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Review: Methodology to Assess the Biodegradation of Synthetic Plastic in Controlled Environment

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ABSTRACT: “Plastic” is a general term used for high molecular weight polymer. Plastic are inexpensive, lightweight and the uncontrolled use of plastic has led to various environmental and health problems. Biodegradation of plastic refers to change in its physical and chemical properties of polymer induced by heat, light, moisture and biological agents such as Bacteria and Fungi, yet also a slow process. Not only pollution and global warming are caused because of increase in the problem of waste disposal of plastic and land filling but also due to release of CO₂ and dioxins because of burning plastic waste. Different Bacterial and Fungal sp. degrade types of plastic waste. Different methods used for evaluation of biodegradation of plastic such as FTIR, Strum Test, etc. have been reviewed in this article. Biodegradation of plastic promises a future with reduced plastic waste.

KEYWORDS: Bacteria; Biodegradation; Plastic; Polymer; FTIR; Strum Test.

I. INTRODUCTION

Plastic are lightweight, durable, inexpensive and strong. Plastic are long chain polymer molecule [1]. Plastic comes from a Greek word “Plastikos” means able to be mold in different shapes [2]. Plastic usually consist of carbon, nitrogen, oxygen and hydrogen. It is derived from different sources such as oil, coal and natural gas. The backbone is the part of the chain on the main linking a large number of repeat units together. In order to customize the properties of a plastic, different molecular groups hang from the backbone, this property of the polymer by repeating unit molecular structure has allowed plastics to become an unavoidable part of 21st century world. In our day-today life we use different types of plastic such as Polyvinyl chloride (PVC), Polyurethane, Nylon, Polyethylene terephthalate, Polyamides, Polystyrene, etc. From the last three decades, polymeric materials are largely used in clothing, shelter construction, medical and recreation industries, fishing nets, packaging, food industry, transportation, food, and agricultural field [3]. Degradation of plastic can be induced by a variety of mechanisms such as chemical, thermal, photoxidation and biodegradation [4].

Biodegradation of plastic by micro-organism is a slow process, as over 90 genera of Fungi, Bacteria and Actinomycetes posses the ability to degrade plastic [5]. Most of the marine animals die due to waste plastics by swallowing the debris of waste plastic, exert ruinous effects on the ecosystem [6]. Some plastic products cause human health problems as they mimic human hormone. International Agency for the Research on Cancer (IARC) has classified Vinyl chloride as carcinogenic to humans [7].

Burning plastics usually produces harmful gases such as furans and dioxins which are dangerous greenhouse gases and also plays an important role in depletion of ozone layer. In fact, dioxins is becoming a major concern for the human health as it cause serious problems in the endocrine hormone activity [8]. A global estimate suggested plastics production up to three hundred and eleven million tons in 2014 and reached up to three hundred and thirty five million tons by 2015 which clearly depicts its enormously rapid production which will become twice in the next two decades whereas will reach nearly four-folds by 2050 [9].

1.1 Synthetic plastics

Synthetic plastics are extensively used in packaging of products like food, pharmaceuticals, cosmetics, detergents and chemicals. Approximately 30% of the plastics are used worldwide for packaging applications. This utilization is still

expanding at a high rate of 12% per annum [10]. They have replaced paper and other cellulose-based products for packaging because of their better physical and chemical properties, such as their strength, lightness, resistance to water and most water-borne microorganisms. The widespread applications of plastics are not only due to their favorable mechanical and thermal properties but also mainly due to the stability and durability [11]. Because of their durability and visibility in litter, plastics (polymers) have attracted more public and media attention than any other component of the solid waste stream. Chemical structure of Synthetic plastic is shown in figure 1.

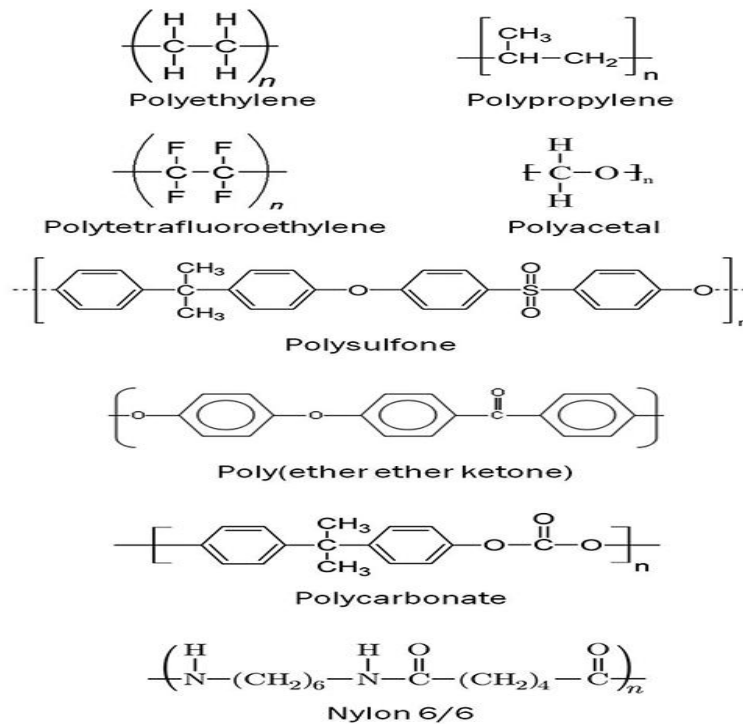


Figure 1: Chemical structure of Synthetic plastic

1.2 Biodegradable plastic

The biodegradable plastics (polyesters), namely polyhydroxyalkanoates (PHA), polylactides, polycaprolactone, aliphatic polyesters, polysaccharides and copolymer or blend of these, have been developed successfully over the last few years. The most important are poly (3- hydroxybutyrate) and poly (3-hydroxybutyrate-co-3-hydroxyvalerate). Bioplastics (Biopolymers) obtained from growth of microorganisms or from plants which are genetically-engineered to produce such polymers are likely to replace currently used plastics at least in some of the fields [12]. PHA's key properties are its biodegradability, apparent biocompatibility, and its manufacture from renewable resources. The global interest in PHAs is high as it is used in different packaging materials, medical devices, disposable personal hygiene and also in agricultural applications as a substitute for synthetic polymers like polypropylene, polyethylene etc. Chemical structure of biodegradable plastic is shown in figure 2.

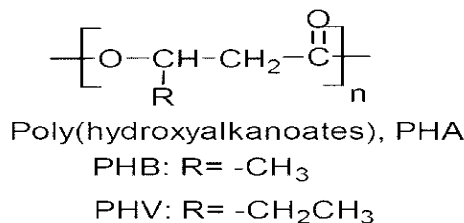
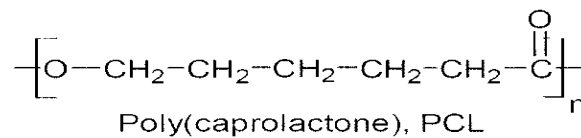
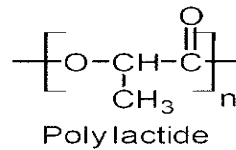


Figure 2: Chemical structure of biodegradable plastic

II. DEGRADATION OF PLASTIC

Any physical or chemical change in plastic structure as a result of various environmental factors, such as light temperature, moisture, chemical conditions or biological activity [13]. Processes that induce changes in polymer properties due to physical, chemical or biological reaction resulting in subsequent chemical changes are categorized as polymer degradation. Degradation is reflected as changes in properties of material in discoloration, phase separation, cracking, erosion, and delamination (means a polymer fractures into layers). The changes include chemical transformation and new formation of functional groups. The degradation can be of different types such as– Mechanical, Photo (Light), Thermal, Chemical.

2.1 Mechanical degradation

Mechanical degradation occurs due to compression, tension and shear forces. The causes of these forces are numerous. It includes a range of compulsion during material installation, ageing due to load, air and water turbulences and bird damages. At the macroscopic level, damages are not visible immediately but at the molecular level degradation could have started. Mechanical factors are dominant during biodegradation process, but mechanical damages can activate it or accelerate it [14].

2.2 Photo-degradation

Several materials are photosensitive. The energy carried out by photons can create unstable states in various types of molecules. Energy transfer can be established by photo-ionization, luminescence, fluorescence and thermal radiation. Sometimes, the resistance of the materials can be affected by impurities that are present in manufactured products. In other cases, structures of photosensitive molecules are intentionally added such as by simple addition or copolymerization into the polymer frame work to induce a macromolecular degradation through light. For example, pro-oxidants agents that can be activated depending on the light intensity and time of exposure can be added into a polymer [15, 16]. This strategy is used by polyolefin's manufacturers to enhance degradability of plastic bags, packing and agricultural films. The action of photo radiation is one of the most important parameters in abiotic degradation [17, 18].

2.3 Thermal degradation

Thermal degradation of thermoplastic polymer occurs at the melting temperature when polymer is transformed from solid to liquid [19]. The environmental temperature is generally lower than the melting point of thermoplastic polymer. Some thermoplastic polymers exhibit melting temperature near to environmental condition; this is the case for the thermopile stage of composting. Degradation polymers possess amorphous and crystalline region [20]. Structural changes take place at their glass transition stage (T_g), and the motility and the volume of the polymeric chains are modified. Above rubbery state, the disorganization of chains facilitates the accessibility to chemical and biological degradation [21].



2.4 Chemical degradation

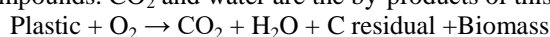
Chemical transformation is the other most important parameter to light in the abiotic degradation. Atmospheric pollutants and agrochemical may interact with polymers changing the macromolecules properties [14]. Among the chemicals provoking the degradation of materials, O₂ is the most powerful. Atmospheric form of O₂ or O₃ attack covalent bond producing free radicals. The oxidative degradation depends on the polymer structure such as unsaturated links and branched chains. This oxidation can be concomitant or synergic to light degradation to produce free radical such as peroxy radical resulting from the oxidative degradation leading to cross linking reactions [22].

III. BIODEGRADATION OF PLASTICS

Any physical or chemical change in a material caused by biological activity is known as Biodegradation. Microorganisms such as bacteria, fungi and actinomycetes are involved in the degradation of both natural and synthetic plastics. Plastics are usually biodegraded anaerobically in sediments, aerobically in nature, and landfills and partly aerobically in soil and compost. CO₂ and H₂O are produced during aerobic biodegradation, while anaerobic biodegradation produces CO₂, H₂O and methane [23].

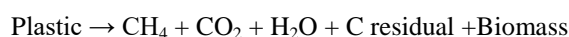
3.1 Aerobic Biodegradation

Aerobic biodegradation is an important part of the natural attenuation of contaminants in many hazardous waste sites, also known as aerobic respiration. Aerobic microbes use oxygen as an electron acceptor, and break down organic chemicals into smaller organic compounds. CO₂ and water are the by-products of this process [24].



3.2 Anaerobic Biodegradation

Anaerobic biodegradation is the breakdown of organic contaminants by microorganisms in absence of oxygen and also an important component of the natural attenuation of contaminants at hazardous waste sites. Some anaerobic bacteria use sulphate, iron, nitrate, manganese and carbon dioxide as their electron acceptors, to break down organic chemicals into smaller compounds.



IV. METHODS FOR EVALUATION PLASTIC BIODEGRADATION

4.1 Visual observations:

Effects used to describe degradation include the roughening of the surface, defragmentation and changes in color or formation of biofilms, formation of holes or cracks on the surface. In terms of metabolism, these changes do not prove the presence of a biodegradation process but the parameter of visual changes can be used as a first indication of any microbial attack. More sophisticated observations can be obtain about the degradation mechanism using either scanning using SEM, transmission optical microscopy or atomic force microscopy AFM [25].

4.2 Change in the physical properties:

Change in polymer physical properties such as density, contact angle, viscosity, Molecular weight distribution (using GPC), melting temperature (T_m), glass transition temperature (T_g) with TGA and DSC and changes in the crystalline and amorphous regions by using X-ray diffraction, SAXS and WAXS [26]. Biodegradability is also evaluated by weight loss, tensile strength loss, changes in present elongation and change of polymer molar mass [27].

4.3 Changes in the chemical properties:

Changes in structure of polymer in synthetic media, including the formation or removal of functional groups as determined by FTIR, each spectrum can be measured as absorbance under 100 N. The molecular weight and molecular weight distribution of the degraded products or intermediates are observed by techniques such as TLC, GCMS and NMR [28].

4.4 CO₂ evolution / O₂ consumption:

Under aerobic conditions, microbes use oxygen to oxidize carbon, and form carbon dioxide as a major metabolic end product. Consequently, **Respirometry test** - the consumption of oxygen or **Strum test** - the formation of carbon dioxide is the most often used method to measure biodegradation in laboratory tests, using a static aqueous test system and the evolution of CO₂ as the analytical parameter [29].



4.5 Biological tests:

A very simple semi-quantitative method is the 'clear-zone' test. This is an agar plate test in which the polymer is dispersed as very fine particles within the synthetic medium agar, which results in the agar having an opaque appearance. After inoculation with microorganisms, the formation of a clear zone around the colony indicates that the organisms are at least able to degrade the polymer, which is the first step of biodegradation. This method is usually applied to screen organisms that can degrade a certain polymer [30]. Measurements of clear-zone formation in agar plates and the metabolic activity of the cells in the culture and in the biofilm can be done by protein analysis, ATP assays and FAD analysis [28].

V. CONCLUSION

The present study implicates the methods to estimate the structure of polymer and weight of polymer before and after biodegradation. Utilization of microbes for degradation of plastics is eco-friendly method. Various properties of plastics affect its rate of biodegradation. The weak forces such as hydrogen bond, the covalent forces, affect the physical and chemical properties of plastics and thus affect the rate of degradation. In future, Biodegradation of plastic promises reduction in plastic waste.

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