Degradation, Residuals, Toxicity, and Safety of Degradable Plastic

The by-products of the biodegradation of compostable polymers have minimal environmental effect. The by-products of compostable plastics are water, CO_2, and a biomass similar to plant biomass. The biomass residue provides carbon and nitrogen amendments as it is absorbed by the soil.

Degradable plastics can break down into smaller particles if blended with an additive to facilitate degradation. However, oxodegradable plastic bags in compost environments can take several years to biodegrade, depending on the amount of sunlight and oxygen exposure. Polyethylene plastic bags produced with starch additives also partially degrade over time as microorganisms digest the starch, but leave the polyethylene intact.

Degradable plastics break down in one of two ways:

- **Disintegration** occurs when the plastic materials break up and are no longer visible, but the polymer still maintains a finite chain length.
- **Mineralization** occurs after the initial oxidation process and the polymer chains are metabolized by microorganisms into carbon dioxide, water, and biomass.

Oxodegradable polymers break down into small fragments over time but are not considered biodegradable, since they do not meet the degradation rate or the residual-free content specified in the ASTM D6400 standard. The plastics do disintegrate but leave small plastic fragments in the compost, which violates the ASTM D6400 standard.

Results From Similar Biodegradable Plastics Studies

Mater-Bi™ is a wholly compostable polymer based on a blend of at least 50 percent starch and a synthetic hydrophilic degradable polyester. The polymer was evaluated for suitability in disposal by composting. The results indicate that Mater-Bi is readily degradable in standard laboratory biodegradation tests, including a semi-continuous activated sludge (SCAS) test for simulating breakdown in municipal wastewater treatment plants and pilot composting systems. The degradation rate of Mater-Bi™ bags depends on the exact formulation used and the physical properties of the product. Toxicity tests undertaken with the Mater-Bi™ bags and composted products have shown that they are nontoxic in standard animal and plant tests.

Biological degradation of the aliphatic-aromatic copolyester, Ecoflex®, was investigated by evaluating the degree of degradation and the intermediates that are formed during the degradation process. No significant toxicological effects were observed, either for the monomeric intermediates or the oligomeric intermediates. The risk for Ecoflex in a composting process was assessed as minimal and indicates no environmental risk. More research is needed to assess the environmental risks and fate of intermediated products of other biodegradable plastics in composting environments.

Biodegradation

The research documented in this report is a continuation of a previous research study on the biodegradation of several compostable plastics that are commercially available in California. That research found that the selected compostable materials degrade under laboratory compostable conditions as specified in ASTM D6400.

The degradation and disintegration results at the university farm demonstrated that the compostable materials degrade in moist, manure-based compost in 90 days. The potato starch based tray, cornstarch based trash bag, PLA plate, PLA straw, and PLA container degraded at rates similar to the cellulose control.

The degradation and disintegration results at the municipal compost facility demonstrated that the compostable materials degrade in moist greenwaste compost. The PLA container, PLA cup, and PLA knife degraded at a rate similar to the Avicell cellulose control and degraded completely in seven weeks. The cornstarch-based trash bag and sugar cane plate degraded at a rate similar to the Kraft paper control. The three materials degraded 80-90 percent after 20 weeks.

The biodegradability of five different biodegradable garbage bags was analyzed according to the DIN-standard. The tests proved that a biodegradable polymer can be degraded under controlled composting conditions. The bags were made from cornstarch, polycaprolactone (PCL) and Kraft paper. PCL is a biodegradable polyester that is often used as an additive for resins to improve their processing characteristics while lowering cost and increasing biodegradability. The results demonstrated that all five plastic products decomposed to the European standards of 60 percent within six months. The bags were considered fully biodegradable since they degraded and disintegrated by breaking down into carbon dioxide and water, and left no toxic residue in the soil. The bags are not considered compostable since they were not tested for phytotoxicity.

Toxicity

Compostable materials must also not leave any toxic residues or chemicals that negatively affect the compost soil quality. The quality of the compost can be evaluated using analytical and biological criteria, including soil density, total dry solids, salt content, inorganic nutrients content, and eco-toxicological behavior. The inorganic nutrients evaluated in the compost are total nitrogen, phosphorous, magnesium or calcium, and ammonium-nitrogen. The eco-toxicological tests include determination of growth inhibition with tomato and radish plants.

Phytotoxicity testing on the finished compost that contains degraded polymers can determine if the buildup of inorganic materials from the plastics is harmful to plants and crops and if they slow down soil productivity. ASTM 6002 establishes the standards for phytotoxicity testing. The ASTM procedure determines phytotoxicity by blending the compost containing the compostable plastic material with compost soil. Plant emergence survival and growth are then evaluated. Three plant species are generally tested. The results from compost containing plastic material are compared to compost without plastic material and a soil control. The plant species can be tomato, cucumber, radish, rye, barley, or grass. Plant biomass tests can reveal quality differences between composts and can indicate potential plant stress induced by the compost at the level used in the test.

The PLA cup and container, sugar cane plate, and corn starch-based trash bag met the phytotoxicity requirements and supported growth of tomato seedlings after ten days. Soil samples from the compostable materials did not leave any toxic residue and had very little detectable heavy metals, i.e., lead and cadmium were 100 times lower than established limits.

Safety

A safety assessment of the biodegradable plastics is listed on each product's materials safety data sheet (MSDS). The MSDS for the Ecoflex plastic states that the hot plastic can cause thermal burns and that frequent or prolonged skin contact can cause irritation. However, the MSDS does not provide any data on human, plant, or aquatic toxicity. The overall health hazard for Ecoflex is listed as low.

The MSDS for the Novomont Mater-Bi biodegradable plastic states that there is no evidence of harmful effects to the eyes, skin, or lungs with the product. Furthermore, the MSDS states that the Novomont product is not harmful to health if handled correctly.

The MSDS for the PLA plastic states that contact with the PLA fibers may cause skin irritation, that PLA fibers may cause discomfort for individuals who experience bronchitis or asthma, and that PLA is not hazardous to skin absorption or inhalation. The overall health hazard for PLA is listed as low.

The health risks for Mirel PHA should also be low, though an MSDS is not available.

Sugar cane powder can cause respiratory irritation. The LD-50 for sugar cane in rats is 29,700 mg/kg, which translates into a lethal dosage for 50 percent of the rats that were given 29.7g of sugar cane per kg of rat.

Some aromatic aldehydes, ketones, quinones, metal complexes, and salts can activate photodegradation in plastics. However, caution should be observed since some of them might also contribute to the toxicity of the final product. Dithiocarbamates, for example, are skin irritants and responsible for long-term abnormal thyroid function. They are considered a probable carcinogen. Anthracene is a suspected endocrine disruptor, and a gastrointestinal and skin toxicant. Low molecular weight sensitizers might leach out of the plastics by diffusion and this therefore, would prevent their use in food packaging applications. Pyrene, which can be used as a sensitizer in degradable plastics, can cause health problems.

The overall health risks for UV-degradable plastics are minimal due to their LDPE basis and benign UV-additive. Oxodegradable plastics might cause some health risks due to the use of transitional metal complexes and salts. The oxodegradable additives are typically based on ionic Cobalt (II). Co (II) and its compounds may cause adverse effects to humans and the environment. It is classified as a possible human carcinogen and is very toxic to marine organisms.