

# **Technical Report**

# BIODEGRADABLE POLYMERS: A REVIEW

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#### **Executive Summary**

The commodity polymers with which we are most familiar were developed to provide durability and resistance to various forms of degradation including photo degradation (the effects of sunlight) as well as the attack of fungi and microbial agents.

During the decade of the 80's and into the 1990's the so-called "landfill crisis" spawned the notion that the "crisis" would be mitigated if more materials entering the landfills could be made to degrade and thereby relinquish the space they once occupied. This notion was ill founded.

Anticipating a market opportunity a number of companies, in North America and elsewhere, developed materials that were purported to degrade by photo or biological means. Most of these products were compounded versions of conventional resins. A number of municipalities in Canada and the United States tried some of these products as collection bags in their new municipal composting programmes but failed to realize the benefits anticipated.

Since the time of the first forays into the market biodegradable plastics have matured greatly. New polymers offering properties, one of which is true susceptibility to microbial attack, have entered the marketplace. In addition standards have been developed which assess the propensity of a material to degrade biologically. Biodegradable products are no longer pitched at eliminating landfill issues but rather are targeted to specific applications such as the collection of leaf and yard waste destined to composting operations. In this end use a truly compostable bag, compatible with the operation may afford economic benefit and/or improved quality of finished compost.

In July 2000 the US Composting Council and the Biodegradable Products Institute announced a labeling (certification) programme based on the ASTM Standard D 6400-99 for materials suitable for composting applications.

The following report reviews the now accepted definitions for Biodegradable and Compostable Plastics and the standards used to characterize the materials. Included in the report is a description of the chemistry of the manufacture of biodegradable plastics.

Biodegradable and compostable plastics are not a panacea for issues surrounding the management or waste nor are they universal substitutes for the common resins of commerce.

The products have been demonstrated to be capable of being processed by most conventional plastics processing techniques. The key factor in the marketing of them is a demonstrated "value in use" in the application being considered. In addition the use of the products demands a life cycle assessment to determine if there are true environmental benefits to be derived from them.

Sellers of biodegradable plastics should be capable of supporting their claims through conformance with a certification, labeling programme or be willing to provide information indicating that their products meet recognized standards or be willing to demonstrate through field testing that their products will meet the buyer's expectations.

Buyers of biodegradable, compostable plastics should seek evidence that the product being offered has been certified or meets recognized standards or degrades in his specific conditions in a manner that meets his needs.

# **BIODEGRADABLE POLYMERS: A REVIEW**

#### 1.0 Introduction

The commodity polymers with which we are most familiar were developed to provide durability and resistance to various forms of degradation including photo degradation (the effects of sunlight) as well as the attack of fungi and microbial agents. Materials such as the polyolefines performed their function well and displaced other less resistant materials such as "Cellophane" with the result that they are now ubiquitous in our society.

During the decade of the 80's and into the 1990's the so called "landfill crisis" in many parts of the developed world including North America spawned the notion that the "crisis" could be mitigated if more materials entering the landfills could be made to degrade and thereby relinquish the space they once occupied. This notion was ill founded and failed to account for the characteristics of a modern sanitary landfill. In addition since it was focussed solely on space it never considered the products of degradation and their environmental footprint. None the less the matter left products manufactured from plastics carrying the label that they were not biodegradable.

Anticipating a market opportunity a number of companies, in North America and elsewhere, developed materials that were purported to degrade by photo or biological means. Most of these products were compounded versions of conventional resins, some of which disintegrated over time into small pieces, but failed to exhibit the characteristics of biological degradation which result in the total mineralization of the substance into carbon dioxide or methane, water and humic residues. A number of municipalities in Canada and the United States tried some of these products as collection bags in their new municipal composting programmes but failed to realize the benefits anticipated. In most instances the bags neither composted nor disintegrated in the required time span. As a result the so-called biodegradeable materials received a bad press from which it has been difficult to recover.

Since the time of the first forays into the market biodegradable plastics have matured greatly. New polymers offering properties, one of which is true susceptibility to microbial attack, have entered the marketplace. In addition standards have been developed which assess the propensity of a material to degrade biologically. Biodegradable products are no longer pitched at eliminating land fill issues but rather are targeted to specific applications such as the collection of leaf and yard waste destined to composting operations. In this end use a truly compostable bag, compatible with the operation, affords substantial economic benefit and/or improved quality of finished compost.

In July 2000 the US Composting Council and the Biodegradable Products Institute announced a labeling (certification) programme based on the ASTM Standard D 6400-99 for materials suitable for composting applications.

In the light of the progress which has been made it is probably an opportune moment to review once again the subject of degradable plastics.

#### 1.1 Definitions

- 1.1.1 Biodegradable Plastic a degradable plastic in which the degradation results from the action of naturally occurring microorganisms such as bacteria, fungi and algae. (ASTM D 6400-99)
- 1.1.2 Compostable Plastic a plastic that undergoes degradation by biological processes during composting to yield CO<sub>2</sub>, water, inorganic compounds and biomass at a rate consistent with other compostable materials and leaves no visible, distinguishable or toxic residue. (ASTM D 6400-99)

Several other definitions are useful in understanding the complexity of claims made regarding specific materials. The definitions given below have been taken from the journal "Biocycle" March 1998 which has based its report on work done at ASTM and CEN (Europe).

- 1.1.3 Degradable "A material is called degradable with respect to specific environmental conditions if it undergoes a degradation to a specific extent within a given time measured by specific standard test methods."
- 1.1.4 Degradation ... "an irreversible process leading to a significant change of the structure of a material, typically characterized by a loss of properties (eg. integrity, molecular weight, structure or mechanical strength) and/or fragmentation. Degradation is affected by environmental conditions and proceeds over a period of time comprising one or more steps."
- 1.1.5 Disintegration "The falling apart into very small fragments of packaging or packaging material caused by degradation mechanisms."

The latter definitions are broader in scope than the definitions that invoke biological activity (1.1.1 and 1.1.2). In addition the definition of a compostable plastic relates the degradation of the plastic to the time frame of other biological activities. The subtle differences inherent in the various definitions are extremely important when making claims regarding products.

For a material to receive the new logo of the US Composting Council it must meet all of the requirements of ASTM D 6400-99.

The necessity of fulfilling all of the steps and requirements of the ASTM Standard has led to a continuing debate between promoters of some specific products and the standards community. Some materials are claimed to exhibit mechanisms of initial degradation which are not biological in nature (eg. chemical oxidation). However to be classed as a compostable plastic, meeting the time constraint in Definition 1.1.2 is of paramount importance and must be demonstrated.

# 2.0 The Chemistry of Biodegradable Polymers.

Any discussion of the chemistry of biodegradable polymers will inevitably invoke a discussion of natural and synthetic polymers as well as a discussion of polymers derived from renewable and non-renewable resources. In order to put these matters to rest immediately it should be noted that biodegradable polymers may be naturally occurring or they may be synthesized by chemical means. In addition the feedstocks used to produce the polymers may come from the processing of crops grown for the purpose or the by products of other crops (so called renewable resources) or they may come from petro-chemical feedstocks (so called non-renewable resources). Whether renewable sources of feedstocks are better than non-renewable sources is a judgment that cannot be made without carrying out an environmental impact analysis on each source. For example; the growing of agricultural crops may involve the application of fertilizers, herbicides and pesticides which may leave a deep environmental footprint. Unless appropriate soil management practices are in place the soils risk severe depletion of nutrients, microorganisms etc. In addition chemical or biochemical processes usually are required to extract and purify the polymer. These processes may require water, energy and chemical or biological additives. They also produce wastes which require treatment and disposal.

#### 2.1 Naturally Occurring Polymers

The history of man is strongly linked to a wide variety of naturally occurring polymers. For most of this history the fact that these substances were polymers was not known. In many quarters this ignorance persists. The natural polymers fall into four broad groups:

- Polysaccharides Starch, Cellulose
- Proteins

Gelatin, Casein, Silk, Wool

Polyesters

Polyhydroxyalkanoates

Others

Lignin, Shellac, Natural Rubber

It cannot be automatically assumed that natural polymers, "are beautiful for environmental degradation". (E. Chiellini, U.of Pisa) The rate of degradation and the formation of the ultimate metabolites depend very much on the structural complexity of the material and the environmental conditions selected for the degradation trial.

# 2.2 Synthesized Biodegradable Polymers.

There are many polymers produced from feedstocks derived from petrochemical or biological resources that are biodegradable. Many of these have been around for some time either as curiosities or materials of commerce filling very special market niches as for example "dissolving" suture material used in the medical field. Others such as certain biopolyesters attempted for many years to compete against the standard commodity resins but failed to make significant market advances due to their high prices.

The introduction of new materials, unless niche oriented, is generally caught in the volume, price conundrum. High sales volumes are not achievable because of high prices, but in order to reduce price costs must be reduced through the benefits that accrue from high volumes of production.

In more recent times several sizable niche markets have opened for biodegradable plastics eg. bags for municipal composting. In addition the potential value of wastes from industries such as sugar refining as feedstocks has been recognized. The drive for sustainable development has promoted interest in the development of chemicals derived from the farming of particular crops among a number of large multi-national corporations. As a result the capital resources, marketing expertise and capability in research and development are coming together to lay the foundation of a new industry.

As previously stated there are a number of biodegradable synthetic resins. The list includes:

- Polyalkylene esters
- Polylactic acid and its copolymers
- Polyamide esters
- Polyvinyl esters
- Polyvinyl alcohol
- Polyanhydrides

Each of these has its particular properties and potential applications. Polyvinyl alcohol is widely used because of its solubility in water. Polylactic acid is growing in terms of production volume and applications. All of the materials in the list have been found to exhibit degradation promoted by microorganisms often coupled to chemical and/or mechanical degradation.

#### 2.3 Additives.

Most conventional plastics contain additives to facilitate their processing and to enhance the physical characteristics of the products manufactured from them. This is also true for the biodegradable materials appearing in the market. Plasticizers, antioxidants, pigments and stabilizers are all found in the "new" materials.

One of the requirements of the ASTM definition of Compostable Plastic is that it leaves "no visible, distinguishable or toxic residue" after degradation. The ASTM Standard specifies certain tests to determine conformance.

The requirements related to residues means that it is the product in its final form that must conform. The fact that a resin conforms in all respects is not adequate if, in the production of a product, additives are incorporated.

# 2.4 Applications

Biodegradable polymers have been demonstrated to be capable of being processed by most conventional plastics processing techniques. This is not to say that modifications of machinery and adjustment of processing conditions are unnecessary. Products may be formed by film extrusion, injection moulding, blow moulding, thermoforming etc. As a result a myriad of products is potentially available. The key factor in the marketing of them is a demonstrated "value in use" in the application being considered. The current relatively high prices of truly biodegradable, compostable materials will, at least for the time being, discourage their "frivolous use".

As previously stated biodegradable and compostable plastics are not a panacea for the issues surrounding the management of waste. Indeed, they are not universal substitutes for the common resins of commerce. As pointed out in section 2.0, "The Chemistry of Biodegradable Polymers", these materials may be derived from the processing of crops or from petro-chemical feedstocks. Neither of these sources of raw materials is environmentally benign and the environmental impact associated with them can only be ascertained by carrying out a life cycle assessment.

In a similar vein the use of the products also demands an environmental assessment. Even in a simple application such as a bag for the conveying of garbage to landfill and the depositing of the bag in the landfill the determination of whether a conventional plastic bag or a biodegradable bag has a lower impact requires an analysis. A conventional bag in a landfill is essentially inert while a biodegradable bag will over the active life of the landfill decompose into carbon dioxide (CO<sub>2</sub>) and methane (CH<sub>4</sub>), both of which are greenhouse gases.

No one anticipates that biodegradable materials or polymers derived from 'fenewable resources' will displace over the short term the familiar commodity materials derived from petrochemical sources. As previously stated the applications for these materials will be driven by special needs either tangible or philosophical that justify their use.

#### 3.0 Standards.

In the early 90's, as mentioned earlier, a number of products, most notably starch filled polyethylene, were introduced to the market with claims of biodegradability. The U.S. Federal Trade Commission, some states attorneys general, state legislators and indeed the

U.S. Congress became very concerned over some of the claims that were being made. In Canada, several Provinces, notably Quebec, also expressed concern. Over a two year period in the United States 48 separate legal actions were initiated for misleading environmental advertising. The highest number of actions, were on claims of biodegradable plastics and the use of the terms biodegradable and recyclable.

It became increasingly clear that standard test methods were needed to establish and quantify the degradability of polymers, and to confirm the benign nature of the products of breakdown. As a result ASTM Committee D-20 on Plastics commenced the development of standards in the area of degradable plastics.

The ASTM work effectively culminated in 1999 with the publication of;

# ASTM D 6400-99 "Standard Specification for Compostable Plastics".

The "Scope" of this document states that it "covers plastics and products made from plastics that are designed to be composted in municipal and industrial aerobic composting facilities." In addition the specification "is intended to establish the requirements for labeling of materials and products, including packaging made from plastics, as "compostable in municipal and industrial composting facilities"." A further statement in the scope mentions that "the properties in this specification are those required to determine if plastics and products made from plastics will compost satisfactorily, including biodegrading at a rate comparable to known compostable materials. Further, the properties in the specification are required to assure that the degradation of these materials will not diminish the value or utility of the compost resulting from the composting process."

**ASTM D 6400-99** references a number of other ASTM documents including several test methods:

D 6002-96 Guide for Assessing the Compostability of Environmentally Degradadable Plastics.

D 5338-98 Test Method for Determining Aerobic Biodegradation of Plastic Materials Under Controlled Composting Conditions.

D 6340-98 Test Methods for Determining Aerobic Biodegradation of Radiolabeled Plastic Materials in an Aqueous or Compost Environment.

ASTM Publications are available from;
ASTM
100 Barr Harbor Drive
West Conshohocken, PA 19428-2959

In order to use the logo of the US Composting Council and the Biodegradable Products Institute a product must meet the criteria of ASTM D 6400-99.

Although it is anticipated that the ASTM Standards will be the most widely referenced standards in North America standards have also been developed in Europe.

CEN/TC 261/SC 4 N 99 Packaging – Requirements for Packaging Recoverable through Composting and Biodegradation – Test Scheme and Evaluation Criteria for Final Acceptance of Packaging.

ISO 14855 Evaluation of the Ultimate Aerobic Biodegration and Disintegration of Plastics under Controlled Composting Conditions – Method by Analysis of Evolved Carbon Dioxide.

These Standards may be obtained from the Standards Council of Canada, Ottawa Ontario.

With the advent of published standards, test methods and protocols anyone making claims regarding the biodegradation or compostable nature of plastics would be well advised to substantiate these claims by showing conformance with the standards. The only other method might be a full-scale demonstration for a potential user of the products. This demonstration, if successful, may only be applicable to the particular user and his unique systems.

#### 4.0 Commercial Products.

Biodegradable and compostable plastics are available on the market from many sources. The March 1998 number of the journal "Biocycle" listed resin products and their trademarks from sixteen different companies which ranged in size from relatively small enterprises to the multinationals such as Bayer, Dow Cargill, DuPont, Monsanto and Eastman. The same article also lists manufacturers of bags produced from the resins.

It is beyond the scope of this review to recommend any product to any potential buyer. Any one interested in sourcing a product for an application will find many by carrying out an inter-net search using the terms "biodegradable plastics" or "compostable plastics".

Sellers of biodegradable plastics should be capable of supporting their claims through conformance with a certification, labeling programme or be willing to provide information indicating that their products meet recognized standards or be willing to demonstrate through field testing that their products will meet the buyer's expectations.

Buyers of biodegradable, compostable plastics should seek evidence that the product being offered has been certified or meets recognized standards or degrades in his specific conditions in a manner that meets his needs.

#### 5.0 Conclusions.

There are many polymers produced from feedstocks derived from petrochemical or biological resources that may be demonstrated to be biodegradeable using standardized test methods.

ASTM Standard D 6400-99 sets a "Standard Specification for Compostable Plastics" which is used by the US Composting Council and the Biodegradable Products Institute as the principal criterion which must be achieved in order to use their logo defining a compostable plastic product.

Biodegradeable plastic products are, at present, more expensive than products manufactured from commodity resins and hence their application and acceptance is based on demonstrated "value in use". In addition the user is advised to carry out where-ever possible a life cycle assessment of the product and its application in order to assure that the product provides true environmental benefit and not simply convenience.

Sources of products may be readily determined by an inter-net search using "biodegradable plastics" or "compostable plastics" as key words.

Nov. 24, 2000