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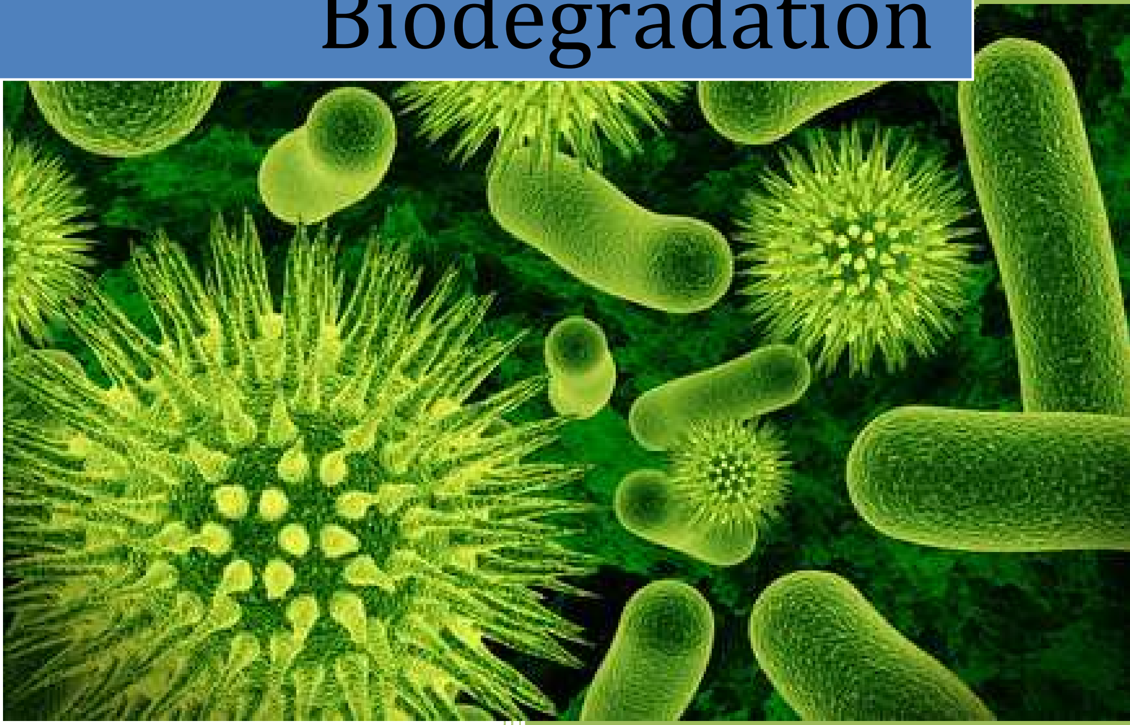

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Aerobic and Anaerobic Biodegradation

A look into aerobic and anaerobic biodegradation

By

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Introduction

This document provides an explanation detailing the processes of aerobic and anaerobic biodegradation. It is intended for general audiences and will provide the reader with the necessary information to understand what is happening during the biodegradation process. For those interested in the biochemical processes of the microbial organisms this document will provide a high level explanation of the aerobic and anaerobic processes in the appendix.

Types of Microbes

It's important to note that the biodegradation process is extremely complex and variable. Scientists are still discovering new microbes and the majority of microbes are extremely difficult to study in lab environments. However, we do know that microbes account for more than 60 percent of all earths organic matter and weigh more that 50 quadrillion metric tons. Microbes are everywhere and constitute nine out of ten cells in the human body.

There is no universal definition of a microbes but it is usually something like "a microscopic single-cell organism". Not all of them are organisms (alive) and some are multi-cellular. Microbes take in nutrients and inorganic elements that other life-forms cannot use.

There are uncountable kinds of microbes. To better study microbes are divided into groups based on their relationships. There are three main groups of microbes:

1) Prokaryotes (these are living organisms) and
2) Eukaryotes (these are living organisms)
3) Viruses and Prions (probably not living)

- **Eukaryotes** – are organisms that contain the genetic material DNA, organized into a distinct cell structure, called a nucleus that is surrounded by a membrane.

  There are three main groups of eukaryotic microbes: protozoa, algae and fungi:

    - Protozoa – simple one celled that are not easily to classify as either animal or plant.
    - Algae – are like plants
    - Fungi – mushrooms, but most forms don't resemble mushrooms and are yeast, mildews and molds.

- **Prokaryotes** – are organisms that contain genetic material, but this material (usually DNA) is not organized into a specific cell structure called a nucleus.

  There are two kinds of prokaryotes: archaea and bacteria:
    - Bacteria – are the most known microbes.
    - Archaea – are different from both eukaryotes and bacteria with their cell structure resembling bacteria.

Microbes are divided into anaerobes and aerobes. Anaerobes either cannot tolerate oxygen or simply ignore it. Aerobes must have oxygen in order to survive – almost all eukaryotes are aerobes.

Microbes are also either autotrophs or heterotrophs.

- Autotrophs – do not eat, they make their own food from light or chemicals (producers).
- Heterotrophs – eat autotrophs or each other (consumers).

Microbes are classified by the way they get energy (heterotrophs or autotrophs) and the way they handle oxygen. Microbes also vary in size from about 0.2 to 10.0 um.

A fascinating observation is that bacteria microbes behave in a coordinated, almost social way, as if they were multi-cellular organisms. This behavior is called quorum sensing. In quorum sensing, bacteria communicate with each other by releasing signaling molecules, sometimes called pheromones. A single bacterium can perceive the number of other bacteria around it by measuring the concentration of signaling molecules. When this concentration reaches a critical mass, the bacteria then can adapt to a change in nutrients, carry out defensive maneuvers, avoid toxins, and even coordinate their virulence so as to evade the host's immune system. Quorum sensing usually refers to aggregations of a single species, but microbes often form heterogeneous communities of many species as well.

An interesting fact is that Bacteria are the source of about half the oxygen you breathe. Most microbes can't grow at all without plenty of water.

A Splash of Chemistry

Before we go any further about microbes we need to present just a few chemistry concepts that are essential for understanding how microbes do what they do. If you've been out of school for awhile don't worry about this section it will be painless and quick.

- Elements are substances that cannot be broken down into simpler substances using chemical methods.
- Atoms prefer stable configurations, where the number of protons in the nucleus equals the number of electrons orbiting the nucleus.
- Organic molecules are molecules that contain carbon atoms. There are many kinds of organic molecules, but four primary ones are:
    - Carbohydrates
    - Lipids
    - Proteins
    - Nucleic acids

Keep these points in mind when you think about how microbes are able to rearrange atoms to utilize the more complex compound for energy and what they leave behind as a result of that process.

Microbes are Living Creatures

All living things are made of cells. Complex creatures such as humans are made of trillions of cells.

Microbes must take in certain chemical elements to build molecules such as carbohydrates, lipids, and proteins to make energy and to survive.

Some microbes can get the carbon they need from almost any source; other microbes are very fussy about carbon sources and will take in only certain ones. The two main methods of microbial eating are diffusion and active transport.

Microbes grow or not in response to a number of factors. Among them are ambient temperature, pH, and the presence (or absence) of oxygen.

PH measures the concentration of hydrogen ions in a fluid. The measure is expressed on a scale from 0 to 14; low numbers means lots of hydrogen ions and a high pH number means fewer hydrogen ions. Seven is neutral; anything below seven is acid and anything above seven is alkaline (also called basic).

Bacteria and protozoa tend to like a near-neutral pH, somewhere between 5.5 and 8.0. The human stomach is a pH of about 2. Fungi and algae mostly like their environment a bit acid, from 4.0 to 6.0, and there are some archaea that can grow at a pH about as low as it can get, near 0.

Some microbes can adjust their pH tolerance a bit when their environments change. A lot of microbes can even control their environments, changing the surrounding pH to suit them better by releasing waste products that are acid or basic.

The microbial world can be divided into aerobes and anaerobes. Almost all multi-cellular creatures need oxygen: they are often called obligate aerobes. Some microbial aerobes cannot tolerate a “normal” level of atmospheric oxygen that is 20 percent. These are microaerophiles, and they need low oxygen levels, under 10 percent.

Obligate anaerobes are, well, obligated to stay away from oxygen or they will die. Facultative anaerobes don’t need oxygen, but they like it and do better when it’s around. Some other anaerobes don’t care either way: oxygen, no oxygen, whatever.

Although microbes are found in almost all environment and conditions on the planet they are very much unlike a marching army that runs to find food and attack it before moving onto the next food source. Microbes need time to multiply and grow the colony and will continue to split and grow until they reach a level that consumes the food source. Once the food source is not enough to sustain the colony, the colony begins to die off, until in the end only soil remains.

The four phases of microbial growth are:

- **Lag phase** – the initial phase where microbes are getting ready to grow. They are making enzymes, proteins and RNA, in general boosting their metabolic activity in preparation for the explosion of activity that is about to occur. No fission yet.
- **Exponential phase, sometimes called the logarithmic or log phase** – when fission begins. Growth is measured in generation time, which is the amount of time for the microbes to double in number, which can be 20 min or 20 hours depending on the conditions and species.
- **Stationary phase** – begins when the population number stabilizes. Cell division and cell death are in balance.
- **Death phase** – begins when fission stops or when the death of cells outpaces replication. Bacteria also die off at an exponential rate just like the log or exponential phase.

Just about all microbes live in communities. This networking is a fact of life and has been for billions of years. It’s called symbiosis. Symbiosis means “living together” and describes the intimate association between two or more different kinds of organisms. The ideal form of mutualism is biofilm, layers of microbes. Biofilm depends on quorum sensing, communication and behavior coordination among a group of microbes, to function. A biofilm is a microbial community. According to experts, there is no such thing as a biofilm-proof surface.

Biofilms couldn’t form without quorum sensing. They need a certain concentration of the bacterial chemicals known as pheromones or autoinducers to estimate cell density, to attract additional residents, and to signal other microbes that it’s time to turn genes on and off.

All life needs nitrogen. Some microbes can use gaseous nitrogen from the air. The majority of microbes get nitrogen from a “fixed” source such as from other compounds.

Note: Keep in mind; microbes have had billions of years to evolve defensive as well as survival strategies.

Microbes on (and in) the Earth

98 percent of the oceans’ biomass (the total weight of all their organic matter) is microbes. Most of this vast community remains unknown to scientists.

The oceans are teaming with microbes. The surface waters teem with millions of them in every milliliter (ml) of seawater (a little over 0.s0 of a measuring teaspoonful). And even in the depths, there are tens of thousands per milliliter.

Almost all photosynthesis is carried out in the top 600 feet. The major energy producers are Cyanobacteria, which are smaller but far more plentiful. There are up to 100,000 members of the Cyanobacteria genus Synechococcus per milliliter of water. The single most successful microbe in the ocean appears to be the SAR11. It is probably an aerobic heterotrophy, incredibly tiny (1/100th the size of a typical bacterium).

Ocean sediment at the bottom of the oceans is teeming with microbes – even as much as a half kilometer down. Not much is known about the microbes in sediment, but it appears that the bacteria and archaea that dominate this sea subfloor may be quite different from oceangoing microbes. The complement of particular microbes varies depending on the nature of the body of water.

Microbes in the soil clean the water and air, and help plants grow. And plants provide food for all, plus oxygen, while they store carbon dioxide and nitrogen. Soil composition varies enormously from place to place. Soil contains a mind-boggling number and variety of organisms, which live in and between soil particles. Soil contains all the microbes: bacteria, archaea, viruses, protozoa, algae, and fungi. Scientists have estimated that just a teaspoon of soil contains between 100 million and a billion bacteria and several thousand (sometimes a million) protozoa. That means that each acre of soil is home to a ton of bacteria – literally a ton.

An average soil is about one-half undigested organic matter (which is available for consumption by organisms) and one-half humus (which is mostly digested organic matter). Numerous as they are in soil, organisms account for less than 5 percent of soil organic matter, and fresh plants less than 10 percent.

Most compost microbes are bacteria, but fungi and protozoa also contribute as do larger creatures like worms. Fungi pose the right kind of enzymes for decomposing the already-decomposed humus even more.

Fermentation is a natural process in which a cell (often a microbial cell) gets the energy it needs by breaking some organic material down into its component parts without using oxygen. The process begins with glycolysis, which is the splitting of a sugar molecule to yield energy.

Biodegradation

Biodegradation is the process by which organic substances (which are carbon based chains or rings also containing hydrogen and/or other elements) are broken down into smaller compounds by the enzymes produced by living microbial organisms. Biodegradable matter is generally organic material such as plant and animal matter and other substances originating from living organisms, or artificial materials that are similar enough to plant and animal matter to be put to use by microorganisms.

Micro-organisms transform the organic substance through **metabolic or enzymatic processes**. Biodegradation processes vary greatly, but frequently the final product of the degradation is carbon dioxide and/or methane and inert humus. Organic material can be degraded **aerobically**, with oxygen, or **anaerobically**, without oxygen.

> **Metabolic Process** is the set of chemical reactions that happen in living organisms to maintain life. These processes allow organisms to grow and reproduce, maintain their structures, and respond to their environments. Metabolism is usually divided into two categories. Catabolism breaks down organic matter, for example to harvest energy in cellular respiration. Anabolism uses energy to construct components of cells such as proteins and nucleic acids.
>
> **Enzymatic Process** is the result of enzymes which are produced by micro-organisms to convert larger molecules into smaller molecules. Enzymes are proteins that catalyze (*i.e.*, increase the rates of) chemical reactions.

Some microorganisms have the astonishing, naturally occurring, microbial catabolic diversity to degrade, transform or accumulate a huge range of compounds including hydrocarbons (e.g. oil), polychlorinated biphenyls (PCBs), polyaromatic hydrocarbons (PAHs), pharmaceutical substances, radionuclides and metals.

Studies have shown that human influences such as pollution, agriculture and chemical applications can adversely affect the microbial diversity, and possibly above and below ground microbial ecosystems. There has been shown a decrease in bacterial biomass and activity in cultivated fields. Soil found to have a high diversity in bacteria and fungi results in higher soil quality and fertility.

Aerobic Biodegradation

Aerobic biodegradation is the breakdown of organic substances by microorganisms when oxygen is present. More specifically, it refers to occurring or living only in the presence of oxygen; therefore, the chemistry of the system, environment, or organism is characterized by oxidative conditions. Many organic substances are rapidly degraded under aerobic conditions by aerobic bacteria called aerobes.

Aerobic bacteria (aerobe) have an oxygen based metabolism. Aerobes, in a process known as cellular respiration, use oxygen to oxidize substrates (for example sugars and fats) in order to obtain energy.

Before cellular respiration begins, glucose molecules are broken down into two smaller molecules. This happens in the cytoplasm of the aerobes. The smaller molecules then enter a mitochondrion, where aerobic respiration takes place. Oxygen is used in the chemical reactions that break down the small molecules into water and carbon dioxide. The reactions also release energy.

Aerobic, unlike anaerobic digestion, does not produce the methane gases.

Anaerobic Biodegradation

Anaerobic digestion occurs when the anaerobic microbes are dominant over the aerobic microbes. Biodegradable waste in landfill degrades in the absence of oxygen through the process of anaerobic digestion. Paper and other materials that normally degrade in a few years degrade more slowly over longer periods of time. Biogas contains methane which has approximately 21 times the global warming potential of carbon dioxide. In a cradle to cradle approach this biogas is collected and used for eco-friendly power generation.

Anaerobic digestion is a series of processes in which microorganisms break down biodegradable material in the absence of oxygen. It is widely used to treat wastewater sludge and biodegradable waste because it provides volume and mass reduction of the input material.

As part of an integrated waste management system, anaerobic digestion reduces the emission of landfill gas into the atmosphere. Anaerobic digestion is a renewable energy source because the process produces Methane and Carbon dioxide rich biogas suitable for energy production helping replace Fossil fuels. Also, the nutrient-rich solids left after digestion can be used as fertilizer.

The Anaerobic Process

The anaerobic biodegradation process begins with bacterial hydrolysis and fermentation of complex organic structures to smaller low-molecular-weight insoluble organic acids, such as carbohydrates (e.g. acetate). These smaller compounds can be used by some bacteria to be directly mineralized to CO2. Acetogenic bacteria then convert the low-molecular-weight organic acids (sugars and amino acids) into carbon dioxide, hydrogen , ammonia , and acetic acids. Methanogens finally are able to convert these products to methane and utilize hydrogen as an energy source.

There are a number of bacteria that are involved in the process of anaerobic digestion including acetic acid-forming bacteria and methane-forming bacteria. These bacteria feed upon the initial feedstock, which undergoes a number of different processes converting it to intermediate molecules including sugars, hydrogen & acetic acid before finally being converted to biogas.

Anaerobic Biodegradation Stages

There are four key biological and chemical stages of anaerobic digestion:

1. **Hydrolysis**
2. **Acidogenesis**
3. **Acetogenesis**
4. **Methanogenesis**

Hydrolysis

In most cases biomass is made up of large organic polymers. In order for the bacteria in anaerobic digesters to access the energy potential of the material, these chains must first be broken down into their smaller constituent parts. These constituent parts or monomers such as sugars are readily available by other bacteria. The process of breaking these chains and dissolving the smaller molecules into solution is called hydrolysis. Therefore hydrolysis of these high molecular weight polymeric components is the necessary first step in anaerobic digestion. Through Hydrolysis the complex organic molecules are broken down into simple sugars, amino acids, and Fatty acids.

Acetate and hydrogen produced in the first stages can be used directly by methanogens. Other molecules such as volatile fatty acids (VFA's) with a chain length that is greater than acetate must first be catabolised into compounds that can be directly utilized by methanogens.

Acidogenesis

The biological process of Acidogenesis is where there is further breakdown of the remaining components by acidogenic (fermentative) bacteria. Here VFAs are created along with ammonia, carbon dioxide and Hydrogen sulfide as well as other by-products. The process of acidogenesis is similar to the way that milk sours.

Acetogenesis

The third stage anaerobic digestion is Acetogenesis . Here simple molecules created through the acidogenesis phase are further digested by acetogens to produce largely acetic acid as well as carbon dioxide and hydrogen.

Methanogenesis

The terminal stage of anaerobic digestion is the biological process of Methanogenesis. Here methanogens utilize the intermediate products of the preceding stages and convert them into methane, carbon dioxide and water. It is these components that makes up the majority of the biogas emitted from the system.

Environmental Benefit of Anaerobic Biodegradation

Anaerobic digestion facilities have been recognized by the **United Nations Development Program** as one of the most useful decentralized sources of energy supply, as they are less capital intensive than large power plants.

Utilizing anaerobic digestion technologies can help to reduce the emission of greenhouse gases in a number of key ways:

- Replacement of fossil fuels
- Reducing methane emission from landfills
- Displacing industrially-produced chemical fertilizers
- Reducing electrical grid transportation losses

Methane and power produced in anaerobic digestion facilities can be utilized to replace energy derived from fossil fuels, and hence reduce emissions of greenhouse gases. This is due to the fact that the carbon in biodegradable material is part of a Carbon cycle. The carbon released into the atmosphere from the combustion of biogas has been removed by plants in order for them to grow in the recent past. This can have occurred within the last decade, but more typically within the last growing season. If the plants are re-grown, taking the carbon out of the atmosphere once more, the system will be carbon neutral. This contrasts to carbon in fossil fuels that has been sequestered in the earth for many millions of years, the combustion of which increases the overall levels of carbon dioxide in the atmosphere.

Landfill Bioreactors are growing in popularity as a method for handling Municipal Solid Waste (MSW). Landfill Bioreactors enhance microbiological processes to transform and stabilize the readily and moderately decomposable organic waste constituents in a shorter period of time (typically 5 to 10 years) in comparison to a conventional landfill (typically 30 to 50 years, or more). This results in a 15% to 30% gain in landfill space. This approach not only allows for utilizing the same space for a longer period of time but also facilitates microbial breakdown over a shorter period of time thus producing more volume of methane gases which are then used to create clean energy.

The environmental benefits of a bioreactor landfill include:

- Shorter time periods (7-10 years) over which air and water emission are generated compared to 30 or more years in a conventional landfill;
- Shorter post-closure care periods (10-15 years) compared to 30 or more years for a conventional landfill;
- Increased efficiency of the gas collection
- Quicker return of the property to a productive end-use

Methane is a combustible gas that is byproduct of the anaerobic biodegradation process. It is also a very potent Green House Gas (GHG) and is a serious concern for MSW managers, EPA and others concerned with the environment. Today's modern landfills are required to collect the landfill gases and destroy the negative environmental effects.

A Few Facts about Landfill Methane to Energy

One method for doing this is to combust landfill gases. The devices used to combust landfill gases have a destruction efficiency of more than 99% for methane and greater than 98% for all other NMOC.

EPA data shows more than 455 operational gas-to-energy projects in 42 states, collecting 7245 million standard cubic feet of landfill gas and generate 1,383 megawatts of electricity per year. The annual environmental benefits from current landfill gas-to-energy project are equivalent to:

- Planting over 20.5 million acres of forest per year
- Preventing the use of over 177 million barrels of oil
- Removing the carbon dioxide emission equivalents of over 14.5 million cars; or
- Offsetting the use of 370,000 railcars of coal

Appendix A:
Are Plastics Biodegradable?

Yes, plastics can biodegrade through decomposition in the natural environment. Biodegradation of plastics can be achieved by enabling microorganisms in the environment to metabolize the molecular structure of plastic polymers resulting in biogases and inert humus material. They may be composed of either bioplastics, which are plastics whose components are derived from renewable raw materials, or petroleum-based plastics with the addition of a biodegradable additive. The use of certain types of additive compounds allows microbes to metabolize the plastic's polymer chain resulting in the assimilation of the plastic hydrocarbon into natural biogases and biomass.

There are some plastics, including some bio-plastics which use the term biodegradable to describe their product in very general and loose terms. These plastics require an initial mechanical or chemical processing phase in order to degrade the polymer into a state that will allow for microbial degradation. These conditions may or may not be naturally found in natural environments.

For example; a common bio-plastics which falls into this category is PLA (Poly-lactic Acid). This material has been marketed as biodegradable in compost environments. PLA requires an initial mechanical breakdown through a chemical process of exposing the polymer to high heat for a period of time (140 degrees for 10 days). This is not an environment that is readily found in nature, however, once PLA has been exposed to this chemical process the polymer has degraded into a state that will allow for the biodegradation of microbes in aerobic environments. This initial chemical breakdown requires that PLA be disposed of in very specific environments such as found in professional composting where the material can be manipulated to produce the desired results.

Another example; are plastics which utilize additive technologies which react to environmental conditions such as oxygen or UV. These additives which are technically identified as degradables sometimes claimed to be biodegradable. These types of additives are added into standard plastics and chemically bond to the polymer. When the additive chemically reacts to the environmental conditions whether that is oxygen, UV or some other reactant the chemical reaction causes the polymer to break at the point of connection. This results in the polymer becoming weak and brittle, eventually breaking down into smaller and smaller pieces of the original polymer. The thought is believed that the polymer will eventually become small enough for microbes to digest the material thus biodegrading the polymer into biogases and biomass. There has been no public data showing microbial biodegradation once this mechanical phase has been completed.

It is important to note that the customary disposal method should be taken into consideration when choosing the best environmental biodegradable plastic solution. If a bio-plastic, biodegradable plastic, or degradable plastic requires a specific environmental condition in order to initiate biodegradation it is extremely important that the biodegradable plastic packaging has the necessary means of making it into that required environment. The best environmental solution should not require special handling or processing of the disposed plastic material and will integrate into the existing disposal processes and methods, such as found in common waste management and recycling systems.

Plastics Degradation Standards

ASTM International, originally known as the American Society for Testing and Materials (ASTM), is one of the largest voluntary standards development organizations in the world and is a trusted source for technical standards for materials, products, systems, and services. Known for their high technical quality and market relevancy, ASTM International standards have an important role in the information infrastructure that guides design, manufacturing and trade in the global economy.

The ISO or International Organization for Standardization which is the world's largest developer and publisher of international standards is internationally recognized for its testing methods and standards for testing biodegradable plastics http://www.iso.org.

ASTM International has developed a set of specifications, test methods and guidelines for biodegradable plastics. Visit the ASTM website at http://www.astm.org.

Note: ASTM testing processes should be run according to the appropriate type of biodegradable plastic.

ASTM Plastics Degradation Standards

Definitions

- D883 Terminology Relating to Plastics

Specifications

- D6400 Standard Specification for Compostable Plastics

Test Methods

- D5210 Standard Test Method for Determining the Anaerobic Biodegradation of Plastic Materials in the Presence of Municipal Sewage Sludge
- D5247 Standard Test Method for Determining the Aerobic Biodegradability of Degradable Plastics by Specific Microorganisms

- D5338 Standard Test Method for Determining Aerobic Biodegradation of Plastic Materials Under Controlled Composting Conditions
- D5511 Standard Test Method for Determining Anaerobic Biodegradation of Plastic Materials Under High-Solids Anaerobic-Digestion Conditions
- D5526 Standard Test Method for Determining Anaerobic Biodegradation of Plastic Materials Under Accelerated Landfill Conditions
- D7081 Standard Specification for Non-Floating Biodegradable Plastics in the Marine Environment

Guides

- D6002 Standard Guide for Assessing the Compostability of Environmentally Degradable Plastics

Appendix B:
Bio-Chemistry of a Micro-Organism for Biodegradation

Although food contains energy, it is not in a form that can be used by cells. Cellular respiration changes food energy into a form all cells can use. This energy drives the life processes of almost all organisms on Earth.

Cellular respiration is the set of the metabolic reactions and processes that take place in organisms' cells to convert biochemical energy from nutrients into adenosine triphosphate (ATP), and then release waste products. The reactions involved in respiration are catabolic reactions that involve the oxidation of one molecule and the reduction of another.

Nutrients commonly used by animal and plant cells in respiration include glucose, amino acids and fatty acids, and a common oxidizing agent (electron acceptor) is molecular oxygen (O_2). Bacteria organisms may respire using a broad range of inorganic molecules as electron donors and acceptors, such as sulfur, metal ions, methane or hydrogen. Organisms that use oxygen as a final electron acceptor in respiration are described as aerobic, while those that do not are referred to as anaerobic.

When cells do not have enough oxygen for respiration, they use a process called fermentation to release some of the energy stored in glucose molecules. Like respiration, fermentation begins in the cytoplasm. Again, as the glucose molecules are broken down, energy is released. But the simple molecules from the breakdown of glucose do not move into the mitochondria. Instead, more chemical reactions occur in the cytoplasm. These reactions release some energy and produce wastes, i.e. methane.

The energy released in respiration is used to synthesize ATP to store this energy. The energy stored in ATP can then be used to drive processes requiring energy, including biosynthesis, locomotion or transportation of molecules across cell membranes. Because of its ubiquity in nature, ATP is also known as the "universal energy currency".

Electron transfer chain

The electron transfer chain, also called the electron transport chain, is a sequence of complexes found in the mitochondrial membrane that accept electrons from electron donors, shuttle these electrons across the mitochondrial membrane creating an electrical and chemical gradient, and, through the proton driven chemistry of the ATP synthase, generate adenosine triphosphate.

Electron Acceptor

Microorganisms such as bacteria obtain energy to grow by transferring electrons from an electron donor to an electron acceptor. An electron acceptor is a compound that receives or accepts an electron during cellular respiration.

The microorganism through its cellular machinery collects the energy for its use. The process starts with the transfer of an electron from an electron donor. During this process (**Electron Transport Chain**) the electron acceptor is reduced and the electron donor is oxidized.

Examples of acceptors include; oxygen, nitrate, iron, manganese, sulfate, carbon dioxide, or in some cases the chlorinated solvents.

These reactions are of interest not only because they allow organisms to obtain energy, but also because they are involved in the natural biodegradation of organic substances.

Electron Donor

Microorganisms, such as bacteria, obtain energy to grow by transferring electrons from an electron donor to an electron acceptor. An electron donor is a compound that gives up or donates an electron during cellular respiration, resulting in the release of energy.

The microorganism through its cellular machinery collects the energy for its use. The final result is the electron is donated to an electron acceptor. During this process (**Electron Transport Chain**) the electron donor is oxidized and the electron acceptor is reduced.

Petroleum hydrocarbons, less chlorinated solvents like vinyl chloride, soil organic matter, and reduced inorganic compounds are all compounds that can act as electron donors. These reactions are of interest not only because they allow organisms to obtain energy, but also because they are involved in the natural biodegradation of organic substances.

Note: Aerobic respiration produces 30 ATP compared to the 2 ATP yielded from anaerobic respiration per glucose molecule.

Adenosine-5'-triphosphate (**ATP**) is a multifunctional nucleotide, and is most important in cell biology as a coenzyme that is the key to intracellular energy transfer. In this role, ATP transports chemical energy within cells for metabolism. It is produced as an energy source during the processes of photosynthesis and cellular respiration and consumed by many enzymes and a multitude of cellular processes including biosynthetic reactions, motility and cell division. ATP is made from adenosine diphosphate (ADP) or adenosine monophosphate (AMP), and its use in metabolism converts it back into these precursors. ATP is therefore continuously recycled in organisms, with the human body turning over its own weight in ATP each day.

In signal transduction pathways, ATP is used as a substrate by kinases that phosphorylate proteins and lipids, as well as by adenylate cyclase, which uses ATP to produce the second messenger molecule cyclic AMP. The ratio between ATP and AMP is used as a way for a cell to sense how much energy is available and control the metabolic pathways that produce and consume ATP. Apart from its roles in energy metabolism and signaling, ATP is also incorporated into nucleic acids by polymerases in the processes of DNA replication and transcription.