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Review Article

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A COMPREHENSIVE REVIEW ON MICROBIAL DEGRADATION OF PLASTIC WASTE

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ABSTRACT
Plastic is a broad name given to different polymers with high molecular weight, which can be degraded by various processes. However, considering their abundance in the environment and their specificity in attacking plastics, biodegradation of plastics by microorganisms and enzymes seems to be the most effective process. When plastics are used as substrates for microorganisms, evaluation of their biodegradability should not only be based on their chemical structure, but also on their physical properties (melting point, glass transition temperature, crystallinity, storage modulus etc.). In this review, microbial and enzymatic biodegradation of plastics and some factors that affect their biodegradability are discussed. Plastics have become an important part of modern life and are used in different sectors of applications like packaging, building materials, consumer products and much more. Each year about 100 million tons of plastics are produced worldwide. Degradation is defined as reduction in the molecular weight of the polymer. The Degradation types are (a). Chain end degradation/de-polymerization (b).Random degradation/reverse of the poly condensation process. Biodegradation is defined as reduction in the molecular weight by naturally occurring microorganisms such as bacteria, fungi, and actinomycetes. That is involved in the degradation of both natural and synthetic plastics.

INTRODUCTION

Plastic is a term derived from the Greek word *plastikos*, which means able to be molded into different shape and is given to any synthetic or semi-synthetic organic polymers with high molecular mass and that are moldable. Plastics are defined as the polymers (solid materials) which on heating become mobile and can be cast into moulds. They are non metallic moldable compounds and the materials that are made from them can be pushed into any desired shape and sizes [1].

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Commonly plastics are used in many purposes including packaging, disposable diaper backing, agricultural films and fishing nets. Plastics and their use has become a part in all sectors of economy [2].

Infrastructure such as agriculture, telecommunication, building and construction, consumer goods, packaging, health and medical are all high growth areas that ensures present demand for plastics. Plastic is the mother industry to hundreds of components and products that are manufactured and used in our daily life like automobiles parts, electrical goods, plastic furniture, defense materials, agriculture pipes, packages and sanitary wares, pipes and fittings, tiles and flooring, artificial leathers, bottles and jars, PVC shoes and sleepers hundreds of household items [3]

Plastics are used in packaging of products such as food, pharmaceuticals, cosmetics, detergents and chemicals. Approximately 35% of plastics produced in the developed countries are consumed for packaging. Today the plastic consumption for food packaging in India itself is about 308,000 tones, which forms 8-10% of all types of packaging materials used in food packaging. Most widely used plastics used for packaging are polyethylene (LDPE, MDPE, HDPE, LLDPE), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC), polyurethane (PUR), polybutylene terephthalate (PBT), nylons. With the advances in technology and the increase in the global population, plastic materials have found wide applications in every aspect of life and industries. At present the industry is split into organized and unorganised sectors.

The organized sector produce quality products whereas unorganized sector is not capable of producing quality products, it produces low quality, cheap products through excessive use of plastic scrap [4] and their increasing accumulation in the environment has been a threat to the planet. To overcome all these problems, some steps have been undertaken. The first strategy involved production of plastics with high degree of degradability [5].

Biodegradable plastics are plastics that will decompose in the natural environment. Biodegradation of plastics can be achieved by enabling microorganisms in the environment to metabolize the molecular structure of plastic films to produce an inert humus-like material that is less harmful to the environment. However, biodegradable plastics can’t be viably used as packaging materials as they are not always degradable under normal conditions. Furthermore, degradable plastics are not consistent with plastics recycling, a viable approach to help solve the municipal solid waste problem.

Degradation can be defined as a change in the chemical structure of a plastic involving a deleterious change in properties. The material is degraded under environmental conditions (e.g.,microorganisms, temperature, light, water) and in a reasonable period of time in one or more steps [6]. Under thermal degradation elevated temperatures can significantly increase the rate of various chemical reactions, such as oxidation, and therefore lead in an indirect way to degradation of the polymer [7]. In Photo-degradation method the UV radiation (290 and 400 nm), can be absorbed by the plastic and lead to bond cleavage and de-polymerization, causing photo-degradation [8].

The second major contributor to the photo-degradation of plastics is ketone photolysis which proceeds via two major reactions called Norrish I and Norrish II. Mechanical degradation of materials is a large field comprising fracture phenomenon, as well as chemical changes imposed by mechanical stress. Natural macromolecules, e.g. protein, cellulose, and starch are generally degraded in biological systems by hydrolysis followed by oxidation. Most of the reported synthetic biodegradable polymers contain hydrolysable linkages along the polymer chain [9]. Low molecular weight hydrocarbons can be degraded by microbes [10]. They are taken in by microbial cells, 'activated' by attachment to coenzyme-A, and converted to cellular metabolites within the microbial cell. However, these processes do not function well in an extracellular environment and the plastic molecules are too large to enter the cell. This problem does not arise with natural molecules, such as starch and cellulose, because conversions to low molecular weight components by enzyme reactions occur outside the microbial cell [9] [11].

Over the last two decades research has been concentrated on microbial degradation of natural and synthetic polymers. At present, there are several general guidelines concerning the structure and biodegradability of polymers. Biodegradable and natural plastics are polyesters which are produced by a range of microbes, cultured under different nutritional and environmental condition. Biodegradation depends directly upon the molecular weight of the polymers and the rate of biodegradation declines with an increase in the molecular weight of polymers. Microbial degradation of these polyethylene films has been reported in pure culture studies with various microorganisms such as *Streptomyces sp, Phanerochaete sp. Pseudomonas, Xanthomonas, Flavobacterium, Micrococci, Streptococcus, Staphylococcus, Bacillus, Penicillium, Alcaligenes, Fusarium, Amycolatopsis sp., Comamonas acidovorans, Alternaria, Spicaria spp., Aspergillus, Aureobasidium, Poecilomyces [4]* [12] [13].

METHODS OF BIODEGRADATION OF PLASTICS

Muhammad, A.I. *et. al* in their study carried out 3 experiments to observe the biodegradation of plastics [14]

Soil burial treatment

In Soil burial treatment soil was taken in different pots and replicate pieces of polyethylene films were buried in the that soil in pots for three months. Ground soil was inoculated with the sewage sludge for the isolation of microbial strains having ability to adhere and degrade the polymer film [15].

Shake flask experiment

Cellulose blended PVC films were incubated with the isolated microbes from soil burial experiments in shaking condition. Mineral salt media used per 1000 mL contained in distilled water were; K_2HPO_4, 1 g; KH_2PO_4, 0.2 g; NaCl, 1 g; $CaCl_2.2H_2O$ 0.002 g; boric acid, 0.005 gm; $(NH_4)2SO_4$, 1 g; $MgSO_4.7H_2O$, 0.5 g; $CuSO_4.5H_2O$, 0.001 g; $ZnSO_4.7H_2O$, 0.001 g; $MnSO_4.H_2O$, 0.001 g and $FeSO_4.7H_2O$, 0.01 g. Cellulose blended PVC film (3 pieces) in MSM (90 mL) were inoculated with 10 mL of spore suspension (10 ± 2.1 × 106 spores mL -1) and incubated at 30°C for 3 months. After every 4 weeks polymer samples were retrieved and evaluated visualy and with infrared spectroscopy measured on Bio- Rad Merlin FTIR [16].

Sturm test

CO_2 evolution as a result of cellulose blended PVC biodegradation was determined by sturm test. The pieces of polymer were added to culture bottles containing MSM (285 mL) without any carbon source. Spore suspension of Phanerochaete chyrosporium PV1 (2.9 × 106 spores mL-1) was used as inoculum 5% (v/v) in test and control bottles (without plastic). Sterlized air was supplied to keep conditions aerobic and reaction bottles were stirred continuously by placing them on magnetic stirrer. After 30 days, gravimetric analysis of CO_2 production was done by trapping the gas in adsorption bottle containing KOH (1 M). The precipitates formed after titration with barium chloride solution (1 M) of test and control were filtered, weighed and calculated for CO produced per liter. In another study by Emmanuel et.al. the ability of a complex enzyme (LIQ 1) to degrade polymers such as Sesbania gum and Guar gum was investigated. The study was based on an assumption that the polymer compounds dissolved in water wold increase viscosity and be able to plug an artificial rock samps (made of pulverized coal) placed in a pressured chamber. The study was also based on an assumption that complex (LIQ1) would slowly degrade the polymer compounds thereby reducing their viscosity and hence forth unplugs the artificial rock. The polymer compounds were not auto degradable at room temperature though showed a decreasing viscosity after one hour. UV light treatment was done by Kenneth et.al. evaluate the photosensitivity of each film of a plastic bag. A UV lamp with long (365-nm)- wave was used. Plastic strips (2.54 by 15.24 cm) were cut in machine direction and placed into a UV box (17.78 by 40.64 cm) at a distance of 17.78 cm from the lamp for 8 weeks. The plastic strips were turned twice a week to ensure even exposure to the light. Samples were removed after 1, 2, 3, 4, and 8 weeks. Film mechanical properties and polyethylene molecular weight distributions were determined

Composting technique

The composting was run under controlled conditions in a thermal insulated composting chamber using a standard mixture of raw materials used for cultivation of white button mushroom (*Agaricus bisporus*) obtained from a local mushroom compost-producing company. Specimen of polymeric foils in small stainless steel containers were buried in the compost pile for 42,100 or 180 days; during first weeks the temperature in the pile was close to 60°C [17].

Fungal treatment

Few fungal strains were obtained from the culture collection of Basidiomycetes. These fungal cultures were prescreened using nutrient rich, glucose rich, extract agar in pertidishes. Surfacesterilized (3% H_2O_2, 2 min) copolyester filaments were put on agar medium surface with simultaneous inoculation with the fungus. Other degradation tests were performed in liquid media, selected fungal strains were cultivated statically in 250 ml Erlenmeyer flask containing 15ml of culture media in which piece of poly (ester-amide) or copolyesters film were immersed. Before inserting into nutrient medium, the polymer pieces were suface sterilized (3% H_2O_2, 2 min). Two culture media were used viz. nitrogen limited medium and the above mentioned nutrient rich glucose malt extract medium [10][13][18-20].

SUMMARY AND CONCLUSION

Plastics are one of the major threats to the environment from last many years. Studies are made all over the world are to degrade plastic. The studies are about the degradation of different kinds of plastic in microbial means. The plastics which were studied are polyvinyl chloride, polyvinyl alcohol, polyethylenes, polyesters, polyhydroxy alkanoates, polylcaprolactone, polylactic acid, polyurethane, nylon and polyethylene etc.

Bacterial and fungal species are widely used for degradation of Plastics. Many strains of *Pseudomonas spp* and other microorganisms involved in degradation of plastics are *Aspergillus spp*., *Bacillus mycoides, Flavobacterium spp., Micrococci, Streptococcus, Staphylococcus, Phanerochaete chyrosporium, Penicillium frequentans, Streptomyces spp., Xanthomonas spp.,* etc. The results are confirmed by the weight, tensile strength and decrease in viscosity in some cases, molecular weight distribution, and fragility. The HDPE plastics are showing resistance to soil conditions than LDPE. This study is useful for the molecular design of biodegradable polymers and for the molecular evolution and breeding of degradation enzymes and microbes. The enzymatic degradation of gum was also effective. The pure culture biodegradation assay shows the ability to identify which portion of the degradation is due to chemical degradation and what can be attributed directly to biological degradation. Through these studies degradation of plastic can be made effective.

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Nil

CONFLICT OF INTEREST

The authors declare no conflict of interest

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