An introduction to anaerobic digestion for the secondary school classroom

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UNIVERSITY OF SOUTH FLORIDA

Anaerobic Digestion

An introduction to the science of anaerobic digestion for the classroom

Contents

Glossary

The terms below are highlighted in blue in the booklet.

Aerobic	An environment with oxygen or a biological process using it
Anaerobic	An environment without oxygen or a biological process occurring in that environment
Aerobic digestion	The process of food or other organic matter breaking down in an environment with no oxygen
Archaea	A type of microorganism found in extreme environments
Biodigester	A special type of tank where anaerobic digestion occurs
Biogas	The gas produced by anaerobic digestion, which is mostly made up of carbon dioxide and methane
Co-digestion	Using multiple types of organic matter in anaerobic digestion
Co-generation	Creation of both heat and electricity from biogas
Competitive advantage	An organism's ability to outcompete other organisms for food, water, and resources
Digestate	A high-nutrient product of anaerobic digestion
Digestion	The breakdown or decay of organic matter
Feedstock	Food for the microorganisms, which is added to the biodigester
Inhibitors	Chemicals that hurt the microorganisms and slow the reactor
Inoculum	A solution with microorganisms that perform anaerobic digestion, used to start up the process inside a biodigester
Microorganism	Tiny organisms including bacteria and archaea
Organic matter	Any carbon-based material that is or once was alive, including plants, animals, and dead bacteria
Pathogenic	Disease-causing bacteria or contaminated surfaces
pH	A measurement of the level of acidity in a solution
Souring	A buildup of acidity in the biodigester causes digestion to stop
Substrate	Another term for feedstock

What is Anaerobic Digestion?

Digestion is the process of organic matter breaking down. Organic matter includes anything that is living or used to be living, and all kinds of things are digested in nature. Food, plants and dead animals are all digested by microorganisms. Digestion is also called decomposition or decay.

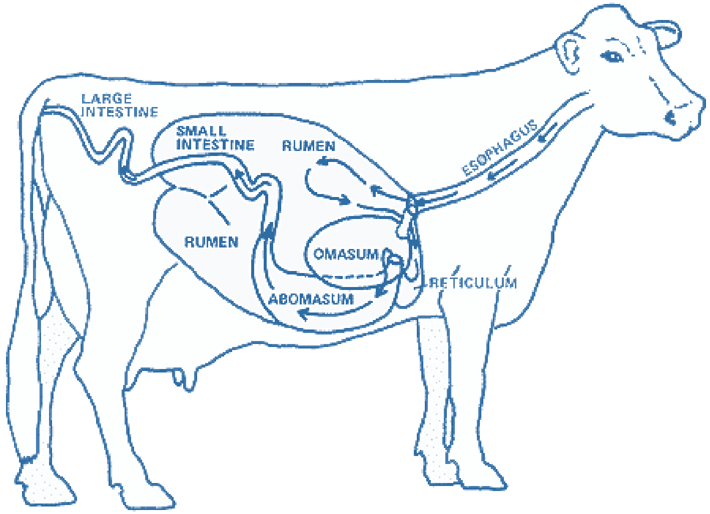
Anaerobic digestion (AD) is the process of food or other organic matter breaking down in an environment with no oxygen.

Microorganisms at work

Anaerobic digestion is a kind of digestion that only happens in environments with no oxygen. Oxygen is a component of the air, so anaerobic digestion can only happen in places like wetlands, wet soil, and the stomachs of some animals.

During aerobic digestion, organic matter is broken down by microorganisms that rely on oxygen to survive. This is apparent when food is left out at room temperature. Changes to the food will occur because chemicals are released from the food and the microorganisms consuming it. Air, moisture, light, and temperature affect the growth of the microorganisms and the rate of digestion.

https://proveg.com/wp-content/uploads/2018/04/Foodplate.jpg



Inside a cow or goat's stomach, microorganisms break down the food that the animal eats.

https://extension.umn.edu/dairy-nutrition/ruminant-digestive-system

The types of microorganisms involved in *anaerobic* digestion can survive without any oxygen. They have a competitive advantage in anaerobic environments, places like a goat's stomach, where aerobic bacteria could never survive.

Cow and goat manure are natural sources of these special microorganisms. This is useful because it means that manure can be used as inoculum to start the process of anaerobic digestion inside a biodigester. It is also the reason why cows and goats release methane gas. Methane is a product of the anaerobic digestion process happening in their stomachs.

The Process of Anaerobic Digestion

Anaerobic digestion has three basic steps: hydrolysis, fermentation, and methanogenesis.

The formation of biogas results from three steps: *hydrolysis, fermentation, and methanogenesis*. The steps run at the same time in an anaerobic environment, but may it be helpful to think of them in the order below. All the microorganisms are working in harmony. In a well-run biodigester, no chemicals are accumulating because each process starts with the end products of other ongoing processes. The only chemicals that build up are methane and carbon dioxide, the end products that we want to use.

Large particles of feedstock

These are particles of feedstock that are too big for microorganisms to consume

Hydrolysis

Large particles are broken down into smaller ones by enzymes produced by bacteria and fungi.

Smaller feedstock particles

These are smaller molecules: fatty acids, carbohydrates, and proteins

Fermentation

Fermentative bacteria consume feedstock, producing hydrogen gas, carbon dioxide, and acetic acid. Fermentation is used in bread and beer making because of the alcohol and gas bubbles produced.

Hydrogen gas, carbon dioxide, and acetic acid

These are some of the end products of fermentation

Methanogenesis

Archaea perform two types of methanogenesis. In this key step, methane is produced from hydrogen gas and carbon dioxide, or from acetic acid.

Biogas

Methane and some carbon dioxide are produced in methanogenesis

The Process of Anaerobic Digestion

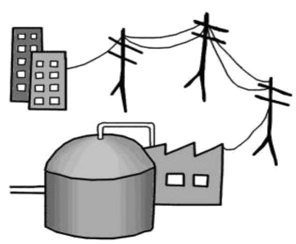
What goes in? What comes out?

There are three main components of the anaerobic digestion system:

Feedstock	Organic material, the substrate (food) for the microorganisms.
Inoculum	A solution with microorganisms to start the process, found in manure.
Anaerobic conditions	No air should enter the system. Air will get rid of the microorganisms' competitive advantage. This occurs naturally when there is water in the system, which limits the oxygen supply for aerobic bacteria.

If all these components are present, anaerobic digestion will occur. It happens naturally in places like landfills, where organic material is digested under mountains of solid waste without air. It also occurs in wetlands and sulfur springs. Engineers can make anaerobic digestion happen by creating a biodigester, a special type of tank or reactor where anaerobic digestion occurs. Feedstock goes into the reactor, and two products will come out: biogas and digestate. The diagram below lists a few types of feedstock and some uses of the end products.

Types of Feedstock
Food waste
Sewage sludge
Wastewater
Livestock waste
Crop waste



Biogas Uses
Heat
Electricity
Cooking
Vehicle fuel

Digestate Uses
Fertilizer
Soil amendment
Livestock bedding

The Process of Anaerobic Digestion

Making energy from waste

One of the most common reasons to build a biodigester is to produce biogas. It can be used for a cookstove, gas lamp, or heater, or it can be sent to a generator to make electricity. Many biodigesters send biogas to a co-generation plant, which is a special generator that can produce both heat and electricity.

Have you used a cookstove like the one below?

https://cdn.shopify.com/s/files/1/2339/1083/products/95518_01_1024x.jpg?v=1574292126

Biogas is 50-70% methane, and the rest is mostly carbon dioxide. Methane is more valuable than carbon dioxide because it produces more energy when it is burned. Biogas can be treated to remove carbon dioxide, and the pure methane can be used as a fuel for cars, trucks and buses.

Digestate and fertilizer

The digestate produced by a biodigester is a combination of dead microorganisms and undigested food waste. It is an effective fertilizer because of its high nitrogen, phosphorus, and potassium content. These elements are needed by plants and all fertilizers contain them.

https://www.foretiafoundation.org/are-we-ready-for-a-new-agricultural-bank-in-cameroon-what-challenges-and-opportunities/

Industrial-sized reactors often process the digestate into pellets and sell it commercially as an alternative to synthetic fertilizer. Synthetic fertilizer production is harmful to the environment and uses energy to produce. Digestate, made from recovered nutrients, reduces waste and requires no energy to produce.

Compared to the feedstock that goes into a reactor, digestate has less of an odor and does not attract pests or other animals. Even if digestate is not needed as fertilizer, it is safe to apply directly to soil, which helps get rid of dangerous waste, like human waste, that can cause disease. This is useful for sanitation, like the case study presented on page 9. Bio-latrines are built in a primary school so that human waste can be made into useful products. Without being treated, human waste is pathogenic, meaning that it can cause disease to humans.

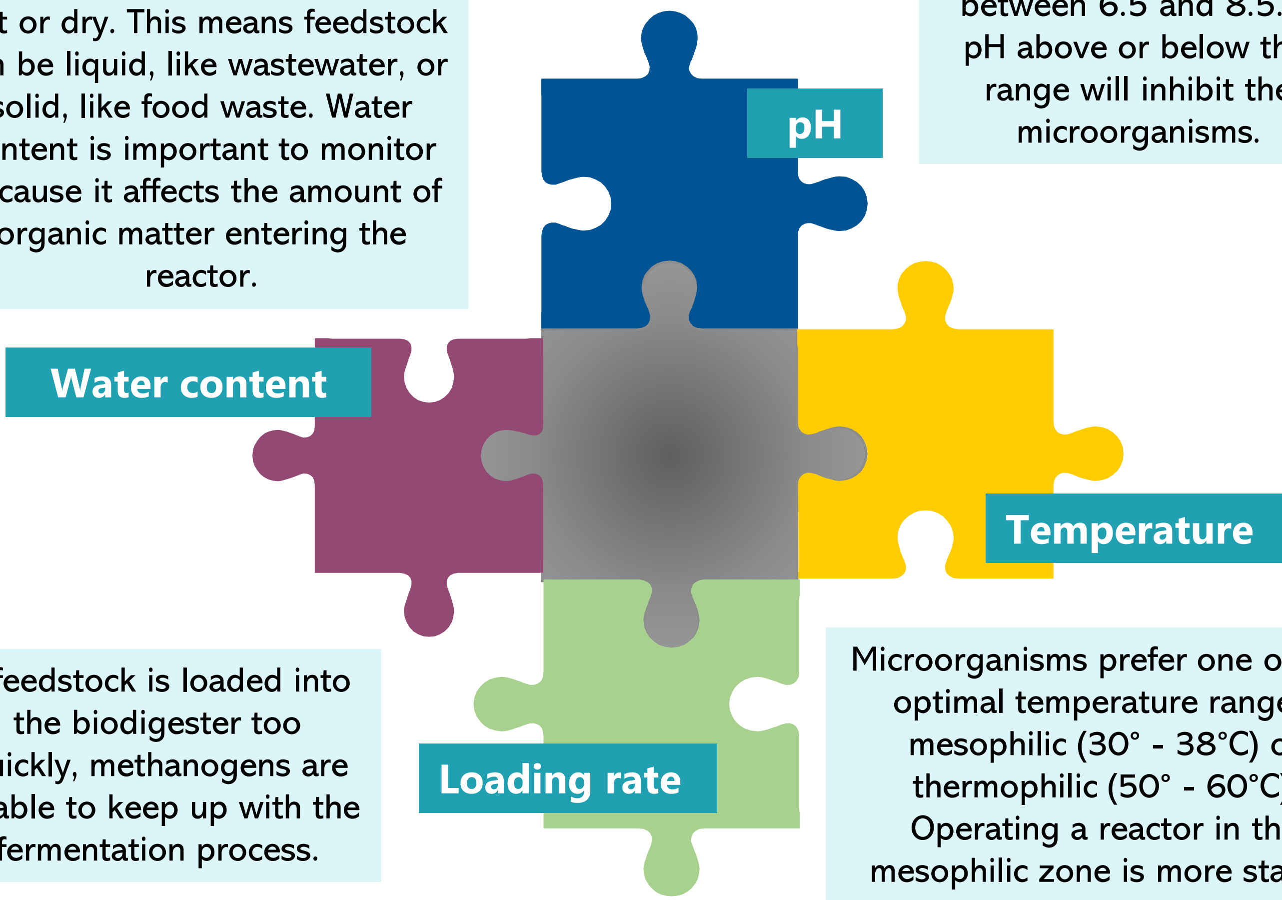
Anaerobic Digestion in a Reactor

Operation and maintenance

The microbes involved in anaerobic digestion are highly sensitive, so certain conditions must be maintained to keep them happy. Some factors affecting the microorganisms are temperature, feedstock loading rate, water content of the feedstock, and pH, which is the level of acidity. If certain conditions are not met, reactor souring can occur, meaning that there is a buildup of acidity.

Biodigesters are designed as wet or dry. This means feedstock can be liquid, like wastewater, or solid, like food waste. Water content is important to monitor because it affects the amount of organic matter entering the reactor.

The optimum pH is between 6.5 and 8.5. A pH above or below this range will inhibit the microorganisms.



If feedstock is loaded into the biodigester too quickly, methanogens are unable to keep up with the fermentation process.

Microorganisms prefer one of two optimal temperature ranges: mesophilic (30° - 38°C) or thermophilic (50° - 60°C). Operating a reactor in the mesophilic zone is more stable, but thermophilic conditions produce more biogas.

Some control factors are easily measured, such as the loading rate and the temperature of the reactor. Other factors must be measured to ensure the operators are aware of issues *before* reactor souring occurs:

- Inhibitors, which are chemicals that are toxic to the microorganisms, include organic acids, metals, and ammonia, which is the most common inhibitor in industrial reactors.
- Oxygen: it is also an inhibitor, since the microorganisms thrive in anaerobic conditions.

Anaerobic Digestion in a Reactor

Small scale biodigesters

Biodigesters are used all over the world to produce heat and electricity for individual households or small communities. For example, in China, India, Nepal, and Vietnam, millions of family-owned digesters produce biogas for cooking and lighting.

https://founder360mag.com/kenyan-based-sistema-bio-wins-2019-ashden-award-for-promoting-clean-cooking/

A biodigester in Kenya produces fertilizer and biogas for clean cooking in the home.

Biogas plants are commonly used for digestate production in agricultural areas. There is a lot of organic matter on a farm, like crop waste, rotting food, and animal manure. Manure functions as both inoculum and feedstock for the reactor.

Many household-sized biodigesters use co-digestion, which is the combination of multiple kinds of feedstocks – for example, cow manure and banana tree leaves.

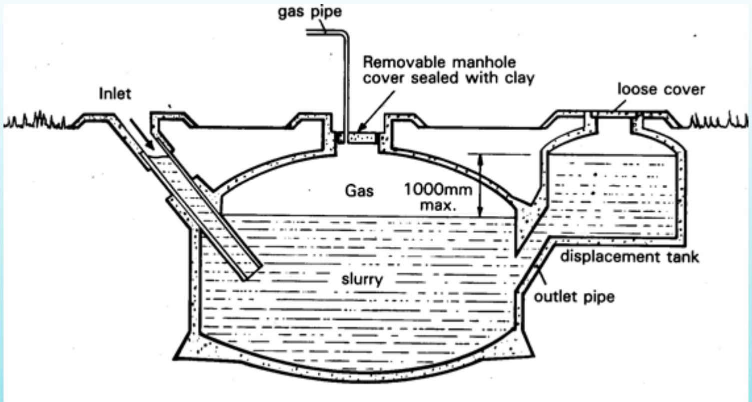
Biodigester design

A biodigester's design depends on the climate, how it will be used, and the abilities of local masons and engineers. Most small biodigesters are inexpensive and easy to manage.

Fixed dome reactors

These digesters are buried for better heat insulation. Feedstock enters through the inlet, gas is piped from the collection area, and digestate is collected through the outlet.

https://www.researchgate.net/publication/275645496_Biogas_potential_in_Pakistan



https://doi.org/10.1016/j.esd.2013.02.001

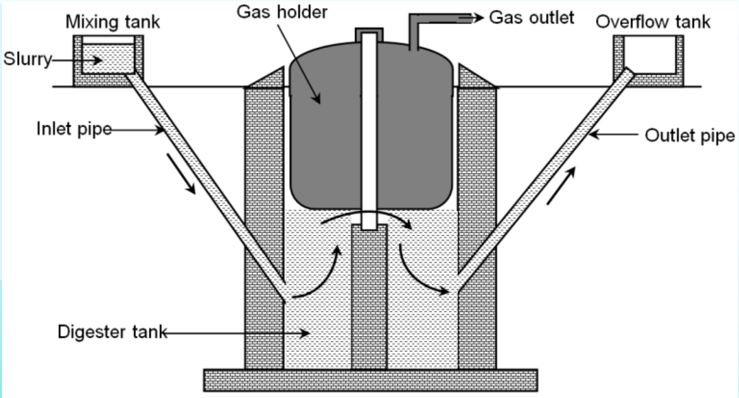
Biodigesters like this one in Arusha, Tanzania must be built gas-tight, so they require skilled engineers. This one has a completed dome and the outlet tank is under construction. Pipes will connect the inlet of the dome to a latrine and a manure mixing chamber.

Anaerobic Digestion in a Reactor

Floating drum reactors

https://funscience.in/floating-gas-holder-type-biogas-plant/

The floating drum reactor is like the fixed dome reactor, but it has a flexible gas collection area made from a big piece of steel. The gas collection area expands as gas builds up, and then it is piped to a kitchen or house.



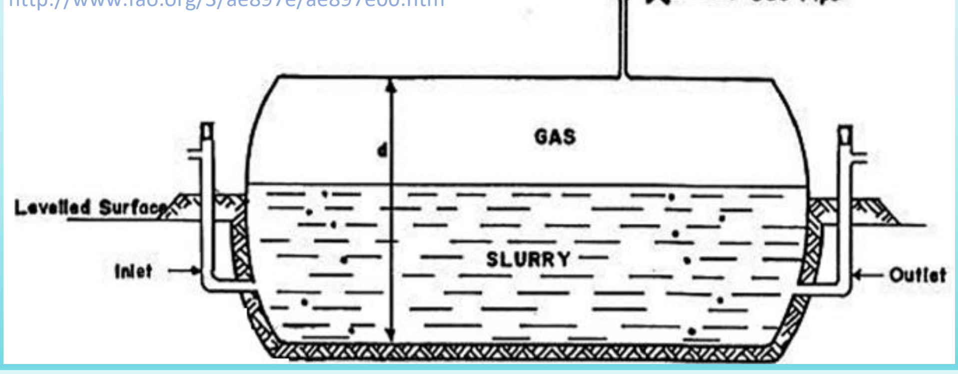
www.build-a-biogas-plant.com/floating-drum-biogas/

The steel drum can be expensive, but it is easier to install than a fixed dome. The drums are smaller than a dome, so they cannot hold as much biogas. Like the fixed dome reactor, feedstock enters through the inlet and digestate comes from the outlet pipes.

Tubular Reactors

These reactors are unusual because they are made of heavy flexible plastic tube. They are halfway buried underground, but they are mostly exposed to the air, and the microorganisms inside them can get cold in winter. They are relatively inexpensive to build but they may not last as long as other types of biodigesters.

http://www.fao.org/3/ae897e/ae897e00.htm



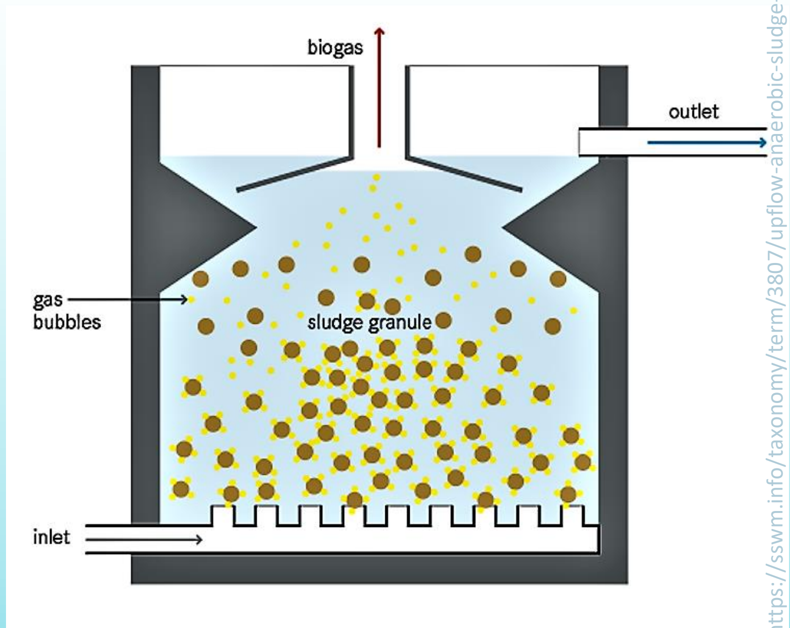
The reactor can be protected from changing temperatures by building a greenhouse, like this one in Costa Rica. A constant temperature will keep the microorganisms more active, increasing biogas production, and the balloon is protected from trees and other sharp things that could cause a leak.

Anaerobic Digestion in a Reactor

Industrial Sludge Treatment

Wastewater contains a diluted mixture of human waste, food waste, and other organic waste. After wastewater goes through a treatment plant, engineers are left with a highly concentrated form of organic waste called sludge. This sludge is often treated using anaerobic digestion to stabilize it and neutralize pathogens.

https://www.viridis-engineering.com/solutions/palm-oil/zero-waste-solution/upflow-anaerobic-sludge-blanket-reactor-uasb/



https://sswm.info/taxonomy/term/3807/upflow-anaerobic-sludge-blanket-reactor-%28uasb%29

This technology can be applied to many types of reactors with different mechanisms. Pictured here is an Upflow Anaerobic Sludge Blanket Reactor, where effluent is piped to the bottom of a large tank. As it flows upwards, it is filtered by a blanket of anaerobic microorganisms, which convert the organic matter to biogas. The treated sludge can be safely disposed of.

Case Studies

The most common uses for anaerobic digestion in industrial settings are for agriculture, sanitation, and energy generation. Sanitation uses include wastewater treatment and processing human waste from toilets or latrines into useful products.

Bio-Latrines for Kansanga Primary School

Kampala, Uganda

All kinds of waste can be used as feedstock for anaerobic digestion – even human waste! At a primary school in Uganda, bio-latrines were built to produce biogas from students' waste. Students use the bio-latrines shown below every day, just like normal pit latrines. The waste is piped to the biodigesters shown on the right, where biogas is produced through anaerobic digestion and piped to the school's kitchens.

Before the bio-latrines, the school was using open wood-burning fire to cook food for the students. Cooking on a fire is bad for the environment because trees are harvested, and the smoke harms the health of the person cooking. Now, the school uses 75% less firewood and the kitchen workers have a healthier environment. The pictures below show a wood-burning fire and the new biogas cookstove at the school's kitchens.

https://www.dw.com/en/clean-green-toilets-help-students-get-to-class/a-36064067

https://www.dw.com/en/clean-green-toilets-help-students-get-to-class/a-36064067

Case Studies

HPW Fresh and Dry Biogas Plant

Adeiso, Eastern Region, Ghana

HPW Fresh and Dry is a company that processes mango, coconut, and pineapple to be sold worldwide. The farm uses two 450 cubic-meter biodigesters to create biogas and digestate. The digestate from the biodigester is used as fertilizer on the crops.

The gas is piped from the biodigesters to two large flexible plastic gas storage tubes shown in the lower left corner. Then it goes to the generator, shown in the lower right corner. A generator is a machine that burns the biogas and turns it into electricity. One problem with this reactor is that the methane content is very low. The generator does not produce much electricity, since it is mostly carbon dioxide.

http://energycom.gov.gh/files/Biogas%20-%20What%20works%20for%20Ghana.pdf

Kishiwada Waste-to-Energy Plant

Osaka, Japan

Built in 2015, this anaerobic digester runs on food waste only. It was designed to be very small because of its location in a crowded area. The Kishiwada plant exists to produce energy for the city of Osaka in Japan. Each year,17 tons of food waste are converted to biogas and burned in a co-generation plant. The food waste comes from a waste processing facility that is nearby, so very little transportation is needed. This biodigester helps reduce the amount of waste produced by the city.

https://www.envitec-biogas.com/fileadmin/media/pdf_downloads/subpage_references/fact_sheets/fact_sheet_Osaka_EN.pdf

Case Studies

South Cross Bayou Water Reclamation Facility

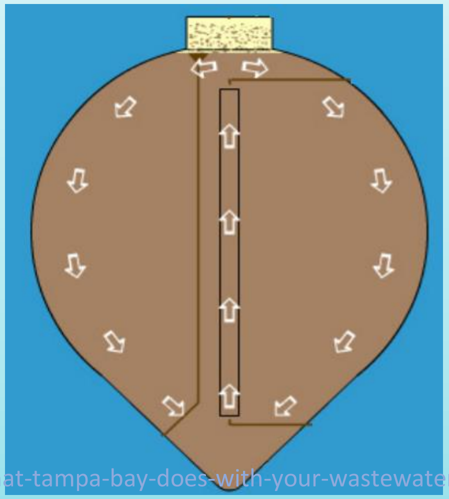
St. Petersburg, Florida, United States

Water is a precious resource, and the South Cross Bayou Water Reclamation Facility (right) uses several treatment methods to produce usable water from wastewater. Though the reclaimed water is not treated enough to drink, it is used to irrigate landscaped areas, saving 14.6 million gallons of drinkable water per day!

https://www.pinellascounty.org/utilities/images/SouthCrossBayou.jpg

Anaerobic digestion occurs in the digesters below. Egg-shaped digesters are common because a single rotating shaft keeps the microorganisms and substrate well-mixed.

https://www.tampabay.com/news/florida/2020/02/10/you-poop-you-flush-heres-what-tampa-bay-does-with-your-wastewater/



https://www.mi-wea.org/docs/Hannon%20-%20Grandville%20Digester.pdf

The South Cross Bayou facility is unique because it processes the digestate that comes out of the reactor into commercially available fertilizer. The facility dries the digestate and turns it into small pellets (bottom right) in the pelletization process. Digestate is transported by trucks to the pelletization facility (left), then dried out in a dewatering machine (center), then fired in a furnace and sold to fertilizer companies.

https://www.synagro.com/granulite-fertilizer-pellets-2/

https://www.greshamsmith.com/project/south-cr reclamation-facility-biosolids-dewatering-improve

https://sustainablesales.com/pellets/8-2-2/

Classroom Experimentation: The Model Biodigester

Now that we have learned about anaerobic digestion in the natural world and in engineered systems, we can apply this knowledge by building our own model of a biodigester.

Using models

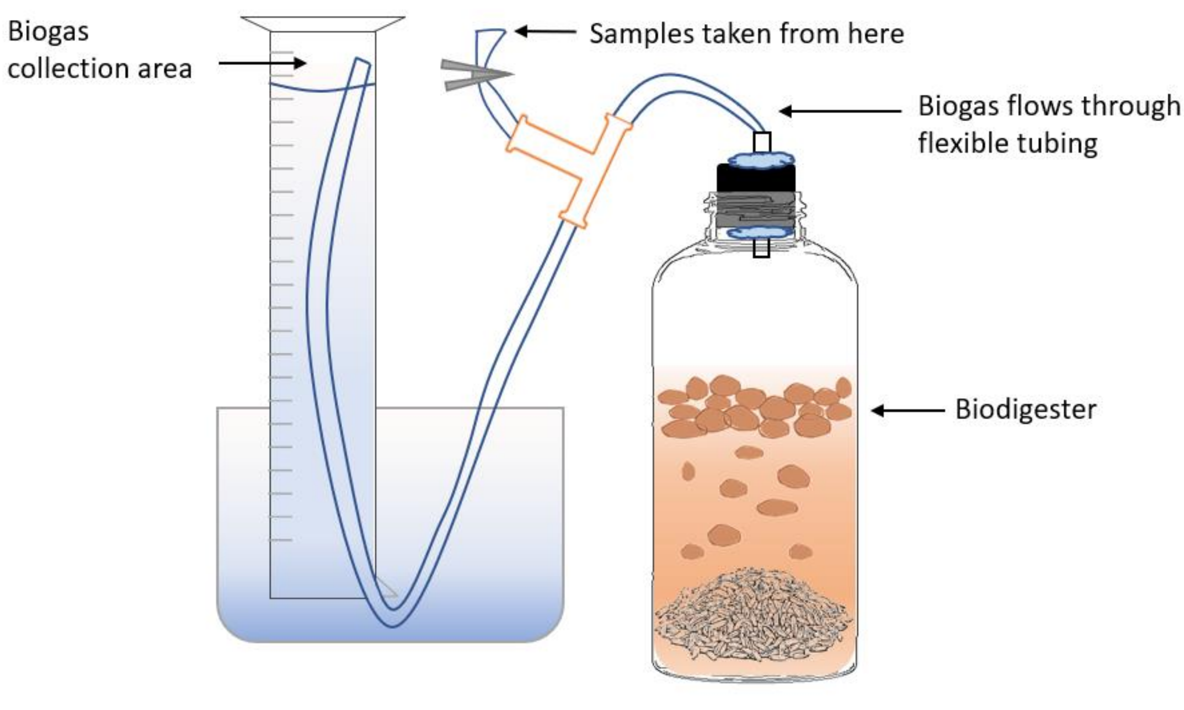
Scientists use models to represent real processes that are happening in the world around us. They are often used to describe the structure of something, to explain how a process works, to test out theories, or to make predictions. Models can be physical creations, computer simulations, or mathematical formulas.

A physical model of the solar system

https://www.fishersci.com/shop/products/solar-system-model-2/S81696

The Model Biodigester

We can use the model biodigester to learn about anaerobic digestion as it occurs naturally or in engineered reactors. This guide will walk through creating a research question, building the model, taking measurements, and recording data. We will use the experimental setup shown below, but there are many ways to build a model biodigester. Some of these can be found in the Educator Resources section at the end of this document.



Classroom Experimentation: The Model Biodigester

Creating a research question

We can format a research question like this:

How does __A__ affect the __B__ of __C__?

A: Independent variable (what you will change)
B: Dependent variable (what you will measure)
C: The subject of your experiment (what you will be experimenting on – the biodigester)

What kinds of independent variables can we use? What can we change about this system?

- Type of organic material used as feedstock
- Source of inoculum
- Ratio of feedstock to inoculum
- Ratio of solids to water
- Temperature

This table, in Eawag's Anaerobic Digestion of Biowaste in Developing Countries (see Educator Resources), lists feedstock types and their varying methane yields. This resource may be helpful in developing realistic research questions about biodigesters.

Substrate	Methane Yield (L/kg VS)
Palm oil mill waste	610
Municipal solid waste	360–530
Fruit and vegetable wastes	420
Food waste	396
Rice straw	350
Household waste	350
Swine manure	337
Maize silage and straw	312
Food waste leachate	294
Lignin-rich organic waste	200

What kinds of dependent variables can we use? What is a variable that we can measure, that might be affected by changing one of the independent variables above? This guide will explain the procedures for testing these three dependent variables:

- Biogas production
- Methane content of the biogas
- pH

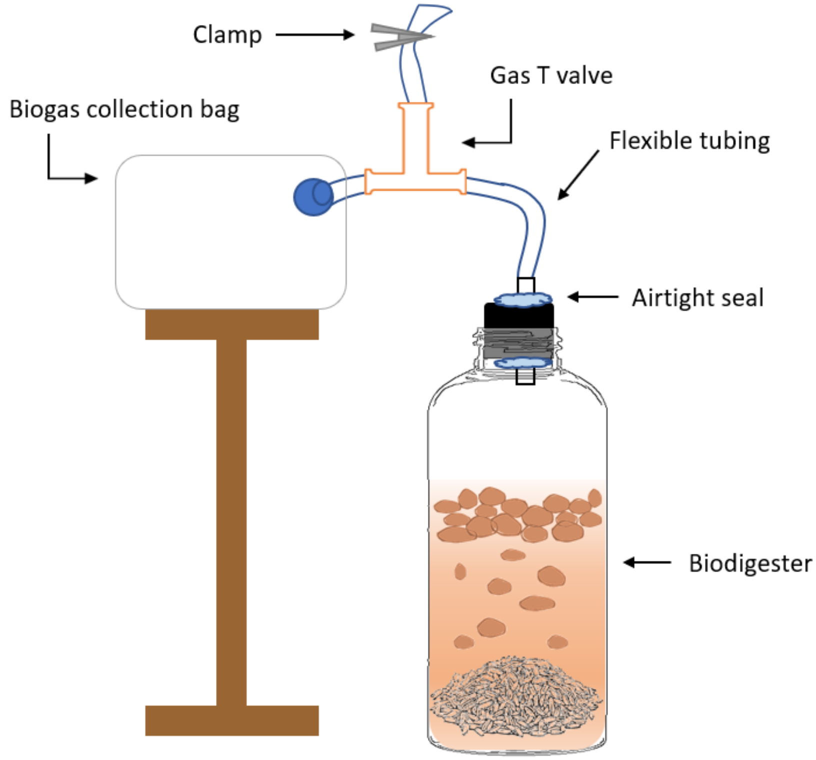
Classroom Experimentation: The Model Biodigester

Adapting the model for the classroom

The model biodigester is a highly flexible classroom experiment. An alternative setup for this experiment (shown below) might include an attached gas bag, which can be purchased online. Latex balloons or plastic bags may be more accessible, but they are not meant to store gas and the biogas will slowly leak from the system.

A diagram of the gas collection bag method is shown on the right. Be sure to keep the bag above the water line of the biodigester to prevent leakage of the fluid into the bag.

Teachers may be interested in demonstrating the flammability of methane by squeezing the biogas out of the gas collection bag and igniting it, though methods and safety precautions for this demonstration are not included here.



It may be advantageous to set up a single, larger biodigester as a classroom demonstration before students develop a research question and build their own reactors. In the demonstration on the right, a biodigester is inflating a rubber tire.

The airtight seal is also an area of flexibility, as it can be made with the plastic lid to the biodigester container or with a rubber stopper. Sealant tape and foaming sealant are commonly available at hardware stores.

http://bio-gas-plant.blogspot.com/2012/01/mini-biogas-digester-project-photo.html?m=1

A biodigester setup where biogas inflates a rubber tire

Classroom Experimentation: The Model Biodigester

Part one: Feedstock preparation

Materials:

- Lab coat or smock to cover clothes
- Gloves
- 100 mL or ½ cup of substrate/organic matter
- 100 mL or ½ cup of inoculum
- Medium or large sealable plastic bag
- 100 mL or ½ cup of water, plus extra
- Measuring cup

Feedstock can be rotting fruit, banana peels, old rice, or anything else that is organic material. Grass or other plant waste may work, but are less likely to produce high methane content. A few types of inoculum may be available to the classroom:

- Fresh manure from a goat, sheep, or cow
- Inoculum from a working anerobic digester

Nearby wastewater treatment plants, water reclamation facilities, or agricultural biodigesters may be willing to give some inoculum away, especially if the facility has education or outreach activities.

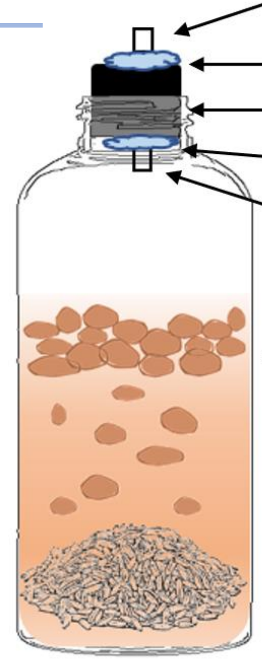
This recipe will make 300-400 mL of mixture (or 1½ - 2 cups), which fills a 16-ounce soda bottle about three-quarters of the way. If the biodigester container is larger, double the recipe so there will be enough. Based on your group's research question, you might change the amounts of each ingredient, but record what goes into the bag.

Procedures:

1. Cut, tear, or mash any big chunks of your feedstock and add it to the bag.
2. Add the same amount of manure to the bag and mash up inside the bag.
3. Add the water and mix by shaking the bag or with hands. If the mixture is still too solid to pour into the bottle, you can add a bit more water, but be sure to record how much goes into the bag.

Classroom Experimentation: The Model Biodigester

Part two: Biodigester building



The diagram on the right shows the finished biodigester using the materials and procedures below.

Materials:

- Clear bottle, 16-ounce or 1-Liter
- 5 cm piece of rigid plastic tubing
- Rubber stopper
- Sealant tape or sealant foam
- Nail and heat source
- Feedstock and inoculum solution
- Funnel

This part of the experiment is flexible and can be changed with the adaptations given earlier in the chapter. For instance, the bottle's original lid may be used instead of a rubber stopper, but it could be more challenging to puncture.

Procedures:

1. Clean the bottle using soap and water. Set it aside to dry.
2. Create a tubing-sized hole in the rubber stopper by heating up a nail and carefully pushing it through.
3. Slide the rigid plastic tubing all the way through the stopper.
4. Use the glue gun to seal the edges of the tubing where it meets the rubber stopper on both sides. Set it aside to dry.
5. Using a funnel, fill the biodigester bottle with the inoculum and feedstock solution. Again, if it is too thick to pour, it needs more water. Be sure to record how much water you add to the solution.
6. Using your hand or the bottle's original cap, cover the bottle and shake until the contents are well mixed.
7. When the rubber stopper is dry, replace it on the bottle. Your system is set up! Double check that it looks like the system above.

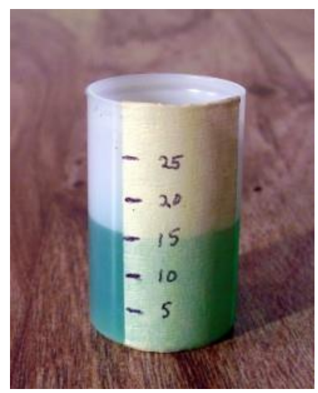
At this point, the biodigester will begin producing carbon dioxide as part of the fermentation process. No methane will be produced for a few days. This is a good place to stop and allow the biodigester to "off-gas" the carbon dioxide.

Classroom Experimentation: The Model Biodigester

Part three: Gas collection system building

Again, these materials and procedures may be changed, given what is available. This procedure was chosen due to its stability and relatively available components. If using the gas bag method, skip this step – the gas bag can simply be fitted to the biodigester using a long piece of flexible tubing. You may choose to include a gas T valve for the purpose of taking biogas samples.

If glass graduated cylinders are unavailable, one can be easily made using a glass bottle or other container. This is done by measuring increments of water – 50mL should work well – and marking a line on the glass. Increments of 50 mL can be added gradually and marked with a marker or tape. It might be wise to write the numbers upside-down, since you will be inverting the container.



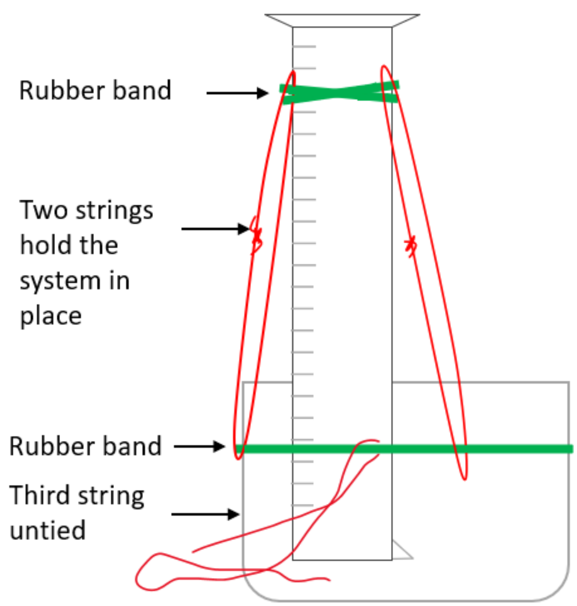
Materials:

- 50 mL or 100 mL glass graduated cylinder
- Shallow basin (a bowl is fine, as long as it has no lip)
- 1 piece of flexible plastic tubing, about 45 cm long
- Water

If no glassware is available, plastic graduated cylinders can be used, but they should be stabilized with the following method because they will float or fall over. If using glassware, skip to step 3 on the next page.

1. Put one rubber band around the water bath and one around the neck of the graduated cylinder, close to the base.
2. Put the graduated cylinder upside-down inside the shallow basin, as shown in the diagram, without water. Tie two of the pieces of string between the two rubber bands, making sure you can still tip the graduated cylinder out of the shallow basin.

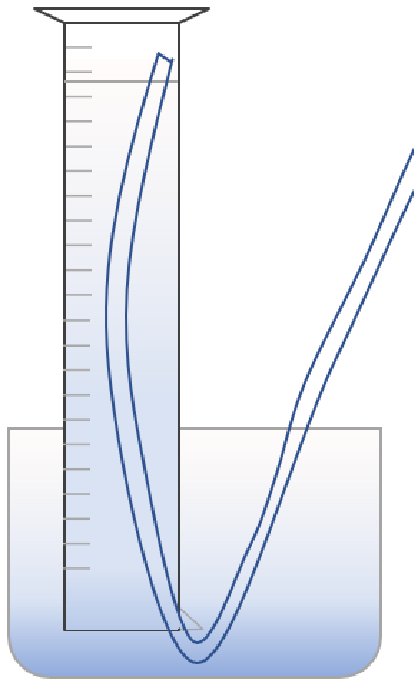
The system should look like the one shown on the right.



Classroom Experimentation: The Model Biodigester

Procedures, continued:

3. Fill the shallow basin with water.
4. With the graduated cylinder as close to upright as possible, insert the tubing all the way to the bottom of the graduated cylinder. Holding it there, fill up the graduated cylinder with water.
5. Quickly tip the graduated cylinder, upside-down, into the shallow basin of water. The graduated cylinder should be as full of water as possible.



Steps 3,4, and 5 will take practice - it’s okay if you don’t get them right on the first try!

6. If using string, tie the third string, making sure the system is secure and will not be knocked over accidentally.
7. Make note of the amount of water in the graduated cylinder. This is your Day 0 measurement of biogas production.

If rubber bands are unavailable, you may choose to drill holes in the base of the graduated cylinder and the water bath (if they are plastic). If the biogas is being collected in heavy glassware, it probably isn’t necessary to stabilize the system. However, the tubing needs to be inserted before flipping the glassware down into the water bath.

Classroom Experimentation: The Model Biodigester

Part four: Assembly

Now we have our gas collection system and our working biodigester, and we need to assemble them.

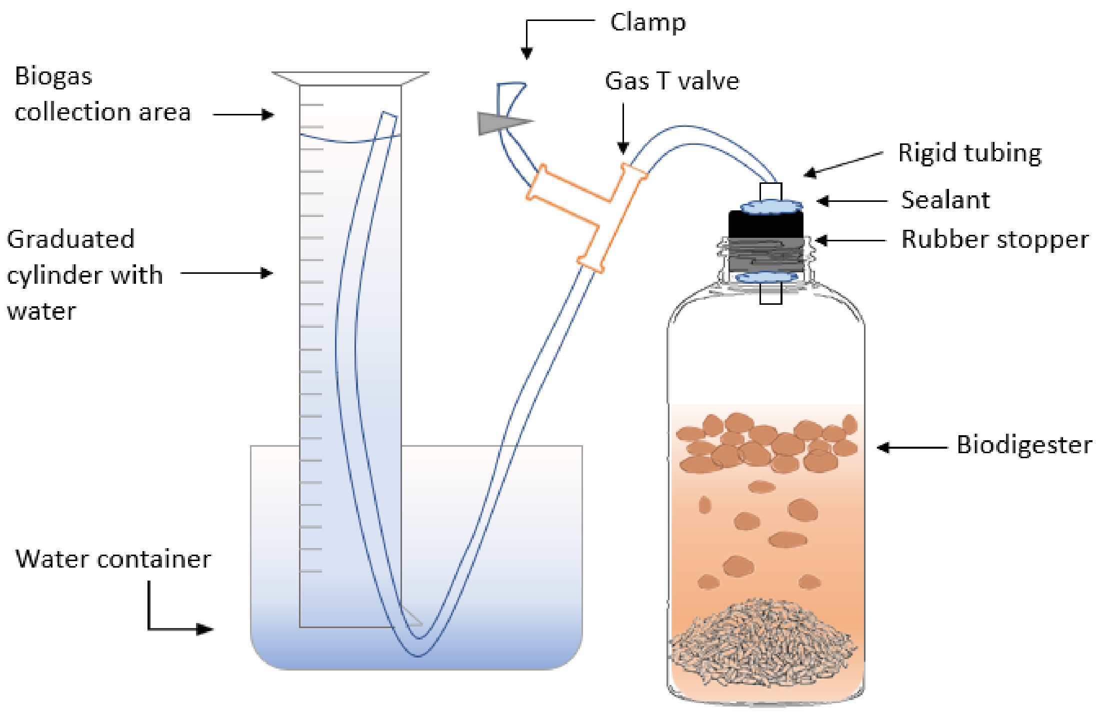
Materials:

- Flexible plastic tubing (one 20 cm piece and one 8 cm piece)
- Gas T valve
- Clamp
- Water

Procedures:

1. Attach the 20 cm piece of flexible tubing to the rigid tubing in the rubber stopper.
2. Connect this piece of tubing and the gas collection tubing to the gas T valve.
3. Cut another small piece of flexible tubing, about 8 cm, and attach it to the gas T. Use the clamp to seal it shut, so no gas can enter or exit the tube.

Keep in mind that the gas collection area should always be higher than the gas collecting in the biodigester. Gas rises because it is less dense than water, and it wants to move in an upwards direction. If the gas collection area is too low, liquids from the digester might spill into it. This is true for any gas collection method, including the gas bag.



Classroom Experimentation: The Model Biodigester

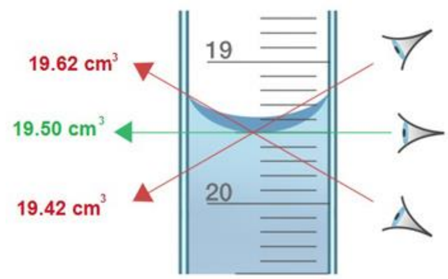
Taking measurements

What data are we collecting?

- Biogas production
- pH
- Methane content of the biogas

Biogas production

This is read using the markings on the graduated cylinder. Because of surface tension, the level of water forms an arc shape in a graduated cylinder. To read the correct measurement of the gas we have collected, we will:

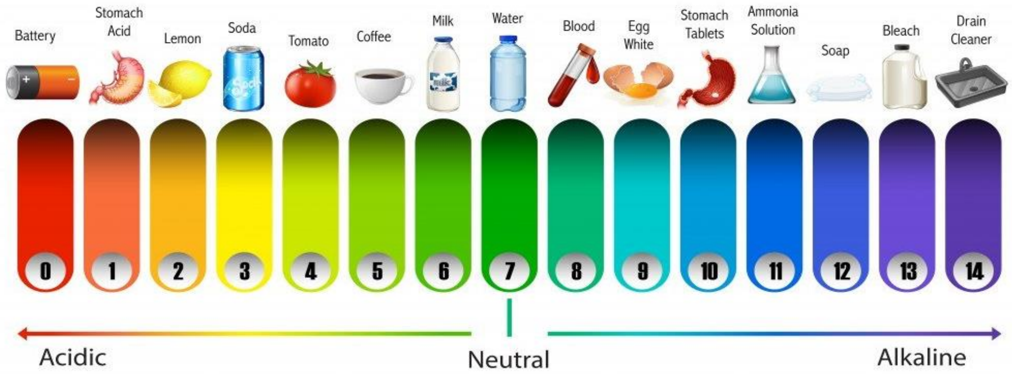


1. Look at the graduated cylinder from eye level
2. Read the lower level of the middle of the meniscus arc
3. Subtract this amount from the total volume of the graduated cylinder

Every two days, record the amount of gas in the graduated cylinder. It should go up quickly at first and then level off, because the **fermentation** process will start making CO_2 quickly but **methanogenesis** will take longer to begin.

pH

The microorganisms involved in anaerobic digestion are sensitive to acidity. Measuring pH is common in large-scale reactors because it is a good way to ensure that the microorganisms are happy. Recall that if conditions become too acidic, the reactor can **sour**. Acidity can be measured with test strips at the end of the experiment or by sacrificing one of the reactors every few days. pH test strips are widely available at hardware supply stores.



https://www.scienceabc.com/pure-sciences/can-ph-have-values-out-of-the-0-14-range.html

https://glossary.periodni.com/dictionary.php?en=parallax+error

Classroom Experimentation: The Model Biodigester

Methane content

Every two days, check the biogas's methane content using this method. Because fragile glassware and a strong base are used, it may not be suitable for all age groups, but the teacher can demonstrate. NaOH is commercially available as lye, found at hardware supply stores.

Materials:

- Eye protection
- Gloves
- Lab coat or smock
- 3 molarity NaOH (lye) or KOH solution
- Syringe with blunt needle
- Fermentation tube (see image on the right)

It may be a good idea to practice this procedure with water before using biogas and a strong base. It can be tricky to fill up the fermentation tube completely, and also to inject the gas all the way into the tube without it leaking out. Simply inject air into the fermentation tube, filled with water, trying to keep all the bubbles within the tube.

Procedures:

1. Put on gloves, eye protection, and a lab coat to cover your uniform
2. Carefully pour the NaOH or KOH solution into the fermentation tube (see photo on the next page). It is ok if the tube isn't completely full, but record the amount of gas at the top of the tube.
3. Between the digester and the gas collection system, there is a gas T valve. Disconnect the gas T valve from the tube which is connected to the graduated cylinder. Using the syringe, withdraw 3 mL of gas from the tube leading to the graduated cylinder, and quickly re-attach the tube to the T valve.
4. Inject the 3 mL of biogas solution into the KOH solution with a syringe, making sure no bubbles escape. You may want to practice this step with an empty syringe and a fermentation tube full of water.
5. Measure the final volume of gas at the top of the tube. All the gas at the top of the tube is methane, as long as anaerobic conditions are maintained. All the gas that was absorbed by the KOH or NaOH solution is CO_2.

Classroom Experimentation: The Model Biodigester

How does the fermentation tube method work?

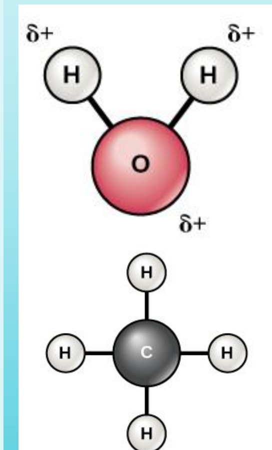
When carbon dioxide, CO_2, is injected into the solution, it is absorbed by the solution according to one of the following formulas:

$$KOH_{(liquid)} + CO_{2\,(gas)} \rightarrow K_2CO_{3\,(solid)} + H_2O_{(liquid)}$$

$$NaOH_{(liquid)} + CO_{2\,(gas)} \rightarrow Na_2CO_{3\,(solid)} + H_2O_{(liquid)}$$

Carbon dioxide (CO_2) is a gas, but it quickly reacts and turns into a different, non-gaseous product. Therefore, it does not bubble up to the top of the fermentation tube.

The solution inside the fermentation tube is either potassium hydroxide (KOH) or sodium hydroxide (NaOH). Both of these are polar molecules, meaning that they are made of a positively charged particle (either K+ or Na+) and a negatively charged particle (OH-). This makes them soluble in water, because water (H_2O) is also polar molecule (see diagram at right).



Methane, however, is nonpolar (see diagram at right). Its carbon atom is surrounded by hydrogen atoms on all sides, so it has no "positive side" or "negative side." This makes it insoluble in water, so it does not react and it bubbles up to the top of the fermentation tube.

Therefore, since biogas is a mixture of methane and carbon dioxide, everything at the top of the fermentation tube is methane. However, if your biodigester is not completely anaerobic, some air might have entered the system. Air will also bubble up to the top of the tube, giving a false impression of high methane content.

https://courses.lumenlearning.com/suny-biology1/chapter/the-building-blocks-of-molecules/

<u>Qualitative observations</u>

Students should check each day for fungus in the reactor, which indicates the presence of air in the system. Fungus appears in reactors as fuzzy dots or chunks, usually on the surface of the liquid in the biodigester. Students may also notice biogas bubbles moving up through the liquid and chunks of feedstock settling at the bottom. Note any interesting color or volume changes.

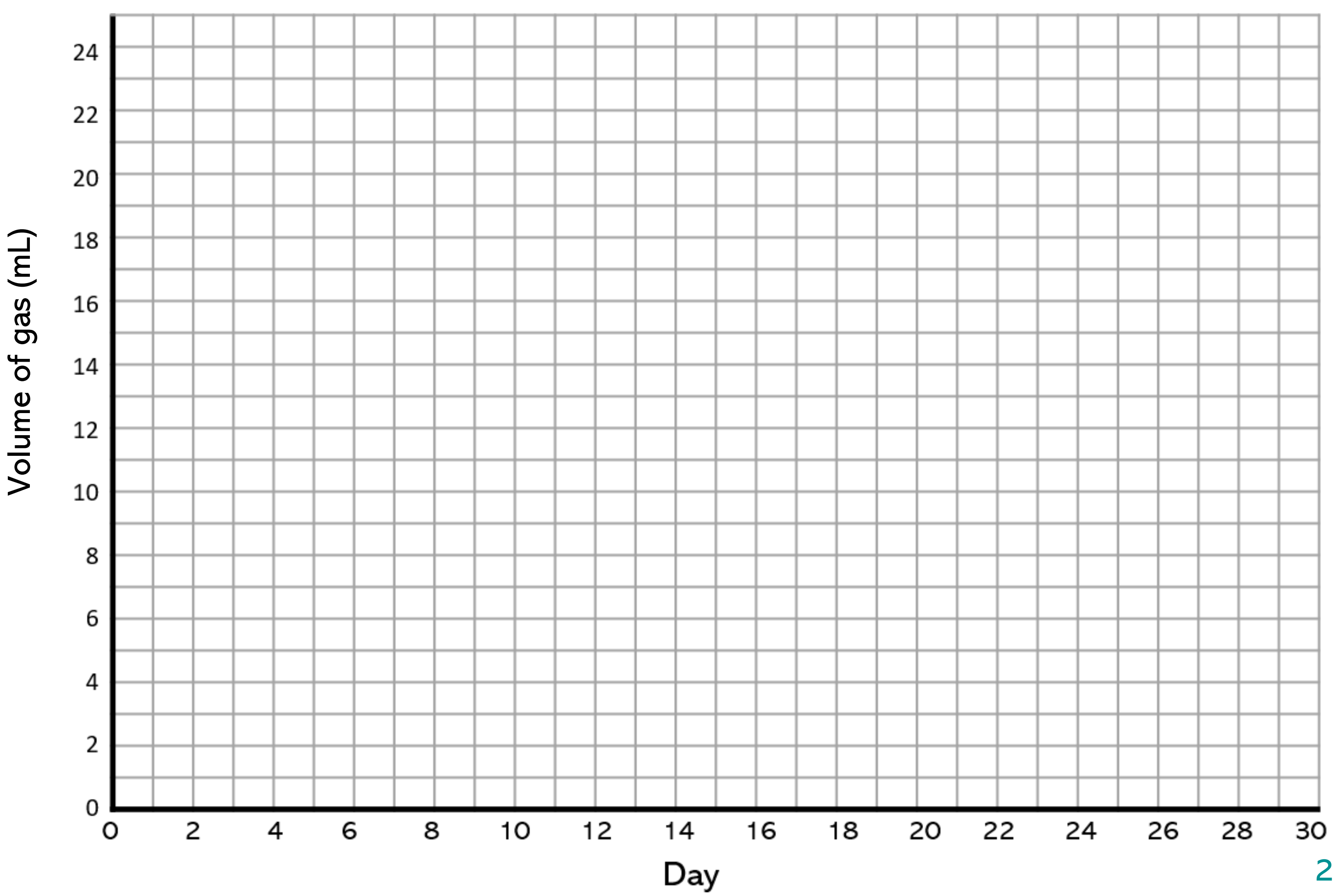
Classroom Experimentation: The Model Biodigester

Data collection

The following data tables and charts can be copied or printed for students. They should also record qualitative observations and any other dependent variables studied in the experiment. Additional data collection worksheets can be found in "Educator Resources" on the next page.

Day	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Volume of gas (mL)																

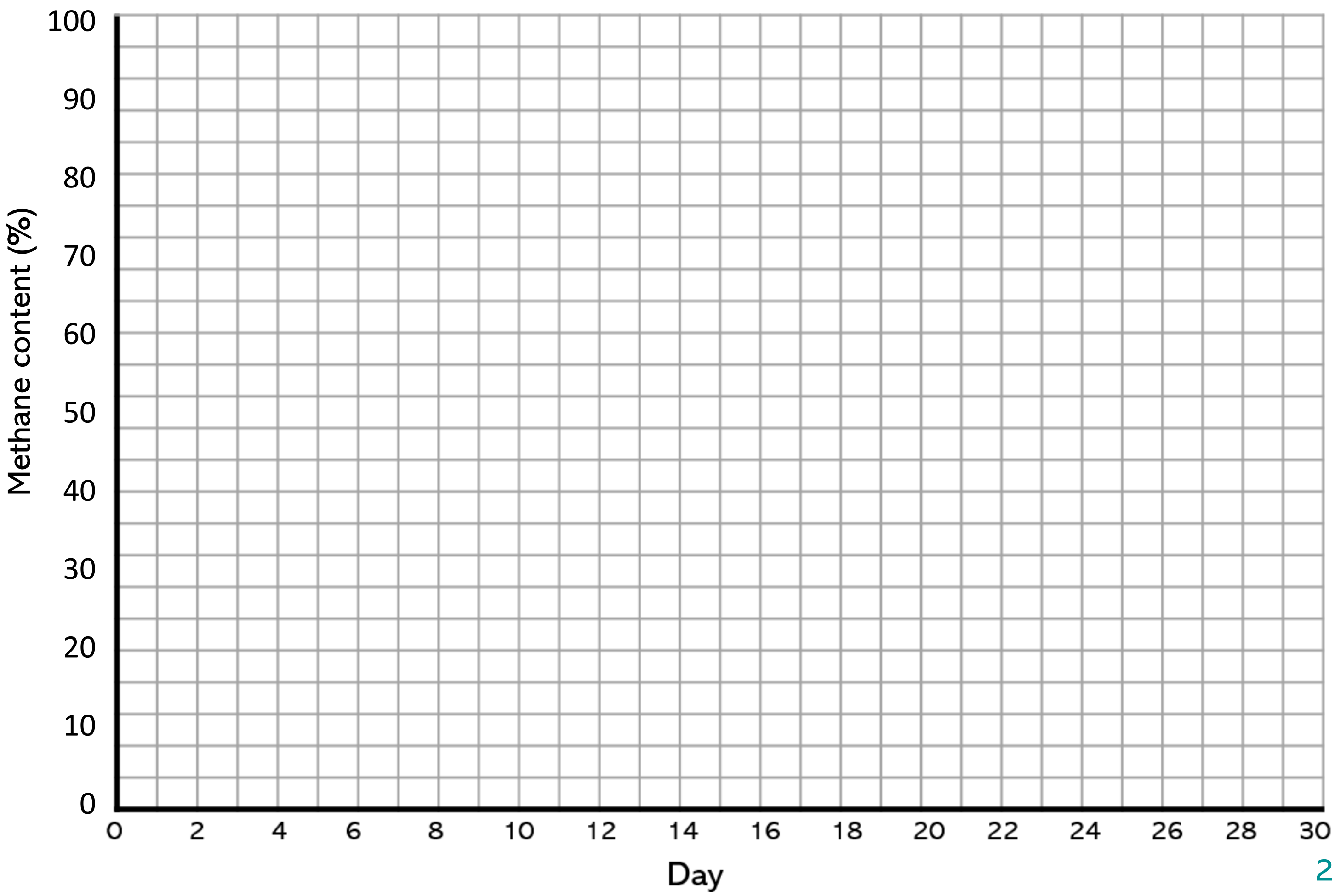
Day	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Volume of gas (mL)																



Classroom Experimentation: The Model Biodigester

Day	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Methane content (%)																

Day	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Methane content (%)																



Educator Resources

Anaerobic Digestion of Biowaste in Developing Countries

This comprehensive guide to anaerobic digestion was developed by Eawag SANDEC. It gives an overview of the process and digester design and operation in developing communities.

Biogas Technology: What Works for Ghana?

This is a presentation from the Ghana Energy Commission about the different uses of biogas in Ghana, as well as the issues and challenges for anaerobic digestion projects.

Clean, green toilets help students get to class

This article and video from Germany's DW News discusses the bio-latrine project at Kansanga Primary School in Kampala, Uganda.

Penn State Extension Manure-to-Biogas Guide

This guide from an American university gives terminology, a broad overview, and technical details about building and operating a biogas plant in agricultural settings.

The Power of Poop: Methane production through anaerobic fermentation

This classroom guide will help teachers educate students about anaerobic digestion. There is also a classroom experiment and data collection sheets for students, as well as discussion questions.

Teach Engineering Hands-on Activity

Teach Engineering has detailed classroom experiments and teacher tools for curriculum design. This activity requires students to build biodigesters from plastic soda bottles.

South Cross Bayou Education Program - Teacher Resources

This page has worksheets, activities, and lesson plans related to the South Cross Bayou Water Reclamation Facility given as a case study. Teachers can arrange a virtual tour for their classrooms.