PENNSTATE

College of Agricultural Sciences Cooperative Extension

Agricultural and Biological Engineering

C-17

The Chemical Composition of Degradable Plastics

James W. Garthe, Instructor of Agricultural Engineering
Paula D. Kowal, Research Technician

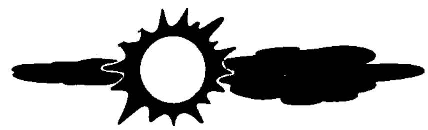
As the public gains a more realistic view of the capabilities of degradable plastics, they are discovering these materials may be very useful for single-use items that are difficult to recycle or recover. One target market for degradable plastics has been agriculture. Not only are degradable products being used by agriculture, but certain types of degradables are being manufactured from agricultural commodities such as cornstarch and dairy products. The influence of degradable plastics on agriculture has made it increasingly important for industry and educators to be aware of new developments in these materials.

Degradable Plastics

Unlike "normal" plastics, which degrade very slowly, degradables are manufactured to accelerate decomposition. This acceleration is accomplished by gradually reducing the toughness of the plastic material. This toughness is caused by small subunits of hydrogen and carbon, called **monomers**. Monomers form long chains, called **polymers**, which break down and disintegrate into natural by-products such as carbon, hydrogen, and oxygen. Basically, there are two methods through which this breakdown of the chain occurs: **photodegradation** and **biodegradation**. Because biodegradable starch-based polymers are fairly well-developed and well-known, they are often considered as a category by themselves.

Photodegradable Polymers

The breakdown of photodegradable plastics depends on irregularities in the polymers. These irregularities cause *all* plastics to slowly degrade when exposed to ultraviolet (UV) light, typically sunlight. In photodegradable plastics, the rate of degradation is increased by adding photosensitive substances, called **promoters**, to the plastic material. Two common promoters are carbonyl groups (carbon double bonded to oxygen) and metal complexes (metals blended with many ingredients).



Carbonyl Group: Ketone Carbonyl Copolymers

This type of photodegradable plastic is produced by adding a carbonyl group, vinyl ketone comonomer, to the polymers of plastics such as polyethylene (PE) and polystyrene (PS). The resulting copolymer degrades when the carbonyl group absorbs sunlight. Similar to most photodegradable plastics, the final degradation requires the material to be consumed by microorganisms, which is actually a biodegradable process. Because these products require direct sunlight in order to degrade, this material is ideal for mulch film and products that usually end up as litter.

Carbonyl Group: Carbon Monoxide Copolymers

In this material, the carbonyl group carbon monoxide is added to produce a degradable copolymer, called carbon monoxide copolymers. Manufacturers of this material—including Dow Chemical, DuPont, and Union Carbide—claim that carbon monoxide copolymers are able to degrade into benign by-products. However, questions remain about the extent of degradation. More research needs to be done to determine whether carbon monoxide products completely degrade into non-plastic products or whether they simply disintegrate into smaller pieces of plastic.

Metal Complexes

A new approach to photodegradable plastics is adding metal salts to initiate the breakdown process.

The main difference between plastics containing metal salts and other photodegradable materials is its ability to break down in the absence of light. In fact, if they receive enough UV light before burial, these products may even be able to degrade in landfills. Products being made from metal complexes include mulch films and tree shelters. Currently, the main concern with this material is the heavy toxic metal residues remaining after degradation takes place; however, experiments have shown negligible effects of these metals on plant growth.

Biodegradable Polymers

The term "biodegradable" is often mistakenly used to describe all degradable plastics, even though this term actually refers only to materials that are consumed by microorganisms such as bacteria, fungi, and algae. These microorganisms break down the polymer chain and consume the material through several methods. Biodegradable plastics can be either hydrolyzable (able to change chemically in water) or water-soluble (able to dissolve in water). Some common biodegradable plastics are polyesters, polyhydroxybutyrates, and vinyl polymers. An in-depth description of these biodegradable plastics is listed in Table 1.

Starch-Based Polymers

Because the oil embargo in the early 1970s caused the price of plastics to almost double, researchers began to look for a less expensive, non-plastic filler. The result of their search was starch-based polymers. Since that time, starch-based polymers have remained the most commonly used and lowest-costing ingredient of all biodegradable polymers.

The natural polymer starch significantly determines the degradability of these plastics. This starch can be derived from many agricultural commodities, including

Table 1: Types of biodegradable plastics.

Plastic Type	Name	Abbreviation	Description	Uses
Polyesters	Polyglycolic acid	PGA	Hydrolyzable polyhydroxy acid	Specialized applications; controlled drug releases; implantable composites; bone fixation parts
	Polylactic acid	PLA	Hydrolyzable polyhydroxy acid; polymers derived from fermenting crops and dairy products; compostable	Packaging and paper coatings; other possible markets include sustained release systems for pesticides and fertilizers, mulch films, and compost bags
	Polycaprolactone	PCL	Hydrolyzable; low softening and melting points; compostable; long time to degrade	Long term items; mulch and other agricultural films; fibers containing herbicides to control aquatic weeds; seedling containers; slow release systems for drugs
	Polyhydroxybutyrate	PHB	Hydrolyzable; produced as storage material by microorganisms; possibly degrades in aerobic and anaerobic conditions; stiff; brittle; poor solvent resistance	*
	Polyhydroxyvalerate	PHBV	Hydrolyzable copolymer; processed similar to PHB; contains a substance to increase degradability, melting point, and toughness; compostable; low volume and costly production	Films and paper coatings; other possible markets include biomedical applications, therapeutic delivery of worm medicine for cattle, and sustained release systems for pharmaceutical drugs and insecticides
Vinyl	Polyvinyl alcohol	PVOH	Water soluble; dissolves during composting	Packaging and bagging applications which dissolve in water to release products such as laundry detergent, pesticides, and hospital washables
	Polyvinyl acetate	PVAC	Water soluble; predecessor to PVOH; has shown no significant property loss during composting tests	*
	Polyenlketone	PEK	Water soluble; derived from PVOH; possibly degrades in aerobic and anaerobic conditions	*

**Information not available*

corn, potatoes, and rice. Although all of these starches are easily digested by microorganisms, each individual type of starch will result in different plastic thicknesses in the final product.

There are three methods to manufacture starch-based materials:
- surface-modified starch additive
- gelatinized starch additive, and
- thermoplastic starch materials.

Surface-Modified Starch Additive

In this material, starch is treated with a small amount of an unsaturated fat or a fatty acid oxidizing agent, such as vegetable oil. An agent is added to the mixture to improve its compatibility with the polymer. The resulting material can be molded by conventional methods, such as film blowing, injection molding, and blow molding. The time and extent of degradation depends greatly on the type of polymer, thickness of the material, and environmental conditions.

Gelatinized Starch Additive

To help increase the amount of starch-based products, the US Department of Agriculture has developed a process using gelatinized starch, both in films of polyethylene coacrylic acid (EAA) and in a mixture of EAA and low density polyethylene. The material is prepared by premixing 40 to 60 percent starch with EAA and water. Adding EAA is necessary to make this large amount of starch compatible with the polyethylene. Because the resulting material is transparent and flexible, it may be used for mulching applications.

Thermoplastic Starch Materials

Recently, materials have been developed to contain 70-100 percent starch as the base for the polymer. Not only do these materials use a large amount of starch, but their water-solubility is greatly increased. In addition, these materials are very easily consumed by microorganisms. Possible markets include mulch films, bags for animal feed and fertilizer, and products that will end up in waterways or wastewater treatment facilities.

Conclusion

The general public typically believes that all degradable plastics are created equal. However, there are many different types of degradable plastics with many different properties and capabilities. As these degradable plastics evolve rapidly in both technological and commercial availability, their growth promises to have a significant impact on the agricultural industry.

Economics and Starch-Based Plastics

Many people hope that the increase in the production and use of starch-based plastics will provide significant benefits to the agricultural industry. For example, it has been projected that corn starch degradable plastics could eventually consume between 150-300 million bushels of corn each year, approximately two to four bushels for every harvested acre. As most of us know, an increase in demand can also mean an increase in price and profit.

However, these financial benefits have not been realized. What has prevented any notable increase in profit? One factor is the small amount of starch—usually six percent—currently being used in most degradable plastics. Unless the amount of starch increases dramatically, the effect on demand and price will be low. Also, starch-based plastics, which are relatively inexpensive compared to other degradable plastics, still cost about 10 percent more than non-degradable plastics. For agriculture, this means that starch-based plastics will have difficulty competing financially with non-degradable plastics. Therefore, before any substantial economic benefits are realized, the price of degradable plastics must decrease. Another possiblity is the introduction of legislation to mandate increased use of degradable plastics in certain products. There are concerns, however, that this action would inhibit free-market forces from working properly.

PSU 6/94

For a copy of our Fact Sheet Index contact:
Agricultural and Biological Engineering Extension
246 Agricultural Engineering Bldg.
University Park, PA 16802-1909
Telephone 814/865-7685 FAX 814/863-1031