Bioenergetics

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- The dictionary meaning of bioenergetics can be: the biology of energy transformations and energy exchanges (as in photosynthesis) within and between living things and their environments.
- According to Wikipedia: Bioenergetics is a field in biochemistry that concerns energy flow through living systems. This is an active area of biological research that includes the study of thousands of different cellular processes such as cellular respiration and the many other metabolic processes that can lead to production and utilization of energy in forms such as ATP molecules.
- Bioenergetics is the part of biochemistry concerned with the energy involved in making and breaking of chemical bonds in the molecules found in biological organisms. It can also be defined as the study of energy relationships and energy transformations in living organisms.
- Growth, development and metabolism are some of the central phenomena in the study of biological organisms. The role of energy is fundamental to such biological processes. The ability to harness energy from a variety of metabolic pathways is a property of all living organisms. Life is dependent on energy transformations; living organisms survive because of exchange of energy within and without.

- In a living organism, chemical bonds are broken and made as part of the exchange and transformation of energy.
- Energy is available for work (such as mechanical work) or for other processes (such as chemical synthesis and anabolic processes in growth), when weak bonds are broken and stronger bonds are made.
- The production of stronger bonds allows release of usable energy.
- Living organisms obtain energy from organic and inorganic materials. For example, lithotrophs can oxidize minerals such as nitrates or forms of sulfur, such as elemental sulfur, sulfites, and hydrogen sulfide to produce ATP.
- In photosynthesis, autotrophs can produce ATP using light energy. Heterotrophs must consume organic compounds.
- These are mostly carbohydrates, fats, and proteins. The amount of energy actually obtained by the organism is lower than the amount present in the food; there are losses in digestion, metabolism, and thermogenesis.

- The materials are generally combined with oxygen to release energy, although some can also be oxidized anaerobically by various organisms.
- The bonds holding the molecules of nutrients together and the bonds holding molecules of free oxygen together are all relatively weak compared with the chemical bonds holding carbon dioxide and water together.
- The utilization of these materials is a form of slow combustion. That is why the energy content of food can be estimated with a calorimeter.
- The materials are oxidized slowly enough that the organisms do not actually produce fire. The oxidation releases energy because stronger bonds have been formed.
- This net energy may evolve as heat, or some of which may be used by the organism for other purposes, such as breaking other bonds to do chemistry.
- Living organisms produce ATP from energy sources via oxidative phosphorylation.
- The terminal phosphate bonds of ATP are relatively weak compared with the stronger bonds formed when ATP is broken down to adenosine monophosphate and phosphate and then dissolved in water. Here it is the energy of hydration that results in energy release.
- An organism's stockpile of ATP is used as a battery to store energy in cells, for intermediate metabolism. Utilization of chemical energy from such molecular bond rearrangement powers biological processes in every biological organism.

- **Exergonic** is a spontaneous reaction that releases energy. It is thermodynamically favored. On the course of a reaction, energy needs to be put in, this activation energy drives the reactants from a stable state to a highly energetic unstable configuration. These reactants are usually complex molecules that are broken into simpler products. The entire reaction is usually catabolic. The release of energy (called Gibbs free energy) is negative and equal to - ΔG because energy is lost from the bonds formed by the products.
- **Endergonic** is an anabolic reaction that consumes energy. It has a positive ΔG because energy is required to break bonds.
- The free energy (ΔG) gained or lost in a reaction can be calculated: $\Delta G = \Delta H - T\Delta S$
- where G = Gibbs free energy, H = enthalpy, T = temperature, and S = entropy.

Bioelectricity

- A cell derives its electrical properties mostly from the electrical properties of its membrane.
- A membrane, in turn, acquires its properties from its lipids and proteins, such as ion channels and transporters.
- An *electrical potential difference exists between the interior and exterior of cells.*
- A charged object (ion) gains or loses energy as it moves between places of different electrical potential, just as an object with mass moves "up" or "down" between points of different gravitational potential.
- Electrical potential differences are usually denoted as V or DV and measured in *volts; therefore, potential is also termed voltage. The potential difference across a* cell relates the potential of the cell's interior to that of the external solution, which, according to the commonly accepted convention, is zero.

- Potential differences between two points that are separated by an insulator are larger than the differences between these points separated by a conductor.
- Thus, the lipid membrane, which is a good insulator, has an electrical potential difference across it.
- This potential difference ("transmembrane potential") amounts to less than 0.1 V, typically 30 to 90 mV in most animal cells, but can be as much as 150 - 200 mV in plant cells.
- On the other hand, the salt-rich solutions of the cytoplasm and blood are fairly good conductors, and there are usually very small differences at steady state (rarely more than a few millivolts) between any two points within a cell's cytoplasm or within the extracellular solution.
- Electrophysiological equipment enables researchers to measure potential (voltage) differences in biological systems.

- Electrophysiological equipment can also measure current, which is the flow of electrical charge passing a point per unit of time.
- Current (I) is measured in amperes (A).
- Usually, currents measured by electrophysiological equipment range from picoamperes to microamperes.
- For instance, typically, 104 Na+ ions cross the membrane each millisecond that a single Na+ channel is open. This current equals 1.6 pA (1.6 x 10-19 coul/ion x 104 ions/ms x 103 ms/s).

Biochemical fuel cell

- A fuel cell is an electrochemical device that continuously converts chemical energy to electrical energy for as long as fuel and oxidant are supplied to it.
- Beginning with the space programme of the sixties and followed by the energy crisis of the seventies, we have seen a truly substantial improvement in generic fuel-cell technologies.
- Albeit their high operational-efficiency, the advantages of these fuel cells are partially offset by the high cost of catalysts, high operational-temperatures, and the corrosive electrolytes employed with them.
- In this regard, biological fuel cells4–6 are both attractive and promising.
- Unlike chemical fuel cells, biological fuel cells operate under mild reaction conditions, namely ambient operational temperature and pressure.

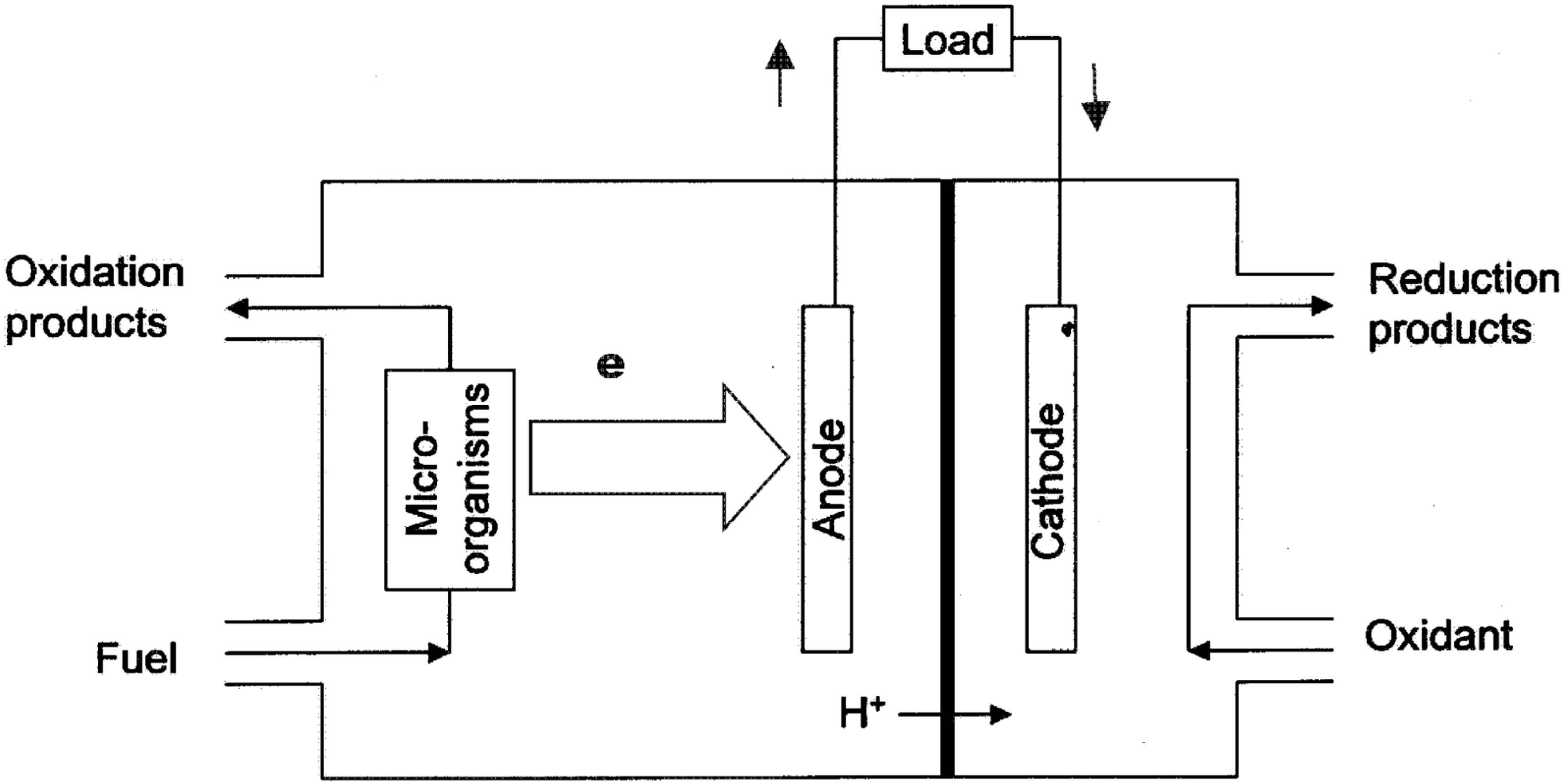
- They also employ neutral electrolyte and use inexpensive catalysts such as platinum.
- In biological fuel cells, the catalyst is either a microorganism as simple as Baker’s yeast or an enzyme.
- Biological fuel cells convert the chemical energy of carbohydrates, such as sugars and alcohols, directly into electric energy.
- As most organic substrates undergo combustion with the evolution of energy, bio-catalysed oxidation of organic substances by oxygen at the two electrode interfaces provides a means for the conversion of chemical energy into electrical energy.
- In normal microbial catabolism, a substrate such as carbohydrate is oxidized initially without participation of oxygen, while its electrons are taken up by an enzyme-active site, which acts as a reduced intermediate, described as follows.
- $C_6H_{12}O_6 + 6H_2O \longrightarrow 6CO_2 + 24H_+ + 24e–$,

  $E_o = 0.014\ V$.

  $(\text{Intermediate})_{ox} + e– \longrightarrow (\text{Intermediate})_{re}$

- In the absence of oxygen, the electrons are diverted to the electrode by some means and made to pass through the outer circuit, and ultimately combine with an electron sink, namely, molecular oxygen as follows
- $6O_2 + 24H^+ + 24e^- \Rightarrow 12H_2O$

  Eo = 1.23 V.
- If a continuous fuel flow to the aforesaid microbial fuel cell is maintained, it acts as a biological fuel cell.


Load
Oxidation products
Reduction products
Micro-organisms
e
Anode
Cathode
Fuel
Oxidant
H⁺

Biofuels

- Biofuels are liquid or gaseous transport fuels such as biodiesel and bioethanol which are made from biomass.
- They serve as a renewable alternative to fossil fuels in the EU's transport sector, helping to reduce greenhouse gas emissions and improve the EU's security of supply.
- By 2020, the EU aims to have 10% of the transport fuel of every EU country come from renewable sources such as biofuels.
- Fuel suppliers are also required to reduce the greenhouse gas intensity of the EU fuel mix by 6% by 2020 in comparison to 2010.

- Biofuels have been around as long as cars have. At the start of the 20th century, Henry Ford planned to fuel his Model Ts with ethanol, and early diesel engines were shown to run on peanut oil.
- But discoveries of huge petroleum deposits kept gasoline and diesel cheap for decades, and biofuels were largely forgotten.
- However, with the recent rise in oil prices, along with growing concern about global warming caused by carbon dioxide emissions, biofuels have been regaining popularity.
- Gasoline and diesel are actually ancient biofuels. But they are known as fossil fuels because they are made from decomposed plants and animals that have been buried in the ground for millions of years. Biofuels are similar, except that they're made from plants grown today.
- Much of the gasoline in the United States is blended with a biofuel—ethanol. This is the same stuff as in alcoholic drinks, except that it's made from corn that has been heavily processed. There are various ways of making biofuels, but they generally use chemical reactions, fermentation, and heat to break down the starches, sugars, and other molecules in plants. The leftover products are then refined to produce a fuel that cars can use.

- Countries around the world are using various kinds of biofuels. For decades, Brazil has turned sugarcane into ethanol, and some cars there can run on pure ethanol rather than as additive to fossil fuels. And biodiesel—a diesel-like fuel commonly made from palm oil—is generally available in Europe.
- On the face of it, biofuels look like a great solution. Cars are a major source of atmospheric carbon dioxide, the main greenhouse gas that causes global warming. But since plants absorb carbon dioxide as they grow, crops grown for biofuels should suck up about as much carbon dioxide as comes out of the tailpipes of cars that burn these fuels. And unlike underground oil reserves, biofuels are a renewable resource since we can always grow more crops to turn into fuel.
- Unfortunately, it's not so simple. The process of growing the crops, making fertilizers and pesticides, and processing the plants into fuel consumes a lot of energy. It's so much energy that there is debate about whether ethanol from corn actually provides more energy than is required to grow and process it. Also, because much of the energy used in production comes from coal and natural gas, biofuels don't replace as much oil as they use.
- For the future, many think a better way of making biofuels will be from grasses and saplings, which contain more cellulose. Cellulose is the tough material that makes up plants' cell walls, and most of the weight of a plant is cellulose. If cellulose can be turned into biofuel, it could be more efficient than current biofuels, and emit less carbon dioxide.

Biodiesel

- **Biodiesel** refers to a vegetable oil - or animal fat-based diesel fuel consisting of long-chain alkyl (methyl, ethyl, or propyl) esters.
- Biodiesel is typically made by chemically reacting lipids (e.g., vegetable oil, soybean oil, animal fat (tallow) with an alcohol producing fatty acid esters.
- Biodiesel is meant to be used in standard diesel engines and is thus distinct from the vegetable and waste oils used to fuel *converted* diesel engines.
- Biodiesel can be used alone, or blended with petrodiesel in any proportions.
- Biodiesel blends can also be used as heating oil.

- Blends of biodiesel and conventional hydrocarbon-based diesel are products most commonly distributed for use in the retail diesel fuel marketplace. Much of the world uses a system known as the "B" factor to state the amount of biodiesel in any fuel mix:
- 100% biodiesel is referred to as **B100**
- 20% biodiesel, 80% petrodiesel is labeled **B20**
- 5% biodiesel, 95% petrodiesel is labeled **B5**
- 2% biodiesel, 98% petrodiesel is labeled **B2**

- Blends of 20% biodiesel and lower can be used in diesel equipment with no, or only minor modifications, although certain manufacturers do not extend warranty coverage if equipment is damaged by these blends. The B6 to B20 blends are covered by the ASTM D7467 specification. Biodiesel can also be used in its pure form (B100), but may require certain engine modifications to avoid maintenance and performance problems. Blending B100 with petroleum diesel may be accomplished by:
- Mixing in tanks at manufacturing point prior to delivery to tanker truck
- Splash mixing in the tanker truck (adding specific percentages of biodiesel and petroleum diesel)
- In-line mixing, two components arrive at tanker truck simultaneously.
- Metered pump mixing, petroleum diesel and biodiesel meters are set to X total volume, transfer pump pulls from two points and mix is complete on leaving pump.

- Biodiesel has promising lubricating properties and cetane ratings compared to low sulfur diesel fuels.
- Depending on the engine, this might include high pressure injection pumps, pump injectors (also called *unit injectors*) and fuel injectors.
- The calorific value of biodiesel is about 37.27 MJ/kg. This is 9% lower than regular Number 2 petrodiesel. Variations in biodiesel energy density is more dependent on the feedstock used than the production process. Still, these variations are less than for petrodiesel.
- It has been claimed biodiesel gives better lubricity and more complete combustion thus increasing the engine energy output and partially compensating for the higher energy density of petrodiesel.
- The color of biodiesel ranges from golden and dark brown, depending on the production method. It is slightly miscible with water, has a high boiling point and low vapor pressure.
- The flash point of biodiesel (>130 °C, >266 °F) is significantly higher than that of petroleum diesel (64 °C, 147 °F) or gasoline (−45 °C, -52 °F).
- Biodiesel has a density of ~ 0.88 g/cm^3, higher than petrodiesel (~ 0.85 g/cm^3).
- Biodiesel contains virtually no sulfur, and it is often used as an additive to Ultra-Low Sulfur Diesel (ULSD) fuel to aid with lubrication, as the sulfur compounds in petrodiesel provide much of the lubricity.

- The power output of biodiesel depends on its blend, quality, and load conditions under which the fuel is burnt.
- The thermal efficiency for example of B100 as compared to B20 will vary due to the BTU content of the various blends. Thermal efficiency of a fuel is based in part on fuel characteristics such as: viscosity, specific density, and flash point; these characteristics will change as the blends as well as the quality of biodiesel varies.
- The American Society for Testing and Materials has set standards in order to judge the quality of a given fuel sample.
- Regarding brake thermal efficiency one study found that B40 was superior to traditional counterpart at higher compression ratios (this higher brake thermal efficiency was recorded at compression ratios of 21:1).
- It was noted that, as the compression ratios increased, the efficiency of all fuel types - as well as blends being tested - increased; though it was found that a blend of B40 was the most economical at a compression ratio of 21:1 over all other blends. The study implied that this increase in efficiency was due to fuel density, viscosity, and heating values of the fuels

- Biodiesel can be used in pure form (B100) or may be blended with petroleum diesel at any concentration in most injection pump diesel engines.
- New extreme high-pressure (29,000 psi) common rail engines have strict factory limits of B5 or B20, depending on manufacturer.
- Biodiesel has different solvent properties than petrodiesel, and will degrade natural rubber gaskets and hoses in vehicles (mostly vehicles manufactured before 1992), although these tend to wear out naturally and most likely will have already been replaced with FKM, which is nonreactive to biodiesel.
- Biodiesel has been known to break down deposits of residue in the fuel lines where petrodiesel has been used.
- As a result, fuel filters may become clogged with particulates if a quick transition to pure biodiesel is made.
- Therefore, it is recommended to change the fuel filters on engines and heaters shortly after first switching to a biodiesel blend.

Bioethanol

- **Bioethanol** is most often used as a motor fuel, mainly as a biofuel additive for gasoline.
- It is commonly made from biomass such as corn or sugar.
- Recently, cars able to run using 100% ethanol have been introduced in Brazil.
- World ethanol production for transport fuel tripled between 2000 and 2007 from 17 billion to more than 52 billion liters.
- From 2007 to 2008, the share of ethanol in global gasoline type fuel use increased from 3.7% to 5.4%. In 2011 worldwide ethanol fuel production reached 22.36 billion U.S. liquid gallons (bg) (84.6 billion liters), with the United States as the top producer with 13.9 bg (52.6 billion liters), accounting for 62.2% of global production, followed by Brazil with 5.6 bg (21.1 billion liters).
- Ethanol fuel has a "gasoline gallon equivalency" (GGE) value of 1.5 US gallons (5.7 L), which means 1.5 gallons of ethanol produces the energy of one gallon of gasoline.

- Ethanol fuel is widely used in Brazil and in the United States, and together both countries were responsible for 87.1% of the world's ethanol fuel production in 2011.
- Most cars on the road today in the U.S. can run on blends of up to 10% ethanol, and ethanol represented 10% of the U.S. gasoline fuel supply derived from domestic sources in 2011.
- Since 1976 the Brazilian government has made it mandatory to blend ethanol with gasoline, and since 2007 the legal blend is around 25% ethanol and 75% gasoline (E25).
- By December 2011 Brazil had a fleet of 14.8 million flex-fuel automobiles and light trucks and 1.5 million flex-fuel motorcycles that regularly use neat ethanol fuel (known as E100).

- Bioethanol is a form of quasi-renewable energy that can be produced from agricultural feedstocks. It can be made from very common crops such as sugar cane, potato, cassava and corn.
- There has been considerable debate about how useful bioethanol is in replacing gasoline.
- Concerns about its production and use relate to increased food prices due to the large amount of arable land required for crops, as well as the energy and pollution balance of the whole cycle of ethanol production, especially from corn.
- Recent developments with cellulosic ethanol production and commercialization may allay some of these concerns.
- Cellulosic ethanol offers promise because cellulose fibers, a major and universal component in plant cells walls, can be used to produce ethanol.
- According to the International Energy Agency, cellulosic ethanol could allow ethanol fuels to play a much bigger role in the future than previously thought.

- The basic steps for large-scale production of ethanol are: microbial (yeast) fermentation of sugars, distillation, dehydration (requirements vary), and denaturing (optional).
- Prior to fermentation, some crops require saccharification or hydrolysis of carbohydrates such as cellulose and starch into sugars.
- Saccharification of cellulose is called cellulolysis. Enzymes are used to convert starch into sugar

- **Fermentation**: Ethanol is produced by microbial fermentation of the sugar.
- Microbial fermentation currently only works directly with sugars.
- Two major components of plants, starch and cellulose, are both made of sugars—and can, in principle, be converted to sugars for fermentation.
- Currently, only the sugar (e.g., sugar cane) and starch (e.g., corn) portions can be economically converted.
- There is much activity in the area of cellulosic ethanol, where the cellulose part of a plant is broken down to sugars and subsequently converted to ethanol.

- **Distillation**: For the ethanol to be usable as a fuel, the majority of the water must be removed.
- Most of the water is removed by distillation, but the purity is limited to 95–96% due to the formation of a low-boiling water-ethanol azeotrope with maximum (95.6% m/m (96.5% v/v) ethanol and 4.4% m/m (3.5% v/v) water).
- This mixture is called hydrous ethanol and can be used as a fuel alone, but unlike anhydrous ethanol, hydrous ethanol is not miscible in all ratios with gasoline, so the water fraction is typically removed in further treatment to burn in combination with gasoline in gasoline engines.

- **Dehydration**: There are basically three dehydration processes to remove the water from an azeotropic ethanol/water mixture.
- The first process, used in many early fuel ethanol plants, is called azeotropic distillation and consists of adding benzene or cyclohexane to the mixture.
- When these components are added to the mixture, it forms a heterogeneous azeotropic mixture in vapor–liquid-liquid equilibrium, which when distilled produces anhydrous ethanol in the column bottom, and a vapor mixture of water, ethanol, and cyclohexane/benzene.

- When condensed, this becomes a two-phase liquid mixture.
- The heavier phase, poor in the entrainer (benzene or cyclohexane), is stripped of the entrainer and recycled to the feed—while the lighter phase, with condensate from the stripping, is recycled to the second column.
- Another early method, called extractive distillation, consists of adding a ternary component that increases ethanol's relative volatility.
- When the ternary mixture is distilled, it produces anhydrous ethanol on the top stream of the column.
- With increasing attention being paid to saving energy, many methods have been proposed that avoid distillation altogether for dehydration. Of these methods, a third method has emerged and has been adopted by the majority of modern ethanol plants.
- This new process uses molecular sieves to remove water from fuel ethanol. In this process, ethanol vapor under pressure passes through a bed of molecular sieve beads. The bead's pores are sized to allow absorption of water while excluding ethanol.
- After a period of time, the bed is regenerated under vacuum or in the flow of inert atmosphere (e.g. N_2) to remove the absorbed water. Two beds are often used so that one is available to absorb water while the other is being regenerated.
- This dehydration technology can account for energy saving of 3,000 btus/gallon (840 kJ/L) compared to earlier azeotropic distillation.

Biogas

- Biogas is generated when bacteria degrade biological material in the absence of oxygen, in a process known as anaerobic digestion.
- Since biogas is a mixture of methane (also known as marsh gas or natural gas, CH4) and carbon dioxide (CO2) it is a renewable fuel produced from waste treatment.
- Anaerobic digestion is basically a simple process carried out in a number of steps by many different bacteria that can use almost any organic material as a substrate - it occurs in digestive systems, marshes, rubbish dumps, septic tanks and the Arctic Tundra.
- Humans tend to make the process as complicated as possible by trying to improve on nature in complex machines, but a simple approach is still possible.
- As methane is very hard to compress, its best use as for stationary fuel, rather than mobile fuel.
- It takes a lot of energy to compress the gas (this energy is usually just wasted), plus you have the hazard of high pressure.
- Variable volume storage (flexible bag or floating drum are the two main variants) is much easier and cheaper to arrange than high-pressure cylinders, regulators and compressors.

History

- Anecdotal evidence indicates that biogas was used for heating bath water in Assyria during the 10th century BC and in Persia during the 16th century AD.
- Marco Polo mentions the use of covered sewage tanks. It probably goes back 2,000- 3,000 years ago in ancient Chinese literature.
- Jan Baptita Van Helmont first determined in 17th century that flammable gases could evolve from decaying organic matter. Count Alessandro Volta concluded in 1776 that there was a direct correlation between the amount of decaying organic matter and the amount of flammable gas produced.
- A digester was built in the 1840's in the City of OTAGO, New Zealand.
- The “first” digestion plant was built at a leper colony in Bombay, India in 1859.
- The first sewage sludge digester was built in Exeter, UK around 1900.

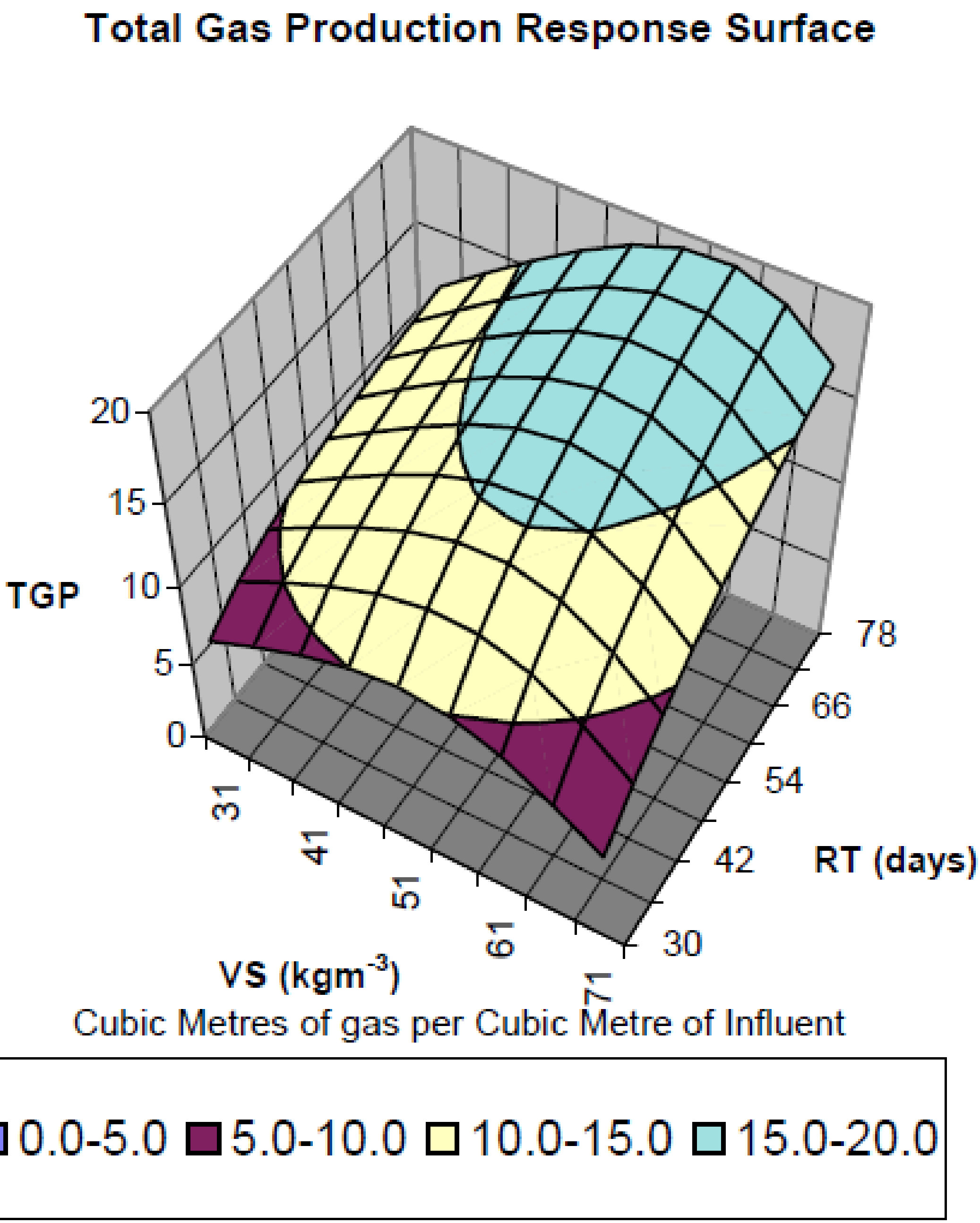
Process

- Anaerobic digestion breaks down readily degradable organic matter in a series of steps, where the product of one step becomes the substrate for the next step.
- The initial step is usually considered to be “hydrolysis” – where extra cellular enzymes break complex organic molecules like fats and starches into simpler molecules like glucose.
- These simpler molecules are then utilised by “acetogenic” bacteria to produce acetic acid, with carbon dioxide as another product of the breakdown.
- “Methanogens” are then able to use the acetic acid and produce methane.
- There is also another group of “methanogens” that convert carbon dioxide to methane.
- As a result of these steps “biogas” is mainly methane (typically 60%, but less if the digester is not operating properly and sometimes up to about 80%) and carbon dioxide with traces of hydrogen sulphide, ammonia, water vapour, other organic volatiles and possibly some nitrogen gas.

- Being a microbiological process the presence of any toxic or inhibitory substances will reduce, or possibly end, biogas production.
- Antibiotics are a potential problem, as are some cleaning chemicals and heavy metals.
- One of the advantages of AD is that the process destroys a large proportion of pathogens that may be present in the waste, so reduces the risk of disease transmission.
- Adequate ventilation, suitable precautions and adequate protective equipment will minimise the dangers associated with biogas, making it a good servant rather than a bad master.
- Like water, electricity, automobiles and most of life biogas is not completely safe, but by being aware of the dangers involved you are well on the way to a safe and happy digestion experience.

Digestor Performance

- When looking at an anaerobic digester as a biogas production unit the performance depends on the type of waste used, the amount of Volatile Solids (VS) put in per day, the operating temperature (T) and the Retention Time (RT).
- Since VS reduction is directly related to both biogas production and Chemical/Biological Oxygen Demand (the pollution load) the same variables apply to the digester as a pollution treatment unit anyway.
- A number of publications recommend 35 °C as the optimum temperature and most designers aim for maximum gas per unit volume of digester (high rate designs to minimise digester size/cost), but digesters operate quite well at lower temperatures and longer retention times also give better gas production.


Total Gas Production Response Surface
TGP
20
15
10
5
0
31
41
51
61
71
VS (kgm^{-3})
78
66
54
42
30
RT (days)
Cubic Metres of gas per Cubic Metre of Influent
0.0-5.0
5.0-10.0
10.0-15.0
15.0-20.0

- Once we know the type of waste we are going to treat, we can look up the Bo (ultimate methane yield) value and how much waste each animal will produce per day. The dilution factor, normally 2-4, will then give you the Volatile Solids value to use for your waste type.
- You then use the digester Operating Temperature to determine the Retention Time to use – based on the “Safety Factor”, which is suggested should be 3 or more. The combination of VS and Safety Factor (from above) then result in a Konst that is used in the SBP equation to give Biogas per unit digester volume (the Specific Biogas Production). Once SBP is known you can calculate Biogas per day and Digester Volume.
- As a guide you will need about 400 litres of biogas per person per day for cooking, so now it is possible to calculate what size digester you need and how much waste will have to be collected to cook for the family building the digester, using information from the Tables below.
- **Waste Required = Design Biogas /[SBP X (dilution + 1) X RT]**
- **Digester Volume = Waste Required X (dilution + 1) X RT**

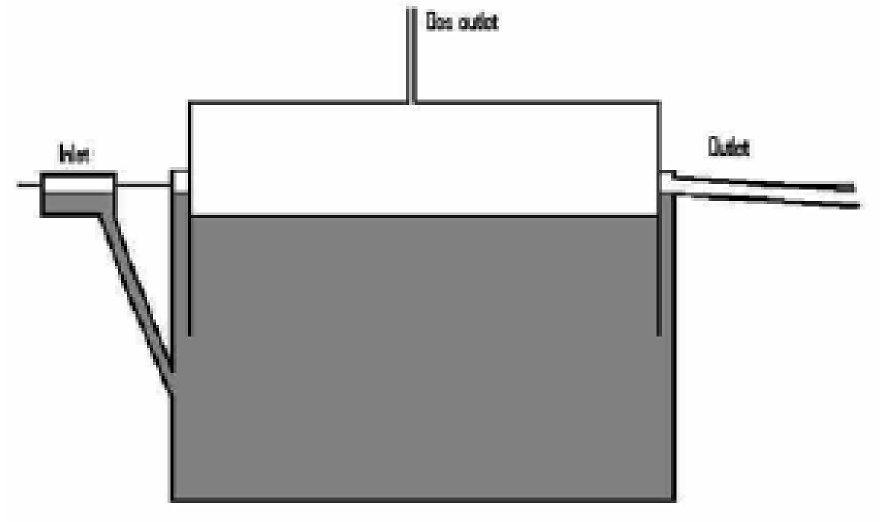


Figure 4 Indian type digester

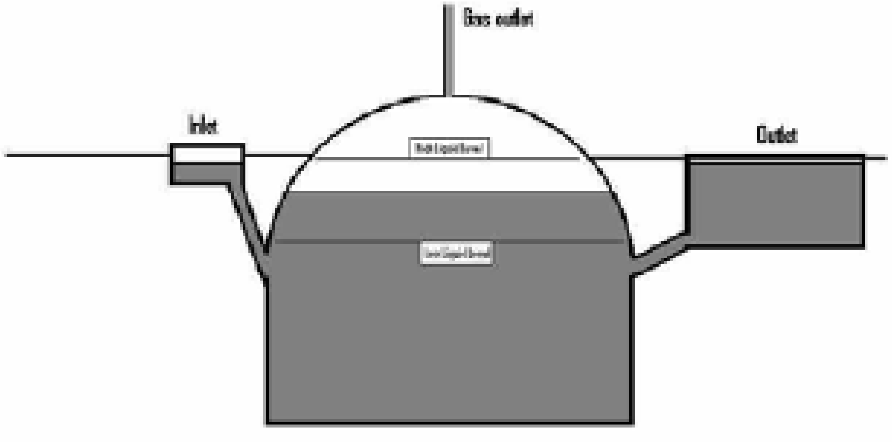


Figure 5 Chinese type digester

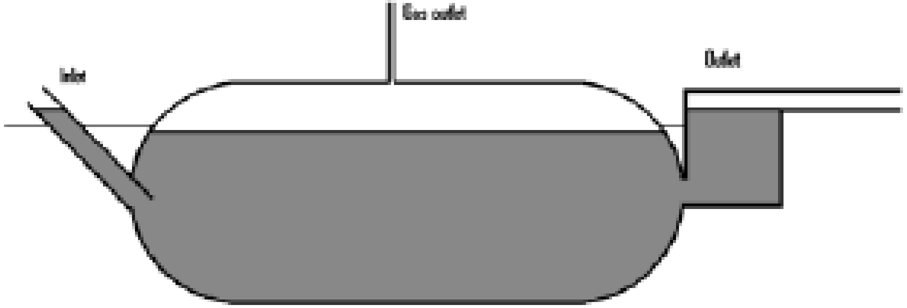


Figure 6 Plug Flow digester

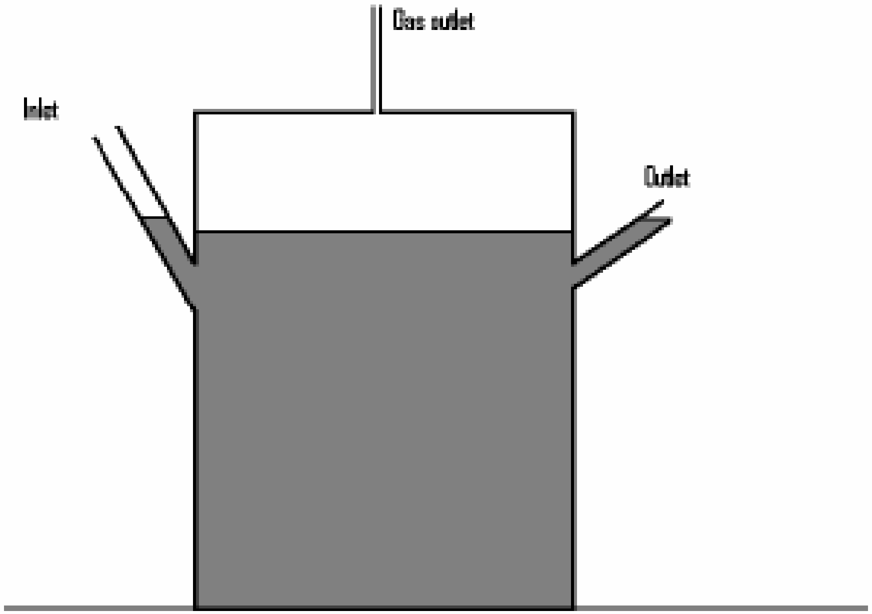


Figure 7 CFST type digester

Checklist in making digester

- You need to have the appropriate bacteria present. In cattle and pig waste there are usually the right bacteria but poultry waste and vegetable waste may need inoculation, so you may have to start with cattle or pig manure and gradually introduce the other waste form.
- Startup will be slow. The actual process is fairly slow and proceeds in a series of steps, just like AD itself. First the oxygen in headspace air has to be used up to get anaerobic conditions, so the first gas collected will be carbon dioxide (which will extinguish a flame).
- Acetogenesis then generates more CO2 and acetic acid, so if this stage gets too advanced methanogenesis can be inhibited. Once there is some acetic acid methanogenesis can start, but of course some initial bacteria must be present.
- Sudden changes can upset the process. If you need to change the amount of waste added per day, the concentration or the type of waste it is better to make the change gradual so the bacterial population has time to adjust. While the change is underway monitor gas quality (see Monitoring), as a drop in quality (more CO2 and/or less CH4) is often the first indication of possible digester failure. If the gas quality does deteriorate it is best to stop feeding and give the digester a chance to recover.

- The preferred way to start a digester is to part fill with water (so you can check operation and make any alterations necessary without having to deal with effluent) and then put in half the working volume of dairy or piggery effluent (or active digester sludge if available).
- Wait until the digester is producing flammable gas, which may take a few weeks if temperatures are cool, before starting feeding at half the design rate.
- Once operation has settled down increase to full rate, still using the initial waste and wait for operation to settle down again.
- If you want to use different waste use a 50/50 mix for at least one retention time before changing over completely, again monitor the digester performance and wait until you are satisfied that the operation has adjusted before making any further change.

- One of the best indicators of proper digester operation is that the gas volume produced per day is consistent with the waste input and that the gas will support combustion (which indicates at least 50% methane).
- As the digester is a well buffered system a simple pH measurement will really only tell you that the digester is in trouble, usually well after the gas quality/volume has dropped.
- A syringe body fitted with some flexible tube and some dilute sodium hydroxide solution can be used to estimate carbon dioxide percentage, as NaOH absorbs CO2 but not methane.
- Draw up 20-30 ml of biogas and put the end of the tube into the NaOH solution, then push out excess gas to get a 10 ml gas sample (you have to allow for the gas in the tube, which may be 4-5 ml).
- Draw up approximately 20 ml of solution and keep the end of the tube submerged while you shake the syringe for 30 seconds. Point the syringe downwards and push out excess liquid, so the syringe plunger reaches 10 ml.
- Read the volume of liquid, which should be 3-4 ml indicating about 30-40% of gas absorbed so we assume the balance is methane. If you get over 50% methane (a reading of less than 5 ml of liquid) and the flame will still not burn properly you must have nitrogen or some other gas present.

- To measure pressure in a digester simply put a clear plastic tube into a container of water (a glass container is easiest) and connect the tube to the digester gas line.
- The digester pressure will push down the water surface in the tube and the difference between inside and outside levels is known as “water gauge”.
- If the pressure is too great gas will bubble out the bottom of the tube.
- You can also make a “manometer” by bending a plastic tube into a U and putting water in – when one end is connected to the gas line and the other is open to atmosphere (you may need to restrict this to a small hole so the levels settle quickly) you can measure the difference in water heights.

- The digester itself provides the simplest gas storage, but supply pressure will fall as gas is used.
- You may need some weights to place on the digester to develop more pressure, but be careful of puncturing the digester body.
- If the use is a fair way from the digester better burner performance may be obtained by having a separate Gas storage near the use point.
- This can be either a flexible, gas tight bag or a floating drum type storage. With the second storage it is a good idea to allow low pressure collection of the gas (to minimise the possibility of gas leaks) and to use weight to increase pressure during burner operation, but you need the “back flow preventer” to make best use of this.
- The storage should be sized to hold one day’s use of gas if possible, which should be as closely matched as possible to digester gas production.
- If production does exceed use then any excess gas needs to be flared, as the methane in biogas is about 23 times worse as a greenhouse gas than carbon dioxide.