Degradation, Residuals, and Toxicity of Degradable Plastic Packaging Food Service Products

Degradable products include three types of materials that degrade over time; one that degrades after exposure to sunlight, oxygen, or other degradation mechanism; one that biodegrades when exposed to micro organisms; and a third that completely biodegrades within 6 months when exposed to compost environment. The by-products of the biodegradation process of compostable polymers have very minimal environmental effects. The by-products of compostable plastics are water, CO_2, and biomass similar to plant biomass. The fate of the biomass residue is to provide carbon and nitrogen amendments to the soil as it is absorbed by the soil. Degradable plastics can break down into smaller particles if blended with an additive to facilitate degradation. However, the oxo-degradable plastic bags in compost environments can take several years to biodegrade depending on the amount of sunlight and oxygen exposure. Polyethylene plastic bags that are produced with starch additives also partially degrade over time as micro-organisms digests the starch, but leave the polyethylene intact. The breakdown of degradable plastics has been categorized into disintegration and mineralization. Disintegration occurs when the plastic materials disintegrate and are no longer visible, but the polymer still maintains a finite chain length. Mineralization occurs when the polymer chains are metabolized by micro organisms after the initial oxidation process to carbon dioxide, water, and biomass. Oxo-degradable 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 standards. The plastics do disintegrate but leave small plastic fragments in the compost, which violates the ASTM D6400 standards.

Biodegradable polymers are those that are capable of undergoing decomposition into carbon dioxide, methane, water, inorganic compounds or biomass by the actions of micro-organisms. Biodegradable polymers break down, but the degradation rate is not specified. Some biodegradable polymers degrade very quickly, while others can take much longer. Also, the way in which degradation is measured is not standardized for biodegradable polymers. Some biodegradable polymers break down more quickly in compost soil than in landfills or in marine environments.

Compostable polymers are those that are degradable under compositing conditions, which include actions of micro-organisms, i.e., bacteria, fungi, and algae, under a mineralization rate that is compatible with the composting process. Compostable polymers, though, must meet a set of clearly defined standards that define the rate of decomposition, residual levels, and by-products that can be measured in standardized tests. The compostable materials must degrade 90% in 180 days in a compost environment per ASTM D-6400. If the biodegradable plastic meets the biodegradation rate requirement then it is accepted as compostable. It also must support plant life and not have any toxic residual substances. This is similar to the European standards.

Also, compostable polymer products undergo degradation that leads to conversion of the polymer into carbon dioxide in aerobic conditions, carbon dioxide/methane in anaerobic conditions and water. Degradation can only occur when the polymer is exposed to micro-organisms found naturally in soil, sewage, river bottoms, and other similar environments.

This research is a continuation of a previous research study that studied biodegradation of several compostable plastics that are commercially available in California. The research found that the selected compostable materials degrade under laboratory compostable conditions as specified in

ASTM D6400. The PLA cup, container, sugar cane plate, and corn starch based trash bag met the phytotoxicity requirements and supported growth of tomato seedlings after 10-days. Soil samples from the compostable materials did not leave any toxic residue and had very little detectable heavy metals, 100 times lower than the Lead and Cadmium established limits. 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, corn-starch based trash bag, PLA plate, PLA straw, and PLA container degraded at similar rates as the cellulose control. The degradation and disintegration results at the municipal compost facility demonstrated that the compostable materials degrade in moist green-waste compost. The PLA container, PLA cup, and PLA knife degraded at a similar rate as the Avicell cellulose control and were degraded completely in 7-weeks. The cornstarch-based trash bag and sugar cane plate degraded at a similar rate as the Kraft paper control. The three materials degraded between 80 and 90% 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 and Kraft paper. Polycaprolactone (PCL) is a biodegradable polyester that is often used as an additive for resins to improve their processing characteristics as well as lowering cost and increase biodegradability. The results demonstrated that all five plastic products decomposed to the European standards of 60% within six months. The bags were considered fully biodegradble 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.

Mater-Bi™ is a wholly compostable polymer based on a blend of at least 50% starch with the remaining 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 semi-continuous activated sludge (SCAS) test for simulating breakdown in municipal waste-water treatment plants and pilot composting systems. The degradation rate of Mater-Bi™ bags depends on the exact formulation used and physical properties of the product. Toxicity tests undertaken with the Mater-Bi™ bags and composted products have shown that they are non-toxic in the standard animal and plant tests.

Biological degradation of 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, neither for the monomeric intermediates nor the oligomeric intermediates. The risk assessment of the Ecoflex in a composting process is very minimal and results in no indication of environmental risk. More research is needed to asses the environmental risks and fate of intermediated products of other biodegradable plastics in composting environments.

The 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 for analytical and biological criteria, including soil density, total dry solids, salt content, inorganic nutrients content, and eco-toxicological behaviour. The inorganic nutrients evaluated in the compost are total nitrogen, phosphorous, magnesium or calcium, and ammonium-nitrogen. The eco-toxicological tests can include determination of growth inhibition with tomato and radish plants. The poisonous effects on plants are referred to as “Phytotoxicity”. Plant 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. The plant emergence survival and growth are evaluated. Three plant species are generally tested. The results from compost containing material are compared to compost without 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 given level used in the test.

Safety assessment of the biodegradable plastics are listed on the materials safety data sheets (MSDS) for each. The MSDS for the Ecoflex plastic states that the hot plastic can cause thermal burns, frequent or prolonged skin contact can cause irritation. However, the MSDS does not provide any data on human or 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. Fibers may causes discomfort for individuals who experience bronchitis or asthma. 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 MSDS are not available. Sugar cane powder can cause respiratory irritation. The LD-50 for sugar can in rats is 29,700 mg/kg, which translates into a lethal dosage of 50% of the rats that were given 29.7g of sugar cane per kg of rat. Di-thiocarbamates are skin irritants and responsible for long-term abnormal thyroid function. They are considered a probable carcinogen. Anthracene is a suspected endocrine disruptor, gastrointestinal and skin toxicant. Low molecular weight sensitizers might leach out of the plastics by diffusion and 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 it 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 very toxic to marine organisms.

Current Standards for Biodegradable Plastics

Several worldwide organizations are involved in setting standards for biodegradable and compostable plastics, including, American Society for Testing and Materials (ASTM), European Committee for Standardization (CEN), International Standards Organization (ISO), German Institute for Standardization (DIN), Japanese Institute for Standardization (JIS), and British Plastics Federation. The standards from these organizations have helped the industry create biodegradable and compostable products that meet the increasing worldwide demand for more environmentally friendly plastics. The German, United States and Japanese certification schemes are cooperating to enable international cross-certification of products