CIBTech Journal of Microbiology ISSN: 2319-3867 (Online)
An Online International Journal Available at http://www.cibtech.org/cjm.htm
2015 Vol. 4 (1) January-March, pp.85-89/Sharma et al.
Review Article

MICROBIAL DEGRADATION OF PLASTIC- A BRIEF REVIEW

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ABSTRACT
Synthetic polymers are widely used both in food or commercial industry. Plastic, one of its products is known to be expanding with changing lifestyles and increasing population. However, it causes deleterious effects on the environment due to its non degrading nature. Burning of this plastic waste and burying of the plastics releases harmful toxic material which is a major pollutant in environment. Also, there is an undesirable influence on the environment and it is known to be cause problems with waste deposition and utilization. The most commonly used non-degradable solid waste is polythene which is a linear hydrocarbon polymers consisting of long chains of the ethylene monomers. Thus, there is a tendency to substitute such polymers with polymers that undergo biodegradable processes. Biodegradable plastics are environment friendly; they have an expanding range of potential application and are driven by the growing use of plastics in packaging. This review describes biodegradation processes and its mechanisms, the microorganisms which involved the reactions of importance in the biodegradation of plastics.

Keywords: *Hydrocarbons, Biodegradation, Microbes, Environment*

INTRODUCTION
The worldwide utility of polyethylene is expanding at a rate of 12% annum and approximately 140 million tones of synthetic polymers are produced worldwide each year. Plastics commodities are used in fishing nets, packaging, food industry and agricultural film (Vatseldutt and Anbuselvi, 2014). Plastics are characteristically inert and resistant to microbial attack and therefore they survive for years (Kavitha *et al.*, 2014). These disposed plastics are a significant source of environmental pollution, potentially harming delicate life forms.

There was a need to design biodegradable polymers which degrade upon disposal by the action of living organisms. These polymeric materials are potential sources of carbon and provide energy for microorganisms like bacteria and fungi that are heterotrophic in nature. Recently several microorganisms have been reported to produce degrading enzymes (Gnanavel *et al.*, 2012).The microorganisms act either directly or indirectly which includes discoloration and deterioration of plastics and serving as carbon or nitrogen source for the growth of the microorganisms. Microorganisms (bacteria, fungi, algae) recognize polymers as a source of organic compounds (e.g., simple monosaccharides, amino acids, etc).Under the influence of intracellular and extracellular enzymes (endo- and exoenzymes) the polymer undergoes chemical reactions and the polymer degrades by the process of cutting of the polymer chain, oxidation, etc (Premraj and Mukesh, 2005). The result of this process is affected by a large number of different enzymes are increasingly smaller molecules, which enter into cellular metabolic processes (such as the Krebs cycle), generating energy in the form of water, carbon dioxide, biomass and other basic products involved in biotic decomposition. The byproducts formed after decomposition are non-toxic in nature and in living organisms. It is considered to be the safest method of breakdown which anticipated producing less toxic side products and having potentials of bio-geo chemical cycling of the substrate (Pramila *et al.*, 2012).

There are many biological species which have an orchestred mechanism to degrade large and complex hydrocarbons into simpler biomolecules or biodegradation. They are mainly of bacterial and fungal origin and were identified. They are mainly Gram positive and two Gram negative bacteria, and few species of fungal origin like *Aspergillus*. Oher species of microbes like *Streptococcus*, *Staphylococcus*, *Micrococcus* (Gram +ve), *Moraxella,* and *Pseudomonas* (Gram –ve) and two species of fungi (*Aspergillus glaucus* and

A. niger) and *Bacillus megaterium*, *Pseudomonas* sp., *Azotobacter*, *Ralstonia eutropha*, *Halomonas* sp., are involved in the breakdown process (Chee *et al.*, 2010). The process which involves the breakdown of large molecule to simpler ones or into natural inorganic components is called mineralization.

Aerobic and Anaerobic biodegradation: Aerobic biodegradation is an important component of the natural scavenging of contaminants. Aerobic microbe's uses oxygen as an electron acceptor, and break down organic compounds into smaller organic components, often producing CO2 and water as the final product. Whereas, anaerobic biodegradation is the breakdown of organic contaminants by microorganisms when oxygen is absent or oxygen free zone. Some anaerobic bacteria use nitrate, sulfate, iron, manganese and carbon dioxide as their electron acceptors, and break down organic chemicals into smaller compounds (Mohan and Srivastava, 2010).

Biodegradation

Due to hydrophobicity and larger fatty acid skeleton of polymers microorganisms are unable to transport the polymers directly through their outer cell membranes.To make it feasible they breakdown or degrade the polymer to simpler products to facilitate their transport into the cell. Biodegradation (i.e. biotic degradation) is a chemical degradation of materials (i.e. polymers) provoked by the action of microorganisms such as bacteria, fungi and algae (David *et al.*, 1994; Chandra *et al.*, 1998; Lenz, 1993; Mohanty *et al.*, 2000). The most common definition of a biodegradable polymer is "a degradable polymer where in the primary degradation mechanism is through the action of metabolism by microorganisms (Das and Chandran, 2010)." Biodegradation is expected to be the major mechanism of loss for most chemicals released into the environment. This process refers to the degradation and assimilation of polymers by living microorganisms to produce degradation products. The extracellular enzymes secreted by microorganisms depolymerize the cell wall components. These, extracellular and intracellular depolymerases are actively involved in biological degradation of polymers. During degradation, exoenzymes from microorganisms break down complex polymers to short chains or smaller molecules, e.g., oligomers, dimers, and monomers that are smaller enough (water soluble) to pass the semi-permeable outer bacterial membranes and then to be utilized as carbon and energy sources (Gu, 2003). This initial process of polymer breaking down is called depolymerization. If the end products are inorganic in nature e.g., CO_2, H_2O, or CH_4, the degradation is called mineralization .If O_2 is available, aerobic microorganisms degrade the complex hydrocarbons with microbial biomass, CO_2, and H_2O as the final products. In contrast, in the absence of O_2 i.e. under anoxic conditions, anaerobic consortia of microorganisms are responsible for polymer deterioration. In this case the primary products will be microbial biomass, CO_2, CH_4 and H_2O under methanogenic conditions (Barlaz *et al.*, 1989; Barlaz *et al.*, 1989; Gu *et al.*, 2001) or H_2S, CO_2 and H_2O under sulfidogenic conditions. As O2 is a more efficient electron acceptor than $SO_2{}^{4-}$ and CO_2, aerobic processes yield much more energy and are more capable of supporting greater population of microorganisms than anaerobic processes. It should be noted that biodeterioration and degradation of polymer substrate cannot reach 100% because a small portion of the polymer will always be incorporated into microbial biomass, humus and other natural products (Alexander, 1977; Atlas *et al.*, 1997; Narayan, 1993; Gu *et al.*, 2006).

Bacterial species importantly involved in the biodegradation process include, *inter alia*, *Bacillus* (capable of producing thick-walled endospores that are resistant to heat, radiation and chemical disinfection), *Pseudomonas*, *Klebsiella*, *Actinomycetes*, *Nocardia*, *Streptomyces*, *Thermoactinomycetes*, *Micromonospora*, *Mycobacterium*, *Rhodococcus*, *Flavobacterium*, *Comamonas*, *Escherichia*, *Azotobacter* and *Alcaligenes* (some of them can accumulate polymer up to 90% of their dry mass (Sangale *et al.*, 2012). Fungal species actively participating in the biodegradation process are *Sporotrichum, Talaromyces, Phanerochaete, Ganoderma, Thermoascus, Thielavia, Paecilomyces, Thermomyces, Geotrichum, Cladosporium, Phlebia, Trametes, Candida, Penicillium, Chaetomium*, and *Aerobasidium*.

Plastics Biodegradation

Increasing interest in plastic biodegradation is observed because of environmental pollution. Plastics are composed mainly of carbon, hydrogen, nitrogen, oxygen, chlorine and bromine, and are used in automobile production, space exploration, irrigation, agriculture, health and other industries. Generally, 2-3 million tons of plastics are used each year in agricultural applications. Plastic trash bags comprised 1% and plastic film, comprising 2.3% of the waste stream. The commercial sector generated about 50% of the waste, the residential sector 30% of the waste, and the self-hauled sector 20%. The main environmental disadvantage of plastic materials is that they do not readily break down in the environment and therefore can litter the natural environment. Using biodegradable and compostable plastics can be used to reduce the amount of plastics in landfills. The use of biodegradable polymers is increasing at a rate of 30% per year in some markets worldwide. Based on the factors responsible for the degradation of the polymers, three types of polymer degradation methods are cited in the literature such as photodegradation, thermo-oxidative degradation and biodegradation (Shah *et al.*, 2008).

Biodegradation of Polyethylene (PE)

Polyethylene is more stable polymer, consisting of long chains of ethylene monomers. Polyethylene cannot be easily degraded with microorganisms. However, it was reported that lower molecular weight PE oligomers (MW = 600-800) was partially degraded by *Acinetobacter* sp. upon dispersion, while high molecular weight PE could not be degraded. Furthermore, the biodegradability of low density Polyethylene blends was enhanced with compatibilizer (Priyanka, 2011). Biodegradability of PE can also be improved by blending it with biodegradable additives, photo-initiators or copolymerization. Environmental degradation of PE proceeds by synergistic action of photo-and thermo oxidative degradation and biological activity (*i.e.,* microorganisms). Polyethylene is widely used for food packaging, retail industry uses and agricultural uses.

These applications lead to a large quantity of plastic waste, causing serious environmental problems (Usha *et al.,* 2011). Irradiation is known to play role in easier decomposition of polyethylene. Polyethylene sheet that had been kept in contact with moist soil for a period of 12 years showed no evidence of biodeterioration. However, some studies demonstrated that UV photooxidation, thermal oxidation or chemical oxidation with nitric acid of polyethylene prior to its exposure to a biotic environment did enhance biodegradation .Polyethylene is a synthetic polymer with –CH2-CH2 repeating units in the polymer backbone. This polymer is resistant to biodegradation, which results from highly stable C-C and C-H covalent bonds and high molecular weight. The mechanism of biodegradability of polyethylene includes alteration by adding a carbonyl group (C=O) in the polymer backbone. PE molecules containing carbonyl groups first get converted to alcohol by the monooxygenase enzyme. After that, alcohol is oxidized to aldehyde by the alcohol dehydrogenase enzyme. Next, aldehyde dehydrogenase converts aldehyde to the fatty acid. This fatty acid undergoes β-oxidation inside cells. Microorganisms that bring about polyethylene biodegradation included inter alia bacteria, fungi which produce biosurfactants which attach on PE surface, biofilm growth on PE surface, and assimilation of such short chains via β-oxidation pathway inside cells using intracellular enzymes. Abiotic factors like sunlight, photooxidation, the addition of carbonyl radicals into -CH2-CH2- backbone also influence the polyethylene degradation process.

Factors Affecting the Biodegradation of Plastics by Microbes

There are many factors that determine the biodegradability of plastics by microorganisms. The chemical and physical properties of plastics mainly influence the biodegradation capacity. Other than that physicochemical nature like surface area, hydrophilic, and hydrophobicity, molecular weight, chemical structure, melting temperature, crystallinity etc play important roles in the biodegradation processes (Tokiwa *et al.*, 2009). In general, polyesters with side chains are less assimilated than those without side chains. The molecular weight is also important for the biodegradability because it determines many physical properties of the polymer. Increasing the molecular weight of the polymer decreased its degradability. Morphological characters of polymers greatly affect their rates of biodegradation. The degree of crystallinity is a crucial factor affecting biodegradability, since enzymes mainly attack the amorphous domains of a polymer. The crystalline part of the polymers is more resistant than the amorphous region. The rate of degradation of Plastics decreases with an increase in crystallinity of the polymer (Iwata and Doi, 1998; Tsuji *et al.*, 2002).

Biodegradation Mode

Microorganisms being a part of delicate biological system are highly adaptive to environment and secrete both endoenzymes and exoenzymes that attack the substrate and cleave the molecular chains into segments (Albinas *et al.*, 2003; Huang *et al.*, 1990). The secreted enzymes are proteins of complicated chemical structure with high molecular weights possessing hydrophilic groups such as -COOH, --OH, and -NH2 (Potts, 1978) which can attack and eventually destroy almost anything. Several factors including the availability of water, temperature, oxygen usage, minerals, pH, redox potential, and carbon and energy source influence the growth of microorganisms (Holmes, 1988; Sand, 2003). The degradative action of fungi and bacteria on the polymeric material is a result of enzyme production and resultant breakdowns to the non living substrate in order to supply nutrient materials.

When biodegradable plastics decompose biologically, the resulting natural components do not affect the environment in any non-ecofriendly way. Even though the ordinary, non-biodegradable plastics do not release harmful by-products into the environment, they are relatively dangerous to ecosystem by causing unnecessary logging and dumping. With biodegradable plastics, which decompose more quickly, these negative effects are not altogether removed, that means the biodegradable plastics must not be dumped in the natural environment. However, if they do they will definitely cause less damage than non-biodegradable plastics. The advantages of biodegradable plastics over other types of plastics are of value only if proper handling of biodegradable plastics is applied; that is, if after they have been used, the plastics are disposed of under such conditions that enable their biological decomposition and the entering of the products into natural cycles.

CONCLUSION: Many different strains of bacteria mostly *Bacillus* sp. and fungi are involved in the degradation of plastic and its hydrocarbons. The degradative action of microbes on the polymeric material and their breakdown to the non living substrate plays a promising role in eco-friendly management of toxic wastes and chemical pollution in future.

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