Enzymatic Enhancing Additives

The Science Behind the Additive

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1. Recycling

Products in the waste stream which are recycled are often never recycled more than 1-2 times due to the lack of stable intrinsic viscosity(IV/Polyethylene Terephthalate) or molecular weight(MW/Olefins(which are PP, PE, LDPE, HDPE) Styrene, etc). Products like polyethylene terephthalate water bottles are recycled at an average of .7-.85 viscosity and after recycling these products reduce their IV to .40-.70 and are used in the manufacturing of synthetic fabrics for use in the textile industry such as activewear and t-shirts. Once those products are used they get discarded and are not recycled in the recycling stream as the IV levels are too low to be used again. This does propose the question;

What happens to the products that are made from recycled content?

Most of these products are thrown in landfills and the requirements for these materials are too great and can't be manufactured with biobased polymers such as corn. The biobased materials will not break down in landfill environments and often times are unable to break down in soil or marine environments.(Martin et al. observed no weight loss after 45 days in seawater[1], the California Department of Resources showed no disintegration of water bottles in marine water after one year at 25C[2]). These are a few examples of scientific testing which has been conducted on biobased polymers after disposal in normal or practical disposal methods that showed no evidence or little evidence of biodegradation.

Olefins and Styrene products are utilized greatly in single-use consumer products such as straws, cups, utensils, etc. These products are made with a myriad of plastic resins, these products if recycled are easily converted when the product itself has a molecular weight that is similar to virgin resins. The majority of plastic that isn't PET is not recycled. If olefins are recycled they also will only be recycled 1-2 times before the MW is considered to be unusable and then discarded into a landfill.

Black bags used in Colombia hold household food waste, packaging, coffee, plastic food delivery, or take out. These products are never recycled and often thrown into landfills.

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[1] https://www.researchgate.net/publication/264811234_Marine-degradable_polylactic_acid
[2] https://onlinelibrary.wiley.com/doi/full/10.1002/anie.201805766

White bags are for recycled products that are clean and dry, they hold plastic bottles and glass, paper, metal cans.

Additives that are treated with products that work as a catalyst with enzymes to break down the polymer chain do not change the IV level of the product if the additive from suppliers is manufactured correctly with IV levels of the materials at the same or similar IV levels. They can be recycled without interruption of the recycling chain as the polymer is not changed by changing the values of the IV or MW.

How to achieve this testing for PET and other resin types?

This can be achieved by taking a product after manufacturing and doing a simple test by grinding the finished product up into small pieces with an industrial grinder whether in granules or powder, dry the material and being placed into either an intrinsic viscosity measurement instrument or a molecular weight measurement instrument to validate the final MW or IV levels. high MW product or high IV will allow for further recycling of the final product.

2. Microbes That Produce Enzymes That Break Down Plastic

Microbes that consume plastic have been studied since the early 90's a list of the microbial consortium that consume plastic can be found in various articles and white papers. Some have been listed in this overview of additives that enhance biodegradation based on enzymatic action. Nuclear waste management conducted a series of tests that were for aerobic(with the presence of free oxygen) in 2012 for Styrene resin, they came to the conclusion that styrene resin could be broken down by microbial enzymes[3]. Various bacteria families have been shown to breakdown polyethylene, polypropylene and polyvinyl chloride[4]. Popular science released an article that

[3] https://iaac-aeic.gc.ca/050/documents/56647/56647E.pdf

[4] https://timesofindia.indiatimes.com/city/ahmedabad/Plastic-breaking-bacteria-need-field-test/articleshow/26118361.cms

shows many different polymer types can be consumed by microorganisms in various different environments[5]. Simply put microbes exist in the environment and breakdown plastic.

3. Metabolic Cycle

Aerobic respiration:

The Krebs citric acid cycle also known as the TCA cycle is the metabolic cycle of biodegradation aerobically or within the presence of free oxygen.

Anaerobic Respiration:

The respiration using electron acceptors other than molecular oxygen.

4. How Plastic With Enzymatic Enhancers Biodegrade Aerobically and Anaerobically.

Additives that are used to make plastic breakdown by enzymatic action interacting with the enhancers placed in the additives are different in formulation. Not all additives that work in breaking down plastic as an enhancer with enzymes are the same and they all perform differently. Some break down faster in other environments and may not break down different polymers the same or a mixture of polymers the same. That is why testing is crucial in vetting technologies. The current examples of how plastic is broken down by enzyme enhancing additives are spoken specifically to one additive only, it doesn't apply to every technology or claimed technology on the market. While they may have some various catalysts they don't work the same as each technology is different and performs differently.

Olefins such as LDPE, PP, HDPE etc:

are broken down by microorganisms by using biotic oxidation not to be confused with abiotic oxidation through chemical reactions and mechanical reactions that other technologies like oxo-degradable technologies, these work to reduce the polymer chain into smaller pieces through light, heat, mechanical stresses first and no microbial activity is enhanced, so particles and microplastics are around for decades or centuries, abiotic biodegradation occurs when enzymes

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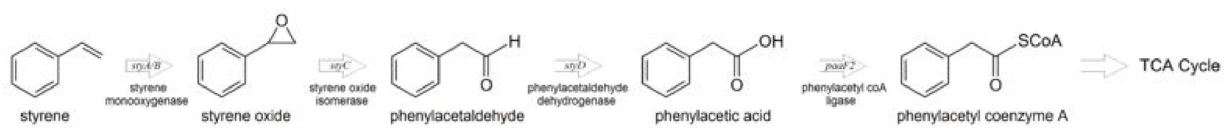
5 https://www.popsci.com/plastic-eating-bacteria/#:~:text=Ideonella%20sakaiensis%2C%20turns%20out%2C%20is,%2C%22%20says%20genetic%20engineer%20Johnson.

perform different actions from reducing functional groups or formation of ketone or aldehyde C=O groups to consume the polymer chain[6]. The additive enhances those features by varying degrees depending on the formulation of the finished product and what polymer types are in use. The biotic degradation of material is enhanced at a rapid rate using enzymatic biotic degradation.

Styrene:

is broken down by many different microorganisms through the following process[7].



Enzymatic degradation of the polymer chain is drastically increased when using additives that enhance the biodegradation of the polymer.

Polyethylene Terephthalate:

is broken down by enzymatic degradation by hydrolysis in a two step process: Enzymes bind to the substrate then catalyze a hydrolytic cleavage. Polymers are then degraded into lower weight oligomers, dimers and monomers converting to CH4, CO2 and H2O. All of these functions are greatly enhanced by enzymatic additives that work as a catalyst.

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[6] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4752946/

[7] https://microbewiki.kenyon.edu/index.php/Styrene_metabolism_in_bacteria#:~:text=Catabolic%20enzymes,-The%20upper%20pathway&text=StyA%20has%20styrene%20monooxygenase%20activity%20and%20converts%20styrene%20to%20styrene%20oxide.&text=The%20lower%20pathway%20of%20styrene,in%20the%20presence%20of%20styrene.

Multiple other polymers exist and have different avenues of biodegradation by microorganisms.

5. Test Methods

Test Method	Environment	Criteria
ASTM D7475	Landfill Accelerated - Three Different Temperatures	Anaerobic and Aerobic
ASTM D6691	Marine - Floating	Aerobic - Under 1.027 Density (PP,PS)
ASM D5526	Landfill Accelerated - Varying Temperatures	Anaerobic and Aerobic
ASTM D5511	Landfill - Single Temperature	Anaerobic and Aerobic
ASTM D5338	Industrial Compost - 60C	Aerobic
ASTM D5988	Soil	Aerobic
ASTM D5210	Sewage Sludge	Anaerobic
None Available	Marine	Anaerobic (PLA, PET, ETC)
OK Compost Home	Home Compost - 35C	Aerobic

*PP: Polypropylene
*PS: Polystyrene

6. Conclusion and Outlook

Enzymatic biodegradation of polymers exist in all environments where plastic is disposed of due to the plethora of microorganisms that break down different kinds of polymers such as Styrene, Olefins, PET and others. The additives used to enhance the biodegradation of these polymers react as an enhancing biotic mechanism alongside enzymes that are secreted by microorganisms to rapidly decompose the polymer for microbial consumption and transition to CO_2, CH_4, biomass and water, through the use of both anaerobic and aerobic respiration. The different test methods such as the ASTM D7475 show respiration of the aerobes, anaerobes or both to detect the amount of biodegradation occuring in environments that are usual disposal methods by consumers.

The listed test methods allow for manufacturers and government bodies to test various different environments where the final product would or may end up. Currently there is not a test method that is available for marine environments which are for plastic or biopolymers that ultimately sink in the ocean environment, the current test method ASTM D6691 only applies to polymers such as polypropylene and polystyrene, no listed biopolymers have a density that would float on the surface of water or salt water.

Home composting under the OK Compost test measurement is for composting in environments where consumers compost the final product within their own compost piles and not in a managed compost facility at 60C.

Consumers, Manufacturers and Government bodies can be confident in knowing that when they dispose of synthetic plastic or biopolymers in different environments that there will not be as great of an impact as the last 100 years on the planet.