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Review on Biodegradation of Plastic Waste by Micro-Organisms

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ABSTRACT
Plastics are light weighted, durable, corrosion resistant materials, strong, and inexpensive. Scientists have reported many adverse effects of the plastic in the environment and human health. The plastics at room temperatures are not considered as toxic. The toxic properties are found in plastics, when heat is released from the food material in which they are covered and then they produce serious human health problems. This review article covers the list of plastics, plastic degrading efficiency by microbes and their involvement to degrade the plastic waste.

KEYWORD: *Plastic; biodegradation; microorganisms; pollution*

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INTRODUCTION

Plastic are the product of the 20th century, they are largely synthetic materials made from crude oil, non-renewable and non expensive resource. In their original forms, plastic were mimicking and replacing natural products such as lacquer, shellac, amber, horns, husks and tortoise shell (APME, 1999). Plastic is defined as the polymer which become mobile on heating and thus can be cast into moulds. Plastics are made up of linking of monomers together by chemical bonds. Polythene comprises of 64% of total plastic, which is a linear hydrocarbon polymers consisting of long chains of the ethylene monomers (C_2H_4). General formula of polyethylene is C_nH_{2n}, where 'n' is the number of carbon atoms (Sangale et al., 2012).

A plastic consists of carbon, hydrogen, silicon, oxygen, chloride and nitrogen. It is derived from different sources such as oil, coal and natural gas. The backbone is the part of the chain on the main "path" linking a large number of repeat units together. In order To customize the properties of a plastic, different molecular groups "hang" from the backbone (usually they are "hung" as part of the monomers before linking monomers together to form the polymer chain). This property of the polymer by repeating unit‟s molecular structure has allowed plastics to become an indispensable part of the twenty-first century world. They are different varieties of plastic such as polyethylene (PE), Poly Ethylene Terephthalate (PET), Nylons, Poly-Propylene (PP), Polystyrene (PS), Polyvinyl Chloride (PVC), and Polyurethane (PUR) (Strong, 2006).

Plastic disposal and hazards

The plastic packing materials are strong, lightweight, easily processable, effective energy and inert in nature. They remain unaffected once disposed of and thus not compatible to environment. Plastic (Polymers) has attracted more public and media attention than any other components of the solid waste stream. The hazard of discarding plastic waste, called "white pollution", has become more severe (Shah, 2007). Plastic waste is released during the stages of production and also before consumption; plastic waste is disposed of through land-filling, incineration and recycling. Both quantity and quality of plastic waste causes environment problems.

Biodegradable plastic can have its impact, depending on the way it is produced. To stop various hazards to health and environment we have to develop efficient microorganisms and their products to solve this global issue (Kathiresan, 2003).

Health hazard

The presence of plastics in municipal wastes, many countries do not allow the incineration of these wastes. Instead, plastics are disposed of through open, uncontrolled burning and landfilling. Various health problems can be present as a result of open burning of these wastes which release pollutants into the air. In addition, the burning of Polyvinyl chloride (PVC) plastics produces persistent organic pollutants known as furans and dioxins, which are dangerous greenhouse gases and play an important role in ozone layer depletion. In fact, dioxins cause serious problems in the human endocrine hormone activity, thus becoming a major concern for the human health (Fehringer et al., 2010). Dioxins also cause very serious soil pollution, causing a great concern for scientific community worldwide. Phthalates and bisphenol A are closely related in thyroid causing dysfunction in humans. The burning of polyethylene, polyurethane, polyvinyl chloride and polystyrene produces toxic irritant products that lead to immune disorders and lung diseases, and are classified as possible human carcinogens (Vatseldutt, 2014). Styrene is classified by IARC as possibly carcinogenic to humans and is shown to cause mammary gland tumors in animal studies. It also acts as an endocrine disrupter (Gray et al., 2009). BPA has been linked with premature birth, intrauterine growth retardation, preeclampsia and still birth (Benachour et al., 2009). It has also been noted that prolonged exposure to BPA shows a significant effect on the sex hormones (progesterone) in females (Wang et al., 2011).

Environmental hazard

Many animals are dying because of waste plastics either by being caught in the waste plastic traps or by swallowing the waste plastic debris to exert ruinous effects on the ecosystem (Usha et al., 2011). Some of the plastic products cause human health problems because they mimic human hormone. Vinyl chloride is classified by the International Agency for the Research on Cancer (IARC) as carcinogenic to humans (Rudel Ruthann et al., 2007). It has also shown to be a mammary carcinogen in animals. Polymers found in the ocean have a considerable effect on marine life, and if ingested cause intestinal blockage in small fish or breathing problem in other marine animals like dolphins, turtles, etc.

Biodegradation

Accumulation of plastic wastes in the environment forces industry to produce a sustainable and a biodegradable type of plastics (Pathak et al., 2014). The term biodegradable involves biological activity.

The biodegradation of polymers consist of three important steps:

➢ **Biodeterioration**

This means the modification of mechanical, chemical and physical properties of the polymer due to the growth of microorganisms on or inside the polymer.

➢ **Biofragmentation**

This means the conversion of polymer or polymers to oligomers and monomers by the action of microorganisms.

➢ **Assimilation**

This means the microorganisms are supplied with necessary carbon, energy and nutrient sources from the fragmentation of polymers and convert carbon of plastic to CO2, water and biomass.

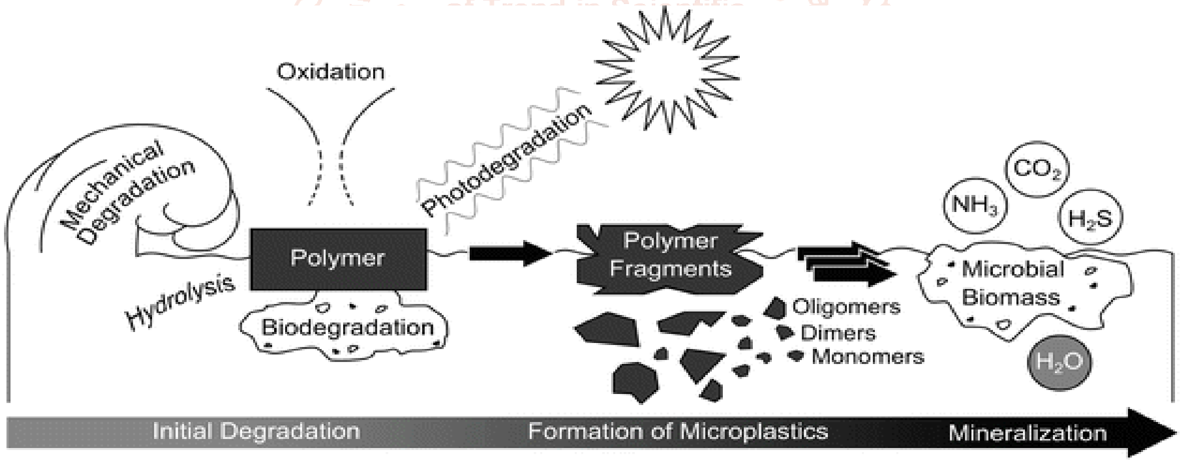

Figure 1: Steps involved in Biodegradation of polymer

Plastics can degrade via different mechanisms: thermal, chemical, photo and biological degradation. The degradation of plastics is a physical or chemical change in polymers that occurs as a result of environmental factors, like light, heat, moisture, chemical conditions or biological activity (Tokiwa et al., 2009). Biodegradation is a bio-chemical process that refers to thedegradation and assimilation of polymers by living microorganisms, to produce degradation products (Raaman et al., 2012).

Biodegradation of Plastics

Biodegradation is defined as any physical or chemical change in a material caused by biological activity. Microorganisms such as bacteria, fungi and actinomycetes are involved in the degradation of both natural and synthetic plastics. Plastics are usually biodegraded aerobically in nature, anaerobically in sediments and landfills and partly aerobically in compost and soil. Carbon dioxide and water are produced during aerobic biodegradation, while anaerobic biodegradation produces carbon dioxide, water and methane (Ishigaki et al., 2004).

Aerobic Biodegradation

Also known as aerobic respiration, aerobic biodegradation is an important part of the natural attenuation of contaminants in many hazardous waste sites. Aerobic microbes use oxygen as an electron acceptor, and break down organic chemicals into smaller organic compounds. CO_2 and water are the by-products of this process (Priyanka et al., 2011).

$C_{plastic} + O_2 \rightarrow CO_2 + H_2O + C_{residual} + Biomass$

Anaerobic Biodegradation

Anaerobic biodegradation is the breakdown of organic contaminants by microorganisms when oxygen is not present. It is also an important component of the natural attenuation of contaminants at hazardous waste sites. Some anaerobic bacteria use nitrate, sulphate, iron, manganese and carbon dioxide as their electron acceptors, to break down organic chemicals into smaller compounds.

C plastic → CH_4 + CO_2 + H_2O + C residual +Biomass

Microorganisms are unable to transport the polymers directly through their outer cell membranes, into the cells where most of the biochemical processes take place, since polymer molecule are long and not water-soluble. In order to use such materials as a carbon and energy source, microbes developed a strategy in which they excrete extracellular enzymes that depolymerize the polymers outside the cells (Gu J-D, 2003). Anaerobic and aerobic biodegradation mechanism pathways are given in (Figure 4). Extracellular and intracellular depolymerize enzymes are actively involved in biological degradation of polymers. During degradation, microbial exoenzymes break down complex polymers, yielding short chains or smaller molecules like oligomers, dimers and monomers. These molecules are small enough to be water-soluble, and can pass through the semi-permeable outer bacterial membranes to be used as carbon and energy sources. This initial process of breaking down polymers is called depolymerization; and when the end products are inorganic species e.g., CO_2, H_2O, or CH_4 the degradation is called mineralization (Gu J-D, 2003).

Mechanism of Biodegradation

Biodegradation of polymers involves following steps:
- Attachment of the microorganism to the surface of the polymer.
- Growth of the microorganism, using the polymer as a carbon source.
- Ultimate degradation of the polymer.

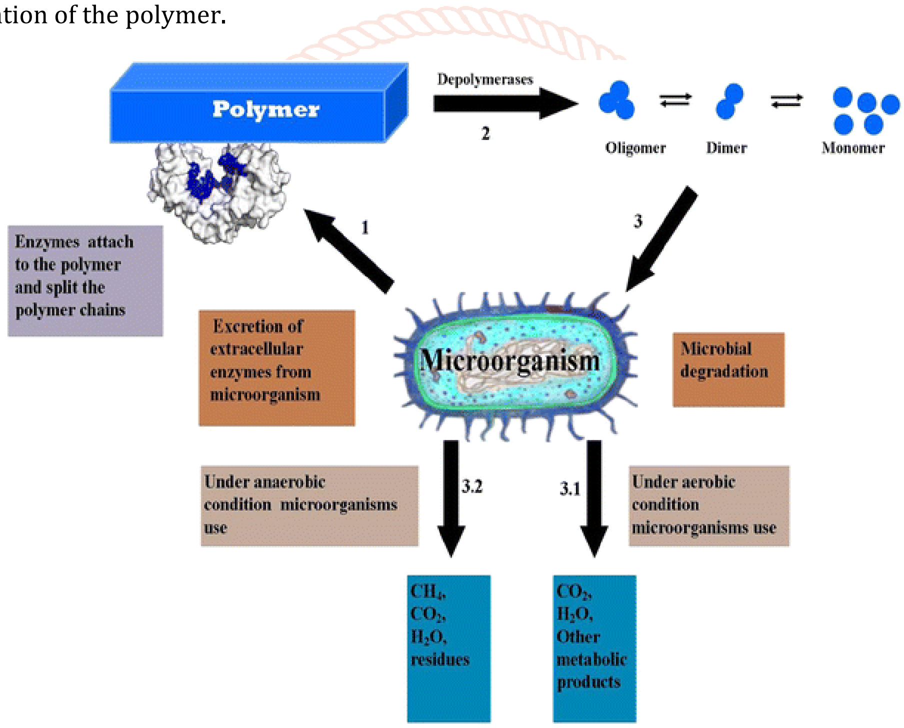

Figure 2: Aerobic and anaerobic degradation of polymer by Microorganisms (1.) Bacterial enzyme attached to polymer (2.) Biodegradation of polymer (3.) Utilized by Bacteria (3.1) Product obtained under aerobic condition (3.2) Product obtained under anaerobic condition

Factors Affecting Biodegradation of Plastics

The biodegradability of a polymer is essentially determined by the following physical and chemical characteristics:
- The availability of functional groups that increase hydrophobicity (hydrophilic degradation is faster than hydrophobic).
- The molecular weight and density of the polymer (lower degrades faster than higher).
- The morphology of TM: amount of crystalline and amorphous regions (amorphous degrades faster than crystalline).
- Structural complexity such as linearity or the presence of branching in the polymer.
- Presence of easily breakable bonds such as ester or amide bonds.
- Chain coupling (ester > ether > amide > urethane). Molecular composition (blend).
- The nature and physical form of the polymer (e.g., films, pellets, powder or fibers).
- Hardness (Tg) (soft polymers degrade faster than hard ones) (Swift, 1993; Kawai, 1995; Mohan et al., 2010).

Biodegradation of Synthetic Plastics

Polyethylene (PE)

Polyethylene is a stable polymer that consists of long chains of ethylene monomers; it cannot be degraded easily by microorganisms. However, it has been reported that lower molecular weight PE oligomers (MW=600–800) can be partially degraded by *Actinobacter* spp. upon dispersion, while high molecular weight PE could not be degraded

(Ghosh et al., 2013). The biodegradation of PE is a very slow process. A wide variety of Actinomycetes like *Streptomyces* strain and fungi like *Aspergillus* and *Penicillium* have been used in research to facilitate this process. El-Shafei et al., (1998) investigated the ability of fungi and *Streptomyces* strains to attack degradable polyethylene that consisted of disposed-of polyethylene bags containing 6% starch (El-Shafei et al., 1998). They isolated eight different strains of *Streptomyces* and two fungi *Mucor rouxii* NRRL 1835 and *Aspergillus flavus*.

Yamada-Onodera et al., (2001) studied a strain of fungus, *Penicillium simplicissimum* YK, which can biodegrade polyethylene without additives (Yamada et al., 2001). Ultraviolet light or oxidizing agents, such as a UV sensitizer, were used at the beginning of the process to activate an inert material, polyethylene. Polyethylene was also treated with nitric acid at 80°C for six days before cultivation with inserted functional groups that were susceptible to microorganisms. With fungus activity, polyethylene with a starting molecular weight in the range of 4000 to 28,000 was degraded to units with a molecular weight of 500, after a month of liquid cultivation. This indicated the successful biodegradation of this polyethylene. Overall, polyethylene degradation is a combined photo- and bio-degradation process. First, either by abiotic oxidation (UV light exposure) or heat treatment, essential abiotic precursors are obtained; allowing selected thermophilic microorganisms to degrade the low molar mass oxidation products. The biodegradation of polyethylene is known to occur by both Hydrobiodegradation and Oxo-biodegradation. These two mechanisms can be used because of two additives, starch and pro-oxidant, used in the synthesis of biodegradable polyethylene. Starch blended polyethylene has a continuous starch phase that makes the material hydrophilic, and therefore allows it to be catalyzed by amylase enzymes. Microorganisms can easily access, attack and remove this section, thus the polyethylene with the hydrophilic matrix continues to be hydrobiodegraded. If a pro-oxidant additive was used, biodegradation occurs following photodegradation and chemical degradation. If the pro-oxidant is a metal compound, after transitionmetal catalyzed thermal peroxidation, biodegradation of low molecular weight oxidation products occurs sequentially (Bonhomme et al., 2003).

Polypropylene (PP)

Polypropylene is a thermoplastic that is commonly used for plastic moldings, stationary folders, packaging materials, plastic tubs, non-absorbable sutures, diapers, etc. It can be degraded by exposure to ultraviolet radiation from sunlight, and it can also be oxidized at high temperatures. The possibility of degrading PP with microorganisms has also been investigated (Sivan, 2011). Even though PP is a polyolefin, and thus prone to oxidative degradation like PE, the substitution of methyl for hydrogen in the beta position makes it more resistant to microbial attacks, as previously discussed in the section dealing with factors that affect biodegradability (namely structural complexity). The decreasing order of susceptibility of polymers to degradation in soil mixed with municipal refuse was PE > LDPE > HDPE. This was revealed by analyzing sample weight loss, CO_2 evolution, changes in tensile strength and changes in FTIR and bacterial activity in the soil. Studies reported on biodegradation of PP, many microbial communities such as certain fungal species like *Aspergillus niger* and bacteria such as *Pseudomonas* and *Vibrio* have been reported to biodegrade Polypropylene. A decrease in viscosity and the formation of new groups, namely carbonyl and carboxyl, were observed during the degradation process (Arutchelvi et al., 2008).

Polystyrene (PS)

Polystyrene is a synthetic plastic that gives products like styrene, benzene, toluene and acrolein on thermal or chemical degradation. There are very few instances of biodegradation of polystyrene reported so far but biodegradation of its monomer styrene has been reported a few times.

It has many commercial and industrial applications like manufacturing of disposable cups, packaging material, electronics and laboratory ware due to its properties like lightweight, stiffness and thermal insulation (Aruna et al., 2015).

Polyvinyl Chloride (PVC)

PVC is strong and has low moisture absorption. It resists abrasion. PVC can be degraded by chemical and photo degradation but there are very few reports on biodegradation of PVC. It has many commercial and industrial applications like rigid pipes, shoe soles, garden hoses, textiles, electrical wire insulation, pipes and fittings, synthetic leather products and floor coverings (Aruna et al., 2015).

Polyethylene Terephthalate (PET)

Polyethylene terephthalate has different properties. It is a semi crystalline polymer and chemically and thermally is a stable. The molecular weight of this polymer range from 30,000 to 80,000 g/mol (Webb et al., 2012). According to pervious study, the degradation of PET transparency sheets by microbes and Esterase enzyme, and detected important chemical changes of polymeric chains by X-ray photoelectron spectroscopy (XPS) analysis. Microbial degradation affect crystalline structure and a presence of microbes inside the polyethylene terephthalate were seen as well, using scanning electron microscopy (SEM) micrographs (Sharon et al., 2012).

CONCLUSION

The present study implicates the ability to degrade plastic and utilizing it as sole carbon source by different species. Now-a-days, plastics are used in packaging, paper coatings, bottles, bags, etc. It is obvious that without plastic we can't meet our day to day life needs, but in view of its detrimental affect it is required to develop competent process for its safe disposal and explore alternative material like starch based and blended plastic. This review discusses on the literature of microbes used for biodegradation of plastic waste. Most of the plastic wastes are degrade by the microorganisms. Based on these literatures available one could conclude that in order to enhance biodegradation of plastics waste the following approaches could be adopted as the biodegradation studies of plastics in dumped soil.

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