Bio-degradable Plastics-
Impact on Environment

CENTRAL POLLUTION CONTROL BOARD
MINISTRY OF ENVIRONMENT & FORESTS
GOVERNMENT OF INDIA
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Foreword

The biodegradable polymers could be an alternative to the conventional plastic materials. These polymers being biodegradable can be disposed in safe and ecologically sound manner, through disposal processes (waste management) like composting, soil application, and biological wastewater treatment. Considering the necessity to assess the degradation pattern of these polymers, Central Pollution Control Board (CPCB) sponsored a study to Central Institute of Plastics and Engineering and Technology (CIPET), Chennai for identification and evaluation of performance of biodegradable polymers in India with reference to its biodegradability under laboratory scale composting conditions as per ASTM D-6400 and IS/ISO 17088:2008. In this document, effort has been made to compile the status of availability of biodegradable polymer materials as well as testing methods for establishing biodegradability of plastics films/products and its impact on environment.

The information in this document has been compiled and collated by the officials of CIPET Chennai, I would like to offer my sincere thanks to the Director General, CIPET and Project Coordinator Sh R. K. Dwivedi, Chief Manager for his valued contribution and supervision during the study. I would also like to thank my colleagues Dr. S.K. Nigam, Senior Scientist for overall supervision and coordination with CIPET team and Dr. A.B. Akolkar, Addl. Director, Shri J.S. Kamyotra, Member Secretary, Shri J.M. Mauskar, former Chairman, CPCB and Additional Secretary, MoEF and Dr. B. Sengupta, former Member Secretary, CPCB for their guidance and timely completion of studies.

I hope this document will be useful to regulatory authorities like State Pollution Control Boards, Local Bodies and manufacturers of biodegradable films.

(Prof. S.P.Gautam)

CONTENTS

EXECUTIVE SUMMARY

The new environmental regulations, societal concerns and growing environmental awareness have triggered the search for new products and processes that are compatible with the environment. In the past few years, authorities & the public have been strongly attracted to the concept and perceived environmental advantages of biodegradable and/or renewable resource based plastics. Keeping in view of the above a field survey-cum-study on **"Establishment & Impact of Biodegradable Plastics on Environment/Food" sponsored by CPCB, New Delhi** was conducted by Central Institute of Plastics Engineering & Technology (CIPET) Chennai, an Institution under the aegis of Department of Chemicals & Petrochemicals, Govt. of India. During the study, samples such as poly-bags, master batches/additives were collected from followings manufactures:

- M/s Harita NTI
- M/s Earth Soul India Ltd.
- M/s Nature Tec
- M/s Surya Polymers
- M/s Symphony Polymers
- M/s Green Craft Polymers
- M/s Overseas Polymers
- M/s Sachdeva Plastics
- M/s Arrow Coated Products
- Samples from various Hotels/Restaurants/Hospitals in & around Delhi.

The samples collected from the aforementioned sources were tested for the Biodegradability in accordance with ASTMD specifications; ASTM D-5338: Standard Test Method for determining the Aerobic Biodegradation of plastic Materials under controlled composting conditions, ASTM D-6400: Specifications for Compostable Plastics. The samples were tested for a period of 45 days and the percentage of CO_2 released with time in days was calculated as percentage biodegradation. The master batches were also tested for toxicological tests.

FINDINGS:

As per the ASTM D-5338 specifications 60 to 67 % biodegradation was obtained from few samples collected from M/s Harita NTI, M/s Earth Soul India, M/s Arrow Coated Products & M/s Nature Tec (Part of NTI), thus confirming to the requirement of a biodegradable/ compostable plastic. However, the percentage of degradation of the remaining samples was noted to be within 4 to 41% as compared with 100% biodegradable plastic i.e cellulose as per ASTM D-5338 for duration of 45 days**.** The minimum percentage of biodegradation of a product made from a single polymer should be minimum 60% in 45 days span. Briefly summarizing, degradable plastics may be either (a) photodegradable or oxo-degradable plastics which disintegrate into small pieces when exposed to sunlight/oxygen; (b) Semi-biodegradable; blends of starch and polyethylene or (c) 100% biodegradable; refers only to those materials which are consumed by microorganisms such as bacteria, fungi, and algae. These microorganisms break down the polymer chain which is ultimately converted to biomass.

However, sustainability requires that a degradable material breaks down completely by natural processes so that the basic building blocks can be used again by nature to make a new life form. Plastics made from petrochemicals are not a product of nature and cannot be broken down by natural processes. Also, there is no data presented to document complete biodegradability within the one growing season/one year time period. It is assumed that the breakdown products will eventually biodegrade. In the meanwhile, these degraded, hydrophobic, high surface area plastic residues migrate into the water table and other compartments of the ecosystem causing irreparable harm to the environment. In a recent Science article (Science 304, 838, 2004) researchers report that plastic debris around the globe can erode (degrade) away and end up as microscopic granular or fiber-like fragments, and that these fragments have been steadily accumulating in the oceans. Their experiments show that marine animals consume microscopic bits of plastic, as seen in the digestive tract of an amphipod. Hence, the use of biodegradable polymers derived from renewable resources has received considerable attraction in the recent years; it is the need of the hour to implement immediate application for biodegradable plastics in several areas - agricultural mulch, industrial packaging, wrapping, milk sachets, foodservice, personal care, pharmaceuticals, surgical implants, medical devices, recreation, etc. The concept of biodegradable plastics is new in India, which is primarily due to the following reasons:

I. **Cost:** The cost of biodegradable plastics is **2- 10 times** more than conventional plastics. As per the available data, the current price trend of Oxo/Photo-degradable plastics (**Based on Polyethylene material)** and Biodegradable plastics for film applications (**copolyester based**) are given below:-

   (i) **Oxo/Photo Degradable plastics film / bags** – Rs.90 – 120 per kg (depending upon prices of polyethylene & additive, which are variable and as per the global trend of polymer pricing.)

   (ii) **Biodegradable plastics film / bags** - Rs.400 – 500 per kg.

II **Lack of initiatives:** There is no legal framework to enforce legislature to acknowledge the disposal problem of conventional plastics, particularly for short lived flexible packaging products. Agro-biotech may be the new buzz word for India's science and technology sector, but alternative biodegradable plastics have still not been identified as a major area for research. During the field survey, it was brought to the notice that for export of products to few countries, the mandatory condition of use of Biodegradable Plastics for packaging is enforced.

III **Precaution on use of biodegradable plastics bags:** Promoting biodegradable plastics will overall increase India's plastic consumption and it is opined that the major cause of concern would be to segregate between non-biodegradable and biodegradable plastics in the waste stream of Municipal Solid Waste (MSW). Hence, introduction of biodegradable plastics would be helpful only if proper "Eco-labeling" system and "Plastics Coding System" as given in Recycled Plastics Manufacture and Usage Rules, 1999, as amended in 2003 is implemented.

The Major Findings:-

1) Degradable plastic film process involve conversion of additive based polyolefin compound into film and then into carry bags, pouches etc. However, these products are basically evolved out of **“photo or oxo degradable**” concept in which first stage degradation or fragmentation depends upon UV light/ sunlight exposure and in 2nd stage they are susceptible to degrade under compostable conditions unlike biodegradable plastics. However on analytical-study-cum testing of all theses degradable plastics are not fulfilling the criteria of ASTM D-5338/6400, hence, they can’t be prescribed to as biodegradable plastics as per the minimum required criteria of 60% biodegradation in 45 days. Therefore, all these degradable plastics, films are in the category of “Oxo/ Photo degradable type and the use of the term “degradable” does not qualify them to be a biodegradable product as well. Since most of these degradable products collected and tested under the study could not meet the minimum criteria of biodegradability, they cannot be construed as biodegradable as per ASTM D-5338/ 6400. Recently BIS has notified IS/ISO: 17088:2008, which defines the criteria for biodegradable plastics under compostable condition Similar to ASTM D-6400.

   The biodegradable products / film provided by M/s Harita NTI, M/S Earth Soul India Pvt. Ltd. and M/s Arrow Coated Products meet the criteria of biodegradable plastics as per ASTM D-5338/ 6400, however these companies don’t manufacture raw material, however, they get the raw material from their principals, M/s BASF Polymers, M/s Nova Mont etc and then convert it into end product (mostly film and injection moulded products). The Industries are the processing biodegradable plastics by Blown film Extrusion/ Injection Moulding.

2) With regard to the degradation rate in the **“photo/oxo-degradable”** polymers, as discussed above, degradable products include three types of materials that degrade over time;

(i) Which degrades after exposure to sunlight, oxygen, or other degradation mechanism;

(ii) Which biodegrades when exposed to micro organisms;

(iii) 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 and are primarily water, CO_2, and biomass similar to plant biomass. The fate of the biomass residue is to provide Carbon and Nitrogen 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 fragments.

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/Photo-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.

3) The shelf life of the degradable plastics primarily depends on product requirements such as storage conditions, disposal environment etc. The photo/ oxo-degradable additives are manufactured in the range of formulations and incorporated at various concentrations in order to control product shelf life and service life. However, at the end of predicted shelf life, these plastics remain as such in the environment in the fragmented state for several years.

CHAPTER – 1
INTRODUCTION

The potential of biodegradable polymers and more particularly that of polymers obtained from renewable resources such as the polysaccharides (e.g., starch) have long been recognized. However, these biodegradable polymers have been largely used in some applications (e.g., food industry) and have not found extensive applications in the packaging industries to replace conventional plastic materials, although they could be an interesting way to overcome the limitation of the petrochemical resources in the future. The fossil fuel and gas could be partially replaced by greener agricultural sources, which should participate in the reduction of CO_2 emissions.

Bio-based and biodegradable plastics can form the basis for an environmentally preferable, sustainable alternative to current materials based exclusively on petroleum feed stocks. These bio-based materials offer value in the sustainability/life-cycle equation by being a part of the biological carbon cycle, especially as it relates to carbon-based polymeric materials such as plastics, water soluble polymers and other carbon based products like lubricants, biodiesel, and detergents. Identification and quantification of bio-based content uses radioactive C-14 signature. Biopolymers are generally capable of being utilized by living matter (biodegraded), and so can be disposed in safe and ecologically sound ways through disposal processes (waste management) like composting, soil application, and biological wastewater treatment. Single use, short-life, disposable products can be engineered to be bio-based and biodegradable.

Polymer materials have been designed in the past to resist degradation. It is widely accepted that the use of long-lasting polymers for short-lived applications (packaging, catering, surgery, hygiene), is not entirely adequate. Most of the today's synthetic polymers are produced from petrochemicals and are not biodegradable. Furthermore, plastics play a large part in waste management, and the collectivities (municipalities, regional or national organizations) are becoming aware of the significant savings that the collection of compostable wastes would provide. Valorizing the plastics wastes also presents some issues. Energetic valorization yields some toxic emissions (e.g., dioxin). Material valorization implies some limitations linked to the difficulties to find accurate and economically viable outlets. In addition, material valorization shows a rather negative eco-balance due to the necessity, in nearly all cases, to wash the plastic wastes and to the energy consumption during the process phases (waste grinding and plastic processing). For these different reasons, reaching the conditions of conventional plastic replacements by degradable polymers, particularly for packaging applications, is of major interest for the different actors of the socio-economical life (from the plastic industry to every citizen).

The objective is to design polymers that have the necessary functionality during use, but also gets destructed under the stimulus of an environmental trigger after use. The trigger could be microbial, hydrolytically or oxidatively susceptible linkage built into the backbone of the polymer, or additives that catalyze breakdown of the polymer chains in specific environments. Importantly, the breakdown products should not be toxic or persist in the environment, and be completely assimilated (as food) by soil microorganisms in a defined time frame. In order to ensure market acceptance of biodegradable products, the ultimate biodegradability of these materials in the appropriate waste management infrastructures (more correctly the assimilation/utilization of these materials by the microbial populations present in the disposal infrastructures) in short time frames (one or two growing seasons) needs to be demonstrated. In July 2000 the US Composting Council and the Biodegradable Products Institute announced a labelling (certification) programme based on the ASTM Standard D-6400-99 for materials suitable for composting applications.

A number of studies have already been carried out on biodegradable plastics. One such study is on the “Technology status and prospects of biodegradable plastics in India” carried out by DSIR, Ministry of Science & Technology, Government of India. The study had recommended for giving priority to indigenous R & D efforts on the development of environmentally degradable plastics, methods for testing of biodegradable plastics by the Bureau of Indian

Standards, identifying possible areas of application for biodegradable plastics and creates awareness on this issue."

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 labelling 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 know 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 reference a number of other ASTM documents including several test methods:

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

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

  To meet the criteria, 60% of single polymer materials must mineralise in six months, and 90% must do in blends. Materials should give way to intense microbial activity and be converted from carbon to carbon dioxide, biomass and water. Materials also should begin to fragment, at which point disintegration begins. In this phase, the material must completely physically and visually disintegrate. Ninety percent (90%) of the disintegrated material should not adversely affect the quality of the compost. Finally, even after land application, remaining materials should be safely converted into carbon dioxide by microorganisms and not toxic.

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

In order to use the logo of 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 Standard 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 Biodegradation and Disintegration of Plastics under Controlled Composting Conditions – Method by Analysis of Evolved Carbon Dioxide.

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

The compostable material is should confirm the followings:-

- the polymer chains break down under the action of micro-organisms (bacteria, fungi, algae);
- total mineralisation is obtained (conversion into CO_2, H_2O, inorganic compounds and biomass under aerobic conditions); and
- the mineralisation rate is high and is compatible with the composting process.

The materials having a degree of biodegradation equivalent to that of cellulose (maximum permissible tolerance of 5%) are considered to meet the compostability criteria under these standards.

CHAPTER – 2

OBJECTIVES OF THE STUDY

The present study on "Establishing Criteria for Biodegradable Plastics on Environment" sponsored by Central Pollution Control Board (CPCB), New Delhi broadly focuses on assessment of the status of manufacture of Biodegradable Polymers in India with reference to its processing technologies, environmental issues etc. The scope of the work includes the following:

- Inventories/assess the manufacturing status of biodegradable plastics industries manufacturing units in India with reference to processing technologies & environmental issues etc.

- Establish the degradation rate w.r.t change in chemical structure, decrease in mechanical strength, fragmentation and weight loss of polymeric material degradability under laboratory scale composting conditions.

- Evaluate the self-life and its impact on environment.

- Evaluate its effect on food stuffs w.r.t natural colour/additives.

CHAPTER – 3

TYPES OF DEGRADABLE PLASTICS

3.1 Concepts: Biodegradability and Renewability

3.1.1. Biodegradability and Compostability

According to ASTM standard D-5488-94d, biodegradable means capable of undergoing decomposition into carbon dioxide, methane water, inorganic compounds, or biomass in which the predominant mechanism is the enzymatic action of micro-organisms that can be measured by standard tests, over a specific period of time, reflecting available disposal conditions. There are different media (liquid, inert or compost medium) to analyze biodegradability. Compostability is material biodegradability using compost medium. Biodegradation is the degradation of an organic material caused by biological activity, mainly by micro-organisms' enzymatic action.

This leads to a significant change in the material chemical structure. The end-products are carbon dioxide, new biomass and water (in the presence of oxygen: aerobic) or methane (oxygen absent: anaerobia), as defined in the European Standard EN 13432:2000. Unfortunately, depending on the standard used (ASTM, EN), different composting conditions (humidity, temperature cycle) must be realized to determine the compostability level. Then, it is difficult to compare the results using different standard conditions. We must also take into account the amount of mineralization as well as the nature of the residue left after biodegradation. The accumulation of contaminants with toxic residues and chemical reactions of biodegradation can cause plant growth inhibition in these products, which must serve as fertilizers. Actually, the key issue is to determine the environmental toxicity level for these by-products, which is known as eco-toxicity.

Similar various definitions of Biodegradable & degradable plastic have also been proposed as per ASTM D-6400:

(i) **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).

(ii) **Compostable Plastic**: A plastic that undergoes degradation by biological processes during composting to yield CO_2, water, inorganic compounds and biomass at a rate consistent with other known compostable materials and leave no visible, distinguishable or toxic residue.

(iii) **Photodegradable/ Oxodegradable Plastics:**

Photodegradable/Oxodegradable plastics disintegrate into small pieces when exposed to sunlight (manufacturers add a sun-sensitive component to the plastic to trigger degradation). But sustainability requires that a degradable material should break down completely by natural processes so that the basic building blocks can be used again by nature to make a new life form. Plastics made from petrochemicals are not a product of nature and cannot be broken down by natural processes. Therefore, despite how small the pieces of plastic may become, they are not and cannot be biodegradable.

a. **Degradable**: A material is called degradable with respect to specific environmental conditions if it undergoes degradation to a specific extent within a given time measured by specific standard test methods.

b. **Degradation**: An irreversible process leading to a significant change of the structure of material, typically characterized by a loss of properties (e.g. 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.

c. **Disintegra8tion:** The falling apart into very small fragments of packaging or packaging material caused by degradation mechanism is called as disintegration.

3.1.2. Renewability and Sustainable Development

Renewability is linked to the concept of sustainable development. The UN World Commission on “Environment and Development in our Future” defines sustainability as the development which meets the needs of the present time without compromising the ability of future generations to meet their own needs. According to Narayan the manufactured products, e.g., packaging, must be designed and engineered from “conception to reincarnation,” the so-called “cradle-to-grave” approach. The use of annually renewable biomass, like wheat, is a complete carbon cycle. This concept is based on the development and the manufacture of products based on renewable and biodegradable resources like starch, cellulose, etc. By collecting and composting biodegradable plastic wastes, carbon-rich compost; humus materials can be generated.

3.1.3 The Chemistry of Biodegradable Polymers

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 ensure that biodegradable polymers are naturally occurring or they are 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 byproducts of other crops (so called renewable resources) or they may come from petro-chemical feedstocks (so called non-renewable resources). Whether renewable petro-chemical feedstocks are better than non-renewable sources is a judgment that cannot be made without carrying out an environmental impact analysis on each sources. 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.

(a) Natural 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:

1.	Polysaccharides	-	Starch, Cellouse
2.	Proteins	-	Gelatin, Casein, Silk, Wool
3.	Polyesters	-	Polyhyroxyalkanoates
4.	Others	-	Lignin, Shellac, Natural Rubber

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.

(b) 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.

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

- Polyalkylene esters
- Polylatic 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.

(c) Additives

Many 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 requirement 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.

CHAPTER – 4

METHODOLOGY

The study has been conducted in the following three phases:

4.1 On site study
4.2 Manufacturing status
4.3 Analysis of Samples

4.1 On site Study

Over the last decade, the performance and availability of Biodegradable Polymers (BP) has developed strongly driven by increasing interest in sustainable development, desire to reduce dependence upon finite resources and changing policies and attitudes in Waste Management. Most of the BP in the market or in development is based on renewable raw material feedstocks from agriculture or forestry. Therefore, information was reviewed to gain an understanding of the following aspects. The Biodegradable Polymers and its manufacturing process available worldwide, major market segments and also the relevant manufacturing companies in India as well as across the globe. Depending on the evolution of synthesis process, different classifications of biodegradable polymers have been proposed. Figure 1 shows an attempt of classification of biodegradable polymers. There are broadly 4 different categories of which only 3 categories (a to c) are obtained from renewable resources:

a) Polymers from biomass such as the agro-polymers from agro-resources (e.g., starch, cellulose),
b) Polymers obtained by microbial production, e.g., the polyhydroxy-alkanoates,
c) Polymers conventionally and chemically synthesised and whose the monomers are obtained from agro-resources, e.g., the poly(lactic acid),
d) Polymers whose monomers and polymers are obtained conventionally, by chemical synthesis.

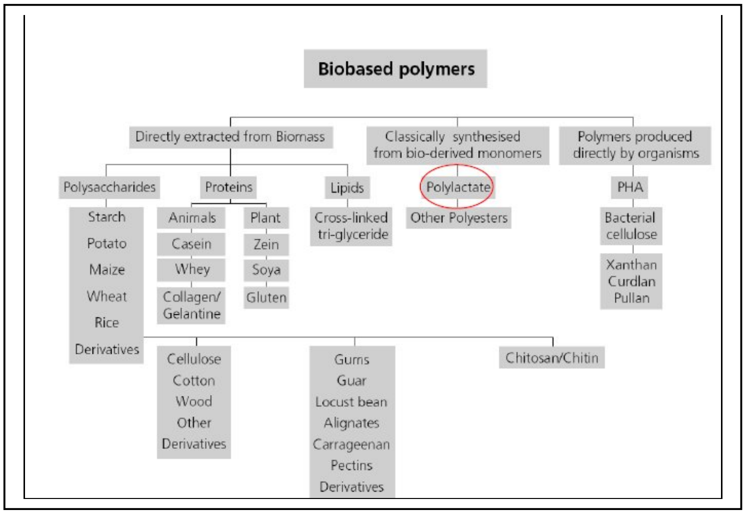


Figure 1. Classification of the biodegradable polymers.

The uses of biodegradable polymers are mentioned below :-

1. Packaging (food containers, wraps, nets, foams)
2. Plastic bags for collection and composting of food waste and as super market carrier bags.
3. Catering products (cutlery, plates, cups straws etc).
4. Agriculture (mulch films, plant pots, nursery films etc)
5. Hygiene products and
6. Medical & Dental Implants (sutures etc)

There is a lot of awareness among the research institutions on the potential of biodegradable plastics in India. However, India appears to be investing only in first generation of oil based plastics that have starch to impart it with biodegradability. Biodegradation of polymers can be achieved in two ways. One way is to synthesize polymer like PLA/PHB, which are biodegradable in nature. The other way is to modify the properties of non-biodegradable plastics by the incorporation of additives that help in breaking the molecular chain and permit direct metabolisation by microbes when disposed in nature (CDC, 2001). In India the R&D efforts have focused more on the second approach of biodegradation.

The biodegradable plastics is estimated to be 46,000 tonnes in India and is likely to go up to 98,000 tonnes in 2007-08 based on a 15% penetration level of potential segments. However in India, research is still in preliminary stage in the development of biopolymers. Survey indicated that a majority of manufacturers in India are primarily concentrating in the development of photo/oxo degradable polyolefins in which a prodegadant additive was added to the tune of 1-3 wt% to the master batch. The manufacturers claim that the resultant photo/oxo degradable polyolefins break-down into smaller fragments which can be easily consumed/ assimilated by the microorganisms.

As regards to the stakeholders dealing with inherently biodegradable units only 03 nos of manufacturing units have been reported i.e. M/s Harita NTI, Chennai, M/s Earth Soul India Ltd, Mumbai and M/s ARROW Coated Products, Mumbai. However the aforementioned units imported the base resin from abroad i.e. BASF polymers under the trade name Ecoflex, Novamont, Biomax respectively. Product applications for biodegradable plastics will largely depend on its material properties like its strength, lifespan, resistance to heat and water and the ability to package food items. Further the successful introduction of these products also depends on their functional advantage, cost, waste management attributes (ways of dealing with bio waste), and ways of marketing and legislation.

4.2 Manufacturing status, processibility, performance characteristics and cost of biodegradable/degradable plastics industries in India.

A detailed survey on the various plastics industries manufacturing biodegradable/degradable plastics in India was conducted. The factory sites were visited & samples such as poly bags, master batches etc. were collected. Some of the major units are enumerated here as under:

- M/s Harita NTI, Chennai
- M/s Earth Soul India Ltd., Mumbai
- M/s Nature Tec Products (product of Harita NTI), Chennai
- M/s Surya Polymers, New Delhi
- M/s Symphony Polymers, New Delhi
- M/s Green Craft Polymers, New Delhi
- M/s Overseas Polymers, New Delhi
- M/s Sachdeva Plastics, New Delhi

- M/s Arrow Coated Products, Mumbai
- Samples from Various Hotels/Restaurants/Hospitals in & around Delhi

Cost:

As per the available Market data, the current price trend of Oxo/Photo-degradable plastics (Based on Polyethylene material) and Biodegradable plastics for film applications (co-polyester based) are as follows:

1. Oxo/Photo Degradable plastics film / bags – Rs.90 – 120 per kg (depending upon prices of polyethylene & additive, which are variable and as per the global trend of polymer pricing.)

2. Biodegradable plastics film / bags - Rs.400 – 500 per kg.

It is evident from the above that the Oxo/Photo degradable films are cheaper than the biodegradable plastics films bags, which may, perhaps, the reason for spread of Oxo/Photo degradable films and bags in some parts of the country.

4.3 Analysis of Samples:

The samples collected from the above plastic manufacturer's sites and other sources were subjected to biodegradation test as per ASTM D5338: Standard Test Method for determining the aerobic bio-degradation of plastic materials under controlled composting conditions**.**

Scope: The test method determines the degree and rate of biodegradation of plastic materials on exposure to a controlled composting environment under controlled laboratory conditions. The samples were exposed to an inoculum that is derived from compost from municipal solid waste. The aerobic composting takes place in an environment where temperature, aeration and humidity are closely monitored and controlled. The percentage of biodegradability is obtained by determining the percentage of carbon in the test sample that is converted into CO_2 during the duration of the test.

Significance and Use: The degree and the rate of aerobic biodegradability of a plastic material in the environment determine the extent to which and time period over which plastic may be mineralized. Disposal is becoming a major issue with the increasing use of plastics, and the results of this test method permit an estimation of the degree of biodegradability and the time period over which plastics will remain in an aerobic soil environment. The test method determines the degree of aerobic biodegradation by measuring evolved carbon dioxide as function of time that the plastic is exposed to soil. Soil is an extreme species – rich source of inoculums for evaluation of the biodegradability of plastics in the environment. When maintained appropriately with regard to moisture content and oxygen availability, the biological activity is quite considerable, although lower than other biologically active environments, such as activated sewage-sludge of compost.

Apparatus:-

i. A series of atleast 12 composting vessels (1 blank i.e. compost, 1 positive i.e. cellulose (assumed to be 100% biodegradable) mixed with compost, and 1 negative control all in 3 replicates) of approximately 2-5 L internal volume.

ii. Water Bath or other temperature controlling means capable of maintain the temperature of composting vessels at 58±20 C.

iii. Pressurized air system that provides CO_2 free, H_2O saturated air to each of the composting vessels at accurate aeration rate.

iv. Suitable devices for measuring Oxygen and CO_2 concentrations in the exhaust air of the composting vessels such as specific sensors.

v. CO_2 trapping apparatus for each composting vessel: Atleast 5000ml bottles fitted with gas spurging and containing $Ba(OH)_2$, CO_2 scrubbing solution.

Figure: Biodegradation Testing as per ASTM D-5338 (CIPET, Chennai)

Analytical equipments:

Balance, to weigh the test specimen, Burette, 100mL, Bench-top centrifuge for moisture holding capacity determination, Oven set to 104 $\pm$ Analytical equipment, to measure the total carbon content of the test specimen, Analytical 1° C for moisture determinations, Muffle Furnace, set to 550°C for ash determinations.

Reagents and Materials:-

1) **Ammonium Phosphate**, ((NH4)$_2$HPO$_4$), 4.72 g/L.

2) **Barium Hydroxide** solution (0.025 N), prepared by dissolving 4.0 g anhydrous $Ba(OH)_2$/L of distilled water. Filter free of solid material, conform normality by titration to standard acid, and store sealed as a clear solution to prevent absorption of CO_2 from air.

3) It is recommended that 5-20 L be prepared at a time when running a series of tests. When using $Ba(OH)_2$, however, care must be taken that a film of $BaCO_3$ does not form on the surface of the solution in the beaker, which would inhibit CO_2 diffusion into the absorbing medium.

4) Alternatively, potassium hydroxide solution could be used and is prepared by dissolving 28 g of anhydrous KOH/L of distilled water and proceeding in the same way as for the KOH.

5) **Hydrochloric acid**, 0.05 N HCL when using 0.025 N $Ba(OH)_2$, or 0.25 N HCL when using 0.5 N KOH.

Compost Inoculum: The compost inoculums should be 2 to 4 months old, well aerated compost from organic fraction of municipal solid waste, sieved on a screen of less than 10 mm, compost from plants, treating green or yard waste or mixtures of municipal solid waste and green waste should be used. The compost inoculum should produce 50-150 mg of CO_2 per gram of volatile solids over the first 10 days of the test and an ash content of less than 70% and a pH between 7 and 8.2, is desired. The amount of total dry solids may range from 50 to 55%. Moreover the compost inoculums should be free from larger inert materials like glass, stones, metals etc. These items can be removed manually to the extent that it should produce a homogenous compost inoculum. Compost should have sufficient porosity to enable aerobic conditions. Addition of structural material like small wooden particles, persistently or poorly biodegradable inert material can prevent the compost from sticking and clogging during the test.

Test Specimen: Test samples may be in the form of film samples, formed articles, dog bones, granules and powdery state and confirmed to ASTM D618.

Procedure: The composting vessels were incubated in diffuse light minimum for a period of 45 days & the temperature of the system was maintained at 58C. The CO_2 & O_2 concentrations were checked in the outgoing air daily with a minimum time interval of 6 hrs after the first week. The air flow was adjusted to maintain a CO_2 concentration of at least 2% vol / vol to allow accurate determination of CO_2 level in the exhaust air. Composting vessels were shaken weekly to prevent extensive channeling provide uniform attack on test specimen and provide an even distribution of moisture. The incubation time was fixed to a minimum 45 days in case of the homopolymer samples. In copolymer samples or in the samples in which significant biodegradation of the test sample was persistent even after 45 days duration, the incubation period was extended to 180 days.

Carbon Dioxide Analysis: The carbon dioxide (CO_2) produced in each vessel reacted with $Ba(OH)_2$ and was precipitated as barium carbonate ($BaCO_3$).The amount of carbon dioxide produced was determined by titrating the remaining barium hydroxide with 0.05 N hydrochloric acid to a phenolphthalein end point or by automatic titrator. Because of the static incubation, the barium carbonate built up on the surface of the liquid must be broken up periodically by shaking the vessel gently to ensure continued absorption of the evolved carbon dioxide. The hydroxide traps should be removed and titrated before their capacity exceeds. At the time of removal of the traps, the vessel should be weighed to monitor moisture loss from the soil and allowed to sit open so that the air was refreshed before replacing fresh barium hydroxide and releasing the vessel. The vessels should remain open a minimum of min or a max of 1 hour distilled or deionised water should be added back periodically to the soil to maintain the initial weight of the vessel. The carbon dioxide evolution rate should reach a plateau when all of the accessible carbon is oxidised. The test may be terminated at this point or earlier, at the discretion of the user. At the conclusion of the test, the pH and moisture and ash content of the soil is measured and recorded.

Calculation:

1. The total carbon content (Ci) in the test material was determined by elemental analysis.
2. Cumulative CO_2 produced in grams (Cg test) from the test sample, was calculated.
3. Cumulative CO_2 produced in grams (Cg blank) from the blank (compost) sample, was calculated.
4. Percentage of biodegradation was determined by dividing the net average gaseous carbon produced in the test compound by the original average amount of carbon in the test compound and multiplying it by 100.

$$\frac{\text{Mean Cg (test)} - \text{mean Cg (blank)}}{\text{Ci}}$$

Where, Cg = amount of gaseous carbon produced, gm,

Ci = amount of carbon in test compound added, gm

The specification standard ASTM D6400 identifies 3 criteria:-

Complete biodegradation (using ASTM D5338 test method):

a. Conversion to CO_2, water & biomass via microbial assimilation of the test polymer material in powder, film, or granule form.

b. 60% carbon conversion of the test polymer to CO_2 for homopolymer & 90% carbon conversion to CO_2 for copolymers, polymer blends, and addition of low MW additives or plasticizers.

c. Same rate of biodegradation as natural materials -- leaves, paper, grass & food scraps

d. Time -- 180 days or less; if radiolabeled polymer is used 365 days or less.

Disintegration :

Less than 10% of test material on 2mm sieve using the test polymer material in the shape and thickness identical to the product's final intended use as per ISO 16929 (10) and ISO 20200 (11).

Safety

a. The resultant compost should have no impacts on plants, using OECD Guide 208, Terrestrial Plants, Growth Test

b. Regulated (heavy) metals content in the polymer material should be less than 50% of EPA (USA, Canada) prescribed threshold.

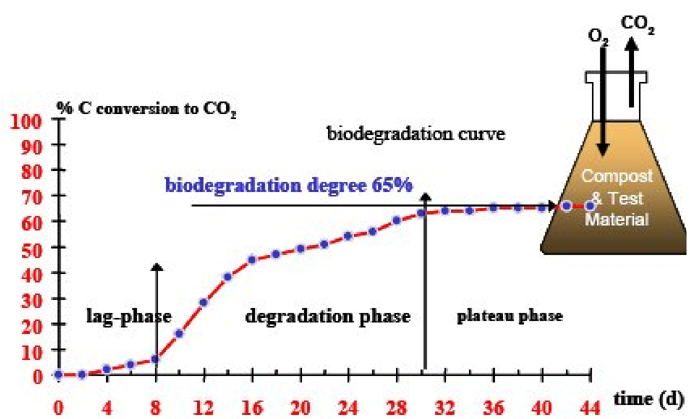


Figure : Test method to measure the rate and extent of microbial utilization (biodegradation) of biodegradable plastics

CHAPTER-5

5.0 Results and Interpretation:

5.1 Results

The test results of the films collected from M/s Surya Polymers, M/s Sachdeva Plastics & M/s Overseas Polymers indicated biodegradation to the tune of 4.40%, 6.66 % & 40.35% respectively. As indicated in the table (ANNEXURE-I), the samples collected from various Hotels/ Restaurants & Hospitals exhibited biodegradation ranging from 8.46% to 29.97% respectively. However, in the present context & standards practised Worldwide, the minimum percentage of biodegradation of a product made from a single polymer should be minimum 60% in 45 days span. Hence, the samples are not conforming to the requirement of prescribed biodegradation level as per ASTM D-6400, Clause 6.3.1. The master batch additive were further tested for toxicity levels, however, they have been reported to be of standard quality as defined in Drugs & Cosmetics Act and Rules.

The results of the samples taken from M/s Harita NTI, M/s Earth Soul India, M/s Arrow Coated Products & M/s Nature Tec (Part of NTI) indicate nearly 60 to 67 % biodegradation as per ASTM D-5338 specifications for duration of 180 days, thus confirming to the requirement of a biodegradable/ compostable plastic. The incubation period was extended to 180 days since the samples exhibited degradation even after 45 days exposure under controlled conditions. Furthermore, the aforementioned samples are also copolymers; hence the duration of exposure is extended.

Briefly summarizing the samples collected from M/s Surya Polymers, M/s Sachdeva Plastics, M/s Green Craft Polymers, M/s Symphony Polymers etc. exhibiting degradation tendency less than 60% in 45 days incubation period are primarily polyolefin's mixed with photo/ oxo-degradable additives. It is assumed that these samples break down into smaller fragments which are eventually biodegraded.

However, there is no data presented to document complete biodegradability within 1 growing season/ one year time period of these samples. Furthermore it has been also established in a recent science article that these plastic debris around the globe erode away and end up as microscopic granular or fiber like fragments and that these fragments have been steadily accumulating in the oceans. Experimental results also reveal that the marine animals consume microscopic bits of these plastics as seen in the digestive tract of an amphipod (depicted in the below figure)

Figure: FLOTSAM lab experiments show that marine animals consume microscopic bits of plastic as seen here in the digestive tract of an amphipod. © Science 2004

Figure: Piece of plastic washed ashore on remote Mozambican island, complete with colonists, BY ANTHONY ANDRADY, RTI

The algalita marine research foundation also reports that degraded plastic residues attracts and holds hydrophobic elements like PCB & DDT upto 1million times background levels.

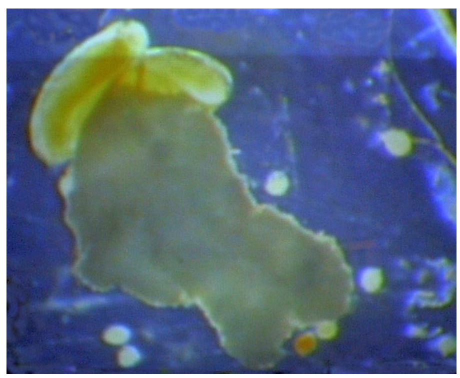


Figure: Plastic fragments with toxins colonized & consumed by birds, fishes Transports of toxins up the food chain, Captain Charles Moore, Algalita Marine Research Foundation

Thus, 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.

5.2 Identification of standards & test methods for biodegradable plastics in India

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, so that a product certified in one of these countries would automatically be eligible for certification in another.

5.2.1 BIS Standard: IS/ISO 17088:2008 specifies procedures and requirements for the identification and labeling of plastics, and products made from plastics, that are suitable for recovery through aerobic composting. The four following aspects are addressed:

- biodegradation;
- disintegration during composting;
- negative effects on the composting process and facility;

- negative effects on the quality of the resulting compost, including the presence of high levels of regulated metals and other harmful components.

This specification is intended to establish the requirements for the labeling of plastic products and materials, including packaging made from plastics, as “compostable” or “compostable in municipal and industrial composting facilities” or “biodegradable during composting” (for the purposes of this International Standard, these three expressions are considered to be equivalent). The labeling will, in addition, have to conform to any international, regional, national or local regulations (e.g. European Directive 94/62/EC).

(a) The Principle of IS/ISO Standard :-

(i) The purpose of this specification is to establish standards for identifying and labelling and labelling plastic products and materials that will compost satisfactorily in well-managed composting facilities where the typical conditions of composting can be consistently obtained (i.e. a long thermophilic phase, aerobic conditions, sufficient water content, a suitable carbon/nitrogen ratio, etc.). Products meeting the requirements outlined below are appropriate for labelling as “compostable”, “compostable in municipal and commercial facilities” or “biodegradable during composting”.

(ii) The test used simulates an intensive aerobic composting process. It measeurs

- the ultimate level of aerobic biodegradation of the test material;
- the degree of disintegration obtained;
- any negative effects on the finished compost;
- the maximum concentration of regulated metals in the compost.

The test is terminated when the plateau phase of the biodegradation has been attained; the standard time for termination is 45 days, but the test could continue for up to six months.

(b) Ultimate Aerobic Biodegradation :

(i) A plastic product is considered to have demonstrated a satisfactory rate and level of biodegradation if, when tested in accordance with ISO

14855-1, ISO 14855-2 or ASTM D 5338, it achieves the ratio of conversion to carbon dioxide (CO_2/$ThCO_2$) specified in (ii) within the time period specified in (iii).

The ultimate aerobic biodegradability shall be determined for the whole material and for each organic constituent which is present in the material at a concentration of more than 1% (by dry mass).

Constituents which are present at concentrations of less than 1% do not need to demonstrate biodegradability. However, the sum of such constituents shall not exceed 5%.

(ii) For al polymers, 90% of the organic carbon (relative to a positive-control reference material) shall have been concerted to carbon dioxide by the end of the test period (iii). Both the positive control and the test sample shall be composted for the same length of time and the results compared at the same point in time after the activity of both has reached a plateau. The positive control used shall be microcrystalline cellulose.

As an alternative, 90% (in absolute terms) of the organic carbon shall have been converted to carbon dioxide by the end of the test period.

NOTE : Although the biodegradation test includes the conversion of the polymers into biomass and humic substances in addition to carbon dioxide, no recognized standard test methods or specifications exist for the quantification of these conversion products. When such tests and specifications become available, this International Standard may be revised.

(iii) The test period shall be no longer than 180 days.

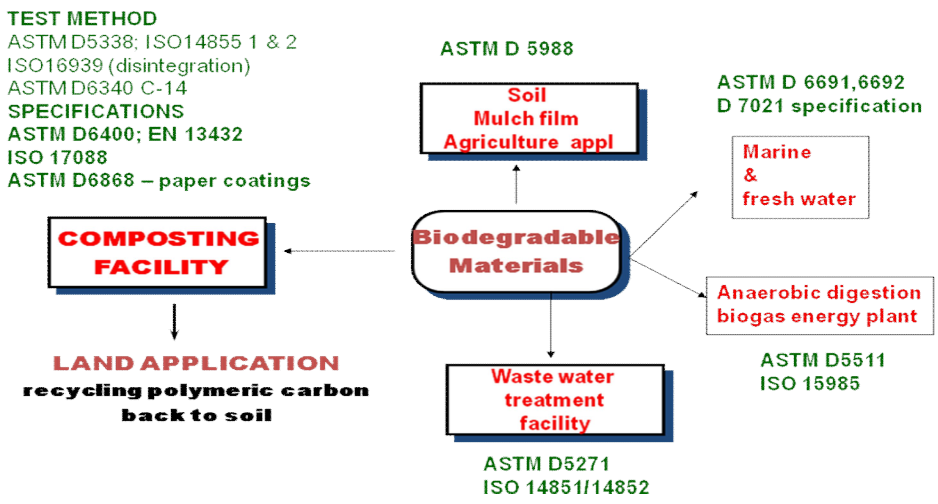
5.2.2 ASTM D6400: In USA, it is the accepted standard for evaluating compostable plastics. The ASTM D6400 standard specifies procedures to certify that compostable plastics will degrade in municipal and industrial aerobic composting facilities over a 180-day time period. The standard establishes the requirements for labelling of materials and products, including packaging made from plastics, as "compostable in municipal and industrial composting facilities." The standard determines if plastics and products made from plastics will compost satisfactorily, including biodegrading at a rate comparable to known compostable materials. The standards assure that the degradation of the materials will not contaminate the compost site nor diminish the quality of the compost in the commercial facility resulting from the composting process. ASTM D6400 utilizes ASTM D6002 as a guide for assessing the compostability of environmentally degradable plastics in conjunction with ASTM D5338 to determine aerobic biodegradation under controlled composting conditions. ASTM 6400 specifies that a satisfactory rate of biodegradation is the conversion of 60% of the organic carbon in the plastic into carbon dioxide over a time period not greater than 180 days. If a biodegradable polymer does not meet the requirements listed in ASTM D6400 or EN13433, then it is not considered compostable. It must degrade in a specified time frame without leaving any residuals in the compost. ASTM D6400 will be followed in the research to test the compostability of several rigid packaging containers, bags, and cutlery that are made from biodegradable and compostable plastics.

5.2.3 EN: 13432: In Europe, compostable plastics are being used in several applications. Compostable plastics, must comply with the European Norm EN13432, which is the criteria for compostability. EN13432 requires a compostable plastic material to break down to the extent of at least 90% to H_2O and CO_2 and biomass within a period of 6 months. ISO14855 standard specifies a testing method to evaluate the ultimate aerobic biodegradability of plastics, based on organic compounds, under controlled composting conditions by measurement of the amount of carbon dioxide evolved and the degree of plastic disintegration at the end of test. The Australian standard for degradable plastics includes test methods that enable validation of biodegradation of degradable plastics. It is a system for certification of degradable polymers that conform to the standard, e.g., EN 13432. The standard provides coverage to the range of potential application areas and disposal environments in Australia. The standard is not so severe as to exclude Kraft paper as do some European standards. Kraft paper is excluded as a positive control due to the potential presence of sulfonated pollutants. A more effective positive control can be either cellulose filter paper or microcellulose AVICEL PH101.

The standard was developed with reference to the existing international standards. The standard differentiates between biodegradable and other degradable plastics, as does ASTM D6400, and clearly distinguishes between biodegradation and abiotic disintegration even though both degradation systems demonstrate that sufficient disintegration of the plastic has been achieved within the specified testing time. The standard addresses environmental fate and toxicity issues, as does ASTM D5152.

5.2.4 JIS Standard: The Japanese JIS standards are based on Green-PLA certification system. The Green-PLA system has very similar testing requirements as the US and European certification methods. In particular, the Green-PLA certification assures biodegradability by measuring carbon dioxide evolution after microbial biodegradation, mineralization by the ability to disintegrate and not have visible fragments after composting, and organic compatibility by the ability of the compost to support plant growth. The same amount of carbon dioxide evolution (60%) in 45 days is required for certification. The 11 regulated metals are monitored in Green-PLA as EN 13432. However, several aspects of the certification are different than the US BPI and European Din-Certco certifications. Green-PLA certification requires toxicological safety data on the biodegradable plastic material from either oral acute toxicity tests with rats or environmental safety test with algae, Daphinia, or fish. Thus, the major biodegradable standards used globally are represented in Annexure- II (**A brief sketch diagram of biodegradable testing standards is given in next page).**

.Figure: Biodegradable testing standards



5.3 Disposal methods of biodegradable plastic application at the end of life:

Designing plastics and products to be completely consumed (as food) by the microorganisms present in the disposal environment in a short time frame is a safe and environmentally responsible approach for the end-of-life of these single use, short-life disposable packaging and consumer articles. The key phrase is "complete" – if they are not completely consumed, then these degraded fragments, which may even be invisible to the naked eye, pose serious environmental consequences.

More specifically:

- Harness the power of microbes in soil to completely remove the carbon based plastics from the environment.
- By ensuing that it is completely consumed by the microorganisms (as its carbon food) for driving its life processes in a short and defined time frame and in the specified environment
- The carbon product is taken inside the microbial cell and biologically oxidized to CO2 which releases energy that is utilized by the microorganism for its life processes – to multiply and grow and populate the soil for biological activity

Composting is one such environment under which biodegradability occurs. In the composting environment, the nature of the environment, the degree of microbial utilization (biodegradation), and the time frame within which it occurs are specified in an ASTM standard. For biodegradable plastics under composting conditions (compostable plastics) that ASTM standard is number D6400. Thus the biodegradable plastics can be easily disposed in composting environment under controlled conditions. Non-floating biodegradable plastics can decompose in a marine environment. The ASTM standard that specifies the marine environment for biodegradability of non floating plastics is D7081. Other ASTM standards define other environments within which biodegradability occurs. For example, ASTM D6868 is the standard for biodegradable plastics used as coatings on paper and other compostable substrates. ASTM's D6006 is the standard for assessing biodegradability of hydraulic fluids.

Microorganisms present in the disposal environments consume the carbon product to extract chemical energy for their life processes. It describes as below:-

- Breaking the material (carbohydrates, carbon product) into small molecules by secreting enzymes or the environment (temperature, humidity, sunlight) does it.
- Transporting the small molecules inside the microorganisms cell
- Oxidizing the small molecules (again inside the cell) to CO_2 and water, and releasing energy that is utilized by the microorganisms for its life processes in a complex biochemical process involving participation of three metabolically interrelated processes (tricarboxylic acid cycle, electron transport, and oxidative phosphorylation). The same has been highlighted in the figure below:

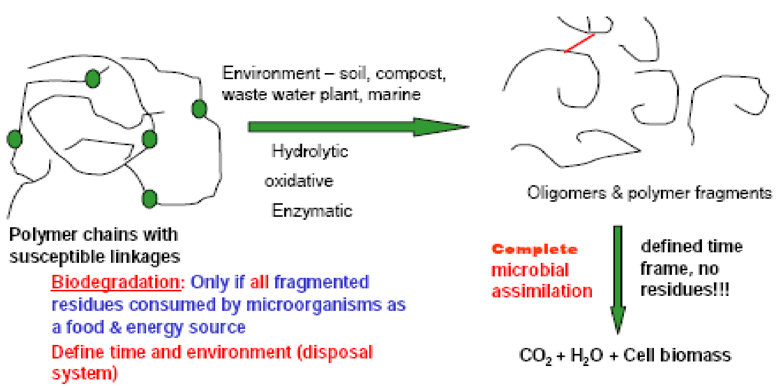


Figure: Disposal method of biodegradable plastics by Prof. Narayan, MSU

The potential disposal environments for biodegradable plastics are:

- composting facilities or soil burial;
- anaerobic digestion;
- wastewater treatment facilities;
- plastics reprocessing facilities;
- landfill;
- marine and freshwater environments; and
- general open environment as litter

In view of the above, it is evident that before designing or defining biodegradable plastics, the main determinant is to specify the disposal environment and accordingly to specify the "Testing Protocol" to be followed. ASTM D-6400 and recently published ISO Standard – ISO 17088 : 2008 should be the guiding standards for adopting in India.

5.4 Technologies for avoiding contamination & sort biodegradable plastics in India & overseas:

The risk of contamination by biodegradable plastics of conventional plastics which are currently recycled and reprocessed is a significant one, and the resultant effects on recyclate has the potential to undermine the growing confidence in recycled plastics. Effective methods for sorting biodegradable plastics would be needed in the event of their significant entry into the Indian market. Possible methods include near infra-red detection, which can be used in a positive sort system, or the use of a specific polymer code, and even colour, to differentiate biodegradable polymers from other recyclable polymers. There are **two main ways** that consumers can use to distinguish biodegradable plastic products from conventional plastic products:

- Firstly, by touch, Biodegradable plastics have a softer feeling and are silkier than conventional plastics.
- Secondly, it is very likely that a product without a quality label is not made of biodegradable plastic. Consumers should look for the presence of labels such as EN 134322, 'ok compost' or similar.

  A product indicating a biodegradable plastic label is represented as below :-

Figure: Representation/confirmation of a biodegradable plastic

5.5 Demerits on the use of biodegradable plastics:

In India, there has not been any potential development and use of biodegradable plastics. A majority of applications particularly packaging has been focused in the development of photo/oxo degradable polyolefins & starch based polyolefins due to high market cost of biopolymers. These photo/oxo degradable polyolefins and starch based polyolefins, have been assumed to be completely biodegradable in due course of time. Thus, it recommended that photo/oxo degradable may be substituted by biodegradable plastics in the areas wherein short shelf life of the products are required.

There are several identifiable environmental benefits that may potentially be derived from the use of biodegradable plastics compared to conventional petroleum-based plastics. These include;

- Compost derived in part from biodegradable plastics increases the soil organic content as well as water and nutrient retention, while reducing chemical inputs and suppressing plant disease.
- Biodegradable shopping and waste bags disposed of to landfill may increase the rate of organic waste degradation in landfills while enhancing methane harvesting potential and decreasing landfill space usage.
- The energy required to synthesise and manufacture biodegradable plastics is generally much lower for most biodegradable plastics than for non-biodegradable plastics. The exception is PHA biopolymers which consume similar energy inputs to polyethylenes. New feedstock for PHA should lower the energy required for their production.

- Biodegradable plastics also offer important environmental benefits through, in many cases, the use of renewable energy resources and reduced greenhouse gas emissions.

5.6 Environmental consideration:

- Pollution in waterways due to high BOD concentrations resulting from the breakdown of starch-based biodegradable plastic.
- Migration of plastic degradation by-products, (such as plastic residuals, additives and modifiers such as coupling agents, plasticisers, fillers, catalysts, dyes and pigments), via run-off and leachate from landfills and composting facilities to groundwater and surface water bodies.
- Trauma and death of marine species resulting from only partial or slow degradation of biodegradable plastic products in marine environments.
- Possible increase in the incidence of littering due to the belief that biodegradable plastics will disappear quickly.
- Soil and crop degradation resulting from the use of compost that may have unacceptably high organic and or metal contaminants derived from biogegradable plastic residuals, additives and modifiers such as coupling agents, plasticisers, fillers, catalysts, dyes and pigments.

5.7 Strategic Intervention:

There are number of factors that impede the adoption of biodegradable plastics. A few of them are mentioned below:

- All biodegradable plastics are relatively expensive than conventional plastics. Further, the scale of production of biodegradable plastics is low, and hence, it is costly. There are technical uncertainties with the right choice of material for selected applications.

- The development of starch-based biodegradable plastics is inexpensive and available throughout the year, and also biodegradable in ambient environment.

  The biodegradable plastic industry is still in its infancy and there are still several uncertainties that prevent the large-scale adoption of biodegradable plastics but continuous research in this direction may ensure that biodegradable plastics will be produced from renewable sources and will display in-use properties similar to those of conventional plastics. This in turn may change the scenario of plastic waste management to a large extent.

Some important points are considered while adopting biodegradable plastics these include;

(i) To explore the full potential of Poly Lactic Acid (PLA) which is a biodegradable polymer and its multi-usage across various industries even though there are a few successful manufacturers of lactic acid. There are many reasons for the slow-phase of growth in production of PLA in India. Without the ingenious research and technological development in India, the inhibiting “cost factor” cannot be resolved.

(ii) Secondly, the existing units do not invest in research and development of molasses–based chemicals and PLA applications. Domestic demand for lactic acid is expected to touch 2000 tonnes in 2011 from the present demand of 560 tonnes. India is considered to be a major producer of molasses and according to the present trend, molasses-based chemicals – like Oxalic acid, Citric acid and Lactic acid.

(iii). Thirdly, the Lactic Acid market within the country is not developed and the usage of this chemical is minimal. Even the existing manufacturers are eyeing export markets where they can expect a better price.

CHAPTER-6

6.0 Conclusion:

6.1 In developing state and local policy related to the environmentally beneficial uses of degradable plastics, it is to consider the implications of any policy or program on the affected waste diversion and disposal systems. Because improvement in one area of a system can sometimes adversely affect another part of the system. In Indian context, considering the local environment, social fabric, culture and habits of public indiscriminate system of plastics waste management wide spread littering etc, introduction of biodegradable plastics, packaging products would further add to the apathy of plastic waste disposal by adding another dimension / family of plastics.

6.2. Degradation from biological sources is called biodegradation and may be defined as compostable, which specifies that plastic is not only biodegrades completely but is also consumed in 180 days, while being in a proper compost environment as per ASTM D-6400 or IS/ISO: 17088: 2008 Standards, which defines the criteria for biodegradable plastics under compostable conditions.

6.3. The compostable bags meeting ASTM D-5338 or IS/ISO : 17088:2008 standards will degrade in a compost environment may not break down on ambient environment. Therefore, it can be concluded that biodegradable or compostable plastics may not be a better option.

6.4. Designing hydrophobic polyolefin plastics to be degradable without ensuring that degraded fragments are completely assimilated by microbial population in the disposal system, in a short time period, poses more harm to the environment, hence it is recommended that biodegradable plastics can be used for short life applications.

6.5. Worldwide the law/ Legislations exist for use of biodegradable plastics in short lived applications particularly in food/ perishable goods packaging etc. The high cost of biodegradable plastics, which are meeting criteria of compostable specifications as per ASTM D-6400 or IS/ISO 17088:2008, is the major concern to introduce in common “grocery/ carry bags” applications.

6.6. It is to be ruled out that biodegradable plastics once thrown or disposed-off, it would biodegrade by its own, however, the biodegradable plastics need to get exposed to the controlled environment for their bio-degradation.

6.7 It is proposed to undertake extensive research in the following areas :

- Indigenous technology development of raw materials for synthesis of biodegradable polymers with main objective of achieving cost effectiveness
- It is necessary to know the effect of degradation residues on wildlife, plants, and marine life.
- Assessment of the life cycle costs incurred during the manufacturing, collection and reprocessing of compostable bags as compared to the costs incurred to manage conventional plastics through processing, recycling and disposal.
- Enacting a law requiring the development of identification code or "Eco-labeling" for compostable bags and containers. This code is necessary to identify and separate compostable plastics from recyclable plastics.
- Eco-labeling of biodegradable bags under compostable conditions can be decided based on fulfillment of Criteria as per the IS/ISO: 17088/2008, the Specifications for Compostable Plastics.
- With the introduction of bio-degradable plastic bags in the waste system, it would be difficult to comply with existing regulations i.e. "Plastics Manufacture and Usage Rules, 1999, as amended in 2003" which is meant for manufacturing and usage of conventional plastic bags, therefore, it needs an amendment.
- There is also need to establish or create testing facilities for testing of Biodegradable plastics as per BIS Standard IS/ISO: 17088:2008.

Annexure- I

S No	Sample Details	Test Specification/ Standard	Biodegradation (%)
Samples collected from Industries			
1	M/s Surya Polymers, Gurgaon	ASTMD 5209	4.40
2	M/s Sachdeva Plastics, Gurgaon	ASTMD 5338	6.66
3	M/s Overseas Polymers, Pondicherry		40.35
4.	M/s Harita NTI, Chennai		63.08
	5 . M/s Earth Soul India Pvt. Ltd		62.03
6.	M/s Arrow Coated Products		60.04
7.	M/s Nature Tec		66.37
8.	M/s Green Craft Polymers		5.97
9.	M/s Symphony Polymers		7.58
Market Samples from in & around Delhi *			
1	Intercontinental Eroz	ASTM21D 5338	10.01
2	ITC Hotel		15.94
3	Park Hotel		19.50
4	Radison Hotel		10.36
5	Hyatt Regency		12.68
6	Grand Hyatt		10.82
7	Vasant Continental		20.54
8	Saleem Restaurant Pvt. Ltd		17.49
9	Urban Pind		23.03
10	TKS the Tri Kitchen, Holy Shrine Hotels, Pvt. Ltd		15.17
11	BERCO Restaurant		8.46
12	New Shanthi sagar		17.49
13	Rockland		12.30
14	Bala Ji Max Hospital		17.31
15	ESI Hospital		20.06
16	Shanti Mukund Hospital		13.28
17	Hotel Uppal Orchid		29.97
18	Frontline Packwood		22.98
19	Juneja Sales		29.64
20.	Escort Heart Institute & Research Centre		24.16

- **Source**: Plastics Testing Centre, CIPET Chennai

Annexure – II

Sl. No.	Standard No.	Description
		ISO STANDARDS
1.	ISO 14851:1999	Determination of the ultimate aerobic biodegradability of plastic materials in an aqueous medium – Method by measuring the oxygen demand in a closed respirometer ISO 14851 : 1999/Cor 1:2005
2.	ISO 14852:1999	Determination of the ultimate aerobic biodegradability of plastic materials in an aqueous medium – Method by analysis of evolved carbon dioxide ISO 14852 : 1999/Cor 1:2005
3.	ISO 14853:2005	Plastics - Determination of the ultimate anaerobic biodegradation of plastic materials in an aqueous system – Method by measurement of biogas production
4.	ISO 14855-1:2005	Determination of the ultimate aerobic biodegradability of plastic materials under controlled composting conditions – Method by analysis of evolved Carbon dioxide - Part 1: General method.
5.	ISO/DIS 14855-2	Determination of the ultimate aerobic biodegradability of plastic materials under controlled composting conditions – Method by analysis of evolved carbon dioxide – Part 2 Gravimetric measurement of carbon dioxide evolved in a laboratory – scale test.
6.	ISO 16929:2002	Plastics – Determination of the degree of disintegration of plastic materials under defined composting conditions in a pilot-scale test.
7.	ISO 17556:2003	Plastics – Determination of the ultimate aerobic biodegradability in soil by measuring the oxygen demand in a respirometer of the amount of carbon dioxide evolved.
8.	ISO 20200:2004	Plastics – Determination of the degree of disintegration of plastic materials under simulated composting conditions in a laboratory – scale test.
9.	ISO 15985:2004	Plastics – Determination of the ultimate anaerobic biodegradation and disintegration under high-solids anaerobic – digestion conditions – method by analysis of released biogas.
10.	**ISO 17088:2008**	**Specifications for compostable plastics (Recently published Standard)**

Sl.	Standard No.	Description

No.		
ASTM STANDARDS		
1.	ASTMD 5209	Standard Test Method for determining the Aerobic Biodegradation of plastic materials in the presence of Municipal sludge.
2.	ASTMD 5338	Standard Test Method for determining the Aerobic Biodegradation of plastic materials under controlled composting conditions.
3.	ASTMD 5988	Standard Test Method for determining the Aerobic Biodegradation in soil of plastic materials or residual plastic materials after composting.
4.	ASTMD 6002	Guide for assessing the compatibility of environmentally degradable plastics.
5.	ASTM D-6400	Specification for Compostable Plastics.
6.	ASTMD 6954	Standard guide for exposing and testing plastics that degrades in the environment by a combination of oxidation and biodegradation.

CHAPTER-7

7.0 References

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