Time to Bioplastics

*Ezgi Bezirhan Arikan, H. Duygu Ozsoy
Faculty of Engineering, Department of Environmental Engineering, Mersin University, Mersin, Turkey

Abstract

Without a doubt, plastic have become an important part of modern life. On the one hand, plastics are light, flexible, strong and cheap to produce. On the other hand, their non-biodegrability has raised environmental concerns about their disposal. Because of environmental pollution problems caused by using plastic made by petrochemicals, the development of "environmental friendly" materials has attracted extensive interest. Recently, bioplastics are developed one of the most innovative environmental friendly materials. 'Bioplastics' are made from renewable resources such as corn, sugars, potatoes, etc., and they are produced by a range of microorganisms. Many countries around the world have already begun to produce these materials. Especially in packaging applications, bioplastics have received great attention. Nevertheless, it seems that bioplastic production and consumption will increase in the future. Despite some benefit of bioplastic, there have been discussing issues about them. Therefore, this paper will look at aspects of the bioplastics from the perspective of sustainability, policy and standards.

Key words: Benefit of bioplastics, bioplastic, environmental friendly, sustainability

1. Introduction

Past ages of human society have been called the Stone, Bronze, Copper, Iron and Steel Ages, based on the material that was relied upon the most during that time [1]. Plastics production worldwide has surpassed steel. Worldwide annual plastics production is estimated to surpass 300 million tons by 2015 [2]. So today humanity has lived to Age of Plastics.

Mostly using oil, coal, and natural gas as raw materials for plastic's manufacturing [3]. They are uniquely flexible materials that have seen them occupy a huge range of applications, from simple packaging to complex engineering [4]. Due to plastics are used in a wide range of applications economic and environmental problems has raised.

The first environmental problem which leads to plastics is landfill problem. A large proportion of plastics in modern use are for single-use applications, and in many countries the end-of-life of these has historically been disposal to landfill [4]. Increasing amounts of plastic waste emerged as a crisis in many areas of the World because of shrinking landfill capacity, rising costs and strong legislation. The second environmental problem is accumulation of plastics in oceans. For example, in a long-term study in the North Atlantic, one seawater sample contained the equivalent of 580 000 pieces of plastic per square kilometer [5]. Also, plastic incineration generates toxic emissions such as carbon dioxide and methane. These greenhouse gases (GHGs) contribute to worldwide climate change. The Intergovernmental Panel on Climate Change (IPCC) trajectory to 2050 for stabilization of atmospheric GHG concentrations at 450 ppm carbon dioxide requires emissions reduction of 80% compared to the 1990 level [6]. The vast majority of plastics in current production are derived from crude

Corresponding author: Ezgi Bezirhan Arikan Address: Faculty of Engineering, Department of Environmental Engineering Mersin University, 33343, Mersin TURKEY. E-mail address: ezgibezirhan@hotmail.com, Phone: +903243610001/7092

oil, thus, their GHG emissions are of concern [4]. The fourth problem is their non-degradability or durability. Plastic is not biodegradable and will persist in the environment for hundreds of years [1]. The economic problem is competition for crude oil and energy security. Overall plastics consumption could grow from the current 250 000 kilotons per year to about 1 million kilotons by the end of this century. In the absence of huge new inexpensive crude oil discoveries, such an expansion in plastics consumption is unsustainable. It might be expected that crude oil will become more expensive and the supply more volatile [4].

In recent years, these environmental problems and social concerns has triggered to developing environmental friendly materials such as bioplastics. According to the European Bioplastics organization, bioplastics can be defined as plastics based on renewable resources (bio-based) or as plastics which are biodegradable and/or compostable [7].

Nowadays, there has been a significant shift in the market for bioplastics from the plastics. Bioplastics are novel materials of the twenty-first century and would be of great importance to the materials world [8]. It showed that the bioplastic production and consumption will grow bigger in the future. Because of this, these materials need to be evaluated carefully for sustainability and bioplastic waste management. Therefore, this review provides state of performance of bioplastics materials, focusing on benefits or disadvantages of bioplastics. Also, it gives an overview of bioplastics standards.

2. Type of Bioplastics

Generally, ‘Bioplastics’ are made from renewable resources such as corn, sugars, potatoes, etc., [9, 10] including proteins, lipids and polysaccharides [11, 12] and they are produced by a range of microorganisms [13]. One hand, there are four types of degradable plastics: photodegradable bioplastics, compostable bioplastics, bio-based bioplastics and biodegradable bioplastics.

Photodegradable bioplastics have light sensitive group incorporated directly into the backbone of the polymer as additives. Extensive ultraviolet radiation (several weeks to months) can disintegrate their polymeric structure rendering them open to further bacterial degradation. However, landfills lack sunlight and thus they remain non-degraded [1].

The Business-NGO Working Group for Safer Chemicals and Sustainable Materials defines *bio-based bioplastics* as “plastics in which 100% of the carbon is derived from renewable agricultural and forestry resources such as corn starch, soybean protein and cellulose [14].

Compostable bioplastics are biologically decomposed during a composting process at a similar rate to other compostable materials and without leaving visible toxic remainders. In order to designate a plastic as bio-compostable, its total biodegradability, its disintegration degree, and the possible eco-toxicity of the degraded material must be determined by means of standard tests [10].

Biodegradable bioplastics are fully degraded by microorganism without leaving visible toxic remainders. The term “biodegradable” refers to materials that can disintegrate or break down naturally into biogases and biomass (mostly carbon dioxide and water) as a result of being exposed to a microbial environment and humidity [1].

On the other hand, there is also a complex classification due to using wide range of applications ıt has required the discovery of new molecules, the blending of molecules, searches for new plasticizers, and latterly the attempts to make identical bioplastics to the petro-plastics but using renewable raw materials of a biological origin. The result is an increasingly diverse range of bioplastics that make it difficult to define any unifying characteristics [15].

3. Biodegradation and Standardization of Bioplastics

Biodegradability is a dilemma and a misused and abused term. Biodegradability results are strongly based on test conditions, such as humidity, temperature and microorganisms. Also, the nature is different from to laboratory conditions. Several of the challenges that face the comparative assessment of the biodegradability of bioplastics are:

Relevance of the test environment: aerobic biodegradation tests are irrelevant to plastics disposed to the methanogenic landfill environment [15].

Many terms: ready, inherent, ultimate biodegradability, hydro-biodegradation, oxo-biodegradation, mineralization (to CO_2 under aerobic conditions or CH_4 anaerobically), comparison to compostable. The proliferation of terminology has led to confusion, and inhibits proper labelling of products [15].

Rapid development of new molecules for different applications [15].

Interaction with other degradation mechanisms, for example photo, thermal [16].

Drives towards labelling and certification require uniform, comparable biodegradation tests [17].

As a result there is much standardization. Standardization bodies are showed in Table 1.

Table 1. Standardization Bodies

National	Acronym	Web
Austria	ÖNORM	www.as-search.at/
France	AFNOR	www.afnor.org
Germany	DIN	www.din.de/
Italy	UNI	www.uni.com
Japan	JIS	www.jsa.or.jp/default_english.asp
Turkey	TSE	www.tse.org.tr/
UK	BSI	www.bsigroup.com/
US	ASTM	www.astm.org
International	ISO	www.iso.org
Europe	CEN	www.cen.eu

The list of available biodegradation standards is considerable (Table 2) [15]. In the interests of environmental relevance, it is recommended that selection of the test methodology be based on potential fields of application of the test polymer and its end of- life, that is compost, soil, fresh or marine water. Some of the widely used standards are: AS4736; ASTM D5338; ASTM D6002; EN 13432; ISO 14855 (for compost exposure), ASTM D5988; ISO 17556 (for soil exposure) and ASTM D6691; ASTM D6692; ISO 15314; ISO 16221 (for marine exposure) [15].

Table 2. List of Published Standards for Biodegradation Of Plastics [15]

Standard	**Description**
ASTM D6954 – 04	Standard guide for exposing and testing plastics that degrade in the environment by a combination of oxidation and biodegradation
AS 4736 – 2006	Biodegradable plastics – biodegradable plastic suitable for composting and other microbial treatment
ASTM D5209 – 92	Standard test method for determining the aerobic biodegradation of plastic materials in the presence of municipal sewage sludge
ASTM D5338 – 98	Standard test method for determining aerobic biodegradation of plastic materials under controlled composting conditions
ASTM D5526 – 94	Standard test method for determining anaerobic biodegradation of plastic materials under accelerated landfill conditions
ASTM D5951 – 96	Standard practice for preparing residual solids obtained after 2002 biodegradability standard methods for plastics in solid waste for toxicity and compost quality testing
ASTM D5988 – 03	Standard test method for determining aerobic biodegradation in soil of plastic materials or residual plastic material after composting
ASTM D6002 – 96	Standard guide for assessing the compostability of environmentally degradable plastics
ASTM D6340 – 98	Standard test methods for determining aerobic biodegradation of radiolabeled plastic materials in an aqueous or compost environment
ASTM D6400 – 99	Standard specifications for compostable plastics
ASTM D6691 – 01	Standard test method for determining aerobic biodegradation of plastic materials in the marine environment by a defined microbial consortium
ASTM D6692 – 01	Standard test method for determining biodegradability of radiolabelled polymeric plastic materials in seawater
ASTM D7081 – 05	Standard specifications for non-floating biodegradable plastics in the marine environment
DIN V 54900-2	Testing of compostability of plastics – Part 2: testing of the complete biodegradability of plastics in laboratory tests
EN 13432:2000	Requirements for packaging recoverable through composting and biodegradation – test scheme and evaluation criteria for the final acceptance of packaging
EN 14045:2003	Packaging – evaluation of the disintegration of packaging materials in practical oriented tests under defined composting conditions
EN 14046:2003	Packaging – evaluation of the ultimate aerobic biodegradability of packaging materials under controlled composting conditions – method by analysis of released carbon dioxide
EN 14047:2002	Packaging – determination of the ultimate aerobic biodegradability of packaging materials in an aqueous medium –method by analysis of evolved carbon dioxide
EN 14048:2002	Packaging – determination of the ultimate aerobic biodegradability of packaging materials in an aqueous medium–method by measuring the oxygen demand in a closed respirometer
EN 14806:2005	Packaging – preliminary evaluation of the disintegration of packaging materials under simulated composting conditions in a laboratory-scale test
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 14852:1999	Determination of the ultimate aerobic biodegradability of plastic materials in an aqueous medium – method by analysis of evolved carbon dioxide
ISO 14855:1999	Determination of the ultimate aerobic biodegradability and disintegration of plastic materials under controlled composting conditions – method by analysis of evolved carbon dioxide
ISO 14593:1999	Water quality – evaluation of the ultimate aerobic biodegradability of organic compounds in aqueous medium – method by analysis of inorganic carbon in sealed vessels (CO_2 headspace test)
ISO 15314:2004	Methods for marine exposure ISO 16221:2001 Water-quality – guidance for the determination of biodegradability in the marine environment
ISO 16929:2002	Plastics – determination of the degree of disintegration of plastic materials under defined composting conditions in a pilot-scale test
ISO 17556:2003	Plastics – determination of the ultimate aerobic biodegradability in soil by measuring the oxygen demand in a respirometer or the amount of carbon dioxide evolved
ISO 20200:2004	Plastics – determination of the degree of disintegration of plastic materials under simulated composting conditions in a laboratoryscale test
CEN/TR 15822	Plastics – biodegradable plastics in or on soil – recovery, disposal and (under approval) related environmental issues
AFNOR NF U52-001	Biodegradable materials for use in agriculture and horticulture-mulching products – requirements and test methods

4. Advantages and Disadvantages of Bioplastics

S. Berkesch in Michigan University reported in March 2005 “Bioplastics: A Rebirth of Plastic”. The future of biodegradable plastics shows great potential. Here are the advantages of bioplastics.

Potentially a much lower carbon footprint; It should be pointed out that the carbon footprint of a bioplastic is crucially dependent on whether the plastic permanently stores the carbon extracted from the air by the growing plant. A plastic made from a biological source sequesters the CO_2 captured by the plant in the photosynthesis process. If the resulting bioplastic degrades back into CO_2 and water, this sequestration is reversed. But a permanent bioplastic， made to be similar to polyethylene or other conventional plastics, stores the CO_2 forever. Even if the plastic is recycled many times, the CO_2 initially taken from the atmosphere remains sequestered [18].

Independence; Bioplastic is made from renewable resources: corn, sugarcane, soy and other plant sources as opposed to common plastics, which are made from petroleum [19].

Energy efficiency; Production uses less energy than conventional plastics [19]. On the other hand, plastics are made from about 4% of the oil that the World uses every year. With oil scarcity the manufacture of plastics becomes increasingly exposed to fluctuating prices [18].

Eco-safety; According to the one source, bioplastic also generates fewer greenhouse gasses and contains no toxins. Yu and Chen [19] reported that bioplastics contribute clearly to the goal of mitigating GHG emissions with only 0.49 kg CO_2 is being emitted from production of 1 kg of resin. Compared with 2-3 kg CO_2 of petrochemical counterparts, it is about 80% reduction of the global warming potential. Comparing bioplastics with conventional plastics are showed in Table 3.

Table 3. Comparing Bioplastics with Conventional Plastics [18]

	Bioplastics	**Conventional plastics**
Renewable	Yes or partially	No
Sustainable	Yes	No
Break down in the environment	Biodegradable and/or compostable	Some degradable by polymer oxidation
GHG emissions	Usually low	Relatively high

However, possible problems might come along with the use of bioplastics. Here are the disadvantages of bioplastics.

High costs; It is acclaimed that bioplastics costs 2 times more than conventional plastics. However, the amount of large-scale industrial production of bioplastics more common in the future with the implementation of cost reduction is expected.

Recycling problems; Bioplastic material might actually contaminate the recycling process if not separated from conventional plastics. For example, working with infrared rays in waste separation system, bioplastics cannot be separated and the separating plastics might be contaminated with bioplastics.

Reducing raw materials; bioplastics produced from renewable sources might to reduce raw material reserves. Indirectly, this will cause erosion is a concern. Moreover, in order to reduce energy consumption during the production of bioplastics and potential competition with agricultural resources for foods and also to provide additional raw material sources, the exploitation of food by-products is also the current trend [20].

Misunderstanding of terms; the description of bioplastic as compostable can be confusing. All bioplastics are not compostable at home like organic food waste but usually require an industrial composting treatment not available at every composting site [21]. Also, Bioplastics and related terms are being misused by various manufacturers to place their products more attractively on the market. Some slogans used by manufacturers such as 'environmental friendly', 'non-toxic', 'degradable/ totally degradable' are trick the uninformed and overwhelmed consumer.

Lack of legislation; as more facilities go on-stream, production of bioplastics is projected to increase to over 6 million tones by the year 2017 [22]. It is expected that bioplastics will replace to common plastics in the future. But still many countries in the world has not develop a new guide for bioplastic usage and bioplastic waste management Also labeling legislation may lead to an "eco-label", based on a product's raw material usage, energy consumption, emissions from manufacture and use.

Conclusions

This review has covered the bioplastics, their types, degradability, standards, advantages and disadvantages.

There are a large number of tests which are used to determine the extent of degradation of plastics. Many are respirometric, determining the amount of carbon dioxide released on exposure to fungi, bacteria, activated sludge (aerobically or anaerobically), compost or soil. It is important to have comparable international standard methods of determining the extent of biodegradation. Unfortunately, the current standards have not been equated to each other and tend to be used in the countries where they originated. There is an urgent need to standardize all details so that researchers may know that they have all worked to the same parameters. Also, there isn’t any standard for just bioplastics. Therefore, a new guide and standard for just bioplastics should develop for usage and bioplastic waste management both in Turkey and the world.

The advancement of biodegradable technology has risen in recent years and there are growing signs that the public shows a high amount of curiosity in the product. Based on advantages of bioplastics, there certainly are an abundant amount of materials and resources to create and fund more uses for bioplastic both in Turkey and World. Based on disadvantages of bioplastics, for the sustainability, several parameters must be considered, including the raw materials from which the bioplastic is generated, the energy consumed during bioplastic conversion and its life cycle assessment analysis from production to ultimate disposal or recycle, with due recognition to the design and engineering of the bioplastic.

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