Biodegradation

IUPAC definition

Degradation caused by enzymatic process resulting from the action of cells.

Note: Modified to exclude *abiotic enzymatic* processes.[1]

Yellow slime mold growing on a bin of wet paper

Biodegradation is the chemical dissolution of materials by bacteria or other biological means. Although often conflated, biodegradable is distinct in meaning from compostable. While biodegradable simply means to be consumed by microorganisms and return to compounds found in nature, "compostable" makes the specific demand that the object break down in a compost pile. The term is often used in relation to ecology, waste management, biomedicine, and the natural environment (bioremediation) and is now commonly associated with environmentally friendly products that are capable of decomposing back into natural elements. Organic material can be degraded aerobically with oxygen, or anaerobically, without oxygen. Biosurfactant, an extracellular surfactant secreted by microorganisms, enhances the biodegradation process.

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. Some microorganisms have a 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, pesticides[2] and metals. Major methodological breakthroughs in microbial biodegradation have enabled detailed genomic, metagenomic, proteomic, bioinformatic and other high-throughput analyses of environmentally relevant microorganisms providing unprecedented insights into key biodegradative pathways and the ability of microorganisms to adapt to changing environmental conditions.[] The advent of nucleic acid-based stable isotope probing has made it possible to identify specific microorganisms responsible for biodegradation in within complex ecosystems.[3] Products that contain biodegradable matter and non-biodegradable matter are often marketed as biodegradable.

Monona Rossol wrote that "biodegradable substances break down into more than one set of chemicals, which are usually called primary and secondary degradation products. Any of these may be toxic."

Metrology

In nature, different materials biodegrade at different rates. To be able to work effectively, most microorganisms that assist the biodegradation need light, water and oxygen. Temperature is also an important factor in determining the rate of biodegradation. This is because microorganisms tend to reproduce faster in warmer conditions. The rate of degradation of many soluble organic compounds is limited by bioavailability when the compounds have a strong affinity for surfaces in the environment, and thus must be released to solution before organisms can degrade them.[] Biodegradation can be measured in a number of ways. Scientists often use respirometry tests for aerobic microbes. First one places a solid waste sample in a container with microorganisms and soil, and then aerate the mixture. Over the course of several days, microorganisms digest the sample bit by bit and produce carbon dioxide – the resulting amount of CO_2 serves as an indicator of degradation. Biodegradation can also be measured by anaerobic microbes and the amount of methane or alloy that they are able to produce. In formal scientific literature, the process is termed bio-remediation.[4]

Approximated time for compounds to biodegrade in a marine environment[5]

Product	Time to Biodegrade
Apple core	1–2 months
General paper	1–3 months
Paper towel	2–4 weeks
Cardboard box	2 months
Cotton cloth	5 months
Plastic coated milk carton	5 years
Wax coated milk carton	3 months
Tin cans	50–100 years
Aluminium cans	150–200 years
Glass bottles	Undetermined (forever)
Plastic bags	10–20 years
Soft plastic (bottle)	100 years
Hard plastic (bottle cap)	400 years

Plastics

Biodegradable plastic is plastic that has been treated to be easily broken down by microorganisms and return to nature. Many technologies exist today that allow for such treatment. Currently there are some synthetic polymers that can be broken down by microorganisms such as polycaprolactone, others are polyesters and aromatic-aliphatic esters, due to their ester bonds being susceptible to attack by water. Some examples of these are the natural poly-3-hydroxybutyrate, the renewably derived polylactic acid, and the synthetic polycaprolactone. Others are the cellulose-based cellulose acetate and celluloid (cellulose nitrate).

Under low oxygen conditions biodegradable plastics break down slower and with the production of methane, like other organic materials do. The breakdown process is accelerated in a dedicated compost heap. Starch-based plastics will degrade within two to four months in a home compost bin, while polylactic acid is largely undecomposed, requiring higher temperatures.[6] Polycaprolactone and polycaprolactone-starch composites decompose slower, but the starch content accelerates decomposition by leaving behind a porous, high surface area polycaprolactone. Nevertheless, it takes many months.[7]

Many plastic companies have gone so far even to say that their plastics are compostable, typically listing corn starch as an ingredient. However, these claims are questionable because the plastics industry operates under its own definition of compostable:

"that which is capable of undergoing biological decomposition in a compost site such that the material is not visually distinguishable and breaks down into carbon dioxide, water, inorganic compounds and biomass at a rate consistent with known compostable materials." (Ref: ASTM D 6002)[8]

Using this new definition, "carbon dioxide, water, inorganic compounds and biomass" encompasses every substance in the known universe, it makes no restriction on what the plastic leaves behind after it has biodegraded. So, while plastic manufacturers may legally be on solid ground, "compostable plastics" can not be said to be compostable in the traditional sense. However the word biodegradable does still apply.

Biodegradable technology

In 1973 it was proved for first time that polyester degrades when disposed in bioactive material such as soil. As a result, polyesters are water resistant and can be melted and shaped into sheets, bottles, and other products, making certain plastics now available as a biodegradable product. Following, Polyhydroxylalkanoates (PHAs) were produced directly from renewable resources by microbes. They are approximately 95% cellular bacteria and can be manipulated by genetic strategies. The composition and biodegradability of PHAs can be regulated by blending it with other natural polymers. In the 1980s the company ICI Zenecca commercialized PHAs under the name Biopol. It was used for the production of shampoo bottles and other cosmetic products. Consumer response was unusual. Consumers were willing to pay more for this product because it was natural and biodegradable, which had not occurred before.[9]

Now biodegradable technology is a highly developed market with applications in product packaging, production and medicine. Biodegradable technology is concerned with the manufacturing science of biodegradable materials. It imposes science based mechanisms of plant genetics into the processes of today. Scientists and manufacturing corporations can help impact climate change by developing a use of plant genetics that would mimic some present technologies. By looking to plants, such as biodegradable material harvested through photosynthesis, waste and toxins can be minimized.[10]

Oxo-biodegradable technology, which has further developed biodegradable plastics, also emerged. By creating products with very large polymer molecules of plastics, which contain only carbon and hydrogen, with oxygen in the air, the product is capable of decomposing anywhere from a week to one to two years.The chemical degradation process involves the reaction of very large polymer molecules of plastics, which contain only carbon and hydrogen, with oxygen in the air. This reaction occurs even without prodegradant additives but at a very slow rate. That is why conventional plastics, when discarded, persist for a long time in the environment. With this reaction, formulations catalyze and accelerate the biodegradation process.[11]

Biodegradable technology is especially utilized by the bio-medical community. Biodegradable polymers are classified into three groups: medical, ecological, and dual application, while in terms of origin they are divided into two groups: natural and synthetic.[12] The Clean Technology Group is exploiting the use of supercritical carbon dioxide, which under high pressure at room temperature is a solvent that can use biodegradable plastics to make polymer drug coatings. The polymer (meaning a material composed of molecules with repeating structural units that form a long chain) is used to encapsulate a drug prior to injection in the body and is based on lactic acid, a compound normally produced in the body, and is thus able to be excreted naturally. The coating is designed for controlled release over a period of time, reducing the number of injections required and maximizing the therapeutic benefit. Professor Steve Howdle states that biodegradable polymers are particularly attractive for use in drug delivery, as once introduced into the body they require no retrieval or further manipulation and are degraded into soluble, non-toxic by-products. Different polymers degrade at different rates within the body and therefore polymer selection can be tailored to achieve desired release rates.[13]

Other biomedical applications include the use of biodegradable, elastic shape-memory polymers. Biodegradable implant materials can now be used for minimally invasive surgical procedures through degradable thermoplastic polymers. These polymers are now able to change their shape with increase of temperature, causing shape memory capabilities as well as easily degradable sutures. As a result, implants can now fit through small incisions, doctors can easily perform complex deformations, and sutures and other material aides can naturally biodegrade after a completed surgery.[14]

Etymology of "biodegradable"

The first known use of the word in biological text was in 1961 when employed to describe the breakdown of material into the base components of carbon, hydrogen, and oxygen by microorganisms. Now biodegradable is commonly associated with environmentally friendly products that are part of the earth's innate cycle and capable of decomposing back into natural elements.

References

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[5] http://cmore.soest.hawaii.edu/cruises/super/biodegradation.htm [Mote Marine Laboratory, 1993]

[6] http://www3.imperial.ac.uk/pls/portallive/docs/1/33773706.PDF

[7] http://www.kyu.edu.tw/93/epaperv6/93-129.pdf Fig.9

[8] http://www.compostable.info/compostable.htm

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External links

- Biodegradation vs. Degradation (http://greenaircleaning.tumblr.com/post/22607370517/green-product-labels-biodegradable-degradable/)
- European Bioplastics Association (http://www.european-bioplastics.org/)
- The Science of Biodegradable Plastics: The Reality Behind Biodegradable Plastic Packaging Material (http://www.fpintl.com/resources/wp_biodegradable_plastics.htm)
- Biodegradable Polyesters for Medical and Ecological Applications (http://web.mit.edu/course/10/10.569/www/ikadaPEreview.pdf)
- Biodegradable Plastic Definition (http://www.biosphereplastic.com/uncategorized/what-is-biodegradation/)

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