent in agriculture to replace chemical fertilizers.

Basic Parameters to be Considered in the Design

- → Feedstock pH: 6.5 – 8
- → Feedstock C / N ratio: 20 – 30
- → Liquid Temperature
- → Fluid Consistency
- → Hydraulic Retention Time
- → COD and BOD
- → TS and VS

pH

The ideal pH level varies between the different process phases of biogas formation. While the optima for hydrolysis and fermentation is between 5.2 to 6.3, the optima for acetogenesis and methanogenesis is between 6.5 and 8. If the entire digestion process takes place in one digester, pH should be kept between 6.5 and 8 since during methanogenesis the essential biogas production takes place. In general, a pH balance is created by the bacteria themselves, but can be disturbed by e.g. introduction of too much substrate (See Figure 3).

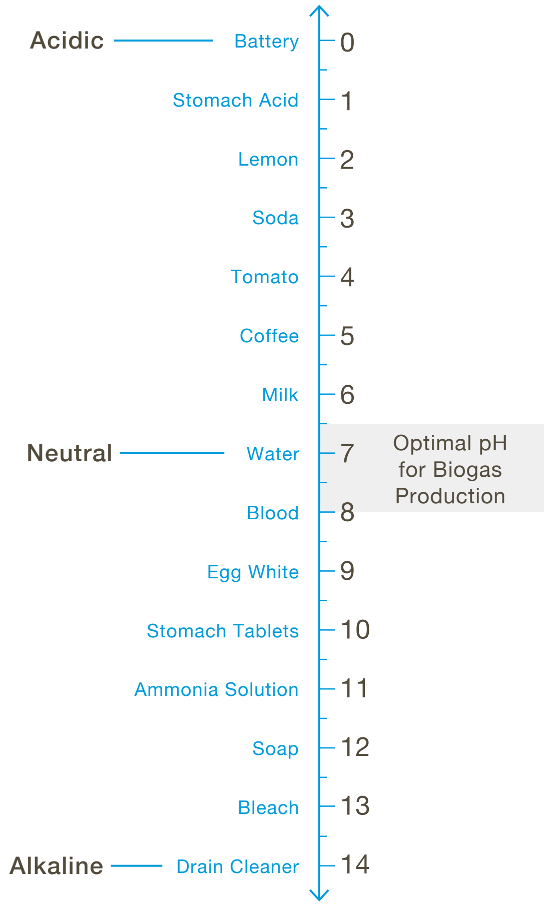


FIGURE 3: pH scale. [3]

Temperature

There are 3 ranges of temperature where methane bacteria works best:

→ Psychrophilic (15–20 °C)

→ Mesophilic (35–45 °C)

→ Thermophilic (55–70 °C)

In general, process stability is higher in a psychrophilic or mesophilic temperature range, while growth rate of methanogens is higher in a thermophilic temperature range. Furthermore, thermophilic temperatures are more desirable for input material such as faeces to eliminate pathogens - at least 55°C and 24 hours retention time. Depending on the location, the energy demand to realize high digester temperatures may be very high. In practice, it should be tried to keep the temperature at a constant level and avoid high and abrupt changes (See Figure 4).

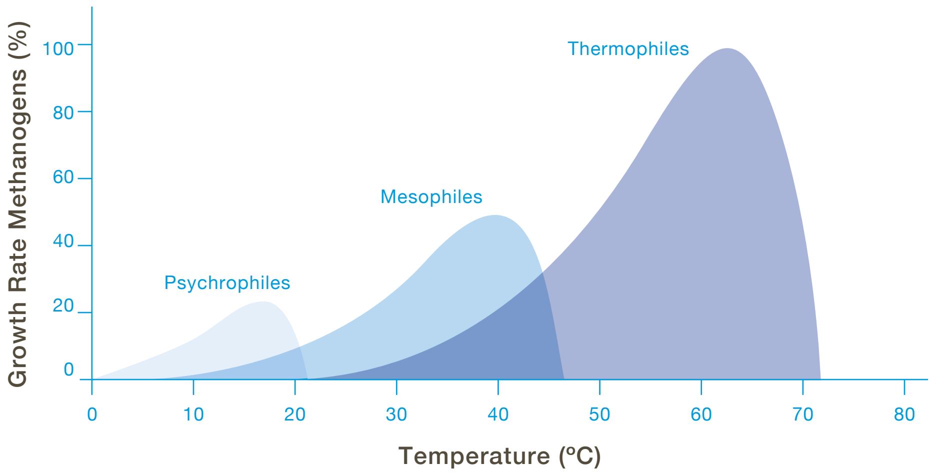


FIGURE 4: Methanogens Growth Rate in relation to the temperature. [4]

[3] Source: https://it.vecteezy.com/vector-art/292506-una-scala-di-ph-su-sfondo-bianco
[4] Source: van Lier et al., 1997

Retention Time

It is the average duration that a particle remains in a constructed bioreactor/ structure. Consequently, the retention time depends on the amount of substrate that is introduced into the bioreactor and the volume of this reactor. If the retention time is too long, the reactor may be oversized what is considered to be uneconomic. If the retention time is too short, only an insufficient gas yield can be achieved. Furthermore, if sanitization of the input material is the objective, retention time should be long.

The design of a biogas sanitation unit requires a smaller volume if it designed for black water or brown water, excreta or faecal sludge only, depending on the way how active bacteria are retained, and the time required to degrade and sanitize the input material.

In a biogas settler (BS), to achieve that the sludge retention time (SRT) for its decomposition is longer than the hydraulic retention time (HRT) of the liquid, a baffle or a separation wall should be added when it is operated as stand-alone system. The accumulated settled sludge must be periodically removed from the base of the BS.

The design further depends on the process temperature and the type and concentration of the (mixed) substrate. This will then determine the volume of the digester. The digester should be designed for an optimum economic balance between gas yield, volume resulting in the optimum HRT.

Therefore, the retention time is chosen as the total time required to produce continuously a reliable amount of biogas. To size the digester to obtain the theoretically amount of biogas is often not economic. (See Figure 5).

The required hydraulic retention time (HRT) of the substrate in the digester depends on the process temperature and the type and concentration of the mixed substrate itself. This will then determine the volume of the digester.

In a biogas-sanitation system the overall HRT should not be less than 20 days required for the reproduction time of methanogenic bacteria. Under health aspects, the HRT should be extended to at least 60 days, if no adequate post-treatment is foreseen. In this case the volumetric load may not exceed 2 kg of COD per m^3 of active digester volume.

In a BS, to achieve a result where that sludge retention time (SRT) is longer than the hydraulic retention time (HRT), a baffle or a separation wall should be added when it is operated as stand-alone system.

The accumulated settled sludge must be removed from the base of the BS periodically. Based on experience, this will be necessary every 5–7 years.

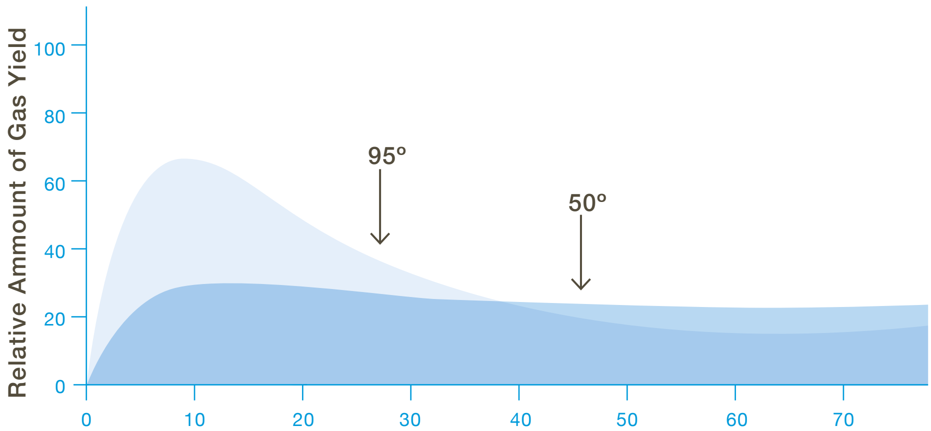


FIGURE 5: Relative Gas Yield in relation to time (in degree F).

A sludge retention time (SRT) of at least 10 days is necessary to promote methanogenesis in the anaerobic treatment of primary sludge at a process temperature of 25°C [5] while an SRT of 15 days is necessary for sufficient hydrolysis and acidification of lipids. For temperatures as low as 15°C, an SRT of at least 75 days has to be considered in order to achieve methanogenic conditions.[6] Less sludge will remain, contributing to the reduction of pathogens. This is important for bigger units; the handling of sludge can be a huge problem in densely populated areas (See Figure 6).

Different types of biogas sanitation units could be combined with each other (so called combined systems, multi-step systems or decentralized wastewater treatment systems) in order to benefit from the specific advantages of the different systems. The quality of the final effluent from these systems improves with the multiple steps of the treatment facility. Design information of the recommended four design variations are available on many websites, in literature and through expert consultation.

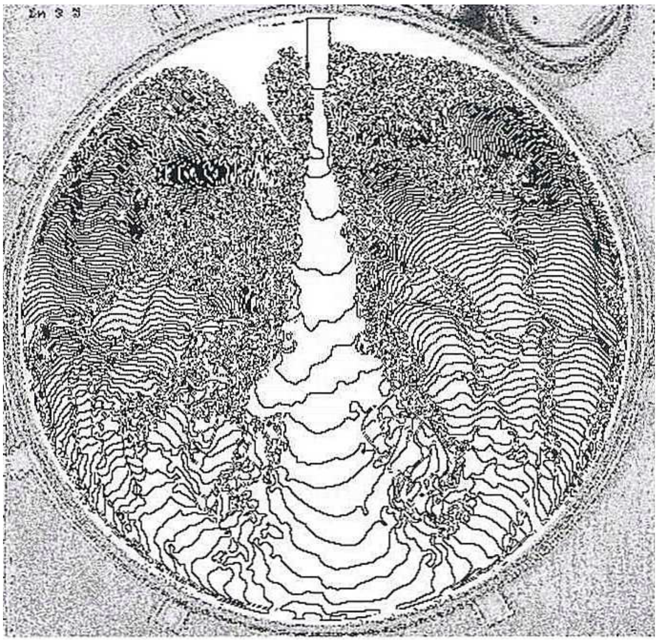


FIGURE 6: Linear overlay of the circular coil's advancement from above in biogas digesters with flat bottom and without baffle. [7]

Fluid Consistency

Different substrates have different dry matter content. In a bioreactor, substrates are mixed. Usually the digester content will have 2–6% Dry Matter as result from toilet waste (See Figure 7). A flush toilet generates wastewater which is not suitable for on-site treatment in a small-scale biogas plant, unless animal excreta is added, because water dilutes the organic matter. This increase in quantity requires a bigger construction volume. Or the flush water amount has to be reduced by means of water saving toilets, manual bucket flush, or pre-settling or screening process.

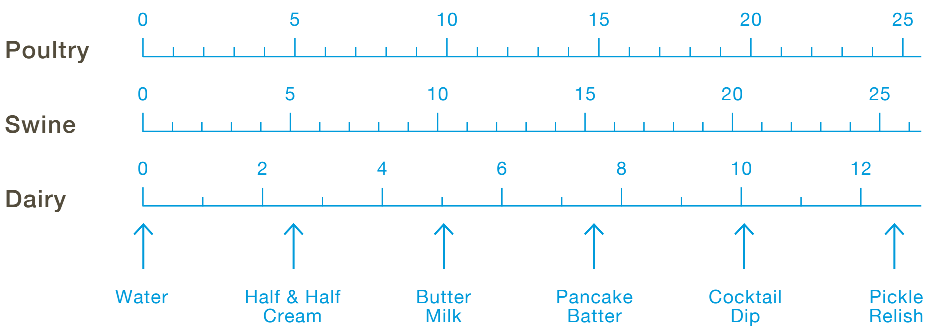


FIGURE 7: Percent solids and consistency. [8]

[5] Source: Miron, 2000.
[6] Source: Zeeman, 2001.
[7] Source: University of Oldenburg, 2004.
[8] Source: Biogas Handbook, David House, 2006.

COD and BOD

Biological Oxygen Demand (BOD) and Chemical Oxygen demand (COD) are indicators for the amount of dissolved oxygen needed by microorganisms to degrade organic and some inorganic components. High BOD/COD is an indirect indicator of the organic content. Ammonia is inorganic and creates an oxygen demand when it is converted to nitrate. Solid substrates are characterized by their dry content (dried in an oven at 110°C), and organic matter burnt to ash in an oven at 600°C. BOD5 and COD are used for wastewater characterization as indirect indicators of the organic content. COD is analysed within few hours. BOD measurement techniques require 3 to 5 days for a reliable result.

The oxygen demand is the unit that measures the weight of oxygen which is required to stabilize polluting matter. It is mostly measured in mg/l. If all matter is biodegradable the BOD is equal to the COD; if all matter is biodegradeble within 5 days, then the BOD5 is equal to the BOD (See Figure 8).

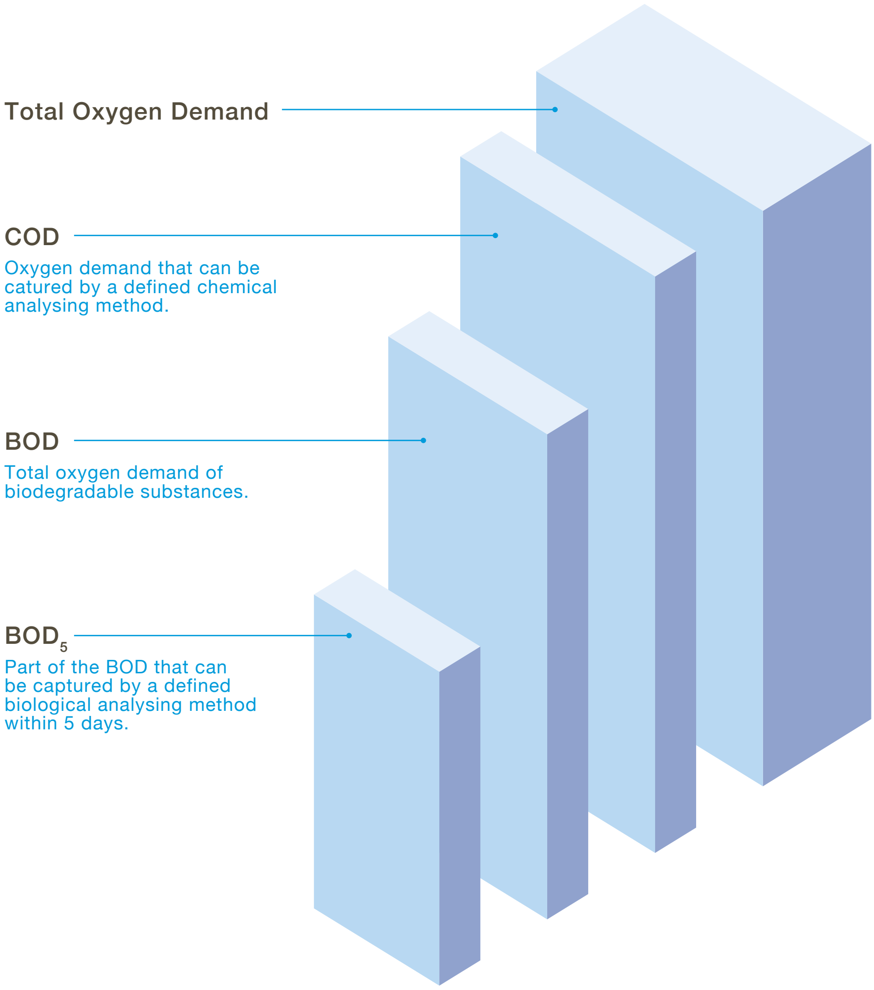


FIGURE 8: COD and BOD. [9]

[9] Source: https://www.unescap.org/sites/default/files/Session%202.6.1_%20BORDA-DEWATS_TrainingMaterial.pdf

How can biogas technology improve sanitation in a camp of large scale?

Biogas systems are currently deployed in about 200 locations within the Rohingya Refugee Camps and in host communities as key technology for decentralized faecal sludge treatment. Some of them incorporate the treatment of organic kitchen waste. They are functioning since more than 10 years. However, these systems are not yet seen as a contribution to a sanitation service chain in the long-term. This is partly due to operational issues with existing stand-alone biogas sanitation systems.

A more thorough assessment is required, in order to test previous/current assumptions and provide additional analysis. A strong integrated approach to waste-to-value management in the camps, together with the ambient annual temperatures might open up new opportunities for the efficient deployment of centralized biogas systems for the treatment of wastewater, sorted organic waste and sludge. For a more effective operation continuous supervision should be set up to build up the capacity of O&M staff.

Biogas sanitation facilities are proved to be appropriate to respond to the needs of the Rohingya refugees in Cox's Bazar in Bangladesh. Operationalizing a full- chain sanitation service would contribute to transition towards longer-term solutions.

Human faeces contain 65–85% of water with 15–30% organic and inorganic matter. The high content of organic matter in human excrement makes it a valuable source for reuse as soil amendment or fertilizer. However, the presence of high concentrations of microorganisms requires that the excreta are safely treated before reuse. Various techniques are available for treating faecal sludge and converting the organic content into a valuable resource. These include composting, anaerobic and aerobic digestion, vermi- composting, deep row entrenchment and solar drying. From the mentioned faecal sludge treatment techniques, anaerobic digestion is of particular interest because this process leads to the production of biogas and sludge which could be used as fertilizer or soil amendment. Biogas contains C from the initial feedstock, and the digestate contains the initial amounts of NPK. Only N is converted partially in NH_4+. There is no loss of plant nutrients.!

Biogas sanitation plants have demonstrated their capability to reduce desludging activities and produce biogas to serve to the community people in a shared kitchen. The installed biogas digester sizes are 4–10m^3 Fermenter Volume, which can serve for around 50 to 400 families for sanitation and 7–20 families for cooking. In recent years glass fiber biogas plants were set up. Biogas sanitation systems are nowadays considered to reduce desludging intervals from 6–12 times per year for toilet pits, to once or twice per year for biogas settler tanks.

The following elements of a biogas sanitation model incl. the use of biogas for cooking, including technical, institutional, and financial aspects, are conducive to sustainability. The facilities (toilet cabins, biogas tanks, and kitchen) are of relatively robust quality and could last several years if they are well maintained. The users, mainly the toilet cabin cleaners and people who empty the biogas tank from sludge, have been trained not only to ensure toilet maintenance and sludge emptying but also to carry out some small repairs. They possess thus both skills and tools to contribute to the functionality of the treatment systems.

The official handing over of the facilities to the community and camp management is an important first step. Additionally, the agreement with a WASH NGO operating a faecal sludge treatment site nearby to ensure de-sludging of the biogas tanks and sludge treatment represents a promising mid- term perspective. However, a number of challenges remain in terms of ensuring a smooth transition towards effective and sustainable solutions: Who will be responsible for toilet cleaning, and who will pay for it? How will supply chains, for example of soap or spare parts for sanitation work? How will the supply chain for cooking facilities be put in place?

Biogas technology and feeding materials: What is important to know?

Biogas sanitation systems with and without attached kitchen facilities could be easily upgraded to community sanitation centers, aiming to provide basic sanitation facilities, such as bathrooms, a wash area, a water point, and a wastewater treatment plant with a biogas interceptor settler under the toilets.

Co-processing of faecal sludge with organic waste was promoted by some NGOs as an option for joint treatment of waste and faecal sludge in biogas sanitation plants. The addition of organic matter could increase the proportion of solid matter and thus the production of biogas. However, due to the limited capacity of current biogas sanitation facilities, co-processing is not recommended in this context as it will increase the quantity of material to be processed, and increase the risks for health.

Organic Waste

→ Organic waste is material that is biodegradable and comes from either a plant or an animal or a human being.

→ Organic waste is broken down over time by other organisms; it is also termed as wet waste.

→ Examples:
- vegetable and fruit leftover;
- human and animal excreta;
- excreta / litter from birds / poultry.

C/N Ratio

1. The ratio of Carbon to Nitrogen in organic material is important for bacteria activity.
2. According to the organic content introduced, the anaerobic process is very suitable for treatment of brown water, black water and total wastewater.
3. The optimum C/N ratio of 20–30 can be achieved by mixing different materials.
4. If C/N ratio is very high, the gas production will be lower.
5. If the C/N ratio is very low, the pH value increases, and this will have a toxic effect on the bacteria. Both will lead to a halt of the fermentation.
6. Depending on the input composition, the high Carbon to Nitrogen rate and pH of urine can have inhibitory or even toxic effect on the process.

TABLE 3: Carbon to nitrogen ratios depending on imput compositions. [10]

Feedstock	Carbon Content of Feedstock by Weights %	Biogas Yield m^3/kg of Volatile Solids	Nitrogen Content of Feedstock by Weight %	Carbon Nitrogen Ratio (C/N)
Rice Husks	46.23	0.28	0.98	47:1
Sugar Cane	45.23	0.20	0.75	53:1
Bagasse	53.27	0.15	0.65	82:1
Neem Leaves	14.00	0.65	0.54	26:1
Grass Silage	14.60	0.35	0.58	25:1
Sheep Excreta	10.00	0.70	0.42	24:1
Cow Excreta	15.80	0.50	1.20	13:1
Horse Excreta	48.72	0.55	2.19	22:1
Chicken Excreta	36.12	0.35	2.40	15:1
Pig Excreta	60.00	0.028	6.00	10:1

TRAINING TOPICS

Design of a Biogas Plant, Intermediate Settlers and Mode of Calculation

Four types of biogas sanitation units are usually known:

a. the biogas settler (BS) or biogas septic tank (BST);
b. the anaerobic baffled reactor (ABR);
c. the anaerobic filter (AF);
d. the upflow anaerobic sludge blanket reactor (UASB).

Types of Anaerobic Reactors

Low Rate Anaerobic Reactors

- Anaerobic Pond
- Biogas Septic Tank
- Imhoff Tank
- Srandar Rate Anaerobic Digester

- Slurry type bioreactor, temperature, mixing, SRT or other environmental conditions are not regulated
- Organic removal efficiency 30–60%.
- Loading of 1–2 kg COD/m^3 day.

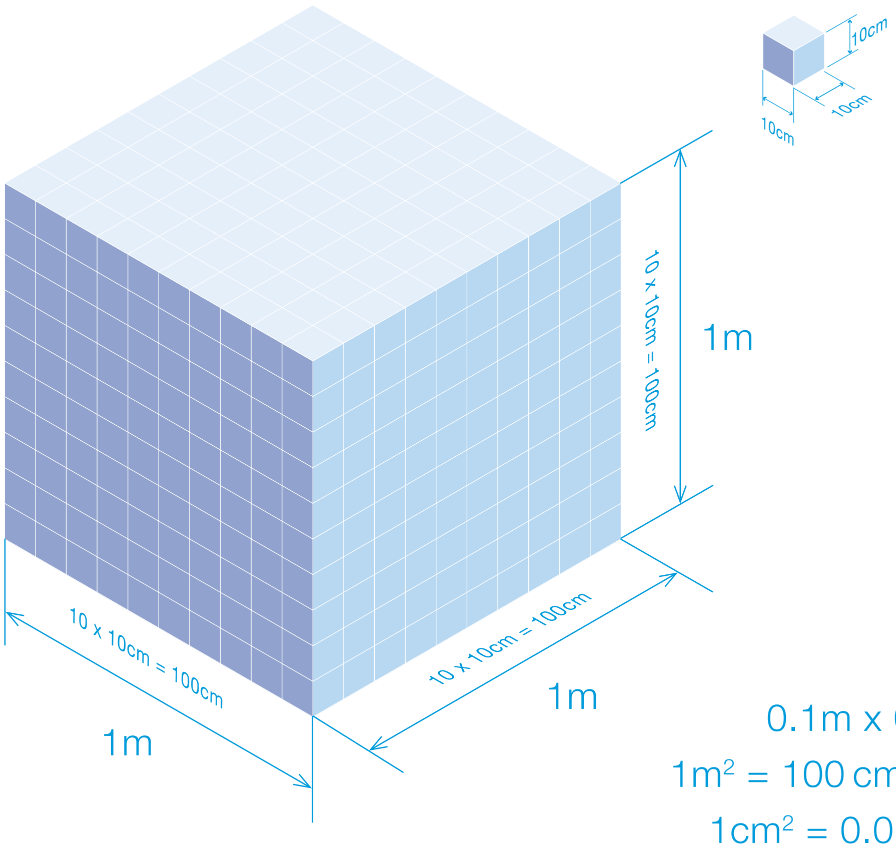
High Rate Anaerobic Reactors

- Anaerobic Contact Process
- Anaerobic Filter (AF)
- Upflow Anaerobic Sludge Blanket (UASB)
- Fluidized Bed Reactor
- Hybrid Reactor: UASB/AF
- Anaerobic Sequencing Batch Reactor (ASBR)

- Able to retain very high concentration of active biomass in the reactor. Thus, extremely high Sludge retention time (settled sludge) (SRT) could be maintained irrespective of Hydraulic retention time (HRT).
- Organic Removal efficiency 80–90%.
- Load 5–20 kg COD/m^3 day.

[10] Source: https://www.semanticscholar.org/paper/EFFECT-OF-CARBON-TO-NITROGEN-RATIO-ON-BIOGAS-Dioha-Ikeme/20bb83b3468 93739931db40073a96e9bf08627b6

Biogas Plant Design



$1m = 100\ cm$

$1cm = 0.01\ m$

$1m^3 = 1{,}000\ l$

$10\ m^3 = 10{,}000\ l$

$1\ l = 0.001m^3$

$10\ l = 0.01m^3$

$100\ l = 0.1m^3$

$1{,}000\ l = 1m^3$

$0.1m \times 0.1m \times 0.1\ m = 0.001m^3$

$1m^2 = 100\ cm \times 100\ cm = 10{,}000\ cm^2$

$1cm^2 = 0.01m \times 0.01m = 0.0001m^2$

FIGURE 9: Representation of the area for 1m³.

Design Example: The Fixed Dome Biogas Plant

The technical concept of a biogas system shall be explained by the example of a hemispherical fixed dome plant with 16m³ digester volume. Fixed dome plants are next to e.g. floating drum plants and balloon plants, common small- scale biogas plants.

Fixed dome plants are characterized by a dome-shaped digester with a fixed, non-movable gas holder which is on top of the digester, and a displacement pit, also called compensation tank. When gas production begins, the digestate / slurry is displaced into the compensation tank.

These systems are usually made of masonry structure, structures of cement and ferro-cement.

Input Material and Its Biogas Potential

TABLE 4: Input Material and Its Biogas Potential.

Parameter	Data
People	500
Faeces (only daytime, i.e. school)	250g faeces/person/day = 125 kg/day
Urine	1 L/person/day = 500L/d
Water from anal cleansing	1 L/person/day = 500L/d
Other water (average for handwashing)	0.250 L/person/day = 125L/d
Total Daily Input	1,300 kg/d
Volume required for retention time of 20 days	1,300 kg/d * 20 d = 26m^3 volume
Biogas production	500 persons * 0.03 m^3 = 15m^3/d

How does the mix of organic matter and water behave in a biogas plant?

A mixture of organic matter and water will separate into sinking material, water and swimming layers (See Figure 10).

Regarding gas production, the water layer is less productive and has the lowest viscosity. It will be discharged first if the outlet of the biogas plant is in this zone. The design of fixed dome plants considers this effect, leading to improved efficiency of the system.

In case much more water enters the biogas plant, e.g. sewage from households, the water component is discharged first, while the organic matter remains in the digester, is degraded and produces biogas. This justifies that fixed dome plants can be fed with sewage and soft organic matter including animal manure.

Larger systems should have a sludge discharge pipe so that inert sludge from the bottom can be removed without emptying the entire system.

The older parts of the floating layer are discharged automatically, when the plant creates its maximum pressure; they are transferred into the displacement tank.

FIGURE 10: Example of Organic Matter Separation in the Digester.

The following flow diagram shows what happens in a biogas plant which is fed with organic matter and sewage: The system separates the filling material into the three states *gaseous*, *liquid* and *solid*.

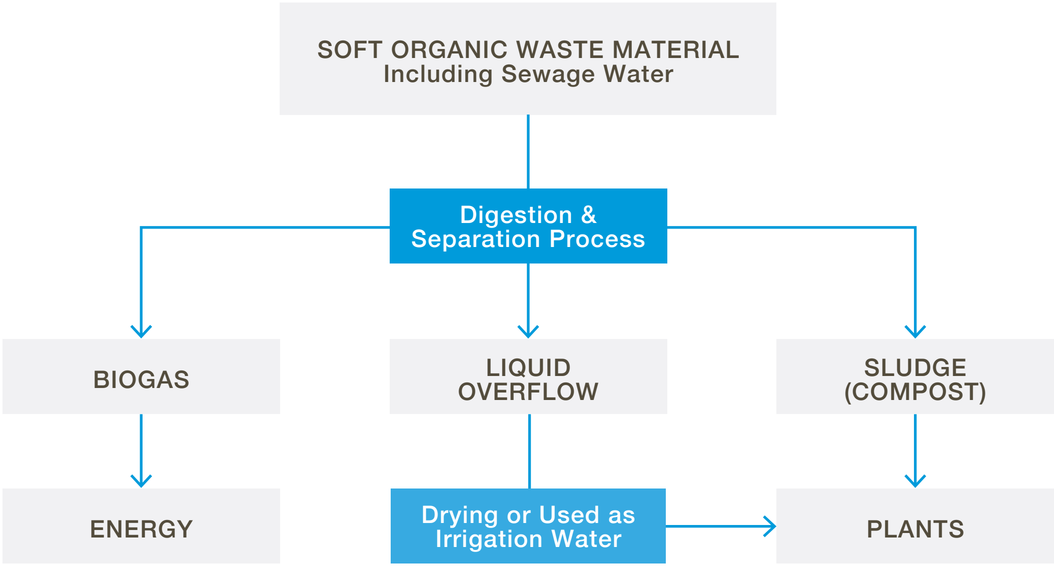


FIGURE 11: Overview of separation in a biogas system.

Design Criteria

TABLE 5: Design criteria.

N°	Criteria	Result
1	Easy feeding	No measuring, no mixing
2	Direct stable connection	Convenient cleaning of stable / re-use of liquid for biogas production
3	Accept any soft organic waste	Paper also gives biogas!!
4	Wastewater entering by gravity	No additional work
5	Easy to remove solids from compensation tank	Light but children-safe lids
6	Easy use of liquid effluent in the garden	Accessible but protected slurry pit
7	Secure gas outlet pipe	No clogging in gas outlet; no slurry in gas pipe
8	Automatic water trap in not-disturbing position	No condensed water in gas pipe hindering gas flow
9	Good position of piping system and gas use device (stove, generator …)	Gas pipe does not provoke accidents; biogas is used because of convenience for users
10	User training	How to get most benefits …

What is standardized in a fixed dome plant design with inflow pipe toilet connection?

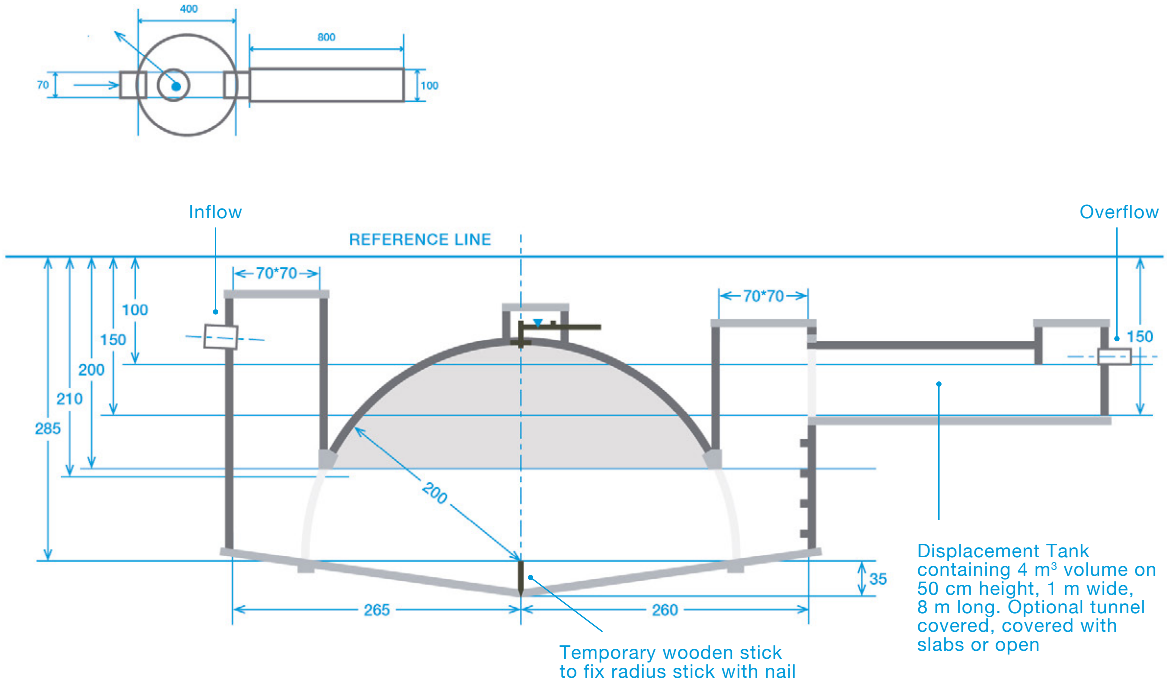


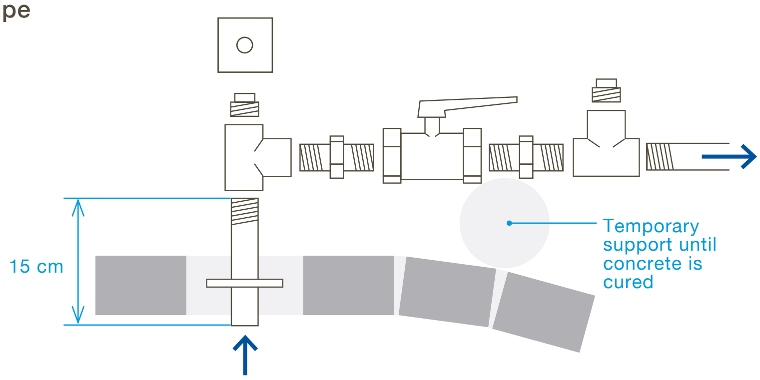
FIGURE 12: Fixed dome bio digester (16m^3, gas storage capacity of 4.3m^3).

TABLE 6: Standardized elements.

Component	Standard
Reference line	1 m above overflow point
Digester shape	Hemisphere
Expansion chamber	Long stretched canal, covered with tunnel
Free board	15 cm
0-Line (Zero-Line) level	1.5 m from reference line
Lowest slurry level	2 m from reference line
Thickness of wall	¼ brick or block (7 cm) (finally depending of local brick quality)

More standardized elements

TABLE 7: More standardized elements.

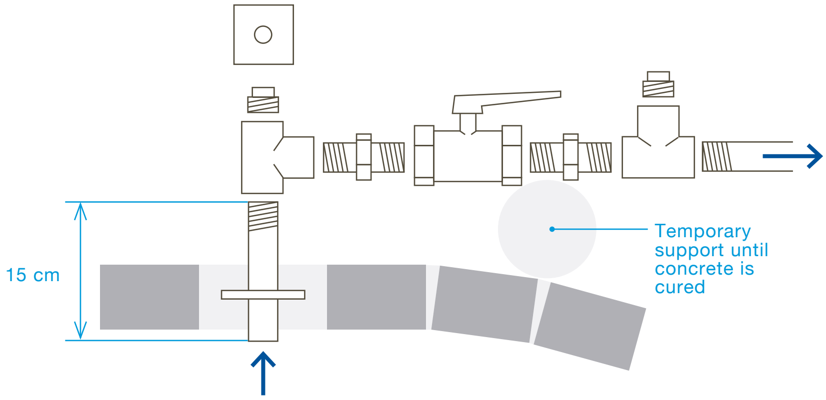
Component	Standard
FIGURE 13: Gas outlet pipe with testing unit.	
FIGURE 14: Chamber for gas outlet pipe.	
FIGURE 15: Chicken wire in outside plaster. The entire hemisphere receives an outside plaster which is strengthened with chicken wire. It helps to distribute and pick up forces. Other steel support is not required for the dome.	
FIGURE 16: Convenient inlet. The inlet as well as the opening of the outlet (manhole for the digester and opening of the expansion chamber) are commercially available manhole covers made of Aluminum and dimension of 55*55 cm². They are easy to open and close and will neither corrode nor break. Furthermore, they look neat. They are also children proof. They integrate very well in a garden or walking path.	

Never standardized components

Never standardized components, because they must be adapted to the location:

- → Shape of expansion chamber.
- → Overflow point at best possible place of the location.

Gas outlet pipe options



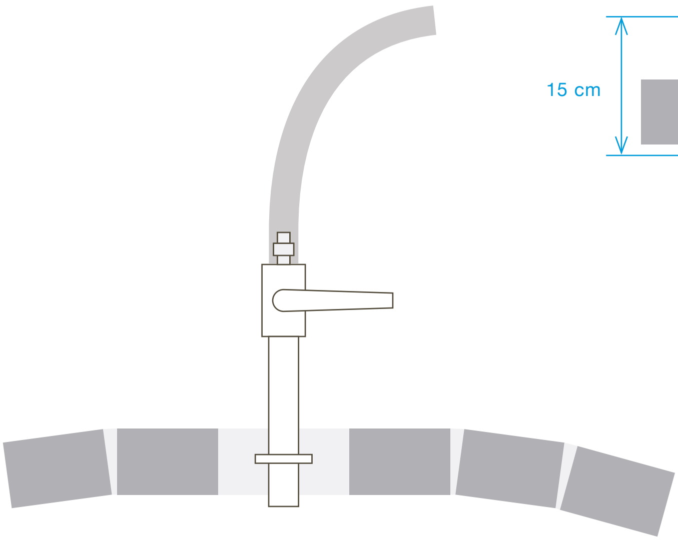


FIGURE 17: Gas outlet pipe with testing unit (top).

FIGURE 18: If gas hose leads "through the air" (center).

FIGURE 19: Standard gas outlet pipe (bottom).

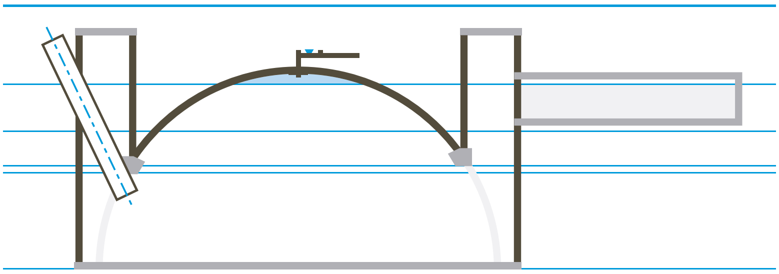
Functional Zones (Caps) in a Fixed Dome Digester

The horizontal lines in the following sketches divide the digester in functional zones or bowl segments:

Segment 1:

Free board

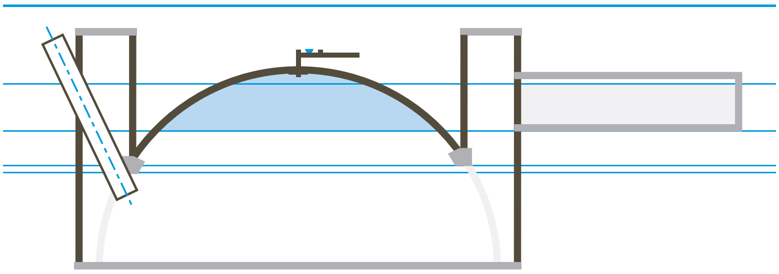
It can accommodate foam and scum and prevent the gas outlet pipe from clogging.



Segment 2:

Gas reserve and Cap 1

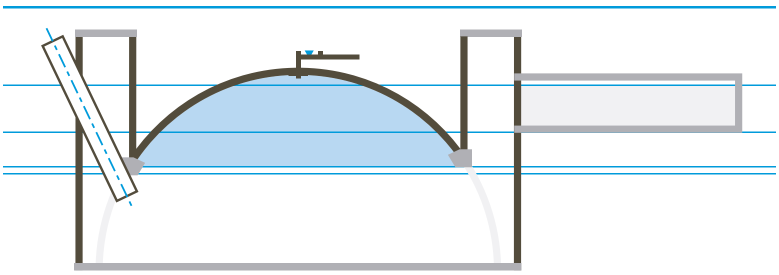
The gas is released if the digester is fed for a longer period, and gas consumption is higher than gas production. The 0-Line will rise into this area.



Segment 3:

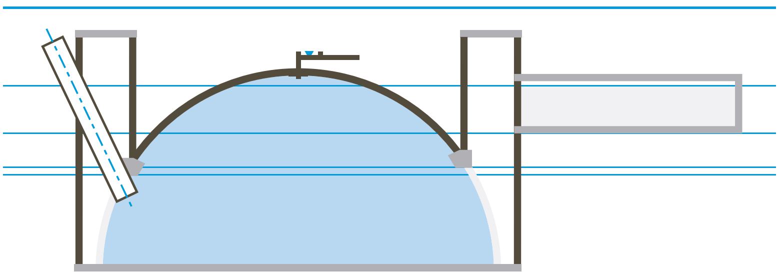
Maximum total gas space

Including Segment 2 and Segment 2.



Segment 4:

Total hemisphere volume



Segment 3 – Segment 2:

Active gas storage volume

The gas is replaced by the effluent which is pushed in the dark blue area (inlet and compensation tank) by the produced gas.

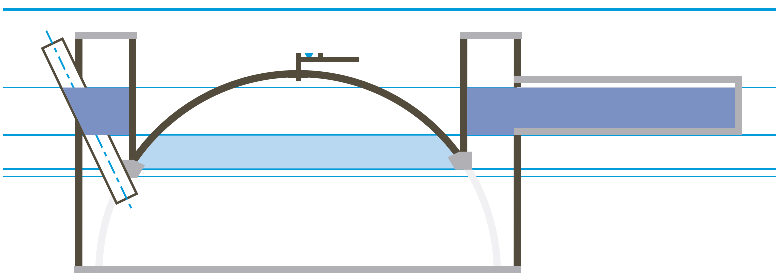
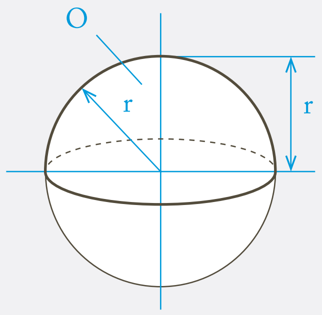
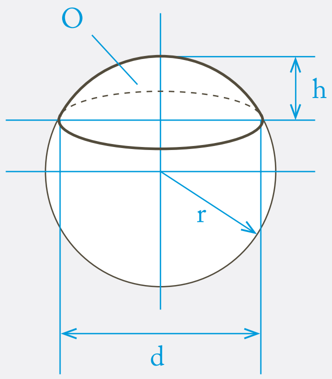


FIGURE 20: Functional zones of a digester.

Design Calculation for a Fixed Dome Digester





$V = 2/3\pi * r^3$

$O = 2\pi * r^2$

$V = \pi h^2 (r - h/3)$

$O = 2\pi * r * h$

Example with radius of 2.0m:

→ Cap 1: $V = \pi * (0.15m)^2 * (2m - 0.15m/3) = 0.138\ m^3$

→ Cap 2: $V = \pi * (0.65m)^2 * (2m - 0.65m/3) = 2.367\ m^3$

→ Cap 3: $V = \pi * (1.15m)^2 * (2m - 1.15m/3) = 6.717\ m^3$

→ Cap 4: $V = V = 2/3 * \pi * (2m)^3 = 16.755\ m^3$

→ Cap 3 – Cap2 = $4.35\ m^3$ (gas storage)

Volume of hemisphere formula:

$V = R^3 * 2 / 3 * \pi$

→ Transformed: $R = \sqrt[3]{3V / 2 * \pi}$

$V = 16\ m^3 \quad R = 2m$

→ Nominal: $16\ m^3$

- $4\ m^3$
- Height 50 cm = 0.5 m
- Width * Length = $8\ m^2$
- $0.5\ m * 8\ m^2 = 4\ m^3$

- 1 m * 4 m
- 0.5 m * 8 m
- 2 m * 2 m
- 4 m * 1 m
- Round:
  – Radius 1.2 m
  – Diameter 2.4 m

Whereby:

→ V = Volume in m^3

→ R = Radius of the hemisphere in m

→ π = 3.14 = PI

Volume of gas storage:

Formula Cap (2 or 3):

$V = \pi * h^2 (R - h / 3)$

Cap 2, h = 65 cm
Cap 3, h = 115 cm
$V_{gas\ storage}$ = Cap 3 – Cap 2

Size of compensation tank is calculated - for the shape of the compensation tank exist many possibilities:

A 16 m³ plant holds a liquid volume of 4 m³ in the expansion chamber.

Other Digester Dimensions

By increasing the radius of the digester, volume and gas storage capacity increase as well.

Table 8 shows the volume increase that can be realized through increasing the radius by 10cm.

TABLE 8: Digester volume increment by radius increment of 10 cm.

Radius in cm	Digester Volume in m^3	Gas Storage m^3
200	16	4.3
210	19	4.5
220	22	4.7
230	25	5
240	28	5.2
250	31	5.5
260	36	5.8
270	42	6
280	45	6.2
290	51	6.5
300	56	7

19m³ Digester Treating Sewage and Kitchen Waste

Figures 21 & 22 show a biogas plant which is fed with a mix of sewage and kitchen waste. The feeding material enters through two different inlets which are shown on the two drawings.

The outlet and expansion chamber are designed to hold back solids to avoid that they enter the attached planted gravel filter. The solids could be removed from the different manholes at outlet and expansion chamber. The expansion chamber is built as a canal and closed with a tunnel structure.

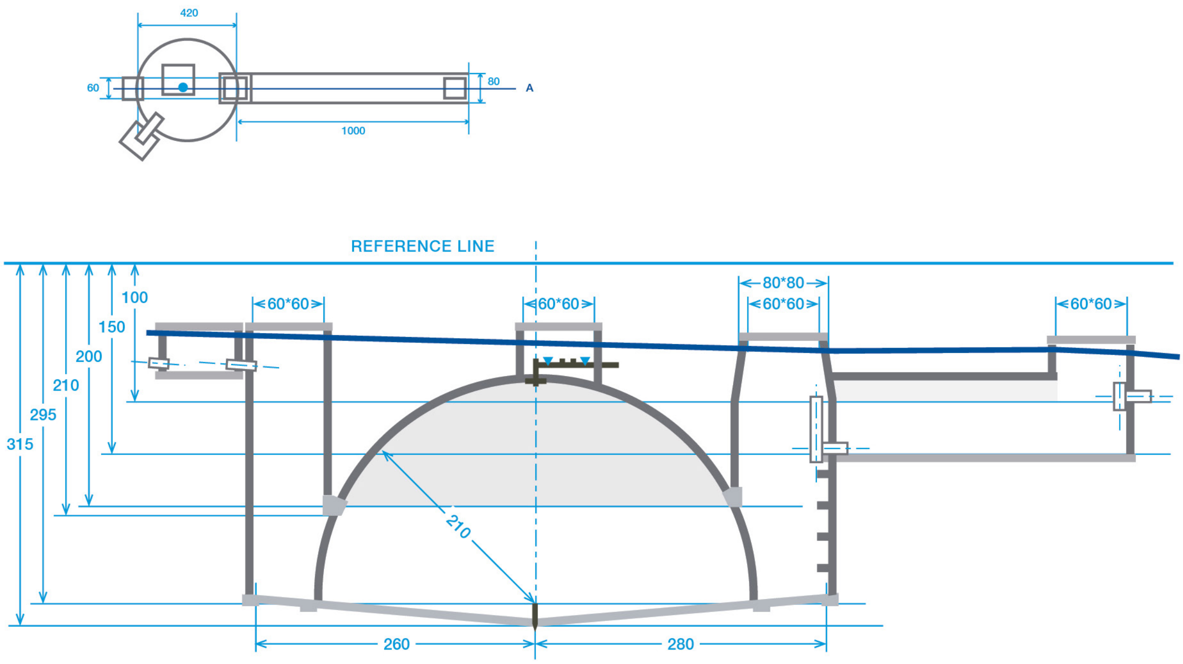


FIGURE 21: Fixed dome biodigester (20m³, gas storage capacity of 4.6m³).

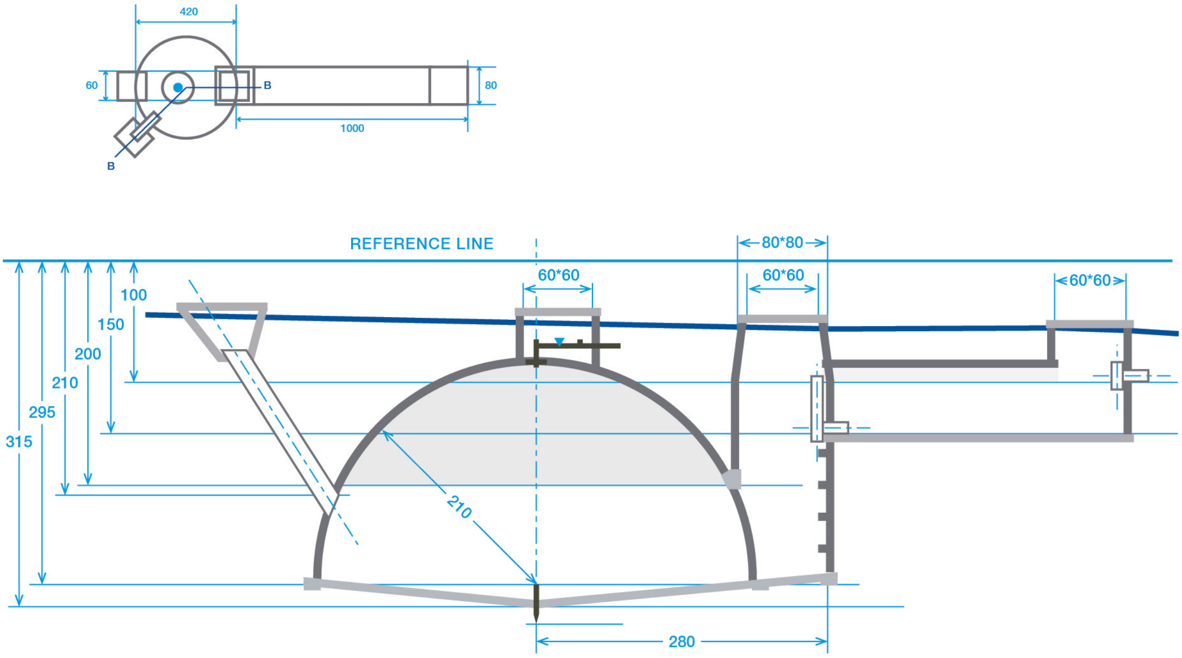


FIGURE 22: Fixed dome biodigester (20m^3, gas storage capacity 4.6m^3).

16m³ Digester for Sewage and Soft Organic Matter

The thickness of the brick wall of the hemisphere is 5.6 cm. The outside plaster will receive chicken wire, adding static strength to the wall. The wall sits on a circular strip foundation. The next step is the outside plaster, then the bottom is dug out to form a cone. The dug-out soil is thrown behind the wall as backfilling and compacted. Only now the floor is cast. Inlet and outlet are square shafts. The lintels for these openings have been cast inside the digester using the round wall as shuttering. This order of activities saves labor and speeds up the construction (See Figure 23).

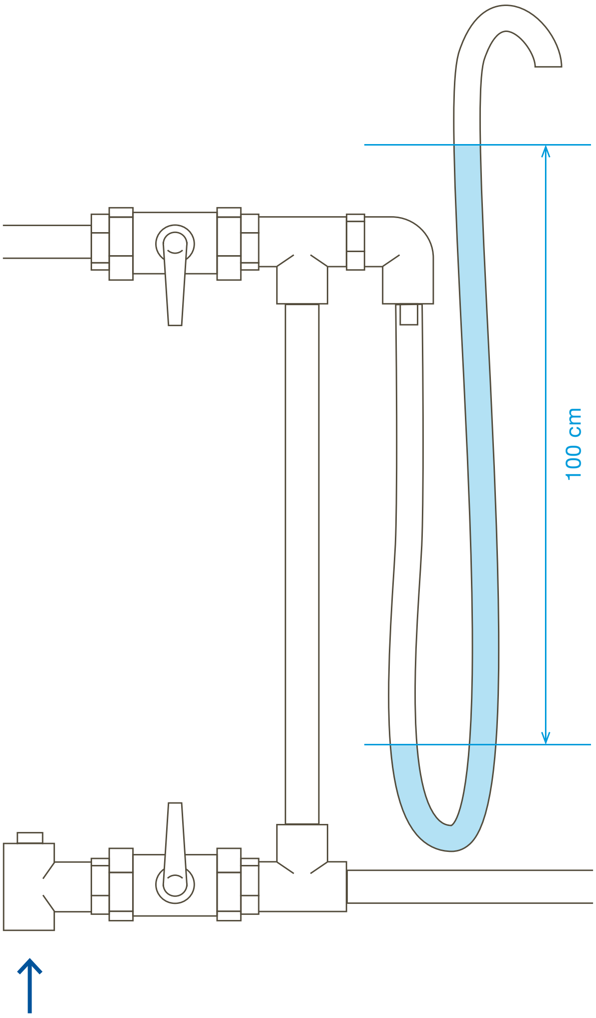
FIGURE 23: Bottom of biogas plant with in- and outlet shafts.

FIGURE 24

FIGURE 25

The same digester after completion
Inlet and outlet shafts receive a 55*55 cm^2 Aluminum lid. The gas outlet pipe with testing unit and main valve is under the small lid, 30*30 cm^2. Any visible parts integrate smoothly in the garden. The expansion chamber is not visible and ends in another manhole (See Figures 24 & 25).

FIGURE 26: 100 cm water column.



It is mandatory that after completion of the digester and the piping system, both are pressure tested. This is done with the help of the testing unit. Temporarily, a steel pipe is attached to the T-joint after the main valve. It has a mouth-piece which can be closed with a valve and a transparent hose pipe which is filled with water. If the main valve is closed, the piping system can be blown up with the help of the mouth-piece and the valve. The pressure in the pipe is read as cm Water Column (WC) in cm level difference. After an hour, the pressure should not have dropped, otherwise the pipe is not tight. The leakage is searched with foam made of liquid soap and water. The leaking joint must be re-done. It is not possible to seal a leakage from outside.

Once the piping is tight the same pressure indicator position can be used to see if the digester is tight. The digester is filled with water, with the main valve closed. The water compresses the air in the digester. The air pressure should rise to 100 cm WC and remain for 2 hours. If the pressure falls the digester is either loosing water or gas. If the water is filled up back to overflow level the pressure should read 100 cm again. That means the digester loses water and not gas. Small water losses can be tolerated as organic matter fed into the digester will seal such leakages quickly and reliably (See Figure 26).

A properly modified industrially produced gas stove will have a small hot flame and cook very efficiently (See Figures 27 & 28).

Stove adjustment and a flame like this will lead to energy inefficient cooking (See Figure 29). For a layman, such a flame may look impressive, but the truth is that a lot of gas will be wasted and, in the long run, the end-user will be disappointed by the performance of the biogas plant, even though this picture suggests the opposite at the beginning.

FIGURE 27

FIGURE 28

FIGURE 29

50m³ Agricultural Digester Treating Dung and Urine

FIGURE 30

Dung and urine are entering the 50m³ digester. Solids are discharged via a sludge discharge pipe. More liquid sludge flows out via the expansion canal. Parallel to this is a compost heap made of crop residues and weeds.

The effluent is scooped on the compost heap. The heap is then turned over and forms a parallel second heap.

The compost soil is used in vegetable production in the background. Gas is used for cooking by 10 families.

Two 200m³ Digesters Treating Market Waste and Sewage

Two systems of 200 m³ digester volume each. For such large domes, it is advisable to reinforce the dome with three steel rings which are positioned at the foundation, below the inlet and above the outlet opening. The openings are weakening the structure which needs the support. Like all digesters, it receives the chicken wire reinforcement in the outside plaster. The inlet allows that rougher market waste enters smoothly. Sewage helps to liquefy the digester content. Swimming particles are discharged at maximum pressure. Settling sludge is discharged via a sludge discharge pipe (See Figure 31).

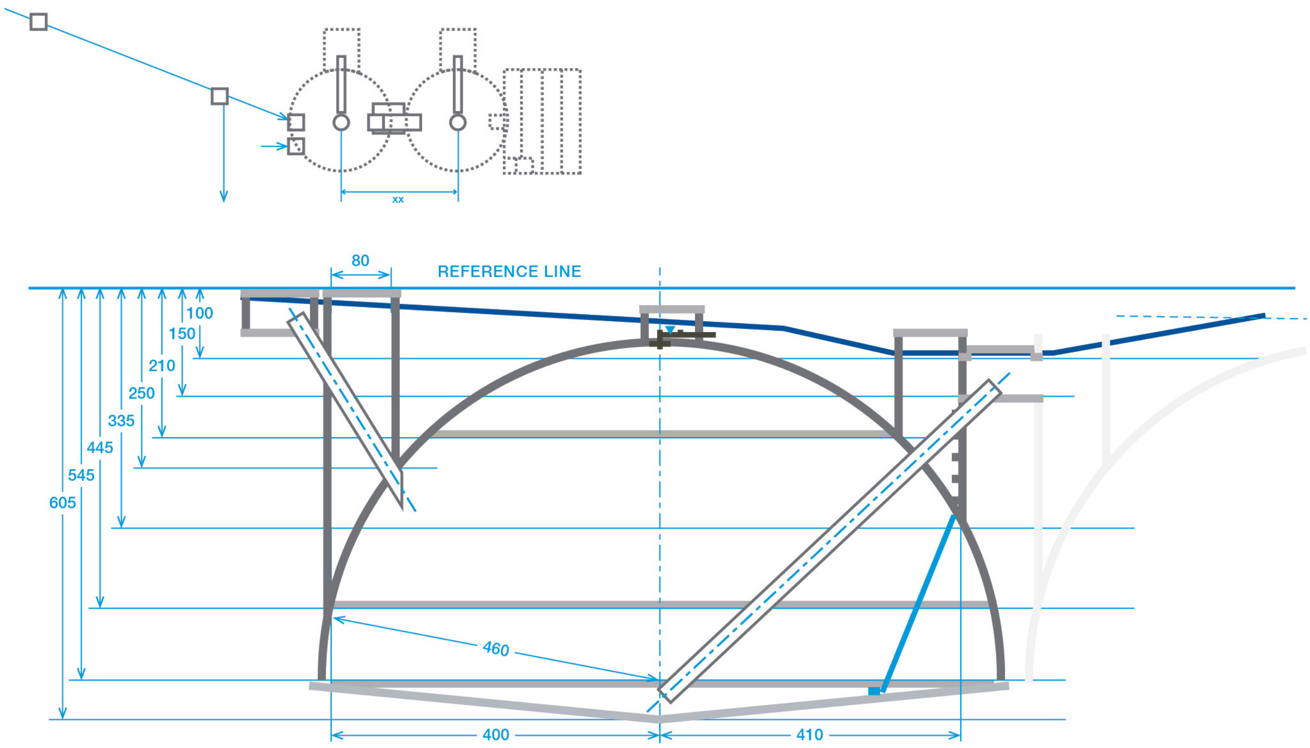


FIGURE 31: Double digester system for solid waste.

Biogas Toilet

Biogas Toilets provide an on-site dry toilet technology which generates fertilizing digestate from human excreta. The systems are characterized by low maintenance, or low-flush (pour flush) water requirement, which makes them ideal for water-scarce areas. They can be an alternative to pit latrines.

FIGURE 32: Biogas-toilet built on digester with well-sealed components.

The following Figure 33 shows a system consisting of six toilets which are attached to one biogas toilet with one common ventilation pipe.

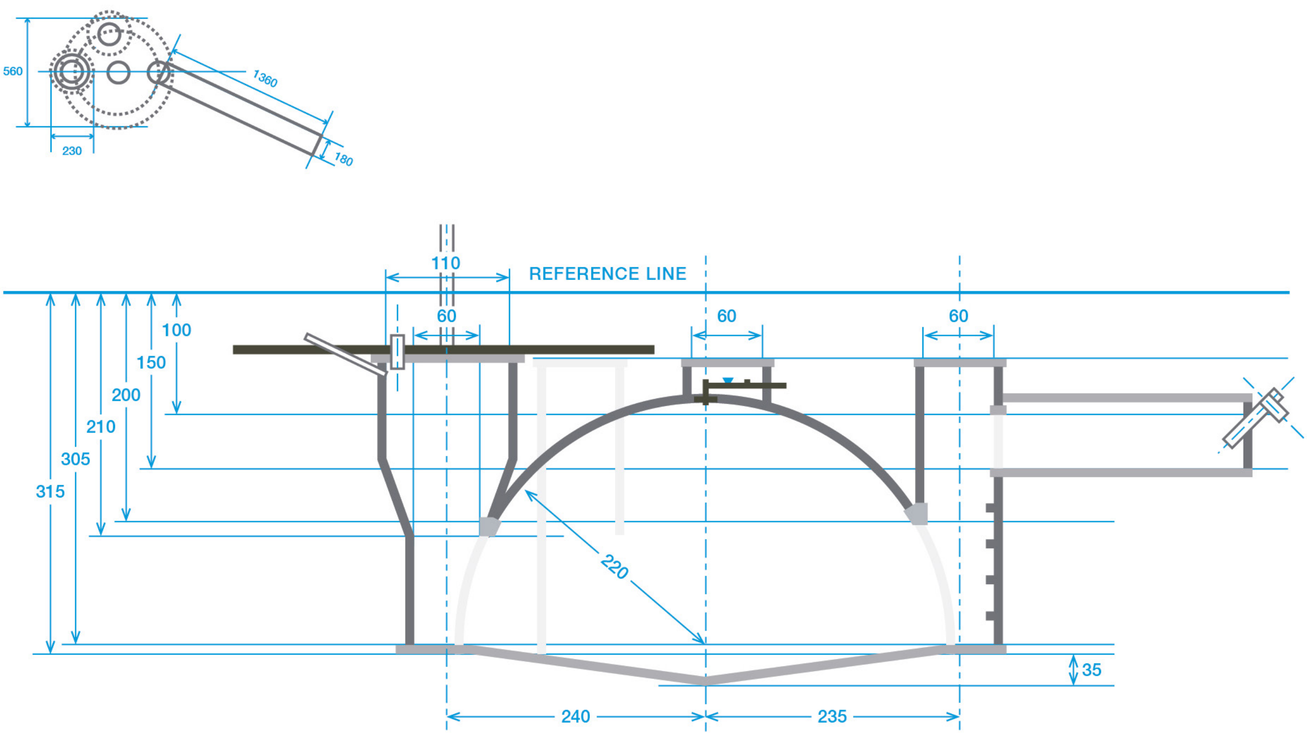


FIGURE 33: Biogas-toilet (Gas storage capacity 5m³).

Biogas toilets can vary significantly in size, from household level to community system. The following Figure 34 shows a biogas toilet with a second inlet for kitchen waste.

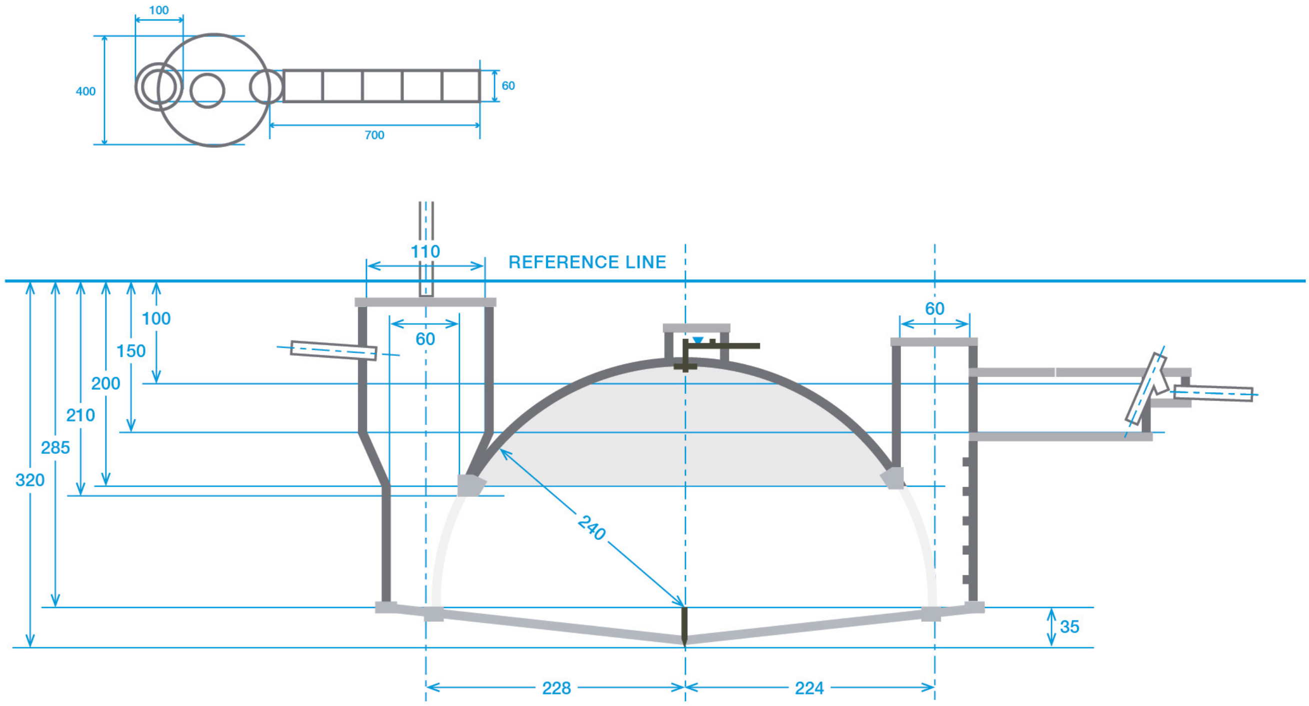


FIGURE 34: Fixed Dome Biogas-toilet (30m^3, gas storage capacity 5.5m^3).

Wastewater Treatment

To achieve an effluent which can be discharged in a planted gravel filter, it is recommended to build two digesters in a row with one jointly used expansion chamber and two sludge discharge pipes fine sediments in the second digester will flow back in digester 1.

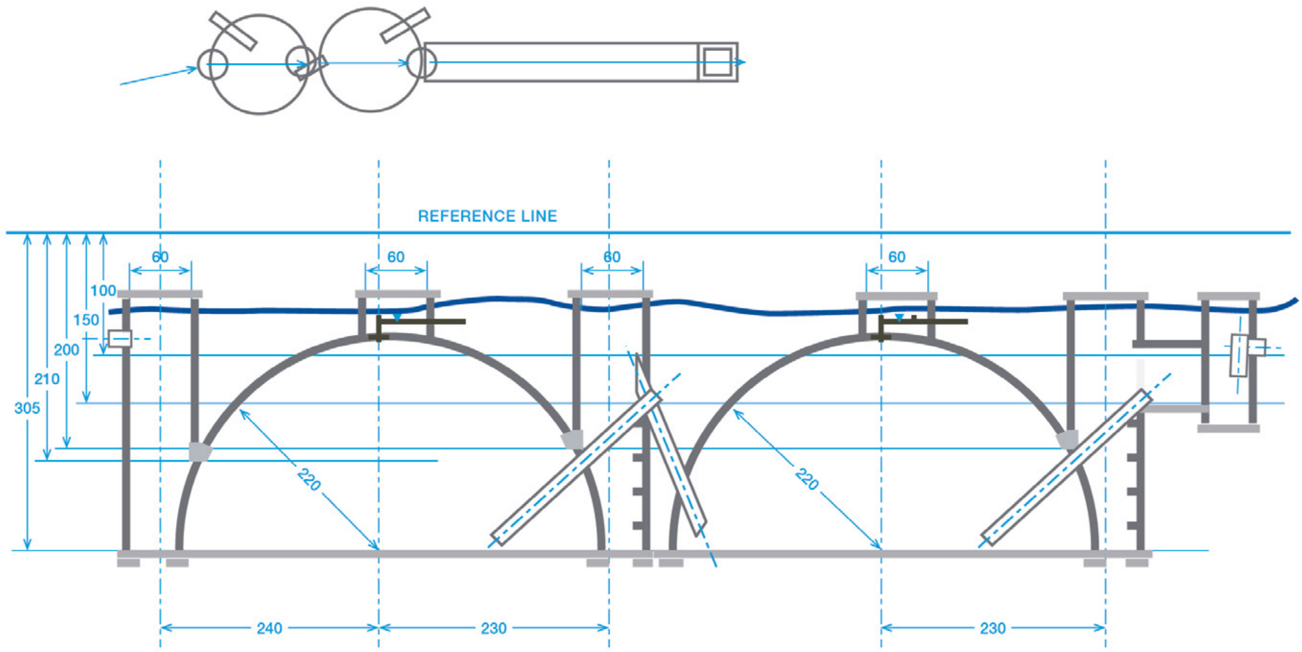


FIGURE 35: Double digester for wastewater treatment.

Biogas Potential of Wastewater and per Person

- → Theoretical constant 350 l methane per 1 kg COD removed.
- → Practical use 200 l biogas per 1 kg COD removed.
- → Maximum 83% of the COD is converted to biogas.
- → Maximum 90% of the BOD is converted to biogas.

One person produces a daily quantity of excreta that corresponds to the pollution index of (30 to) 60 g BOD5 or (60 to) 120 g COD per person per day.

- → Removing daily 90% BOD of one person results in 0.054 kg * 350 l = about 19 l methane/day.
- → Removing daily 83% COD of one person results in 0.0996 kg * 200 l = about 20 l biogas/day.

Depending on the mode of operation and the food intake, the daily biogas volume can be 0.5 to 1 m^3 per m^3 digestion chamber or 16 to 30 l biogas / person. In Asia, usually 30l biogas / person is applied.

Toilet black water alone could not produce enough biogas to cover the energy demand for cooking or lighting of a household. The biogas yield could be increased by additional feeding of easy biodegradable organic kitchen waste or animal dung into the digester. An organic garbage disposal unit in the kitchen sink (grinder), is useful in this respect. But in this case the design and volume of a biogas plant system should be adapted to treat higher solid content than only black water alone.

One adult person on a meat based diet will produce 100 to 250 grams of faeces per day. On a vegetarian diet, an adult person will produce 300 to 600 grams per day (both with 24–27% DM). Therefore, the biogas potential forecast has to be adopted locally on diet, age and climate. Average values for urine are 1 to 1.6 liters volumes per person per day. [11]

Common figures for biogas production are given below:

- → 0.350 m^3 CH_4 / kg COD removed; or 1 kg COD removed results in 0.35 m^3 methane at 273oK and p=po; energy content of methane = 35.8 MJ/ m^3. Based on Dutch figures the production of black water and organic kitchen waste is 100 g BOD per person per day results in 35 l methane per person per day. [12]
- → Based on Nepal figures 27 l biogas from faeces per person per day are produced under operational temperatures of 26–30°C, including organic kitchen waste it increases to 62 l biogas per person per day, with a methane content ranging from 57% to 78%. [13]
- → Out of faeces with organic dry matter (ODM) content of 93%: 0.450 m^3 biogas / kg ODM or 0.290 m^3 methane / kg ODM or 0.210 kg methane / kg ODM may be produced. [14]

[11] Source: House, David, 2006.
[12] Source: Zeeman, Grietje 2006.
[13] Source: Red Cross, Nepal 2009.
[14] Source: Jekel, Martin 2006.

Modification of Gas Appliances

All standard gas appliances can work with biogas.

However, they need to be adjusted because of the fact that biogas only contains 60% inflammable methane.

This is done as follows:

1. The gas nozzle has to be expanded.
2. The air intake in relation to the gas has to be reduced.

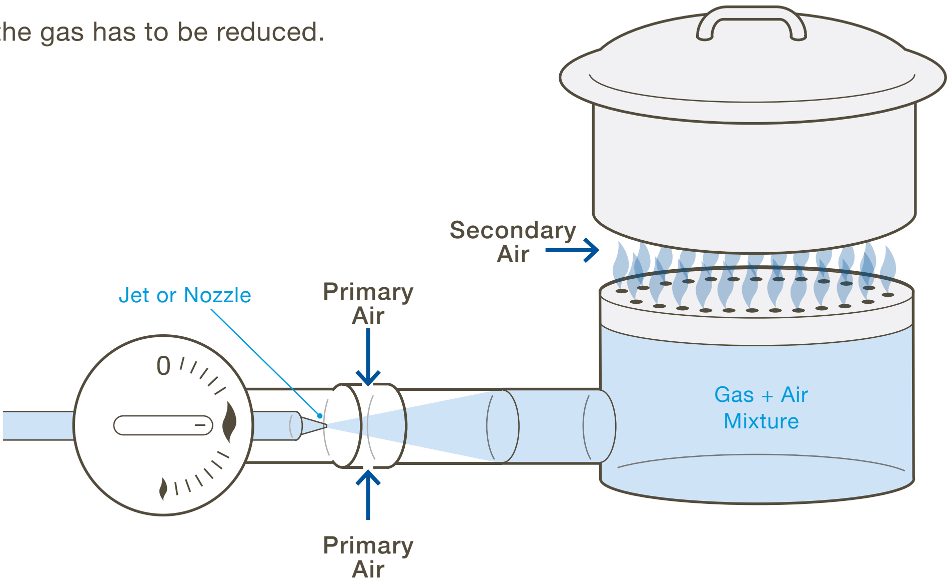


FIGURE 36: Modification of gas appliances.

As far as plants operate only on pure faeces an increased Sulphur content in the gas as result of an increased production of hydrogen sulphide (H2S) has to be taken into account and possibly filtered out or eliminated chemically. H2S is a colorless gas having a strong door of rotten eggs; it fatigues the sense of smell which cannot be counted on to warn of the continued presence of the gas. While the biogas is used for cooking the presence of H2S in the biogas result consequently in smell disturbance and faster corrosion of the cast iron burner parts which get in direct contact with biogas. Additionally, a part of H2S might be converted through the uncomplete combustion of biogas into Sulphur dioxide (SO2), which could result in headache and breathing problems. Even it is known that H2S needs a lower (260°C) combustion temperature than Methane (CH_4) — at 560°C, temperatures over 850°C throughout the flame are necessary to prevent the formation of carbon oxides, partially oxidized hydrocarbons, dioxins and furans, and polycyclic aromatic hydrocarbons (PAHs).

Solid-Free Sewer System; Intermediate Settler

Sewers are made of pipes and with a manhole at each bend or in the interval of certain length. In common practice, manholes are not gas tight and sewers have no pressured flow in the sewer system. It is assumed that aerobic condition prevail in sewers. However, the oxygen available is little and foul smell is always found when solid settling down. If the manhole is designed as gas-tight interceptor tank, methane can be extracted.

In 1895, the biogas sanitation technology was developed in Exeter, England, where a septic tank was used to generate gas for the sewer gas destructor lamp, a type of gas lighting. Also, in England, in 1904, the first dual-purpose tank for both sedimentation and sludge treatment were installed in Hampton, London. By the early 20th century, anaerobic digestion systems began to resemble the technology as it appears today. In 1906, Karl Imhoff created the Imhoff tank; an early form of anaerobic digester and model wastewater treatment system throughout the early 20th century. After 1920, closed tank systems began to replace the previously common use of anaerobic lagoons, covered earthen basins used to treat volatile solids. Research on anaerobic digestion started in the 1930s. [15]

Already in early designs of small-bore sewer systems, septic tanks are typically used for interceptor tanks. [16] “The interceptor tank is a buried watertight tank with baffled inlet and outlet. It is designed to detain the liquid flow for 12 to 24 hours and to remove both floating and settleable solids from the liquid stream. Ample volume is also provided for storage of the solids, which are periodically removed through an access port Typically, a single-chamber septic tank is used as an interceptor tank”. Biogas septic tanks could easy take over this function, also to avoid smell and emissions typically for septic tanks.

Small-bore sewers must be designed to handle peak flows. Interceptor tanks provide some surge storage which attenuates peak flows, and therefore, the sewer diameter can be reduced.

Screening, grit removal and primary sedimentation or treatment in anaerobic ponds are not needed at the final treatment steps, since these processes are performed in the interceptor tanks.

The principal disadvantage of the small bore sewer system is the need for periodic evacuation and disposal of solids from each interceptor tank in the system. A well-designed biogas settler could perform this task, incl. contribution to climate emission reduction and providing cooking energy.

If solids are removed before the sewer, the diameter of the sewer can be much smaller. It can be installed at a shallow depth and does not require a minimum wastewater flow or slope to function. They do not carry solids and have very few manholes. Tolerances for excavation and pipe laying may be greater than for conventional sewers, allowing lesser skilled labor to be used. In result, construction costs are significantly lower than for conventional gravity sewers.

Such solids-free sewers can be built for new areas or where soil infiltration from pit latrines and septic tanks is not appropriate (i.e. densely populated areas, clogging of sub-surface, high ground water table, flood prone areas). Although solids-free sewers require also a constant supply of water, less water is needed compared to conventional sewers because self-cleansing velocities are not required. Alternatives are air flushed sewers where additional water is not required.

Solid-free sewers are also referred to as settled, small- bore, small-diameter, variable-grade gravity, or septic tank effluent gravity sewers and are expected to contribute a substantive portion of the wastewater conveyance in refugee camps in Bangladesh. Interceptor design should consider features of the camp environment, notably the limited space and the need to keep desludging to the minimum for long- term operation and maintenance costs affordable.

A precondition for solid-free sewers is efficient primary treatment at the toilet or household level.

[15] Source: https://en.wikipedia.org/wiki/Anaerobic_digestion.
[16] Source: Worldbank, 1985.

An interceptor, typically a single-chamber Septic Tank, Biogas settler, Imhoff settling tank, Upflow Anaerobic Sludge Blanket Reactor, ABR, Anaerobic Filter or a Biosolid filter, capturing settleable particles that could clog small pipes. The solids interceptor also functions to attenuate peak discharges. Solid-free sewers bring the pre-treated wastewater to a further treatment or to a discharge point connected to another sewer system.

The solid free sewer is an abstract term since it is relatively impossible. However, less solid sewers can be made with the interceptors or sediment collector in-between source and treatment place. TS reduction by biogas digesters is quite high. In this study, the reduction was observed with 83% in average, which means it can well work as interceptor tank for solid free sewer.

Septic interceptor tanks receive raw sewage, allow it to settle and pass the relatively clear liquid onto the adsorption field which is the next stage of treatment. The remaining solids digest slowly at the bottom of the tank. Built as one chamber interceptor tanks, they are inexpensive, but they are suitable only for small flows. The anaerobic decomposition, which takes place in the absence of free O in the septic tank, is a slow process. In order to maintain practical detention times, the reactions cannot be carried far. Therefore, the effluent is often malodorous; containing a multitude of microorganisms and organic materials, it requires further decomposition. Efficiency of this method is up to 15 % reduction of BOD and removal of up to 40 % suspended solids. Multiple chambers will increase the settling capacity. Non-air/gastight interceptor tanks presenting the option to harness biogas from the anaerobic digestion that, to a greater or lesser extent, will take place within the tank. Therefore, designing interceptors specifically to optimize biogas collection is an option, but it is assumed that it will increase the complexity and cost of construction significantly.

Drawings for the different techniques could be found in the Eawag Compendium. [17]

The process that takes place in Imhoff tanks is similar to septic tank, except that the tank is so designed that the flow through the upper chamber is separated from the lower digestion chamber, resulting in a two-storey tank. The upper compartment acts only as a settling zone where little or no decomposition takes place. This chamber remains aerobic, and its effluent has a lower BOD than the effluent from a septic tank. In the lower chamber, anaerobic digestion happens. Since the effluent is of a higher quality, the process is also suitable for decentralized neighborhoods and small communities. The efficiency of Imhoff tank is up to 35% reduction in BOD and up to 60% removal of suspended solids.

Biomass retention in the biogas settlers may be achieved by gravity settling. Thus, as in any settling unit there needs to be an outlet for the supernatant liquid in the upper part of the reactor. Baffles of any kind further enhance the retention of the biomass by holding back unsuspended solid compounds of the inflowing wastewater. Biogas settlers are similar in construction and design as “fixed-dome or floating drum biogas plants” or “membrane covered one chamber interceptor septic tanks”. However, in opposition to biogas reactors, biogas settlers are designed for the retention of biomass and are thus typical high-rate biogas reactors. Other high-rate biogas plants are anaerobic baffled reactors (ABRs); anaerobic filter (AF) and up-flow anaerobic sludge blanket reactors. High-rate biogas reactors are characterized by a mixed flow regime: the liquid flows through (continuous flow), while the sludge is retained (in batch) and treated over a long time until it is removed and further treated to become fertilizer or soil improver. Thus, biogas settlers are characterized by relatively short hydraulic retention times (HRT) for the liquor and high sludge retention times (SRT) for the solid fraction (both, organics and inorganics). The settled sludge is transformed into biogas by anaerobic digestion. Gas bubbles to the top of the reactor are collected for use. Biogas settlers can achieve up to 80 removal of biological oxygen demand (BOD) and chemical oxygen demand (COD), but the efficiency strongly depends on the settling properties of the organic matter and the HRT and SRT design. As a large fraction of the organic matter is volatilized into biogas, sludge production is very low, and the reactors bottom need to be emptied only once every several years (depending of the SRT).

[17] Visit: https://www.eawag.ch/en/department/sandec/publications/compendium/

Imhoff tanks or Biogas settlers' function much like one-chamber interceptor septic tanks with the difference that biogas is recovered. Biogas, a mixture of methane (CH_4) and carbon dioxide (CO_2) can be used either directly for cooking and lighting or it can be transformed into heat in a gas heater system or into combined heat and power (CHP) in a cogeneration unit or used in up-graded form as transport fuel.

Beside local masonry work it should be considered that well designed and maintained prefabricated concrete, fiberglass, or plastic tanks and membrane covered boxes should last about 50 years. In all systems the desludging interval can be strongly influenced by the ambient temperature, the designed sludge volume and the operational monitoring and could reach more than 6 years.

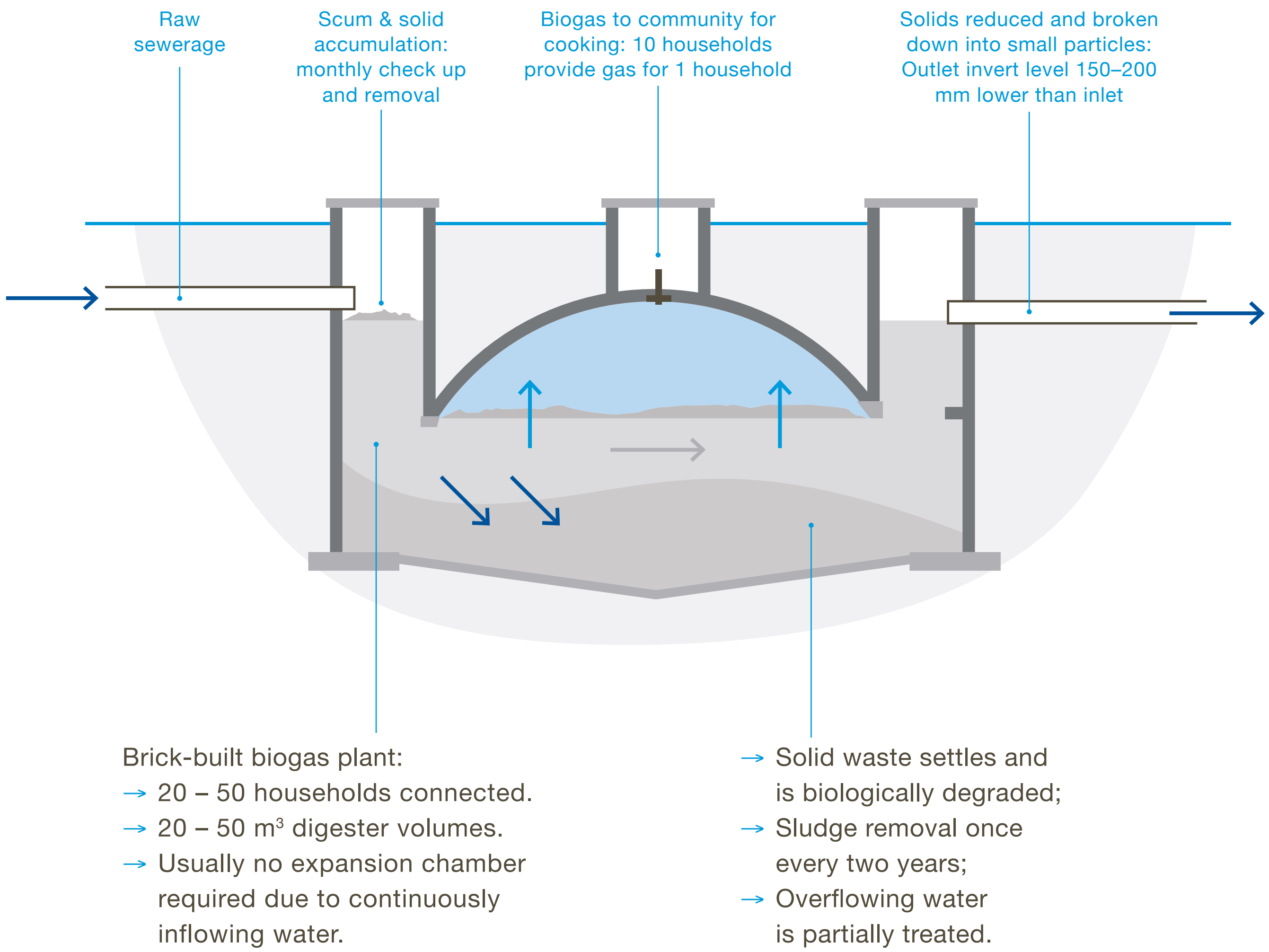


FIGURE 37

Advantages of the Fixed Dome Model

- → All sizes have the same maximum pressure.
- → Easy to construct.
- → Funnel (or similar) as inlet.
- → Measurements in cm are rounded to next 0 or next 5.
- → Digester functions as water trap.
- → Slurry access as easy as possible.
- → Direct toilet (and/or stable) connection if possible.
- → Nominal size (not exactly identical with calculation).
- → Relatively low construction costs.
- → No moving or rusting parts involved.
- → Long life span.
- → Underground construction saves place and protects against temperature changes.

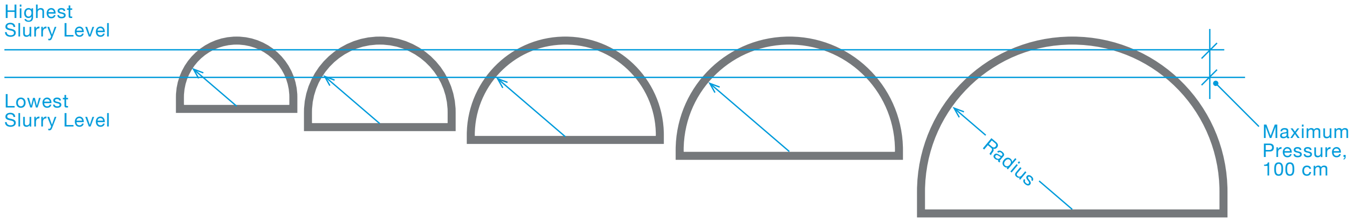


FIGURE 38

TRAINING TOPICS

Gas production

During the digestion process, organic matter is decomposed into a burnable gas mixture, biogas, which has the main components methane and carbon dioxide. The calorific value of biogas varies depending on the methane concentration.

TABLE 9: Chemical composition of biogas. [18]

Components	Household waste	WW treatment plants sludge	Agricultural wastes	Waste of agrifood industry
CH_4 % vol	50–60	60–75	60–75	68
CO_2 % vol	38–34	33–19	33–19	26
N_2 % vol	5–0	1–0	1–0	—
O_2 % vol	1–0	< 0.5	< 0.5	—
H_2O % vol	6 (à 40 °C)	6 (à 40 °C)	6 (à 40 °C)	6 (à 40 °C)
Total % vol	100	100	100	100
H_2S mg/m^3	100–900	1,000–4,000	3,000–10,000	400
NH_3 mg/m^3	—	—	50–100	—
Aromatic mg/m^3	0–200	—	—	—
Organochlorinated or organofluorated mg/m^3	100–800	—	—	

[18] Source: http://www.biogas-renewable-energy.info/biogas_composition.html

TABLE 10: Physical characteristics of biogas. [19]

Types of gas	Biogas 1 Household waste	Biogas 2 Agrifood industry	Natural gas
Composition	60% CH_4 33 % CO_2 1% N2 0% O2 6% H_2O	68% CH_4 26 % CO_2 1% N2 0% O2 5 % H_2O	97.0% CH_4 2.2% C2 0.3% C3 0.1% C4+ 0.4% N2
PCS kWh/m³	6.6	7.5	11.3
PCI kWh/m³	6.0	6.8	10.3
Density	0.93	0.85	0.57
Mass (kg/m³)	1.21	1.11	0.73
Indiex of Wobbe	6.9	8.1	14.9

What can 1m³ biogas do? [20]

- → It can illuminate a gas lamp equivalent of 60 W old fashioned bulb for about 7 hours, resulting in a light performance efficiency of only 7%, 93% of the energy content is transformed in heat.
- → It can cook 3 meals for a family of 5-6 persons.
- → It can generate 2 kW of electricity, the rest turns into heat which can also be used for heating applications.
- → It is average equivalent to 5.5 kg of firewood.
- → It is equivalent to 1.5 kg of charcoal.
- → It is equivalent to 0.45 liter of petrol, 0.55 liter of diesel, 0.60 liter of kerosene or of gasoline, or 0.5 kg of LPG.

Conventional cistern-flush, pour-flush toilets and non-sewer toilets can be linked to a biogas digester. The human waste flows into biogas plant by gravity through a separate pipeline from the toilet into the digester unit. Since the quantity of human faeces generated by a small family is too little, a biogas plant linked only to one toilet will generate very little quantity of gas, thus making a biogas plant solely based on human waste of a family technically unsuitable and economically unjustifiable.

To cover the daily cooking energy need of one person, the faeces from 5–8 persons are needed. It is possible to mix human waste with animal waste, such as cow dung, and preferably with kitchen waste. A biogas digester cannot be considered as a primary faecal treatment unit of a (low flush) toilet, but it can be said that a toilet is an auxiliary supply unit of a biogas plant.

Depending of the reactor type, retention time and biodegradability, about 40% to 90% of organic matter could be converted to biogas. All the mentioned figures should consider that one non-vegetarian adult will produce between 100 to 250 grams of faeces per day, whereas with a vegetarian diet, an adult will produce between 300 to 600 grams per day (both with 24–27% DM). Therefore, the biogas potential has to be adopted locally on diet, age and climate. Normal values for urine are 1 to 1.6 liters volumes per day for adult person. [21]

The quantity of feedstock flow is calculated based on the standard population served by one toilet cubical (usually 20) and average quantity of water allocated per person per flush. For example, if a biogas plant is connected to 12 toilet cubicles, it can serve i.e. 12 * 20 = 240 people. As per the standard quantity of 2.5 liters per person per day for toilet usage, the quantity of inflow amounts to 240 * 2.5 = 600l/day.

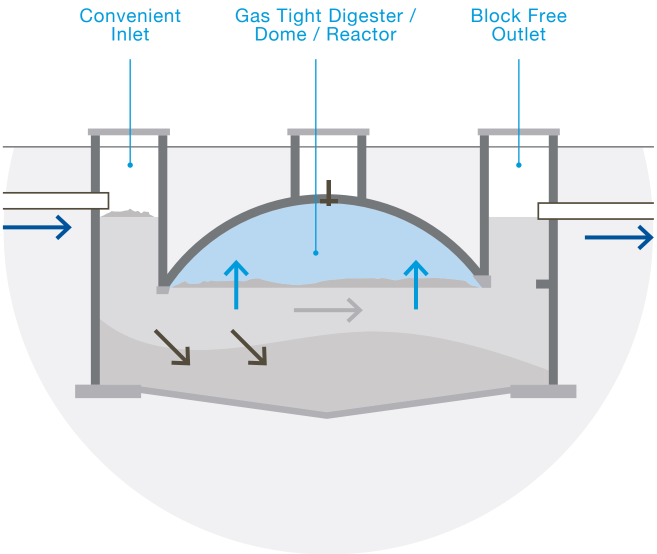
Low gas production indicates that there is potential to generate biogas from the overflow slurry. This happens if the size of the plant is too small compared to the amount of feedstock, or if the sludge is not retained (SRT = HRT).

[19] Source: Ibid.
[20] Source: Amrit Kaki, 1984.
[21] Source: House, David, 2006.

Digester sizes: in-situ or prefab designs?

The components of a sanitation biogas system can be classified into three parts: Inlet, Digester and Outlet.

The left figure shows the schematic diagram of a biogas system whereas the right figures shows a three-dimensional diagram of a prefabricated fiber glass biogas plant: a FRP prefab biogas plant; its section view and its plan.



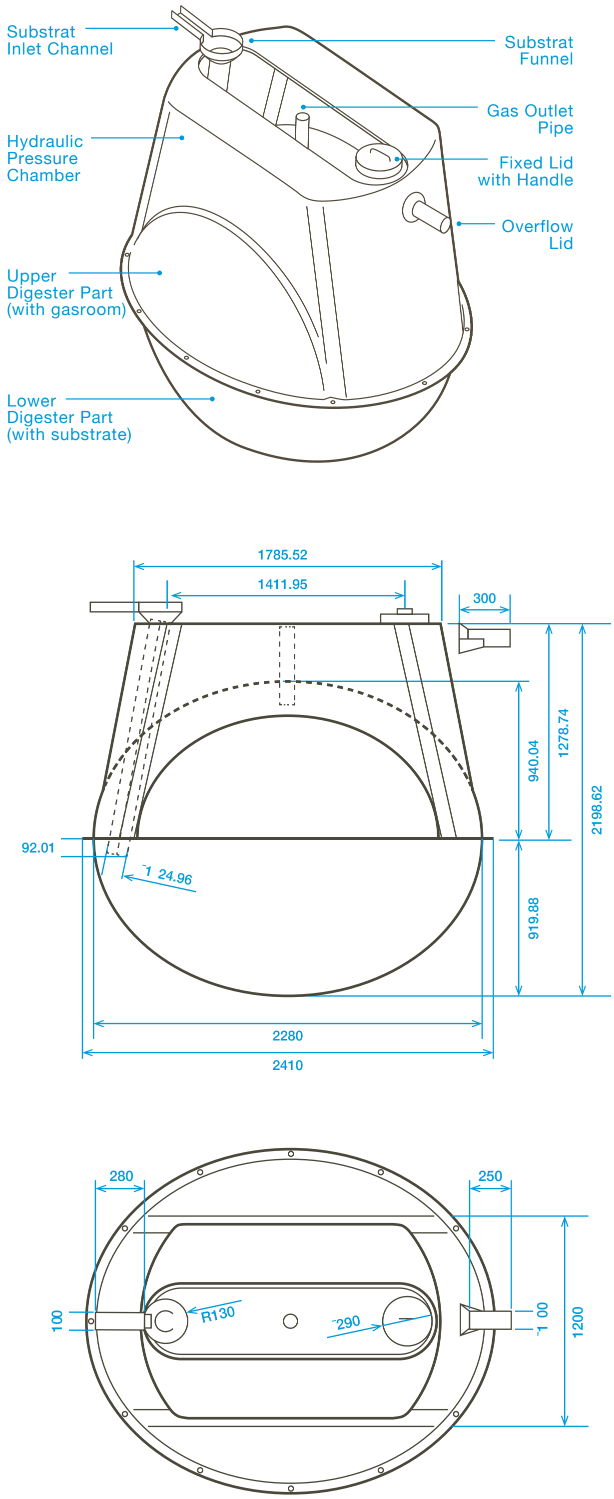


FIGURE 39: Diagram of biogas system (left).

FIGURE 40: FRP prefab biogas plant (right top);
its section view (right center) and its plan (right bottom).

Typical biogas plant sketch of a household biogas plant in Nepal is shown below: basic fundamentals of this plant are that the digester wall can be made of bricks or stones and the dome is made of cement concrete with standard soil mold.

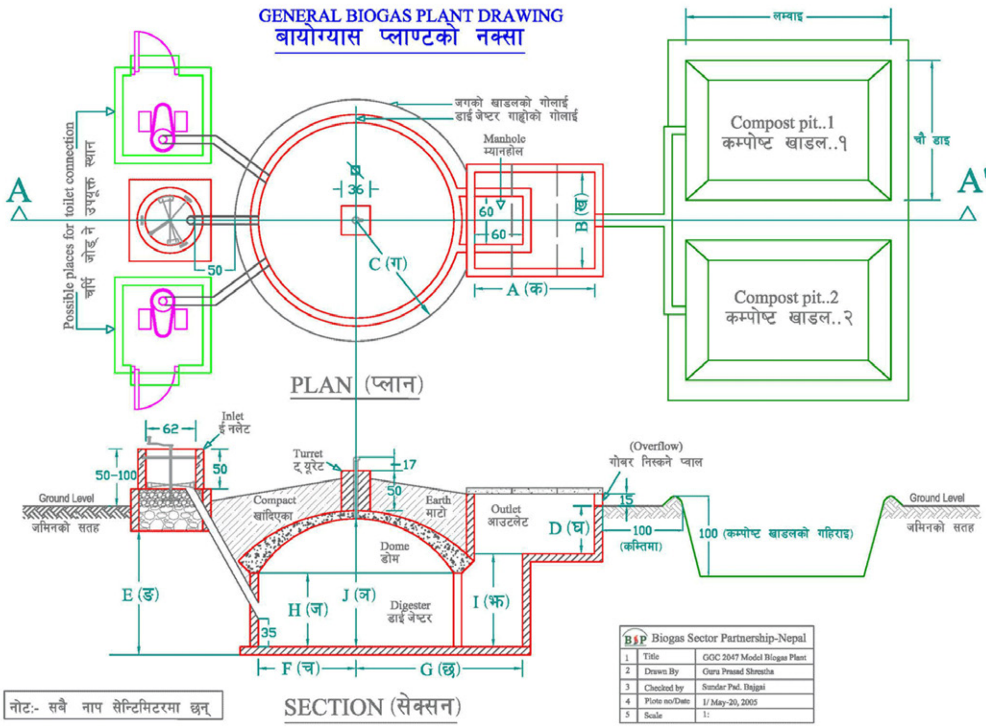


FIGURE 41: This type of plant is known as GGC2047 model and is widely adopted in Nepal.

FIGURE 42: The axis of inlet, dome and outlet should be in 180°.

FIGURE 43: It is always better if the overflow of outlet is directly connected to the slurry pit and agriculture waste shall be put in this pit.

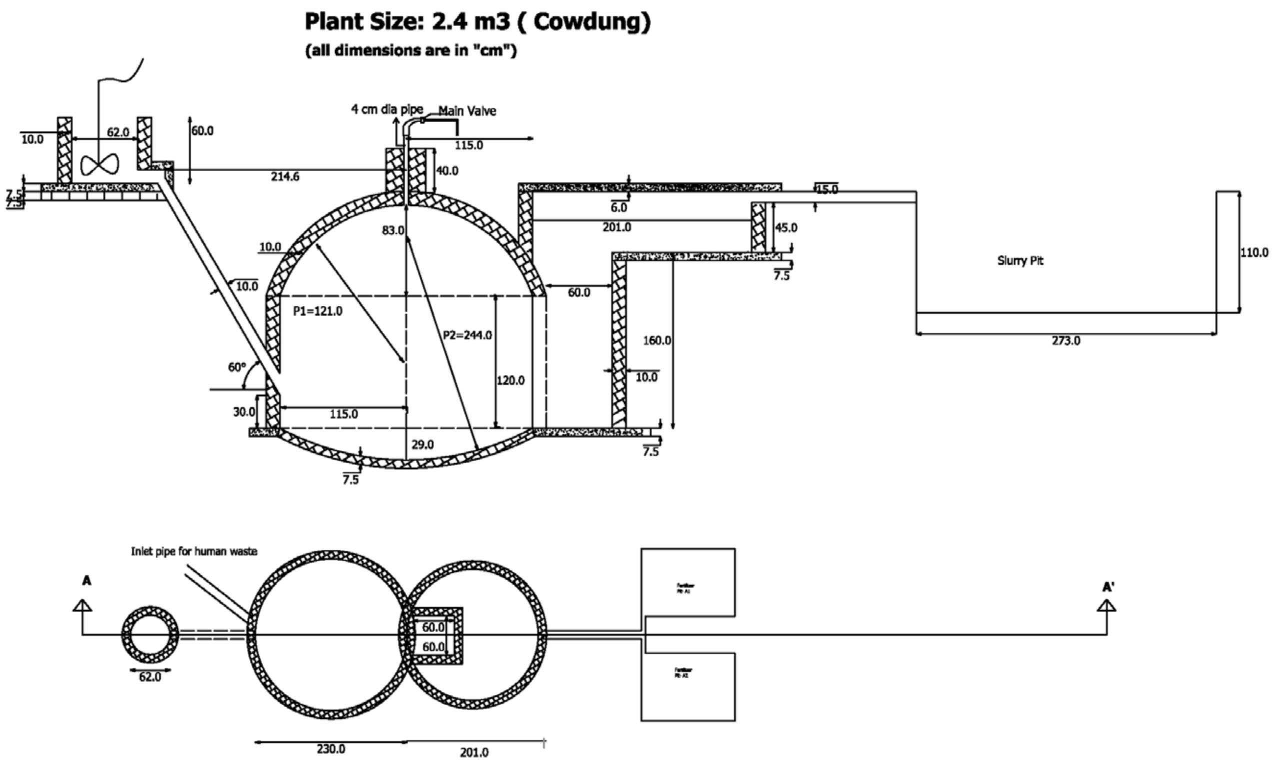


FIGURE 44: Plan & Section of IDCOL biogas plant.

FIGURE 45: Feeding of the biogas plant: lifting of waste may not be convenient.

FIGURE 46: Finished digester with chicken wire in the outside plaster.

FIGURE 47: The direction of inlet, digester and outlet.

FIGURE 48: Gas use in the kitchen, smile of happiness.

How to fit digesters in the landscape?

“Must-have” components of a well-functioning biogas system are:

1 Convenient inlet

The inlet should be so convenient that every person can easily feed the system. In the case of a sanitation system it should be directly connected to the toilet to avoid human contact with contaminated excreta. Similarly, the placement of the inlet should be easily reachable. More water than customary in biogas plants cannot harm the system.

2 Easy outlet

A biogas system works like a human body - if the outlet is blocked and feeding continues from the inlet, the plant will be overloaded and ultimately not work; hence an easy outlet is important for an operating biogas plant.

3 Leak-proof dome

Usually gas is stored in the top part of the dome. If leakage occurs, gas cannot be stored, and will consequently not be available when needed. The leaked gas is very harmful to the environment. Hence, a leak- proofed dome is a pre-requisite for a well-functioning biogas plant.

4 Leak-proof piping system

The available gas should safely reach the kitchen without losses; this is only possible with a leak-proofed piping system.

5 Efficient gas use

Even if gas generation is low, the gas should be efficiently used and not released into the environment. At least, it should be burned with a minimum of primary making only a little sound when burned (with a biogas stove) and no smell at all.

6 Proper effluent use

The effluent of a biogas system contains a lot of nutrients; it is always recommended to use it as fertilizer or soil amendment or fertigation water. A biogas system usually acts as primary treatment for organic wastes. In the case of a sanitation plant, the effluent shall be used only after a secondary treatment, e.g. composting.

Channel system to distribute overflow by gravity

FIGURE 49: Effluent slurry guided in a fodder grass plantation: the surrounding is dry, but the plantation is productive.

Bananas in Planted Gravel Filter

FIGURE 50: Banana planted in a gravel filter made of broken bricks.

FIGURE 51: After one year, the banana are producing fruits.

FIGURE 52: After two years, bananas are growing vigorously and clean the effluent water effectively.

TRAINING TOPICS

Effluent Management

Introduction: Meaning & Composition of Slurry

Slurry is an anaerobic digested organic product released from a biogas plant.

- → Quality of slurry depends on several factors: the kind of organic matter (human or animal excreta, or other feedstock), water, diet, age, and breed of animals.
- → Cow dung and poultry dropping are the major raw materials for biogas production in Bangladesh.
- → Human faecal sludge is usable for biogas production at Rohingya camp but use of effluent needs post treatment (controlled composting, solar disinfection, solar drying...).

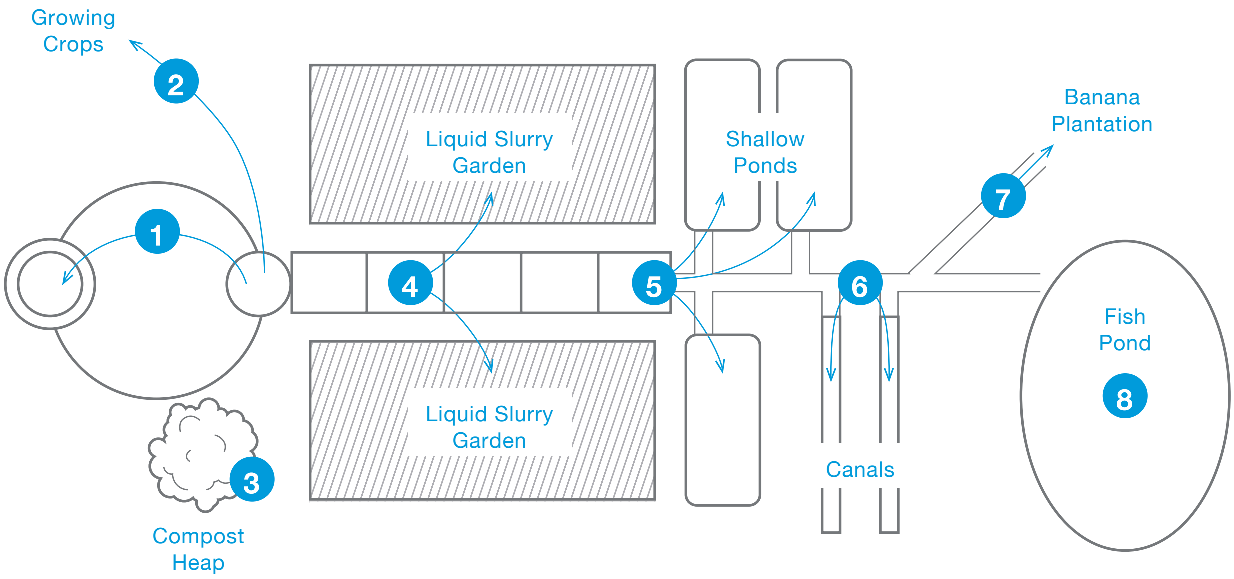
TABLE 11:

Post-treatment	Frame conditions	Effect	Advantage	Disadvantage
Composting	• The higher the temperature, the shorter the time needed for treatment. • WHO gives a recommendation of a minimum one week of treatment above 50 °C for composting of faecal matter. • Alternate composting platforms or -pits for batchwise management.	• May give good hygienic quality. • Temperature / time dependent.	• Low-tech equipment possible. • May degrade organic pollutants.	• Labour-intensive. • Eutrophying emissions. • Risk for re-growth. • Leaching water effluent (may be reused for digestion).
Further anaerobic digestion steps for liquid effluents (AF, ABR)	• During mesophilic anaerobic digestion many pathogenic and indicator bacteria, as well as some viruses, need more than 2 days for a 1 log10 reduction. • Thermophilic digestion of sewage sludge in a large-scale continuous process reduces indicator bacteria and Salmonella sufficiently. • On the other hand, mesophilic digestion has proven to be more efficient in degrading organic pollutants such as benzoic acid, m- and p-cresol compared with thermophilic digestion. • By using a process adapted for high ammonia content (8 g L– 1) at a pH close to 8, it is possible to have a sanitising mesophilic process.	• May give good hygienic quality. • Temperature / time dependent.	• More valuable energy produced. • Mesophilic treatment degrades organic pollutants. • The evaluation of biogas itself always indicated a low risk regarding disease transmission.	• Risk for re-growth and methane emissions.

Ammonia treatment	• Ammonia is added either as aqueous ammonia solution • or as granulated urea. This treatment is efficient for inactivation of bacteria, • parasites and some viruses. • Recommended treatment is either 0.5% NH3 for one week, or 2% urea for two weeks at temperatures above 10°C, or for one month at temperatures below 10°C. • Covering needed to avoid ammonia emissions.	• Gives good hygienic quality. • pH and uncharged NH_3 dependent.	• Low-tech equipment needed. • Ammonia recycled as a fertiliser.	• Low risk for re-growth.
Land application	• May be spread-on, sub-surface drainages or worked-in.	• Only application weeks before planting or seeding, or before winter.	• Studies have shown a more rapid reduction in the Soil (“worked-in”), in general enteroviruses seem to be reduced faster than indicator bacteria.	• Needs storage capacity. • Survival of pathogens in soil, grass and silage for close to 2 months has been shown under laboratory conditions and survival on soil and biosolids for over one year has been proven (spread-on, sub-surface drainages).
Sludge drying bed	• If the slurry is not used directly used, it may be collected and treated in sludge drying beds. • Partially dig up the ground and pile up the excavated soil to earthen bunds. • Alternate composting platforms or -pits for batchwise.	• May give good hygienic quality. • Temperature / time dependent.	• Low-tech equipment possible. • Perimeter bunds will help in keeping surface run-off water from entering the sludge drying beds.	• Low risk for re-growth. • Should be rainwater dilution protected. • Not applicable in monsoon areas.

Possibilities for Slurry Utilization

The expansion canal has two manholes with lids easy to open. The operator of the digester has many options about what to do with the slurry, described from left to right in the following figure:



1. Recycle effluent to dilute new feedstock.
2. Pump the effluent with a treadle pump to growing crops, like fruit trees.
3. Use a grid or fork or swimming pool cleaner to remove the solids and pile up a compost heap.
4. Use watering cans and irrigate the slurry garden around the biogas plant (short distance), directly out of the expansion canal.
5. Guide the effluent in shallow ponds alternately to evaporate the water and dry it. Crops are planted around these beds to pick up seeping liquids with their roots.
6. Guide the effluents in canals which are surrounded, e.g. by fodder grass.
7. Guide the effluent in a banana plantation. Banana needs a lot of water and nutrients (B&B = Biogas and Banana).
8. Guide the effluent controlled in fishponds.

FIGURE 53: 8 Methods to use slurry.

Slurry as Organic Fertilizer

- The composition of the slurry can consist of 80–95% water and 5–20% dry matter, of which 60-80% is organic matter and 20–40% inorganic matter.
- It contains nutrients such as N, P, K, Ca, Mg, Fe, Mn, organic matter, different amino acids and metals like copper and zinc.
- Bio-slurry is a 100% organic fertilizer most suitable for organic farming.
- This fertilizer can effectively be used for all high value fields and horticultural crops including vegetables, fruit, flowering as well as ornamental plants and roof top garden.
- Compared to chemical fertilizers, bio-slurry decomposes with a slow process which is better for nutrient uptake and assimilation for plants.

TABLE 12: Nitrogen, phosphorus and potassium in slurry and manure.

Kinds of slurry manure	Nitrogen %	Phosphorus %	Potassium %
Digested slurry	1.5 to 2.0	1.0	1.0
Sun-dried slurry	1.4 to 1.8	1.1 to 2.0	0.8 to 1.0
Slurry compost	0.8 to 2.23	0.7 to 2.11	0.5 to 1.5
Farmyard manure	0.3 to 0.5	0. to 0.2	0.5 to 0.7

Soil Conditions Inducing Nutrient Deficiency in Crops

TABLE 13: Solid conditions inducing nutrient deficiency in crops.

Nutrient	Major conditions inducing nutrient deficiency
Nitrogen	Low organic matter content, wetland soil.
Phosphorus	Acidic, leached and calcareous soils.
Potassium	Sandy, leached and eroded soil.
Calcium	Acidic, alkali and sodic soil.
Magnesium	Acidic, alkali and sodic soil.
Sulphur	Low organic matter content, submerged soils, burning of crop residues.
Iron	Calcareous soils, high soil P, Mn, Cu, Zn and HCO_3 contents.
Manganese	Sandy soils, saline soils, submerged soils, low organic matter content, high soil P, Ca, Mg and Cu contents.
Zinc	Calcareous soils, saline soils, submerged soils, low organic matter content, high soil P, Ca, Mg, and Cu contents.
Copper	High N, P and Zn contents.
Boron	Sandy soils, high pH soils, dry soils.
Molybdenum	Calcareous soils, acid soils with high free Fe content.

Application Forms

Digestion nutrients are transformed from organic states to dissolve states, making them more useful for plant uptake:

- Effluent has considerable amounts of nutrients.
- The appropriate rate of effluent use may depend on the crop and soil (sand, clay, loam).
- It is generally recommended to apply the slurry at a rate of 10 to 20 tons/ha in irrigated areas and 5 tons/ha in dry farming in order to achieve a significant increase in yield.

Liquid Form

- Can be applied through foliar spray, a bucket or irrigation canal.
- Suitable for farmers growing vegetables in the kitchen garden.
- Color from dark grey to black of liquid form performs better.
- Difficult to transport.

Dry Form

- Many farmers prefer the dry form of slurry as it is easier to transport than the liquid form.
- The dried slurry loses part
- of its nitrogen (particularly ammonium) and therefore the nutrient value of the slurry is decreased.
- A well-digested slurry contains 1.4–1.8% N, 1.0–2.0% P_2O_5, 0.8–1.2% K_2O and 25–40% organic carbon.
- Dried slurry was somewhat inferior to a mixture of ammonium sulphate and single superphosphate containing equivalent quantities of nitrogen and phosphate.

Composted Form

- The composted form of slurry is the best way to overcome the transportation issue related to liquid slurry and the nutrient loss of the dried form.
- Minimize the loss of nutrients in the compost.
- It should be taken to the crops only when required and should be mixed with the soil as soon as possible.
- Derive maximum benefit from organic manure application, the compost should be well decomposed and be of good quality.

Meaning of Liquid Clurry Color

- Dark yellowish color of the effluent indicates sufficient use of the installed capacity = well fermented.
- Dark black indicates too long fermentation time = biogas plant may be oversized.
- Light yellow indicates too short retention time = biogas plant is overloaded or short cut flow from inlet to outlet happens.

Result: Field Trial in Manikganj, Bangladesh

Bio-slurry can increase cereal crop productions by 10% to 30% compared to ordinary manure.

A trial was done in Manikganj, Bangladesh applying different mixtures of fertilizers consisting of recommended doses (RD) of chemical fertilizer, cow dung (CD) or/and poultry litter (PL). Table 14 shows that the application of chemical fertilizer increases the yield for cabbage and brinjal by 5 to 6 times, and for tomato by about 4 times. Alternatively, the application of only 50% of the recommended dose of chemical fertilizer mixed with poultry litter bio-slurry results in similar or even increased yield.

TABLE 14: Effect of bio-slurry on the yield of cabbage, brinjal and tomato.

Treatment	Cabbage (T/ha)	Brinjal (T/ha)	Tomato (T/ha)
Control (native fertilizer)	10.00	5.50	6.50
100% RD	56.50	26.30	24.00
50% RD + CD bio-slurry	58.60	24.00	25.00
50% RD + PL bio-slurry	60.00	25.00	27.00
10% RD + CD bio-slurry	44.00	15.00	16.00
10% RD + PL bio-slurry	48.00	17.00	18.50

Advantages of Slurry Practice

Advantages of Slurry Practice

- → Increase soil fertility, and improvement of the soil structure and water holding capacity
- → Decrease of soil erosion.
- → Treat seeds for higher germination, disease resistance, better yields, improved coloration of fruits and vegetables, and tenderness and taste of leafy vegetables.
- → Increase the feed value of fodder with low protein content.
- → Increase the availability of nutrients for soil micro-flora like nitrogen fixing and phosphor solubilizing organisms.
- → Reduce wastewater, water pollution, greenhouse gas emissions and noxious odors.
- → Reduce weed growth and diminish attractiveness to insects.
- → Reduce labor cost.

Slurry Practice in Bangladesh

Present bio-slurry handling at the plant premises is highly unsatisfactory.

The biogas plants have often no proper system of bio-slurry collection, drying, processing and bagging.

Realities

- **Technical and technological barrier**
  Slurry pits are not well structured About 50% of the biogas plant owners are using the slurry without any prescribe guideline. No modern technologies used for slurry transportation.
- **Research constraints**
  Undiscovered the poultry-based slurry practice.
- **Commercial Barrier**
  No bio-slurry market creation, entrepreneurship is not yet well developed for organic fertilizer based on slurry, not proper assessment of expected slurry production.
- **Awareness deficiency**
  Lack of nutrition value of slurry, DAE has no proper slurry utilization guideline for crop production.
- **Policy Barrier**
  Long bureaucratic procedure to be followed for getting registration, weak attention of respective Government office.

Recommendations

- Construct two pits for rotational use.
- Pit composting with bio-slurry and harvest residues.
- Protect the bio-slurry in pits from sun and rain, shade should be provided.
- Extend the organic market activity.
- Slurry packaging sell to market.
- Direct slurry connection to the fish culture pond is not recommended.
- Launch a new department regarding to bio-slurry in IDCOL.
- Publicity of slurry advantages to be focused.
- Organic certification process should be in one stop service.

Laboratory tested result of different organic fertilizer components

The Government approved the organic fertilizer in 2008 by following the parameters in Table 15, to set its standards for Bangladesh.

TABLE 15: Government approved standard for organic fertilizer in Bangladesh. [22]

Parameter		Content
Physical	Color	Dark gray to back
	Physical condition	Non-granular form
	Odor	Absence of foul odour
	Moisture	Maximum 10–20%
Chemical	pH	6.0–8.5
	Organic Carbon	10–25%
	Total Nitrogen (N)	0.5–4.0%
	C:N	Maximum 20:1
	Phosphorus (P)	0.5–3.0%
	Potassium (K)	0.5–3.0%
	Sulphur (S)	0.1–0.5%
	Zinc (Zn)	Maximum 0.1%
	Copper (Cu)	Maximum 0.05%
	Arsenic (As)	Maximum 20 ppm
	Chromium (Cr)	Maximum 50 ppm
	Cadmium (Cd)	Maximum 5 ppm
	Lead (Pb)	Maximum 30 ppm
	Mercury (Hg)	Maximum 0.1 ppm
	Nickel (Ni)	Maximum 30 ppm
	Inert Material	Maximum 1%

Table 16 presents the different organic fertilizer components and the respective laboratory results. Bangladesh Government highlights two basic criteria: Physical and chemical composition shall be fulfilled for producing organic fertilizer in Bangladesh.

Compost, cow dung + vermin and fresh cow dung are also recommended to be applied in agricultural land as organic fertilizer in Bangladesh.

[22] Source: Ministry of Agriculture, 2008.

TABLE 16: Different organic fertilizer properties. [23]

Sample Name	Color	Odor	Physical Condition	Mois-ture %	pH	O.C %	N%	C:N	P%	K%	S%
Bio-slurry	Dark reddish brown	Absence of foul odor	Non granular	4.6	6.8	8.4	0.9	9:01	0.89	0.69	0
Cake dry with sand	Dark black	Absence of foul odor	Non granular	48	6.8	29	3.11	9:01	1.07	0.2	1
Dry faecal sludge	Very dark grey	Absence of foul odor	Non granular	10.2	6.7	21	1.3	16:01	2.59	1.22	0
Dry cake without less sand	Dark black	Absence of foul odor	Non granular	49.9	6.6	30	3.18	9:01	1.22	0.19	1
Enzyme added dry cake	Reddish brown	Absence of foul odor	Non granular	33	7.8	5.6	0.91	6:01	1.35	1.01	0
Dry part of cake	Grey	Absence of foul odor	Non granular	4.4	7.3	7.6	0.92	8:01	1.04	0 + [24]	0
Cake size	Reddish brown	Absence of foul odor	Non granular	41.1	4.8	28	3.06	9:01	1.39	1.28	1
Quick compost	Dark reddish brawn	Absence of foul odor	Non granular	27.2	8.1	28	1.22	23:01	1.36	1.26	0
Faecal sludge + cow dung vermin	Reddish brawn	Absence of foul odor	Non granular	49.5	7	24	1.73	14:01	1.68	0.61	0
Faecal vermin	Reddish brawn	Absence of foul odor	Non granular	49.7	6.4	22	1.79	12:01	1.37	0.43	0
Cow dung vermin	Dark reddish brawn	Absence of foul odor	Non granular	50.4	6.6	29	1.75	17:01	1.12	0.69	0
Solid waste compost	Very dark grey	Absence of foul odor	Non granular	41.6	7.4	12	1.45	8:01	1.33	1.23	0
Only sand (separation from total volume)	Dark black	Absence of foul odor	Non granular	1.6	7.9	4	0.43	9:01	0.59	0.38	0
Fresh cow dung	Dark reddish brown	Absence of foul odor	Non granular	2.2	6.4	44	1.76	23.99:1	0.89	1	0

[23] Source: BINA, 2017.
[24] 0 + vermin compost 81.

TABLE 17: Different organic fertilizer properties II.

Sl. N°	Name of the Sample	Moisture (%)	Ash (%)	Lipid / Fat (%)	Protein (%)
1	Bio-Slurry (Kushtia)	6.82	57.00	1.64	0.00
2	Cake dry with Sand (Kushtia)	58.18	20.25	2.72	10.45
3	Dry fecal (Kushtia)	10.01	50.19	0.57	8.78
4	Dry cake without less sand (Kushtia)	61.56	15.21	1.97	10.80
5	Enzyme added dry cake (Mymensingh)	35.13	53.96	0.24	5.83
6	Dry part of the cake	5.70	73.22	0.60	7.13
7	Cake size (Mymensingh)	36.24	47.01	1.86	10.03
8	Quick Compost (Kushtia)	42.75	23.61	2.18	8.11
9	Faecal + cow dung vermin (Kushtia)	64.29	21.16	0.80	4.90
10	Faecal vermin (Kushtia)	58.76	25.31	0.62	7.35
11	Cow dung vermin (Kushtia)	66.16	13.96	0.36	6.50
12	Solid waste compost (Khulna)	38.08	42.56	0.06	7.50
13	Only sand (Separation of total volume of dry cake)	2.15	88.66	0.07	5.75
14	Fresh faeces (Gazipur)	7.08	15.50	1.64	13.30

Few field level organic fertilizer activities are shown in the following pictures:

Figure 54 shows an example of dewatering and drying beds for fecal sludge, constructed by IFRC at Cox's Bazar Refugee Camp, while Figure 55 shows an example of a storage place for dried sludge in the Fecal Sludge Treatment Plant constructed by Water Aid at Shakhipur Paurashava, Tangail.

FIGURE 54: Drying Bed with Fecal Sludge Cake (above).

FIGURE 55: Dried sludge storage place (below).

Effect of biol, Biosol and bio-slurry on spinach and amaranth production

Bio-slurry has two major fractions, (i) biosol: the solid fraction that is dominated by sludge and fibers, and (ii) biol: the liquid fraction dominated by readily plant available minerals, hormones and other non-specific growth stimulants. The effect of biol (bio-liquid), Biosol (bio-solid) and bio-slurry are displayed in the following picture. Two leafy vegetables were produced, and the effects of organic and inorganic fertilizer impact were observed. Organic fertilizers were performing significantly better compared to no or chemical fertilizer.

FIGURE 56: Effects of fertilizer on spinach (above) and amaranth (below) growth.

FIGURE 57: Poultry dropping based slurry; Slurry flows directly into the pond. Very poorly managed slurry pit of poultry-based biogas plant in Valuka, Mymensingh. This type of slurry pit will contaminate the surrounding and near water bodies.

FIGURE 58: Unstructured pit; slurry filled up the pond.

FIGURE 59: Blackish colored bio-slurry indicates that the biogas plant receives too little feeding. It also indicates a very low content of Nitrogen.

FIGURE 60: Open slurry pit in Balika, Mymensingh: Liquid leached and evaporated. The slurry is therefore completely dried out. The liquid effluent should be used as fertigation water.

Prospects of slurry from view point of Trainees

Chances of bio-slurry

- → Better slurry use.
- → Value addition to the slurry.
- → Organic market creation.
- → Reduce the dependence on chemical fertilizer.
- → Selling bioslurry.

Risks of bio-slurry

- → The pH-value of bio-slurry is usually higher than that of Farm Yard Manure (FYM) which bears the risk of an elevated release of ammonia.
- → High concentrations of ammonia cause damage to vegetation and lead to acidification and eutrophication of soils and water bodies.
- → Not all pathogens present in the manure are always fully eliminated during the digestion process, and they can therefore cause diseases.

TABLE 18: Compost (Organic Fertilizer) Standard in Bangladesh.

Parameter		Content
Physical	Color	Dark gray to back
	Physical condition	Non-granular form
	Odor	Absence of foul odour
	Moisture	Maximum 10–20%
Chemical	pH	6.0–8.5
	Organic Carbon	10–25%
	Nitrogen (N)	0.5–4.0%
	C:N	Maximum 20:1
	Phosphorus (P)	0.5–3.0%
	Potassium (K)	0.5–3.0%
	Sulphur (S)	0.1–0.5%
	Zinc (Zn)	Maximum 0.1%
	Copper (Cu)	Maximum 0.05%
	Chromium (Cr)	Maximum 50 ppm
	Cadmium (Cd)	Maximum 5 ppm
	Lead (Pb)	Maximum 30 ppm
	Nickel (Ni)	Maximum 30 ppm

Hygiene aspects of biogas plants

Anaerobic digestion of animal manure and biogenic wastes may result in new routes of pathogen and disease transmission between animals, humans and the environment.

Wastes of animal and human origin, used as AD feedstock, contain various pathogenic bacteria, parasites and viruses. Pathogenic species that are regularly present in animal manures, slurries and household waste are bacteria, viruses and fungi. Co-digestion of abattoir and fish-processing wastes, fecal sludge and biowaste potentially increases the diversity of pathogens that may be land spread and may enter the animal and human food chains.

The treated effluent (digestate) of a biogas plant is usually applied as fertilizer on agricultural fields, belonging to several individual farms. The risk of spreading pathogens through digestate application must be prevented by implementing standardized veterinary safety measures. The sanitary measures listed below contribute to effective control of pathogens and other infectious matters through anaerobic digestion:

→ Livestock health control: No animal manure and slurries should be supplied from any livestock with health problems.

→ Feedstock control: Biomass types with high risk of pathogen contamination must be excluded from anaerobic digestion.

Test of Knowledge: Right-or-Wrong Game

TABLE 20: Statements and solutions for final Test of Knowledge.

Statement	Solution
The automatic water trap is empty. All gas is escaping. The cause was a blocked overflow point.	**RIGHT** Due to the blocked overflow point the gas pressure has risen and even though the automatic water trap was properly set out, the higher pressure blew out the water and all gas was released.
Surprisingly the expansion chamber was completely empty in the morning and the gas pressure was very high.	**WRONG** The gas must have escaped through a water trap or an open valve and the pressure would be minimal in this case.
The smaller the pipe diameter, the higher the pressure.	**WRONG** The pressure cannot be influenced by the pipe diameter. The misunderstanding is caused by the smaller a jet, the higher the gas speed, not the pressure.
Smoking near a leaking pipe can cause an explosion.	**WRONG** A cigarette tip is not hot enough to light biogas. An open flame can light the gas but can also not cause an explosion. When the accumulated gas in a closed space is within the explosive mixture range (5–15%) it could cause explosion.
You can detect a leakage in a pipe joint by touching the joint and smelling your hand.	**RIGHT** The smallest amount of H_2S is enough to generate Sulphur smell in your nose.
A leaking pipe can be repaired with insulation tape.	**WRONG** The gas under pressure will always finds a way through. Such repairs should never be done or tolerated. Piping systems must be repaired with original parts only.
Oprimary air starts developing a flame near the adjustment knob whenever the stove is lit for some moments. The primary air should be closed with insulation tape completely.	**WRONG** The orifices in the burner head have gradually clogged over time with food residues. All holes at the burner head have to be fully operative so that gas and primary air can transit to the burner head freely. This has to be explained to the cook so that he/she cleans the burner head if such spills happen.
The longer the piping system, the larger the diameter should be.	**RIGHT** There is friction on the pipe walls which leads to pressure loss on the way.
The higher the pressure, the higher the pressure loss in a long piping system.	**RIGHT** But that is not relevant.
The flow rate in a pipe depends on the gas consumption accessories operated with the gas.	**RIGHT** It is much higher for generators than for cooking stoves.
A commercial digester needs a larger diameter piping system than a household digester.	**RIGHT** There is much more gas produced and this has to arrive at the consumption points without much pressure drop.
The automatic water trap is empty. All gas is escaping there. The cause was a blocked overflow point.	**RIGHT** Due to the blocked overflow point the gas pressure has risen and even though the automatic water trap was properly set out, the higher pressure blew out the water and all gas could escape.

Training Programme Evaluation Form

The feedback you provide will help us evaluate the value and effectiveness of the course that you have attended. This will help us in ensuring that only the better organized and better quality programmes are provided to our employees.

TRAINING PROGRAMME EVALUATION FORM				
Course Title:				
Name of Trainer:				
Date of Training:				
1. PROGRAMME CONTENT				
a. Achieved its objectives:		☐Not at all	☐Moderately	☐Completely
b. Level:		☐Too Simple	☐Just Right	☐Too Difficult
c. Subject Coverage:		☐Too Little	☐Just Right	☐Too Much
d. Relevance to Job:		☐Not Relevant	☐Relevant in Parts	☐Relevant
e. Comment 1: What did you find most helpful in the programme?				
f. Comment 2: What did you find least helpful in the programme?				
2. PROGRAMME DESIGN & METHODOLOGY				
a. Length:		☐Too Short	☐Just Right	☐Too Long
b. Pace:		☐Too Slow	☐Just Right	☐Too Fast
c. Training Methods (i.e., lectures, demonstration, role play, games, exercises, group discussions):		☐Not Effective	☐Effective	☐Very Effective
d. Training Aids (i.e., overhead projector, flipchart, whiteboard, videos):		☐Not Effective	☐Effective	☐Very Effective
e. Literature (handouts, etc.):		☐Too Skimpy	☐Just Right	☐Too Detailed
3. PROGRAMME ADMINISTRATION				
a. Planning & Organisation:	☐Poor	☐Average	☐Good	☐Very good
b. Teaching Accommodation (Seating, Acoustics, Lighting, etc.):	☐Poor	☐Average	☐Good	☐Very good
4. EFFECTIVENESS OF TRAINER				
a. Subject Knowledge:	☐Poor	☐Average	☐Good	☐Very good
b. Organisation & Preparation:	☐Poor	☐Average	☐Good	☐Very good
c. Delivery Style:	☐Poor	☐Average	☐Good	☐Very good
d. Responsiveness to Trainees:	☐Poor	☐Average	☐Good	☐Very good
e. Creating a Learning Climate:	☐Poor	☐Average	☐Good	☐Very good
f. Any Other Comments:				
5. OVERALL ASSESSMENT				
a. What is your overall assessment of the programme?	☐Poor	☐Average	☐Good	☐Very good
b. Would you recommend sending any of our employees to this programme in the future?				☐Yes ☐No
Thank you !				

Contributors

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Bangladesh Agricultural University was established as the only university of its kind in Bangladesh in 1961. It started functioning with the College of Animal Husbandry and Veterinary Science at Mymensingh as its nucleus. The university has six faculties and 43 departments covering all aspects of agricultural education and research. BAU was the second highest budgeted public university in Bangladesh for the year 2013–2014. It is ranked number four from 166 universities of Bangladesh according to the webometrics university ranking 2020.

The Bureau of Socio-Economic Research and Training at BAU was established in 1977 at the BAU Faculty of Agricultural Economics & Rural Sociology to promote research, training and extension activities of the faculty staff. The Bureau conducts nationally and internationally funded research projects, while also provides research consultancy and advisement for Government and Non-Government Organisations. The Bureau publishes twice yearly *The Bangladesh Journal of Agricultural Economics*, in addition to reports and monographs based on the research projects completed by the faculty members.

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Established in Munich (Germany) in 1991 with the mission to contribute to climate protection and sustainable energy production, UPM Umwelt-Projekt-Management GmbH (UPM), is strong corporate network specialized in climate change mitigation, adaptation and sustainable development, and is a leader player in international carbon trading markets. UPM established UPM Environment Engineering Project Management Consulting (Beijing) Co. Ltd, its subsidiary in China, in 2008, in order to support clients' servicing and project development in Asia.

UPM provides a service offering based on powerful combination of expertise, experience and dedication to fulfill our mission.

Consulting Services —from research to technical assistance to Renewable Energy & Waste-to-Value projects.

UPM's consulting services, built on more than 25 years of professional experience, are successfully supporting clients in the public and private sectors to tackle energy, climate change and sustainable development challenges. UPM is collaborating with a well-established global network of the most reputable institutions and experts for renewable energy, waste management and rural development and provides teams of experts composed by a combination of qualified internal and external consultants as required.

FIELDS OF EXPERTISE INCLUDE:

Sectors: Climate Change Mitigation/Adaptation; Sustainable Development Goals (SDGs); Renewable Energies (biogas, biomass, wind, solar); Ecological Sanitation, Wastewater Treatment, Fecal Sludge Treatment/Management (FSM), Waste-to-Value in emergency context; Citywide Inclusive Sanitation (CWIS).

Activities: Project Planning and Development; Carbon Trading; Support to access to Climate & Development Finance; Technical Support; Feasibility Studies; Research and Studies; Capacity Building & Training; Monitoring; Tendering support; Due Diligence; Technical Design; etc.

Regional Experiences: Asia (China, Bangladesh, Pakistan, Mongolia, Nepal, Vietnam); Middle East (Jordan, Lebanon); Africa (West-Africa); Pacific Islands (Samoa, Tonga), Central and South-America (Chile, Bolivia, Cuba).

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